MANAGEMENT PRACTICES USING OF AGRICULTURAL DRAINAGE WATER WITH DRIP IRRIGATION FOR CROP PRODUCTION AND LANDS SUSTAINABILITY IN ARID AND SEMI-ARID AREAS

Ali Heydar Nasrollahi[1,*], Saeed Boroomand Nasab[2], Abdol Rahim Hooshmand[3]

Abstract

In addition to lack of water, other elements such as high temperature, severe salinity of soil and water quality create problems in arid and semi-arid areas. Nowadays restricted water resources having acceptable quality has resulted into the reuse of low quality water such as agricultural drainage water in these areas. The use of drainage water and saline water in agriculture requires different management practices on the farm, such as increasing the efficiency of water use, leaching and soil desalinization, in addition to proper drainage and other conventional methods. High efficiency Irrigation methods with such as drip irrigation are suitable solutions for the optimal use of these resources. This study was carried out to investigate the effects of drip irrigation management strategies using saline water on corn crop in the research farm of the Water Science Engineering faculty at Ahwaz, Shahid Chamran University. The experiment was performed on split plots based on a randomized complete block design. In this research the effects of three irrigation management options; that is mixing (M1), one-alternate mixing (M2) and half-alternate mixing(M3) of three levels of saline water (S2, S3 and S4) with the Karun river water (S1), and the reviewing of its effects on yield, irrigation water productivity of corn and soil salinity was investigated. Irrigation management strategies and salinity were the main factor and sub-factors. Salinity levels of S2, S3, and S4 were 4, 6 and 8 dS/m respectively. Results showed that the effects of management and salinity and their interaction on yield and water productivity were significant at levels of 5 percent. The application of the half-alternate (M3) method improved yield indexes, water productivity and the leaching of soil surface layers. The Model coefficients of yield- salinity were calculated under different management scenarios of drip irrigation. The yield reduction per unit increase in soil salinity in the plant root zone the mixing, one-alternate and half-alternate management strategies were calculated respectively as being at 9.86, 12.3 and 7.14 percent. The results of this research show that drip irrigation when applied with proper management is a safe method to reuse large amounts of drainages water volumes in arid and semi-arid regions.

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KEY WORDS: Water quality, Drainage water, Water reuse, Drip irrigation.

Introduction

In addition to the shortage of water, high temperature, severe salinity of the soil create problems in arid and semi-arid areas. Nowadays, drip irrigation can overcome particularly any environmental limitations for sustainable crop production. The Increasing water use efficiency in modern irrigation systems and the use of unconventional water resources such as saline and brackish water are the most effective strategies for optimal use of water resources in agriculture. In this regards, nowadays drip irrigation using saline water has been considered for various crops in many parts of the world (Wan et al., 2012; Wan et al., 2013). The studies show that drip irrigation can distribute water uniformly, and control the amount of water used precisely, moreover it aids in increasing plant yields, reducing evapotranspiration and percolation, and decreasing the dangers of soil degradation and salinity (Karlberg and Frits, 2004). Growth retardation is the most important response of plants to soil salinity. With an increasing solute concentration to more than the root threshold of the plant, the growth rate and plant size declines. Irrigation methods can affect the plant response to salinity. Drip irrigation, with its characteristic low rate of water usage and highly frequent irrigation applications over a long period of time, can retrain a high soil matric potential in the root zone thus compensating the decrease of osmotic potential introduced by the saline water irrigation regimen, and the constant high total water potential that is maintained for crop growth. At the same time, well-aerated conditions can be maintained under drip irrigation. Hanson et al. (2010), stated that the only way to solve the problem of soil salinity and drainage in California is the improving of irrigation methods such as the use of drip irrigation. Kang et al. (2010), studied the effects of drip irrigation with saline water on maize yield. Results indicate that irrigation water with a salinity <10.9 dS/m did not affect the growth of maize. As the salinity of irrigation water increases, seedling biomass, plant height, fresh and dry weight of maize decreases. The decreasing rate of the yield for every 1 dS/m increase in salinity of irrigation water was about 0.4–3.3%. Irrigation water use efficiency (IWUE) increased with the increase in the salinity of irrigation water when salinity was <10.9 dS/m. Wan et al. (2012), tested the feasibility of growing maize in a highly saline wasteland with drip irrigation. The results showed that drip irrigation created favorable soil conditions for maize growth through the forming and maintaining of a high moisture and low salinity region in the root zone when the SMP(soil matric potential) was maintained higher than −25 kPa. This research suggests that drip irrigation can be successfully used in dry and highly saline conditions after appropriate management strategies are adopted; therefore, Drip irrigation has been regarded as the most advantageous method for applying saline water to crops when proper management strategies are used. The irrigation water can be used in a mixture of saline water with fresh water (mixing) or saline water which can be applied in cycles with fresh water (alternative). The selection of an applicable strategy depends on many factors such as water salinity levels, availability of water with different qualities, the relative tolerance of the various crops at different stages of growth, soil properties and the cost-benefit analysis of each strategy. Malash et al.(2005), The effect of two water management strategies i.e. alternate and mixed supply of fresh and saline water in six ratios applied through drip and furrow method on tomato yield and growth, and salt concentration in the root zone were investigated in Egypt. The highest yield obtained was due to the combination of drip system and mixed management practice using a ratio of 60% fresh water with 40% saline water. Abdel Gawad et al. (2005), In order to assess the effects of management on crop production with saline irrigation water, many experiments were conducted using mixing and alternating (cyclic) irrigation management techniques, along with traditional furrows and drip irrigation methods, using different water qualities, and different tomato varieties. The results showed that higher efficiency in water use and higher yields using drip irrigation and mixing management were obtained as compared to traditional methods and cyclic strategy.

Maize tolerance threshold to water and soil salinity is 1.1 and 1.7 ds/m respectively, and it is therefore a moderately sensitive plant to salinity (Mass et al., 1983). Khuzestan is one of the most important regions where maize is cultivated in Iran ; whatsmore this region has the, greatest volume of saline water resources in Iran. The purpose of this study was to investigate the effects of drip irrigation with saline water utilizing irrigation management strategies, by mixing , one-alternate and half-alternate of saline water with fresh water, on the yield, and the irrigation water productivity of corn under salinie soil conditions.

Materials and methods

Experimental site and natural conditions

The experiments were conducted in 2013 at the Agricultural Experimental Station of the Faculty of Water Sciences of the Shahid Chamran University in Ahvaz, Iran(latitude 31 North and longitude 41 East). Metrological data during the experimental period and soil characteristics are shown in tables 1 and 2, respectively. The soil at the experimental site was a silt loam type, and the electrical conductivity of saturated paste ranged between 2.5 and 3.45 dS.m-1. The total pan evaporation was 1407 mm during the whole growing season (Figure.1).

Experimental design

The experimental design was a split plot, in which, water management strategies were applied to the main plots and the subplots were irrigated with four salinity levels of irrigation water i.e. 2.5 (control), 4, 6, 8 dS/m as S1, S2, S3, S4, respectively. The experimental plots were arranged in a completely randomized block design with three replications. The management options were mixing (M1), one-alternate (M2) and half-alternate (M3) of three levels of saline water (S2, S3 and S4) with water abstracted from the Karun river (S1). Maize (SC-704) was sown in 2.25×3.5m plots. The field area was 405 m2 including 36 plots where the distance between any two adjacent plots was 1m. Irrigation water analysis are shown in Tables 3. Other practices such as pest control and fertilization were carried out during the season.

Table 1. Weather data during maize growing period

Month	Temperature(°C)		Cumulative rainfall (mm)	Relative humidity(%)
	Minimum	Maximum		
July	24.4	50.2	0	78
August	22.6	48	0	85
September	20	46.4	0	91
October	9.6	42.4	0	78
November	9.4	33.8	56.7	96

Table 2. Soil properties in different soil layers.

depth	Soil texture	ρ_b(gr.cm^{-3})	EC(ds.m^{-1})	PH	F.C(%)	P.W.P(%)
0-30	**Si-L**	**1.4**	**2.5**	**7.5**	**32**	**15**
30-60	**Si-L**	**1.55**	**3.2**	**7.65**	**32**	**15**
60-90	**Si-L**	**1.6**	**3.45**	**7.8**	**32**	**15**

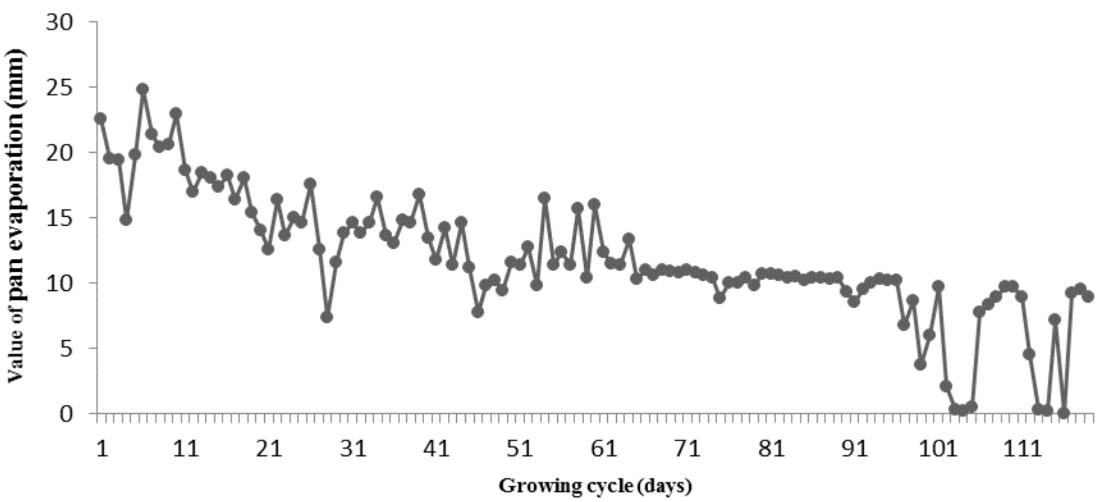


Figure1. Values of pan evaporation in growing cycle

Table 3. Chemical analysis of irrigation water

Salinity levels	EC(ds.m^{-1})	PH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	$Hco3^{-}$	cl^{-}	$So4^{2-}$
			(meq.l^{-1})						
S1	2.5	7.42	7.3	4.09	13.7	0.07	3.4	11.37	9.79
S2	4	7.5	14.5	8.3	23.2	0.09	3.36	38.6	9.17
S3	6	7.45	19.2	8.67	37.6	0.1	3.23	41.35	11.73
S4	8	7.8	21.2	9.8	39.6	0.11	3.47	49.8	12.02

Irrigation

The farm was irrigated using drip irrigation tapes with emitter spacings of 20 cm and the output flow rate of 2 L.h-1. The irrigation scheduled was based on the soil moisture content(SMC). To determine soil moisture during the experiments soil samples with three replications were obtained using an auger at the depths 0-30, 30-60 and 60-90 cm before every irrigation in the control group. soil samples was used to determine the soil moisture content (SMC) using a oven-dry method at 105°C for about 24 h. Irrigation depth was determined according to following equation: $dn = (FC - \theta_v) \times Z / 100$

Where: dn is the irrigation water depth(mm); FC is the volumetric soil water content at field capacity(%); θ_v is the volumetric soil water content before irrigation(%); Z is the root depth. The total irrigation depth was controlled using a water meter.

Sampling and analysis

During the period and at the end of the experiments, soil samples at depths of 0-30, 30-60 and 60-90 cm were collected to determine the level of salinity in the soil in all treatments. For each sample, the electrical conductivity of the saturated extract (ECe) was determined.To evaluate the effect of treatments on grain yield, plant samples were taken from each plot at the end of the experiments. Dry weights were measured 48 hours after the placing of fresh samples in an oven at 105°C ; in addition the grain yield was also determined. Water productivity was calculated by dividing grain yield over the used water. The data obtained from experiments were analyzed standard statistical software that is SPSS and MSTATC.

Results and Discussion

Irrigation management and salinity effect on maize yield and water productivity

The comparison of average grain yield and water productivity for different management statratigies and various salinity levels was done with using a Duncan test (table 4). The obtained results show that in the mixing strategy (M1), grain yield is reduced from 7.31 to 5.52 ton/hectare. This means that with the increasing of irrigation water salinity from 2.5 to 5.5 ds/m, maize yield 24.5 % decreases atabout 8 % per unit with the increase in water salinity. Where as Kang et al (2010), reported this as much less for maize under drip irrigation conditions with saline water. It seems that the main reason for this difference is the irrigation scheduling methods of two studies. In M2 management, the grain yield drops from 7.23 ton/hectare in control treatment to 4.63 ton/hectare in S4 salinity; which in itself is equal to 36 %. In other words, the grain yield of M2 management strategy decreases about 12% more than M1 management. In M3 management, the grain yield drops from 7.17 in S1 to 6.02 ton/ hectare in S4 salinity, thus the amount of yield reduction is equal to 16%. Here, despite a 16% decline in yield, there is no significant difference between M3S1 and M3S4 treatments. A review of the compared averages shows that the greatest effect of management on yield occurs in high salinity areas. Water productivity decreases with salinity increase in all three strategies, also. In S4 salinity the value of this index for M1, M2 and M3 is defined as 0.89, 0.47 and 0.96 kg/m3 respectively, which in itself shows that the highest value occurs in M3.

Table 4. Maize grain yield and water productivity mean in different treatments

treatment	Grain yield (ton.h^{-1})	Water productivity (kg.m^{-3})
M1S1	7.31a	1.17a
M1S2	7.09ab	1.14abc
M1S3	6.12abcd	0.98bcde
M1S4	5.52de	0.89ef
M2S1	7.23ab	1.16ab
M2S2	6.99abc	1.12abc
M2S3	5.83cd	0.93de
M2S4	4.63e	0.74f
M3S1	7.17ab	1.15ab
M3S2	7.03abc	1.13abc
M3S3	6.66abcd	1.07abcd
M3S4	6.02bcd	0.96cde

Values in a column followed by the same letter are not significantly different at P≤0.05.

Salinity – yield models under different irrigation management

The values related to the tolerance threshold ECe and slope of the yield reduction per salinity increase unit in different management scenarios has been calculated and is shown in table 5. The results indicate that the value of threshold ECe for M1, M2 and M3 are 3.86, 3.98 and 4 respectively' where highest value is related to M3 and the lowest is related to M1. On the other hand, the slope of yield reduction for M2 and M3 are the highest and lowest value respectively. In other words, the amount of yield reduction per soil salinity increase in unit in M3 is lower than the other two strategies. The plants reacts to the average salinity of root region, where the highest amount of water extraction is done. The highest absorption is done in theupper root region and M3 management causes that this layer of soil to be leached better, so the lowest yield reduction occurs. Finally, the salinity of the soil saturation extract which causes a reduced yield of 25%, 50% and 75% using derived models for each management method has been calculated (table 6).

Table 5. coefficients of yield-salinity model for different strategies

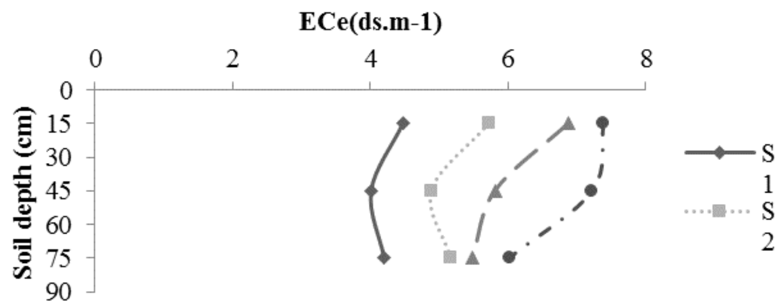
Irrigation management	Threshold EC_e ($ds.^{-1}$)	Yield reduction coefficient ($\%ds.m^{-1}$)	R^2
M1	3.86	9.86	0.91
M2	3.98	12.3	0.85
M3	4	7.14	0.97

Table 6. ECe for different percentages of yield reduction ($ds.m^{-1}$)

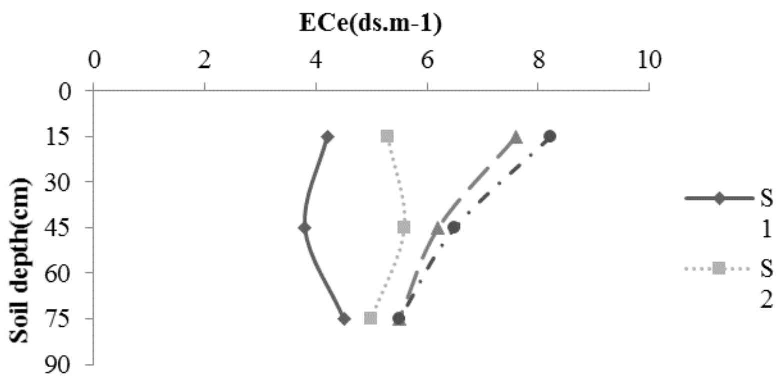
Irrigation management	%25	%50	%75
M1	6.4	8.93	11.47
M2	6	8.04	10.07
M3	7.51	11	14.5

Salinity distribution in the under point of the dripper

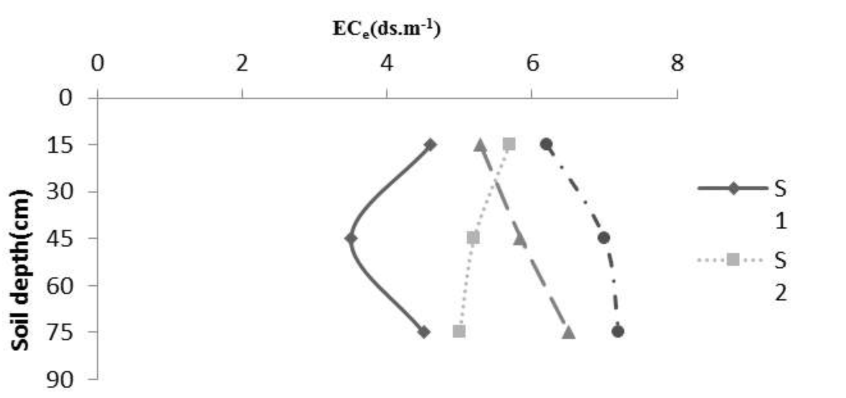
Salinity distribution in the soil profile under different scenarios is shown in figure 2. The Comparison of the figures shows that irrigation management has an effecton salinity distribution in the soil. The first point observed from the comparison of three management strategies, is that in M1 management, salinity distribution is a more regulated trend than the the two other alternative management strategies. Other salinity changes in M2 and M3 strategies are due to the alternative use of water with different salinity that creates a different salinity profile in the soil. Malash et al (2005), research results are consistent with the above results. The highest amount of soil surface layer salinity occurs in M2 management. Since, the greatest density of the plant root is in surface layers ; hence as per uptake patterns, the highest uptake occurs in the surface layer, so in M1 management because of the osmotic potential reduction, water total potential isreduced and plant water uptake is more difficult.



M1



M2



M3

Figure 2. Salinity distribution under different strategies

Conclusion

Drip irrigation, with its characteristic of low rate and high frequent irrigation applications over a long period of time is able to maintain high soil matric potential in the root zone thus compensating for the decrease of osmotic potential which is introduced by saline water irrigation, in addition to the maintaining of a high, constant potential ofwater for crop growth. Moreover, well-aerated conditions can be maintained under drip irrigation. The results of this research showed that the half-alternate management (M3) of fresh and saline water can improve yield performance, water productivity and soil surface leaching using drip irrigation with saline water. The Yield reduction coefficient in M3 management has been shown to be 7.14 which when compared to the mixing and one-alternate strategies (9.86 and 12.3) is at a lesser rate; therefore, sustainable management of irrigation using saline water not only prevents a decline in the level of production. But it also results into land stability.

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FLUCTUATING WATER TABLE QUANTIFICATION USING SATURATED EXCESS WATER CONCEPT (SEW-20 AND SEW-40) AT THE RECLAIMED LOWLANDS OF INDONESIA

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Abstract

Water table within the farm, at the reclaimed lowlands of Indonesia to be used for food production, plantation and pulp wood tree, is a key indicator. The water table position is a function of topography, drainage systems, rainfall, evaporation, crops, operation and maintenance, within a given water management unit. Fluctuation of water table within the farm can be quantified using "Saturated Excess Water - SEW" concept within limit of -20 cm (SEW-20) or -40 cm (SEW-40) below the soil surface. The paper will explain the results of SEW-20 and SEW-40 during one year period covering the rainy and dry months. The value of SEW-20 during the year especially the number of days related with the paddy cropping time. The paddy will be planted if the SEW-20 is more than 120 days. On the other side, the value of SEW-40 will be related with the corn cropping pattern. Corn will be planted when the value of SEW-40 is between 80 to 100 days. The development of rooting zone of rice and corn are determined by the position of water table. The plantation crops and trees would prefer as higher as possible values of SEW-40 during the year.

KEY WORDS: Water table fluctuation, Saturated excess water, SEW-20, SEW-40.

Introduction

Lowlands (swamp lands) in Indonesia is 33 million hectares, consisting of 20 million hectares (60.2%) is a tidal swamp lands and 13 million hectares (39.8%) is non-tidal swamp lands (Dit. Rawa dan Pantai, Departemen PU, 2009). Development of swamp lands for food crops, have excellent prospects in an effort to meet their food needs. This is due to the reduction in productive agricultural land (technical irrigation) due to land conversion for residential, industrial, and other non-agricultural activities. Swamp land reclamation for agriculture has been made by the

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Government of Indonesia since 1969, but the Bugis traditional farmers have opened swamp lands for agriculture and plantations since the 1930s.

A lot of research activities have been done in order to increase production and cropping index (IP) on agricultural swamp lands. At the beginning of reclamation, water management network system built is still an open network system with the main function for drainage. Water regulation are still fully dependent on natural conditions, so the ability of water management services is still very low. In an open network system, the type of tidal flood water becomes a major consideration in the application of the farm system. Noorsyamsi et al. (1984), Widjaja-Adhi et al. (1992), Euroconsult (1996), and Nugroho (2004) classifies the type of overflow on tidal swamp lands based capabilities overflowing tide.

With the construction of water-gate control, then some basic technical issues in agricultural development swamp lands begin to be solved. According to Susanto (1995), the development of tidal swamp lands agriculture require water management at the macro level (the river), meso (hydraulic structures), and micro (plots in farmland level). The rivers are bordered by a reclaimed area, rainfall and tidal water level fluctuations will determine the condition of the water at the macro level. The nature and characteristics of the root zone will be affected by water management at the micro level associated with conditions at the macro level through hydraulic infrastructures (meso level). The design, operation, and maintenance of hydraulic infrastructure must consider the condition of the water at the macro and micro levels.

Suryadi (1996) used the land hydro-topography conditions for preliminary consideration in planning for water management in tidal swamp lands. Hydro topography land is a relative comparison between the surface elevation with the surface water level in the river or nearby channels. Furthermore, Susanto (1998) combines the concepts of land and hydro-topography consideration SEW-30 as a system of evaluation of the status of water in secondary and tertiary blocks. The same system was also reviewed by Edrissea et al. (2000) by using the concept of SEW-30 and DRAINMOD.

According to Susanto (2000), water management will affect groundwater levels in the area. Surface water level in tidal swamp lands fluctuates according to time and space. Control efforts should be made so that the surface water level can support plant growth. Control of surface water level at a specific depth can be done through the strategy planning and/or reclamation network maintenance operations. Consideration of topography, rainfall, tide, type of soil, the type of plants, the depth of layers of pyrite and reclamation system parameters must be done in an integrative manner to support the water management. Objectives of management strategy for water management in swamp lands are to maintain the quality of soil and water, ensure adequate water for the plants, and remove excess water.

This article presents the results of quantification of groundwater level fluctuations in the land with the concept of SEW-20 and SEW-40, so that the pattern and timing of planting can be determined in accordance with the distribution of the depth of the surface water level in a year.

Materials and Methods

The study was conducted in two areas of tidal swamp lands in Banyuasin, South Sumatra Province, Indonesia. Site selection is based on the difference in land hydro topography conditions. The first location in an area of reclaimed land in Delta Telang I is a type B with land elevation 1.27 to 1.34 meters above sea level. Type B land is land that can only be throbbing by the great high tide only, flooding is not take place every day (only occurs on a large pairs in the rainy season), and the drainage lasts longer. Subsequently, a second location in the area of land reclamation Delta Saleh is a type C with land elevation 2.03 to 2.12 meters above sea level. Soil type C is not throbbing tide although when the tide is great, but the surface water level in the soil is influenced by tidal fluctuations.

Observations depth of the surface water level is done through shallow wells (wells) are made of PVC pipe with a length of 3 meters and a diameter of 2.5 inches. The pipe is perforated at the sides and then coated with fibers and planted at a depth of 2.5 meters from the ground. The top of the pipe hole is closed and only opened at the time of observation. Surface water level depth measurement is conducted every day between the hours of 7:00 to 08:00 pm. Furthermore, observations of precipitation is conducted every rainfall event by means of a graduated rainfall manual (ombrograph type observatory) and cup of measuring.

Quantifying fluctuations in groundwater levels in the area are calculated using the concept of Saturated Excess Water (SEW). The calculation result SEW-20 and SEW-40 may show the position of surface water levels at, above and / or below a depth of 20 cm and 40 cm from the surface of the land that is expressed in days per year.

Results and Discussion

Development of swamp lands for cultivation of crops require the management for network of macro water to control groundwater levels in the area, and the network of micro water management to control the level of ground water in the area. Cultivation system in swamp lands must consider the condition of hydro-topography. Hydro-topography of land can be used as a guide to what extent the possibility of flood water may inundate the land, and vice versa for flooding that there can be drained. Hydro-topography is defined as the relative ratio between the elevation of land with the water level of the river or the water level in the canal nearby (Euroconsult, 1996).

In order to optimize control of the surface water level in tidal swamp lands, Ngudiantoro (2009) construct a mathematical model to estimate the groundwater level fluctuations, so the control of surface water level at a certain depth can be done by controlling the water level in the channel.

Furthermore, Ngudiantoro et al. (2011) conducted to manipulate the water system to support increased production and cropping index on tidal swamp lands. By doing network engineering based on characteristics of the water system hydro topography, hydro climatology, as well as the physical and chemical properties of the soil, the cropping pattern can be adjusted as desired.

One of the factor that affect the natural depth of the surface water level in the soil is rainfall. Distribution and thickness of the daily rainfall observations at both locations are shown in Figures 1 and 2.

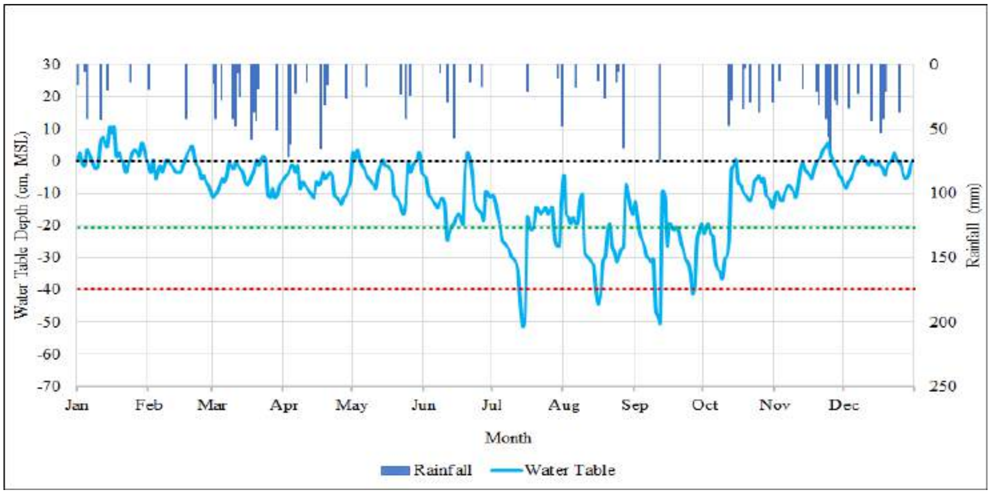

Figure 1. Rainfall and water level fluctuation of the land type-B in Delta Telang I

Figure 2. Rainfall and water level fluctuation of the land type-C in Delta Saleh

Number of rainy days in the Delta Telang I is 70 days with the maximum daily rainfall of 74 mm/day, whereas in Delta Saleh occurred 101 rainy days with the maximum daily rainfall of 96 mm/day. Although the rain events in Delta Saleh more and the maximum rainfall is also bigger than the Delta Telang I, but the total rainfall in the Delta Saleh just 1.255 mm/year, less than the total rainfall in the Delta Telang I, that is equal to 2.218 mm/year. The average daily rainfall in the Delta Telang I is 6.1 mm/day, whereas in Delta Saleh of 3.4 mm/day.

In addition to the rainfall, land topography, hydro conditions also affect surface water level fluctuations in the land. The condition of surface water level relative to the dry season, both Delta and Delta Telang I Saleh. The range of the depth of the surface water level in the Delta Telang I was not too wide, these conditions are different from those in the Delta Saleh. This is caused by differences in rainfall and hydro-topography. Differences in surface water level condition at both locations was evident when seen from the calculation SEW. In summary, the results of calculations SEW SEW-20 and-40 at two different locations are presented in Table 1.

Table 1. Summary for surface water level calculated of SEW-20 and SEW-40

Parameter (cm)	Land Hydro-topography	
	Type B	Type C
High water table (WT)	+10.6	+4.3
Low WT	-51.4	-80.7
Frequency of flooded	59	7
Frequency for WT below 20 cm	294	98
Frequency for WT upper 20 cm	71	267
Frequency for WT below 40 cm	355	150
Frequency for WT upper 40 cm	10	215

Table 1 shows the difference significant for water status at two different locations. SEW calculation results based on observations of water level fluctuations in the land, Delta Telang I indicate: a) the highest surface water level +10.6 cm above the soil surface and the lowest was -51.4 cm below the ground surface; b) Frequency of flood on land spread over 59 days per year (16.16%); c) The frequency of the depth of the surface water level is less than 20 cm dispersed in 294 days per year (80.55%) and more than 20 cm dispersed within 71 days per year (19.45%); and d) The number of times the depth of the surface water level is less than 40 cm dispersed in 355 days per year (97.26%) and more than 40 cm spread within 10 days per year (2.74%).

Furthermore, the calculation results in Delta Saleh SEW indicate: a) the highest surface water level +4.3 cm above the soil surface and the lowest was -80.7 cm below the ground surface; b) Frequency of flood on land spread over 7 days per year (1.92%); c). The frequency of the depth of the surface water level is less than 20 cm dispersed within 98 days per year (26.85%) and more than 20 cm dispersed in 267 days per year (73.15%); and d) The number of times the depth of the surface water level is less than 40 cm dispersed in 150 days per year (41.10%) and more than 40 cm dispersed in 215 days per year (58.90%).

Related to the farm system, if the depth of the surface water level is less than 20 cm with a frequency of more than 120 days, is suitable for rice. However, if the depth of the surface water level is more than 20 cm with a frequency of 80 to 100 days, then the plant from which is corn.

In the implementation, the condition of the surface water level in the land must be controlled according to need. Control of surface water level in tidal swamp land is a key process that must be done properly through water management, both at the macro and micro levels. Water management at the macro (macro water system) that is water management which starts from the main river channel then the primary and secondary channels, whereas water management at the micro level (micro water management) include water management at the tertiary level, quarter, and farmland.

Micro water management will directly determine the environmental conditions for plant growth. It would be done well if in tertiary channels already available for water control infrastructure. Water gate to control the water in the channel, the water intake at the time of high tide and low tide when the drainage in accordance with the requirements of water for crops.

If water quality is decent (not salty or sour), the inclusion of water to farmland can be done to ensure adequate water for crops and improved soil quality. In certain circumstances, a puddle on farmland need to be maintained for many purposes. Inundation of land in a relatively long time should be avoided to prevent the formation of toxic substances in the soil.

Drainage is done in case of excess water on farmland. Drainage is also required on certain conditions such as prior to fertilization, at harvest time, or when the soil and water quality to deteriorate. Drainage can be done by opening the floodgates in tertiary channel at low tide, and shut the door the water at high tide. In certain areas, the drainage that is too deep can cause the risk of oxidation of pyrite below the soil surface.

If the groundwater level drops to a depth of more than 40 cm below the ground surface, it is necessary to retention of water to prevent water shortages and creates the environment for the absorption of nutrients needed by plants. Water retention can be done by closing the sluice gates at tertiary channel at low tide and opened water at high tide. Water retention should not be done in a long time to prevent the formation of toxic substances in the soil.

Conclusion

From the results of the evaluation of the status of water with the concept of SEW-20 and SEW-40, it can be concluded that:

1. Land type B in Delta Telang I suitable for agro-ecosystem with water saturated conditions, namely rice crops, while the C-type land in the Delta Saleh suitable for corn crops.

2. The cropping pattern matching on lands type B in Delta Telang I was rice-rice-corn. The planting season I and II (November-June) is for rice, while the third growing season (July-October) to corn plants.

3. The cropping pattern matching on land type C in Delta Saleh was rice-corn-corn. I cropping season (November-February) is for rice, while the second and third growing season (March-October) to corn plants.

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EXPERIMENTAL PERFORMANCE EVALUATION OF THREE DRAINAGE METHODS FOR PREPARATION OF SECOND CULTIVATION IN PADDY SOILS

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Abstract

Paddy fields have the ability of multi-cultivation as compared to other crops. Low permeability rate and long term waterlogging of paddy soils cause serious problems for non-rice crops. Therefore, the aim of this study is to evaluate three different drainage methods including: 1- surface drainage, 2- subsurface pipe drainage and 3- trench drainage (filled underground trench with high-permeable material along with drainage pipe). Experiments were implemented in a physical model capable of the simulation of 7.5 meters drain spacing. Drainage water and soil moisture at different depths and distances from the drain pipe were measured. The results showed that the drainage of water via trench drainage was far more than other methods; nonetheless, the performance of trench drainage in the reduction of soil moisture was better. The required time for the top soil to reach its lower plastic limit in the subsurface, trench and surface drainage systems were obtained 26, 22 and 16 hours from the start of the experiments and 14, 11, and 15 hours after the depletion of excess water over the soil surface, respectively. Although surface drainage represents in faster depletion of excess water; eventually, the trench drainage proved to be the most effective alternative to provide appropriate qualifications for second-cultivation operations.

KEY WORDS: Physical model, Hardpan, Trench drainage, Soil moisture.

Introduction

Population growth, and consequently the necessity to produce more foodstuffs has caused the excessive utilization of water resources in recent decades. In the next 25 years, it has been predicted that agricultural cropping water requirements will increase twofold (Ritzama, 2007). On the other

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hand, the excess usage of water resources; especially in arid and prone to drought areas have brought about the current water crisis. In such critical circumstances, one of the means of enhancing agricultural production is the optimal and multi-application of agricultural crops with minimum water requirements on farms. According to the Food and Drug Organization reports, rice which is one of the most important and widely used agricultural products provides nutrition of four billion people around the world (FAO, 2010). Paddy fields due to its inherent characteristics, provides a highly moist medium for the growing of rice. In these farms, the top layer of the soil is puddled and deformed to form paddy fields. In puddling, a highly low permeable layer is formed below the top-layer called hardpan. Based on several studies carried out in the Gillan province of Iran, the hardpan of paddy soils has a heavy texture and a low permeability and its infiltration rate is reported as being 1.5 millimeters per day (Razavipour, 2005; Mousavi, 2008, Kamyab, 2008). The low permeability of hardpan causes soil to become waterlogging and saturated and thus unable to reduce and drain extra moisture in an appropriate period of time. As opposed to rice, other agricultural crops are almost incapable of tolerating long-waterlogging or highly humid soils. Therefore, insufficient soil root zone aeration causes stress and even mortality of crops (Greenland, 1985). Hence, in spite of all the potential capabilities inherent in paddy fields such as ease of access to certain water resources, they remain useless and multi-cultivation almost does not exist subsequently (Darzi Naftchali & Shahnazari, 2014). In addition to the problem of the low permeability of paddy soils, in most cases, precipitation is generally intensive in rice cultivation areas. Natural soil drainage due to lack of appropriate infiltration rate is unable to convey the excess water out of the crop root zone, thus mechanization and field operation procedures for a second-cultivation are nearly impossible (Tabuchi, 2004).

The artificial drainage of paddy fields is one of the operational solutions for paddy soil without any destruction and any substantial change in the soil structure. In some cases, the existence of drainage systems is mentioned as being indispensable (Yazdani, 2007). Appling adaptable drainage system enables multi-cultivation in paddy fields. Specific soil structures and layers in paddy fields make the drainage process different form the conventional drainage of soil. Despite the lack of widespread application of subsurface drainage in Iran, several research studies have investigated the effectiveness of subsurface drainage systems in paddy fields (Soong & Wei, 1985; Karimi et al., 2009; Dzhumabekov, 1996; Darzi-Naftchali et al., 2013).

Inadequate research in the field regarding different paddy drainage and also the planting of a second-cultivation in these farms indicate the importance of this research. The main objective of this study was to evaluate three drainage methods including surface drainage and two types of subsurface drainage; conventional pipe drainage and filled trench with pipe drainage which is known as trench drainage (Tabuchi, 1985). Indeed, the capability of these drainage methods for the depletion of excess water and the reduction of soil moisture within a certain time in order to make second-cultivation in paddy fields feasible is a very important issue. In fact, the rapidity and rate of drainage in minimum time is of great importance.

Materials and methods

In order to evaluate the performance of drainage methods in paddy soils, a physical model was constructed. This model is capable of simulating several drainage methods and providing an evaluation of drainage methods by furnishing measurement implements.

Experimental site layout

The experiments were carried out in the Water and Meteorological Research Center affiliated with the faculty of Agriculture and Natural Resources at the University of Tehran, Karaj, Alborz province in 2015. The physical model was located outdoors in order to create a more realistic environment. The experimental site had a Mediterranean climate with a rather warm summer and 250 millimeters average annual precipitation.
A physical model was built from a metal box 3.75,1,1 meters in length, width and height, respectively; the box was enhanced by piezometers, TDR[1] probes and drainage and a deep infiltration collector container. The dimensions of the box were chosen in such a way that it simulates half of the drainage system at 7.5 meters intervals.
The schematic of the physical model is shown in Figure 1 which consist of: 1-Top soil layer (Puddling layer) 2-Hardpan soil layer 3- Bottom soil layer 4- Surface drainage location 5- trench drainage location 6- Water table control encasement 7- Water table (equal to the center of the drainage pipe) 8-water table control valve 9- Deep percolation outlets 10- Surface drainage collector 11- The subsurface drainage coating area 12- Drainage pipe (10 cm Diameter) 13- High permeable layer to transfer deep percolation to outlets. The properties of different soil layers are presented in Table 1.

[1] Time Domain Reflectometry

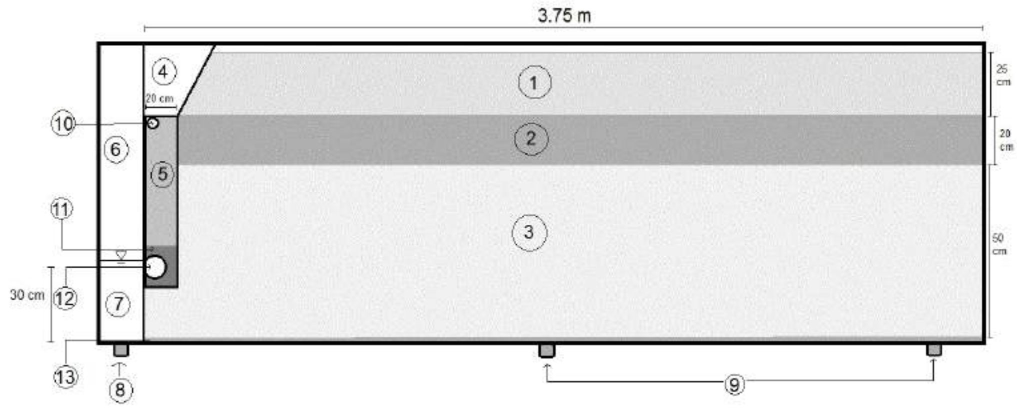

Figure 1. Schematic view of the physical model

Piezometers were placed at various depths and lengths of the metal box in order to observe the water table at different distances from the drain. Also, several TDR probes were placed in different soil layers at different depths and distances from the drainage to measure soil water content. For more reliability, TDR measurements were calibrated for different soil types corresponding to different layers. In order to measure the drainage volume and rate, degraded containers were used. Based on the predominant soil structure and texture in paddy fields, the depths, thicknesses and textures of soil layers were supplied and their characteristics shown in Table 1. In order to assess the paddy farm in terms of preparedness for second-cultivation and mechanization, a lower plasticity level (LPL) criterion has been applied. The LPL of top soil were measured to be 33 percent of the volumetric water content of the soil.

The Drainage systems were tested in the physical model sequentially. To start each treatment, the soil profile was completely saturated and a five centimeters water depth was specified on the surface; due to predominant rice crop submergence. The experiments would resume until the average top soil moisture reached the LPL level.

Table 1. Soil charactristics of different layers

Soil layer	**Thickness (cm)**	**Soil texture**	**Clay (%)**	**Silt (%)**	**Sand (%)**	**Bulk density (g cm^{-3})**	**Saturated water content (cm^3 cm^{-3})**	**Field capacity (cm^3 cm^{-3})**
Top	25	clay loam	31.4	42.2	26.40	1.34	51.0	41.0
Hardpan	20	clay	50.56	25.34	24.10	1.22	57.0	43.0
Bottom	50	loam	13.68	41.61	44.71	1.3	47.0	39.0

Drainage treatments

In this research, three drainage methods including: 1- Surface drainage, 2- Subsurface drainage (Pipe drainage) and 3- Trench drainage were evaluated.

The dimensions of the shallow surface drainage system are illustrated in Figure 2. In this system, half of the surface drainage canal was constructed based on half of the drain intervals simulation. Whatsmore, an excess of five centimeters of the width of drainage was considered to align the axis of the surface drainage and drainage pipe below the soil surface.

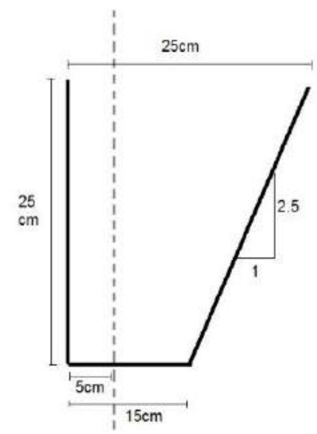

Figure 2. Dimensions of surface draiange

The subsurface drainage consists of a corrugated drainage pipe 10 cm in diameter. Half of the pores in the circumference of pipe was closed due to the simulation of half of the drainage intervals. The pipe was covered by high hydraulic conductivity materials as shown in Figure 3-B.

Trench drainage is a combination of subsurface and surface drainage,. This method extends its envelope materials above the drain pipe to reach the top soil by passing through the hardpan layer. This modification makes a higher hydraulic gradient towards a drainage pipe and connects the top soil to drainage pipe directly through a filled trench. The dimensions and schematics of the trench drainage were demonstrated in Figure 3-A.

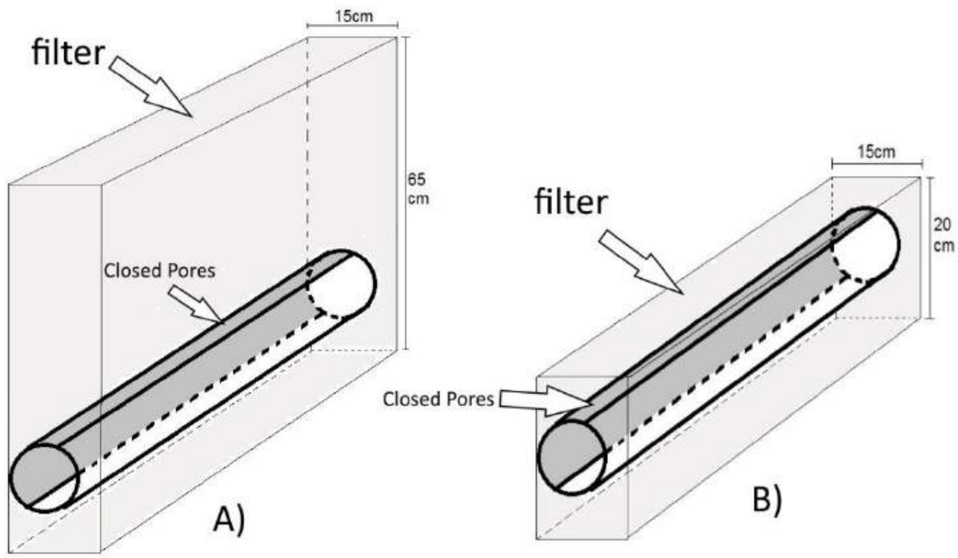

Figure 3. A) Trench drainage dimensions B) Subsurface drainage Dimensions

Results and discussion

The results of the different drainage methods performance on the drainage volume, the drainage discharge, soil moisture distribution and the water table were investigated. According to the results represented in Figure 4, the surface drainage was capable of draining the puddling layer quickly due to its hydraulic characteristics. Surface drainage was able to deplete 175 liters water from the soil surface in less than an hour; however, after that it became practically useless. While the two other drainage systems drained more water than the surface drainage; The Trench drainage was the most effective method for the draining of waterlogged layers and the excess soil moisture in as such that it drained 225 liters.

The hydrograph of the subsurface and trench drainage in Figure 5 indicates that the changes in the drainage discharge is intensive. The surface drainage discharge amount in comparison to other drainage methods is not analogous due to the quick operation of the surface drainage and becomes dysfunctional after the draining of the waterlogging layer.

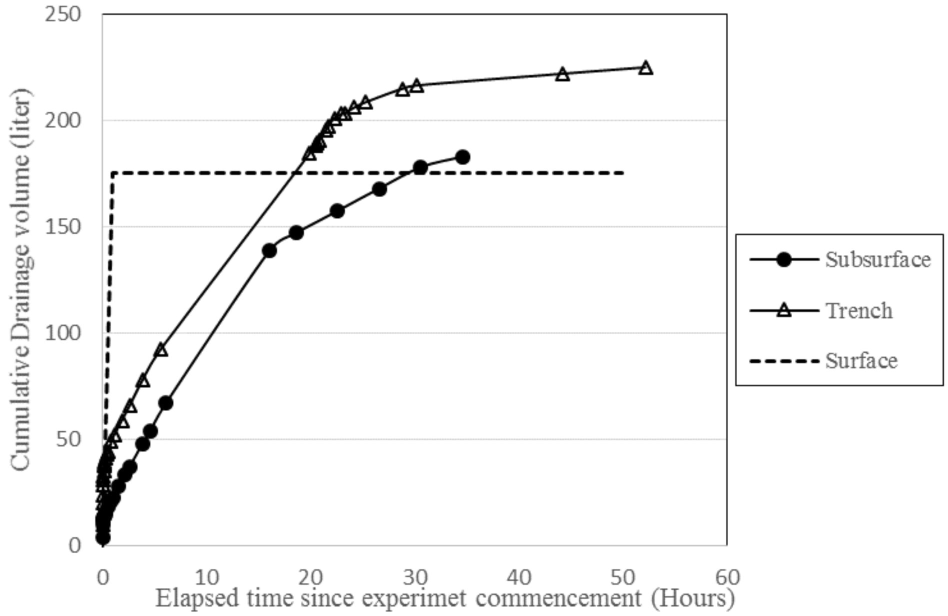

Figure 4. Cumulative drainage volume by Subsurface, Trench and Surface drainage

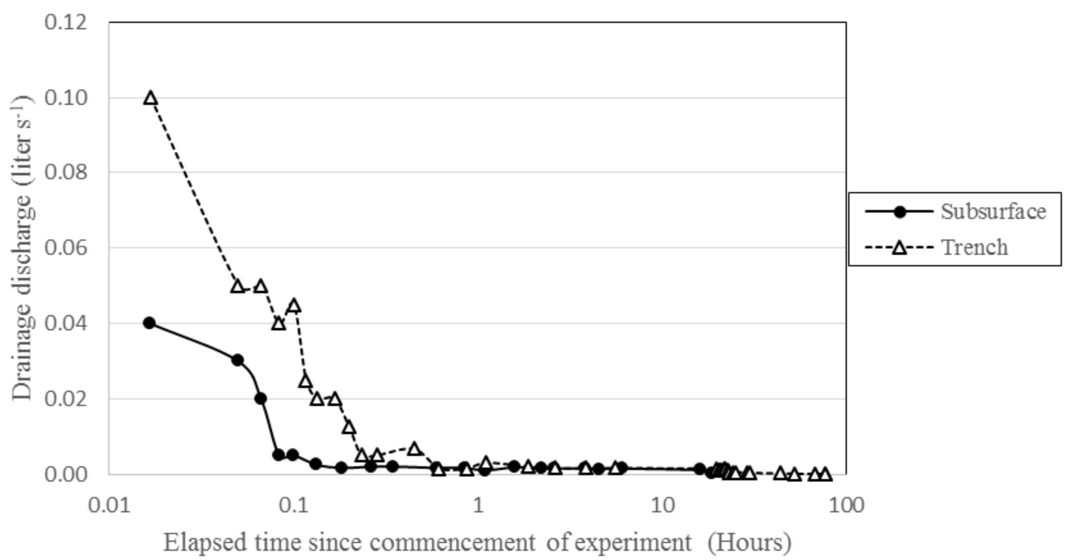

Figure 5. Drainage discharge hydrograph of Subsurface and Trench draiange

The average drainage coefficient of different drainage systems four days after the beginning of each experiment is estimated in Table 2. The results prove that trench drainage has a higher drainage coefficient as compared with the two other systems because of its improved structure.

Other research also indicated that the drainage coefficient of trench drainage is estimated from 10 to 20 millimeters per day (Ebrahimian & Noory, 2014).

Table 2. Average Draiange coefficient in four days since commencement of experiment

Drainage method	Drainage Coefficient (mm day^{-1})
Trench	15
Subsurface	12.33
Surface	11.67

In order to evaluate the performance of different drainage systems, the required time for reaching LPL moisture level was estimated as shown in Table 3. Based on the results, it has been observed that surface drainage reduces top soil moisture to the LPL level in less time (16 hours). The reason that caused surface drainage to be more effective is its ability to deplete the excess waterlogging water in less than an hour; while subsurface and trench drainage require a period of time to drain waterlogging layer. Since the draining of the waterlogged layer is relatively controllable by farmers in paddy fields and the objective of this research is to prepare of the top soil for second cultivation in terms of soil moisture., Therefore, the required time for reducing moisture of tops soils to LPL level after draining of the waterlogging layer is important because the cultivation period for the second crop (winter crop) is very limited due to frequent rainfall events. Based on this assumption, trench drainage, subsurface drainage and surface drainage were able to bring the top soil to the desired moisture level after 11, 15 and 14 hours, respectively. The low variation among the results of different drainage systems is probably due to the effects of climate condition. Experiments were carried out in high temperate days of the year that is in July and August; thus evaporation was shown to be effective in the reduction of top soil moisture.

According to (Figure 6), distributions of average moisture in different depths of soil for drainage methods were represented. Trench drainage proved that it has a better performance in depths of 12.5 centimeters from the soil surface so that the average volumetric moisture in this depth reaches 15% after 80 hours. Similarly Trench drainage demonstrated a better performance in reducing average soil moisture in 20 centimeters depth. No considerable soil moisture reduction occurred in the hardpan layer. Heavy soil texture and low hydraulic conductivity of the hardpan layer caused inefficiency of draining in this layer.

Table 3. Required time after commencement of experiment for reaching the average moisture of top soil to low plastic limit

Drainage method	Required time to reach the plastic limit (hours)	
	After the depletion of waterlogging layer	From start of experiment
Subsurface	14	26
Trench	11	22
Surface	15	16

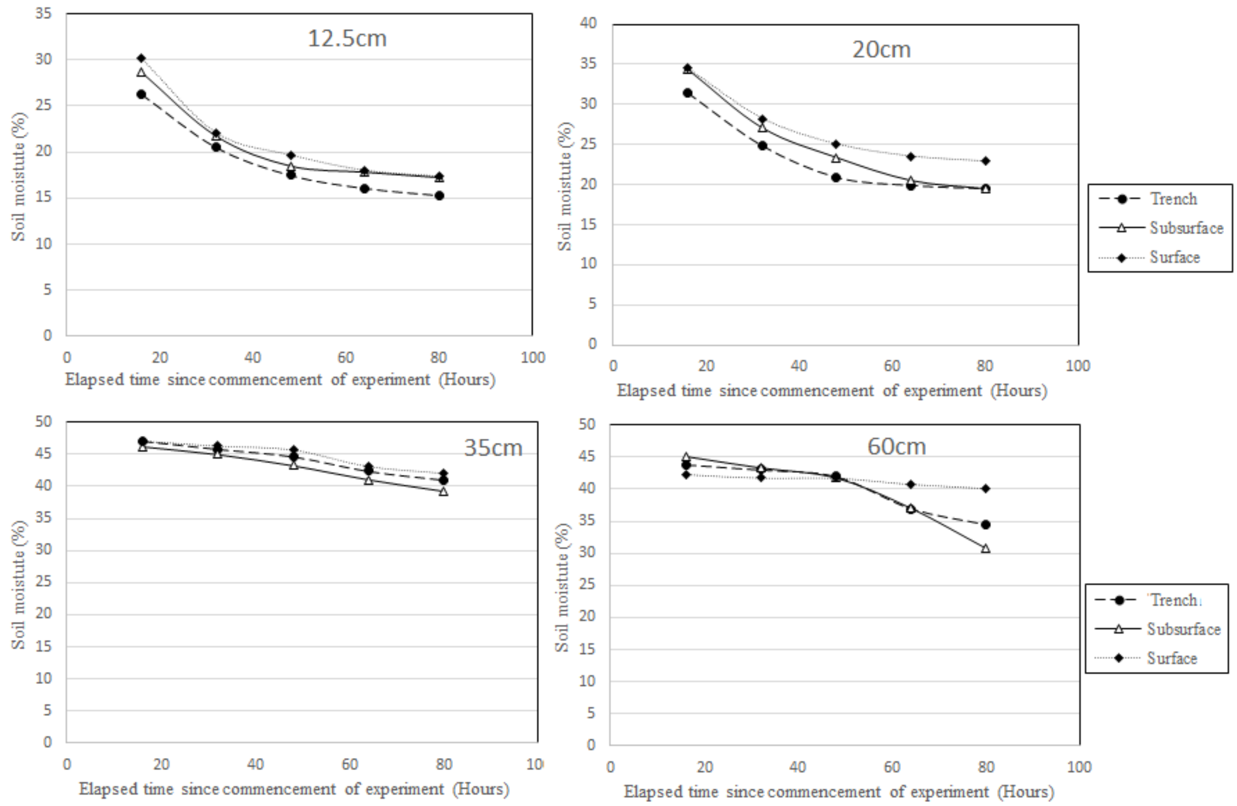

Figure 6. Distribution of soil moisture in different soil depths towards time in different drainage systems after draianing waterlogging condition

The variation of the water table towards the elapsed time after the beginning of the experiment in different drainage systems is illustrated in Figure 7. The Water table drawdown was greater for trench drainage than other drainage systems; the lower drainage flow resistance caused differences between the subsurface drainage and trench drainage. Due to the incapability of the surface drainage system for removing excess water from a deeper layer, it had no significant effect on the water table drawdown.

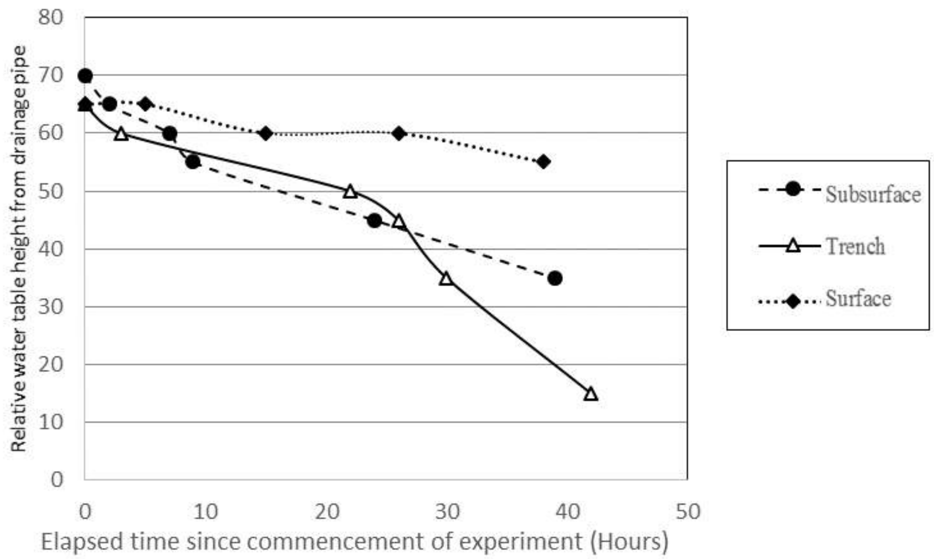

Figure 7. Variation of water table in the farthest distance from drain in different drainage systems

Conclusion

Three types of drainage systems with the aim of preparing a paddy field for second cultivation has been evaluated in this study. A comparision of different drainage systems shows that surface drainage is more capable of draining the retained water from the soil surface more easily than the other methods. Trench drainage which is an ameliorated type of subsurface drainageprovided better results in terms of drainage volume , the drainage rate, the reduction of top soil excess water in the case of post-depletion of waterlogging and water table draw down. Under specific circumstances of paddy fields, a drainage system is capable of draining and controlling excess moisture and the water table in the soil is more efficient. Trench drainage proved to be potential and useful in assisting farmers and stakeholders to exploit more income. It is recommended that futureresearch should in addition to the evaluation of drainage systems in actual paddy field condition, focus on the compilation of surface and trench drainage.

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PROPOSALS TO DIRECT AGRICULTURAL DRAINAGE WATER MANAGEMENT IN THE KHUZESTAN PROVINCE (KARUN-DEZ RIVER AREA) INTO A SUSTAINABLE AND INTEGRATIVE DIRECTION FOR PRESENT AND FUTURE SCENARIOS

Frank Riesbeck[1,*], Simon Dupree[1], Md Zillur Rahman[1,] Hamid Reza Khodabakhshi[2], Arash Mahjoubi[2]

Abstract

Khuzestan, a south-western province of Iran, is the main region of subsurface drainage in the area. Current drainage water management faces major challenges. In particular, high volumes of saline drainage effluent lead to far-reaching environmental, social, economic and political complications. This paper attempts to evaluate possible ways to overcome current inefficiencies. A focus will be put on solutions to achieve a sustainable integrative drainage management approach (IDWM) that focusses on agriculture as the main water consumer within Khuzestan. It integrates water re-use, drainage discharge possibilities, waste water treatment (desalination) and ways to increase water use efficiencies related to irrigation and leaching. All strategies aim to improve the current situation but also to redirect Khuzestan´s drainage water management into a sustainable manner within future scenarios. The ambition is to manage present and future drainage water flows but also future irrigation water supply by establishing monitoring, controlling and modelling structures affecting both water quality and quantity. Moreover, the relation between shallow and saline groundwater within agricultural irrigation and drainage systems plays a key role within agricultural drainage water management and will be examined in detail. The paper is based on collected data and factors of an ongoing empirical research project jointly with Humboldt University Berlin and Khuzestan Water and Power Authority (KWPA).

KEY WORDS: Drainage Water Quality, Integrated Drainage Water Management, Irrigation Control Systems, Methods of Irrigation and Drainage, Monitoring of Quality and Quantity Pollution, Salinity, Treatment Technologies, Water Reuse, Khuzestan, Iran.

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Introduction

The Karun-Dez River basin is subject to a semi-arid to arid climate with fertile but mostly heavy soils. Favourable climate conditions for crop production and water availability have transformed the area to one of the main agricultural production zones within Iran. However, because of low quality of water used for irrigation, low irrigation efficiencies, high salinity of soil and groundwater resources, inadequate drainage technologies, heavy textured soils with low infiltration rates and high evapotranspiration demands, the lands are facing several environmental and agro-economic challenges. One of the biggest challenges to overcome is to reduce the amount of saline agricultural drainage water (ADW).

Agriculture is the biggest extractor of fresh water resources within the Karun-Dez River basin, followed by the industrial and municipal sectors. The current share of water consumption by agriculture in Khuzestan is estimated to be around 88-92% (DADOLAHI-SOHRAB et al. 2012, GHADIRI 2014). This high percentage is related to the need to irrigate and leach agricultural lands in order to enable crop production and to overcome soil salinity problems within the region. Resulting ADW can be defined as the unconsumed part of the irrigation or leaching water applied to crops and soils. Attention, however, must be given the fact that drainage systems constructed in rural irrigated areas are themselves the recipients of foreign (non-agricultural) waste water and that the drainage water considered for reuse may not only have an increased salt content, but may also be polluted by return flows from a variety of other sources and other water users (Williardson et al. 1997).

In Khuzestan, salt has always been a natural part of the soil and groundwater resources and particularly the southern Karun River Basin is defined as a natural salt trap (Afkhami 2003). Subsurface drainage systems are often used in irrigated, waterlogged, agricultural lands in arid and semi-arid regions to reduce or prevent soil salinity. Here the primary goal of agricultural drainage is to remove the accumulated salts from the root zone and to control the secondary salinisation by lowering groundwater levels. With persistent use of irrigation without appropriate salt and drainage management, water quality continues to deteriorate and agricultural land gradually degrades with the elevated levels of salts (Qadir et al. 2015).

The main concern related to subsurface drainage in Khuzestan remains to be the extraordinary high volume of very poor quality drainage water. Even after reclamation periods the drainage outlet is in many cases 5-10 times more saline than the applied irrigation water (Sharifipour et al. 2013). The effluent mostly cannot be recycled into surface water bodies like rivers because it exceeds water quality standards, namely salinity values. Respective discharge salinity thresholds for drainage water in Iran are currently set to a level of 3000 µS/cm. At the present time, there are no re-use strategies/ waste water treatment facilities for drainage water and hence vast amounts are being lost.

Because the drainage effluent is too saline to be fed back into the Karun-Dez River system, main drains are being directed either to western evaporation ponds and wetland structures in close proximity to bordering Iraq or to Shadegan Wetlands in close proximity to the Persian Gulf. The high amounts of saline drainage water ultimately lead to an overflow of evaporation ponds and wetlands in close proximity to main drains and discharge systems.

Although the lack of drainage and wastewater management approaches becomes only visible in certain areas, namely by the overflow of basins and wetlands, Khuzestan´s water management sector in its entirety can be held responsible for this process. Irrigation and drainage inefficiencies, insufficient natural drainage conditions, pollution of water resources, salinity of natural resources and a lack of monitoring and control structures all contribute to the existing situation. Varying climatic trends (higher temperatures, lower rainfall, higher PET-rates, more frequent droughts etc.), population growth and resulting changes in water management strategies and policies, such as an expansion of agricultural production and more domestic water consumption, are threats that vast parts of Khuzestan will be subjected to in the future. Occurring harmful effects will be accelerated by exposing Karun and Dez River to industrial wastewater, urban sewages, and agricultural effluents (Keshavarzi, Mokhtarzadeh et al. 2015). Built on this, it is important to incorporate a well-rounded, holistic water management approach that includes future scenarios and trends as well as strategic water management planning in order to estimate present and future water availability and quality in order to positively affect Khuzestan´s social and environmental development. Corresponding, the implementation of integrated water resource management (IWRM) approaches plays a key role for Khuzestan´s present and future progress. IWRM is defined as "*a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems*." (GWP 2000) Various studies have already identified the prevailing causes responsible for high volumes of saline drainage water in the Karun-Dez basin (e.g. Afkhami 2003, Akram et al. 2013, GHADIRI 2014, Pazira and Homaee 2010, Sharifipour et al. 2013). However, very little research focuses on the evaluation of operational strategies that have the potential to improve current drainage water management deficiencies. In order to shift the direction towards a more practical, implementable approach, the importance of shallow and saline groundwater within irrigation and drainage systems will be discussed, before several technological solutions of how to improve local drainage water management will be presented. The paper concludes by presenting a strategic operational plan that includes short- and long-term technological strategies in order to overcome current agricultural drainage water management challenges and to facilitate the implementation of further IDWM approaches.

Note: The suggested framework is a first qualitative step to promote further planning. To date, data availability is insufficient to quantify assumptions, conclusions and recommendations for detailed planning. Hence, further investigation on the topic is urgently required.

The importance of shallow and saline groundwater within Khuzestan´s agricultural irrigation and drainage systems

It is important to add, that the salt balance of Khuzestan´s agricultural lands depends largely on the water balance, in which the amount of irrigation water is a dominant term. When sufficient irrigation water is applied, the effect of drainage on the salt balance stems from the discharge of salts along with the drainage water and often additional groundwater that is being pumped because deep drains were installed. It is argued, that drain water salinity is highly affected by ground water salinity – a fact that has often been overlooked in the case of Khuzestan (Sharifipour et al. 2013). The main reason that increases groundwater´s contribution to drain water salinity is the drain depth. Additional saline groundwater contribution increases environmental dangers as well as pumping costs, especially after irrigation periods.

If leaching of saline soils is necessary for salinity control, it is important to establish systems that consider irrigation and drainage as one unit. This is of particular importance in areas with shallow groundwater and/or insufficient natural drainage conditions.

In areas located within the Dez River basin, agricultural production circumstances are different compared to regions within the Karun River basin. In the region around Dezful, surface water quality and quantity is acceptable and no problems regarding saline and shallow groundwater exist. Generally, if agricultural areas are more than 10 m over sea level or if they aren`t located in the Khuzestan plain area, mostly no problems in relation to groundwater exist. If the agricultural areas are less than 10m over sea level and they are either located in the Khuzestan plain or they represent a transition from mountain areas to the plains, problems with shallow groundwater levels exist and have negative impacts on agricultural production. Figure 1 indicates, that the majority of southern plain landscapes is located within 0-10 m above sea level therefore inhabiting shallow groundwater conditions.

Studies show, that existing systems of irrigation and drainage (surface and subsurface) in Khuzestan consider soil and groundwater salinity conditions which reflects the state of international knowledge about the need of leaching for desalinisation.
However, the capillary rising dynamics of salts from saline groundwater towards the topsoil after leaching/ irrigation periods end (usually after harvesting) was not considered in the planning process of current subsurface drainage systems. The influence of saline groundwater on agricultural production within Khuzestan is therefore far reaching, as over 70% of agricultural zones and over 80% of sugarcane production sites are located in the plain area and have more or less problems with high and saline groundwater levels.
In can be assumed, that in such areas the amount of drainage water is actually higher than the

amount of irrigation water plus leaching rate. This is due to pumping of additional groundwater into the main drains. The resulting EC level of the drainage water is so high, that it cannot be fed back into the river system; effluents mostly flow into the wetlands of Karkheh basin (on the border to Iraq) and into the wetlands of Shadegan and Korramshahr. Moreover, it is planned to direct drainage flows into the desert area of the Hendijan network.

In areas with shallow groundwater level (> 2,0 m above sea level), leaching of salts hasn`t been and won`t be successful. The salt level in the soils remains although leaching was done. Because of existing heavy soils (clay and silty loams) in the Khuzestan plain, the capillary uprise can be estimated to be at least around 50 - 70 cm. Within current subsurface drainage systems, capillary dynamics that are dominating after irrigation stop lead to a re-salination of soil resources. Deep drains lead to additional saline drainage water quantity and salinity. These processes are illustrated in Figures 3 and 4.

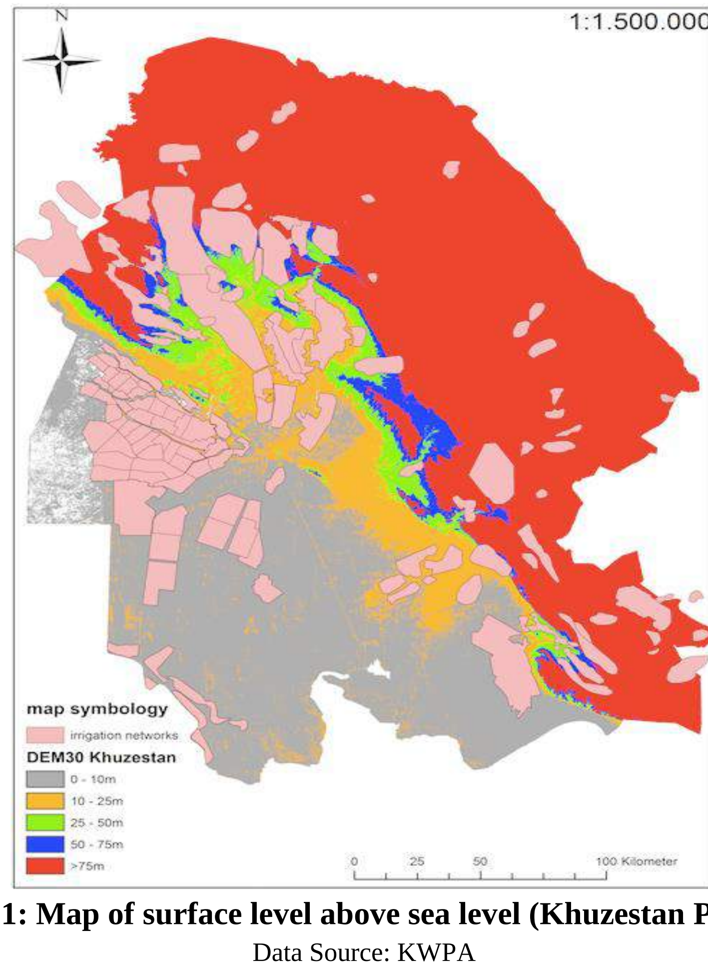


Figure 1: Map of surface level above sea level (Khuzestan Province)
Data Source: KWPA

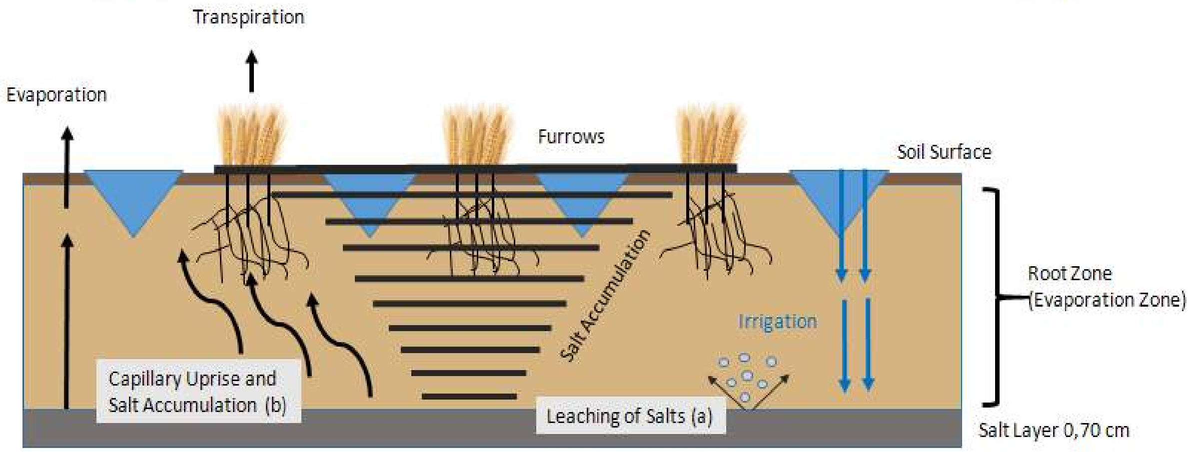


Figure 2: Furrow irrigation and leaching (wheat crops) on saline soil, no groundwater, no sub-surface drainage

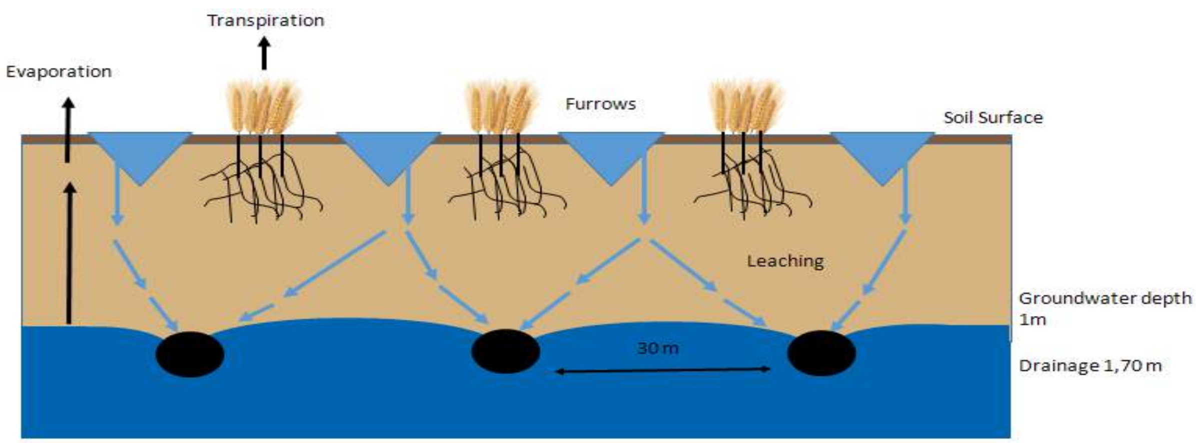


Figure 3: Furrow irrigation and leaching (wheat crops) and subsurface drainage on saline soil with saline groundwater

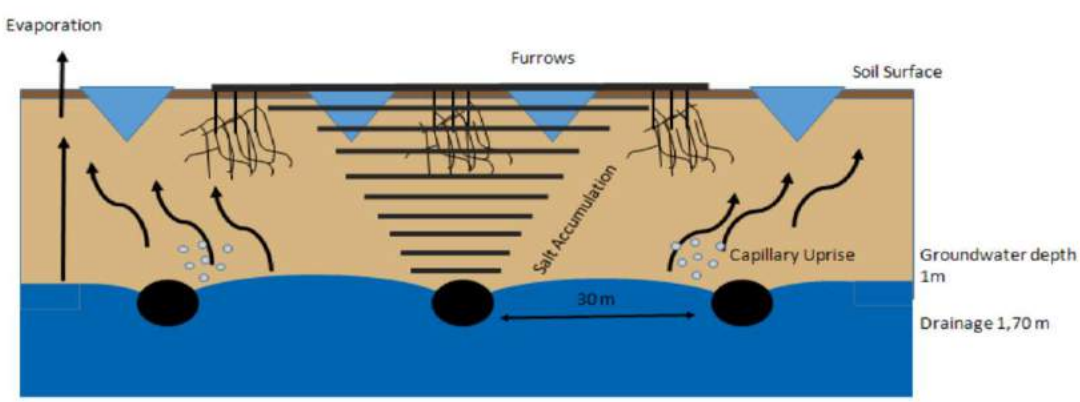


Figure 4: Salinization after furrow irrigation (wheat crops) and subsurface drainage on saline soil with saline groundwater

Proposed drainage water management solutions

Establishing a broader context that facilitates the design of an IWRM approach which positively affects Khuzestan´s natural resources and in turn its society should be a main concern in current strategic planning. As there is an urgent need to overcome drainage water mismanagement circumstances, especially in some southern and western areas, several effective short-term solutions are needed. However, as the overall achievement should be to design and implement a sustainable Integrated Drainage and Wastewater Management System, long-term solutions are equally as important.

Reviewing factors responsible for high volumes of saline ADW in Khuzestan draws a multi-layered picture:

Factors leading to high volumes of saline drainage water in Khuzestan:

- predominance of evaporation over rainfall in non-irrigated lands and anthropogenic influences
- heaviness of soil texture and improper soil drainage conditions (insufficient natural drainage)
- over-drainage (due to over-irrigation, low water use efficiencies)
- improper drain depths and a lack of suitable outlets (Akram et al. 2013)
- additional groundwater pumping: drain water salinity is highly affected by groundwater salinity due to deep drainage (Pazira and Homaee 2010)

Related management strategies should therefore aim on both the quality and quantity of irrigation and drainage water. Embodying monitoring and control devices, ADW re-use strategies as well as water treatment, namely desalination, are seen as key approaches.

Reduction of the amount of irrigation and leaching water (long term solution)

Due to Khuzestan´s semi-arid and arid climate the need to irrigate lands for successful agriculture exists. Whereas precipitation during June-September (Khordad-Shahrivar) is very low e.g. between 0.1 mm to 0.5 mm in Dezful and Hamidiyeh, the evaporation is much higher, e.g. between 322.12 mm to 449.82 mm in Dezful and Hamidiyeh leading to negative water balances. However, from December-March (Azar-Esfand) the precipitation is high e.g. between 25.22 mm to 72.22 mm in Dezful and Hamidiyeh. Contrary, the evaporation is much lower, e.g. between 53.74 mm to 99.11 mm in Dezful and Hamidiyeh. Figure 6 indicates that the annual climatic water balance varies significantly within Khuzestan. Based on these conditions, it is assumed that agricultural drainage water management problems mostly exist during the winter period December-March (Azar-Esfand).

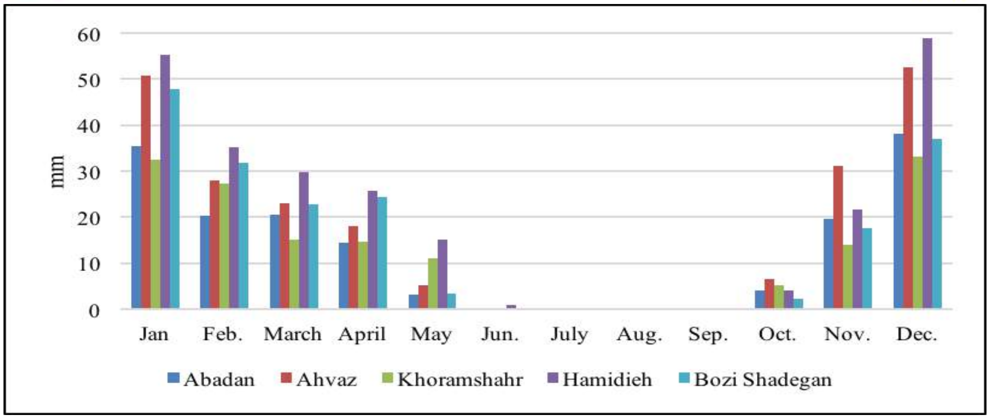


Figure 5 Monthly average rainfall in selected meteorological stations in Khuzestan

Data Source: DCE (2009)

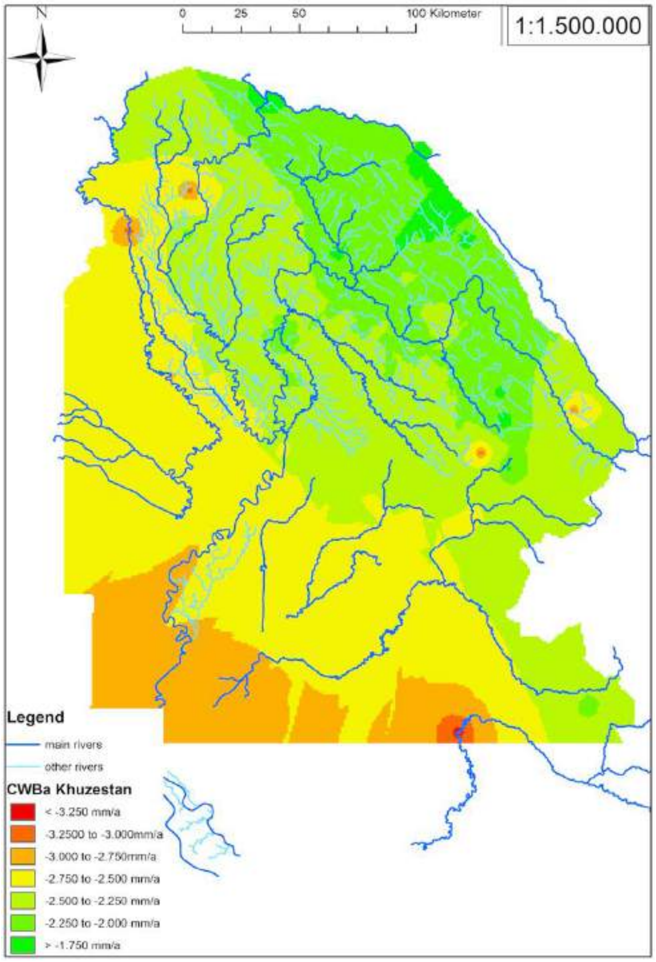


Figure 6: Climatic water balance (annual) Khuzestan

Data Source: KWPA

The annual over-use of water for irrigation is a major problem in Khuzestan. Hence, increasing water use efficiencies automatically leads to a reduction of the amount of the water that enters the drainage network and hence to less drainage water volumes.
Big gaps exist between water delivery from main canals and water application in the field. The emphasis has been much more on the developmental side of water resources instead of sustainably managing existing water resources. High rates of groundwater extraction worsen the situation and due to annual overdrafts, groundwater tables are declining in many areas (Ul Hassan 2007).

One main challenge is to improve the efficiency within existing irrigation techniques: In most parts of Khuzestan, farmers are mainly using traditional irrigation techniques such as furrow irrigation, basin irrigation and border irrigation schemes. There are very few instances of pressurised irrigation systems on large area farms. The comparison between irrigation efficiencies of different systems (surface vs. pressurised systems) shows a big difference in the suitability of the respective method.
Table 1 shows selected irrigation and drainage networks located in the Karun-Dez River basin. In some networks pressurised systems have already been installed (at least partly), whereas in others surface irrigation is the prevailing irrigation technique. Comparing the lowest overall efficiency (Gotvand, 40%) and the highest (Balarood, up to 68%) reveals that pressurised irrigation systems like sprinkler and drip irrigation, can be a better irrigation method, if properly managed.

Due to higher water use efficiencies, pressurised irrigation methods like sprinkler and drip irrigation can increase the surface area under cultivation with the same amount of water compared to traditional surface irrigation techniques. Planning should not only consider new investments into irrigation technology but to optimally equip the respective areas based on local circumstances such as geological conditions and financial budgets. While pressurised approaches can be more effective for irrigation, leaching of saline soils is a prerequisite in some areas. Depending on local conditions, leaching requires surface irrigation methods. Hence, for some cases, a combination of pressurised and surface irrigation methods will be a valuable approach in order to increase yields while saving water.

If the transition of surface irrigation towards pressurised systems is not possible to realise, it is suggested for water resource management to focus on the improvement of the existing system. If these systems are designed well and practiced properly by the farmers, they could still achieve reasonable irrigation efficiencies and fair distribution uniformities in the field without using huge amounts of energy and high costs that are associated with the use of pressurised systems (Heydari 2015).

Table 1: Efficiencies and types of irrigation and drainage in selected networks (Karun Dez basin)

Irrigation and Drainage Networks	Efficiency (%) Overall	Irrigation System	Drainage System
Gargar	65	covered canal + storage basin + pump st. (sprinkler irrigation)	
Mianbandan Shushtar	50	covered canals + pipes (sprinkler, drip, centre pivot)	surface and subsurface
Dez	54	Surface, furrow, basin and border	Surface, sub-surface, concrete canal
Gotvand	40	Border, Basin, Furrow, Sprinkler	
Balarood	64-68	sprinkler-drip- border - furrow and basin	surface; gravity

Data Source: KWPA

Note: If increasing irrigation efficiency equals an expansion of agricultural areas (more fields, higher yields) which requires more additional inputs such as fertilizer and pesticides, the impacts on water quality due to changes in the intensity of cultivation must be considered.

Establishing irrigation control systems

Establishing irrigation control systems based on modern technology to increase water use efficiency will be another step towards reducing the amount of ADW. The incorporation and adaption of historical and future climatic data as well as respective crop water demands is, beside water-saving irrigation technologies, of highest importance towards an increased water use efficiency.

The fact that drainage water discharge lead to an overflow of evaporation ponds and wetlands in Khuzestan means, that the amount of irrigation applied is mostly higher than PET rates. The over-calculation of irrigation water within all irrigation networks of Khuzestan can be seen as one major mechanism leading to the high amounts of drainage water. In order to establish effective irrigation control systems, weekly evaporation rates of respective reservoirs have to be the base for calculations of the required amount. PET rates (mm) accumulated in million m^3 are a basic threshold for irrigation water supplied throughout the year (Tables 2-3). By making use of these factors, respective threshold capacities of drainage discharge structures (e.g. evaporation ponds, wetlands) can be estimated as shown in Tables 4-5. The two examples, Korramshar and Hur ol Azim, can be seen as "hotspots" in terms of ADW mismanagement. Respective drainage water structures as well as their locations are presented in Figure 5.

As climatic data as well as irrigational practices change throughout the course of the year, automated, flexible control technologies, based on weekly or even daily values are needed. As further important input data like salinity of soils and groundwater as well as crop specific water demands do not exist in areas of interest, the scope of research and data collection has to be extended in order to establish adaptive irrigation control systems. By the controlled provisioning of additional water not only the expected improvement of water use efficiencies but also higher yield performance, yield security and product quality can be achieved. This considerably contributes to environmental protection as it leads to controlled nutrient cycling in the soil with optimum soil moisture content and decreased nutrient leaching. For a field-related optimum control of irrigation, information about the course of the weather, soil type, plant stock and irrigation technologies and techniques applied are needed. An example of a commercial irrigation control system presents IRRIGAMA. It can be described as an internet-based modular built expert and management system that is comprehensible and manageable in practice in field-related conventional and integrated agriculture.

Beside quantity control, the establishment of an additional quality monitoring system for irrigation is essential. As irrigation water is almost exclusively taken from surface water bodies without prior treatment, the existing hydrometrical monitoring stations, established and supervised by KWPA, are currently the main institutions for quality control. Additionally, Web GIS, a web-based data portal that delivers basic functionalities on GIS base, would be a valuable extension. GIS in general can deliver huge possibilities and offers an almost infinite amount of tools and functionalities. By incorporating Web GIS, the actual status of the existing water management system could be greatly transformed towards more accuracy and flexibility.

Table 2: Monthly evaporation rate (in Mio. m^3) in the reservoirs Khoramshahr (2005-2014)

Month	Station Bozi Shadegan	Reservoir 1 114 km²	Reservoir 2 145 km²	Reservoir 3 66 km²	Reservoir 4 54 km²
October	300,71	34,28	43,60	19,85	16,28
November	161,71	18,43	23,45	10,67	8,73
December	92,94	10,59	13,48	6,13	5,02
January	70,82	8,07	10,27	4,67	3,82
February	78,79	8,98	11,42	5,21	4,25
March	126,04	14,36	28,27	8,32	6,81
April	174,43	19,88	25,29	11,51	9,41
May	318,65	36,33	46,20	21,03	17,20
June	442,75	50,47	64,20	29,22	23,91
July	497,98	56,76	72,21	32,87	26,87
August	490,89	55,96	71,18	32,40	26,51
September	428,89	48,89	62,19	28,30	23,16
sum	3184,60	363,00	461,67	210,18	171,97

Data Source: KWPA

Table 3: Monthly evaporation rate (in Mio. m^3) in the reservoirs Hur ol Azim wetlands (2005-2014)

Month	Station Hamidiyeh	Reservoir1 84 km²	Reservoir 2 293 km²	Reservoir 3 147 km²	Reservoir 4 304 km²	Reservoir 5 182 km2
October	226,25	19,00	66,29	33,26	68,78	41,18
November	139,72	11,74	40,94	20,54	42,47	25,42
December	63,37	5,32	18,57	9,32	19,26	11,53
January	46,78	3,93	13,71	6,87	14,22	8,51
February	68,24	5,73	19,99	10,03	20,74	12,41
March	116,47	9,78	34,12	17,12	35,41	21,20
April	200,45	16,84	58,73	29,47	68,15	36,48
May	286,02	24,03	83,80	42,04	86,95	52,05
June	399,45	33,55	117,04	58,72	121,43	72,70
July	442,62	37,18	129,69	65,06	134,56	80,56
August	416,18	34,96	121,94	61,17	126,52	75,74
September	347,02	29,15	101,17	51,01	105,49	63,15
sum	2753,45	231,29	806,67	404,75	837,05	501,13

Data Source: KWPA

Table 4: Capacity in mio m³ for the reservoirs 'Khoramshahr' at 1m and 2m depth

depth	Reservoir 1 (114 km²)	Reservoir 2 (145 km²)	Reservoir 3 (66 km²)	Reservoir 4 (54 km²)
1m	114mio m³	145mio m³	66mio m³	54mio m³
2m	228mio m³	290mio m³	132mio m³	108mio m³

Calculations: HU Berlin

Table 5: Capacity in mio m³ for the reservoirs 'Hur ol Azim wetlands' at 1m and 2m depth

depth	Reservoir 1 (84 km²)	Reservoir 2 (293 km²)	Reservoir 3 (147 km²)	Reservoir 4 (304 km²)	Reservoir 5 (182 km²)
1m	84mio m³	293mio m³	147mio m³	304mio m³	182mio m³
2m	168mio m³	586mio m³	294mio m³	608mio m³	364mio m³

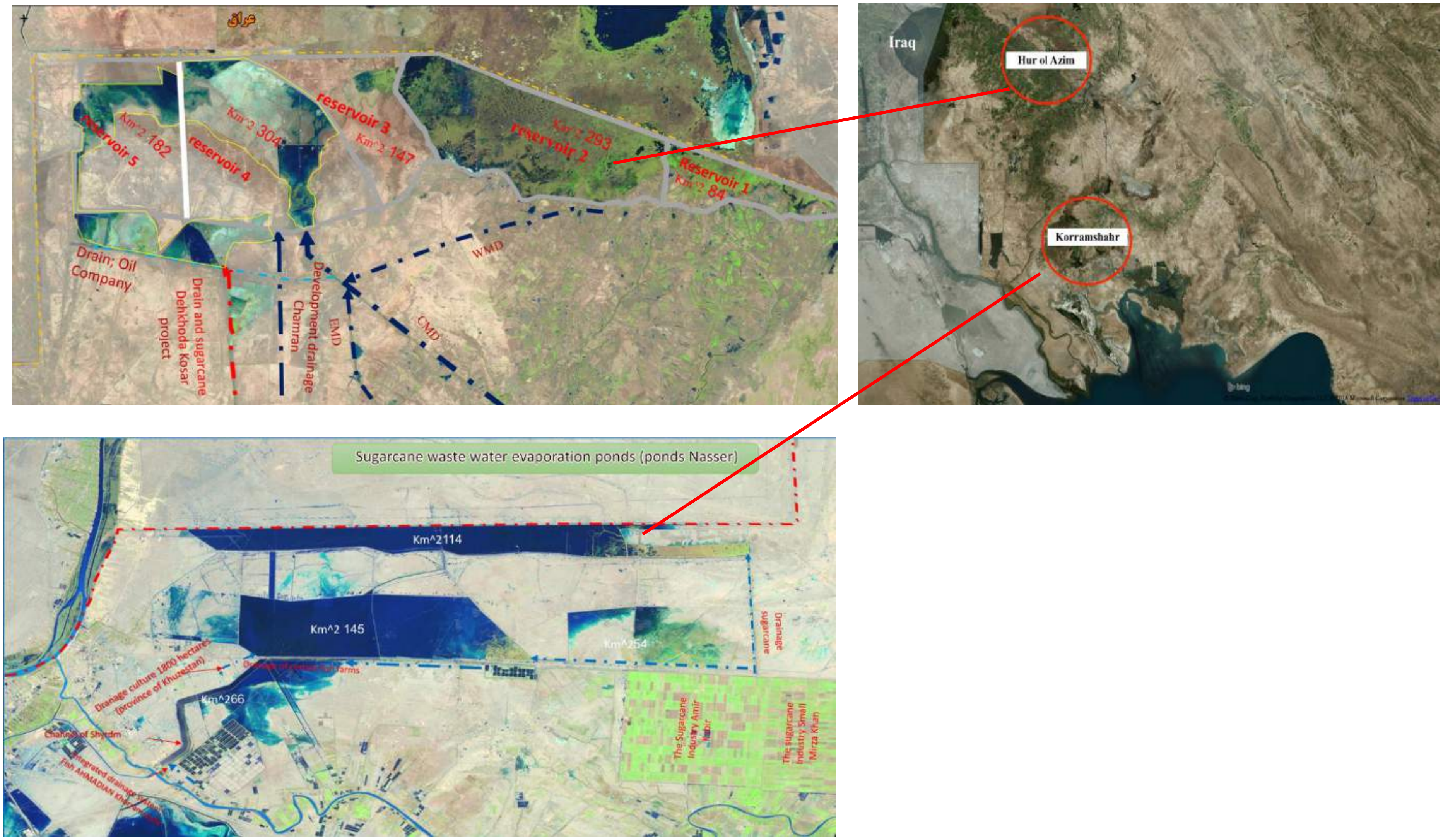


Figure 5: Hur ol Azim and Korramshahr drainage water structures (Data Source: Bing Maps 2016)

Redesign of drainage systems in areas affected by shallow and saline groundwater (long term solution)

In many low-lying parts of Khuzestan, the amount of drainage water is higher than the amount of irrigation water plus leaching rate because of pumping of additional groundwater into the main drains.

Within these areas, it is important to separate the highly saline deep drainage effluent from the leaching and irrigation drainage water. This would positively influence resulting drainage management and reuse strategies in the long run.

In order to solve the problem of saline soils in combination with shallow saline groundwater (<2.00 m under surface), a solution would be to firstly install a dewatering system (deep groundwater drainage) in order to control the groundwater table. In a second step the construction of separate drainage systems that exclusively take care of irrigation and leaching water follows.

Figure 6 illustrates the process: as the groundwater level will be kept low throughout the year by System II and the leaching effluent will be drained by System I (leading to less soil moisture), the evaporation rate will be lower and successful desalinisation can take place.

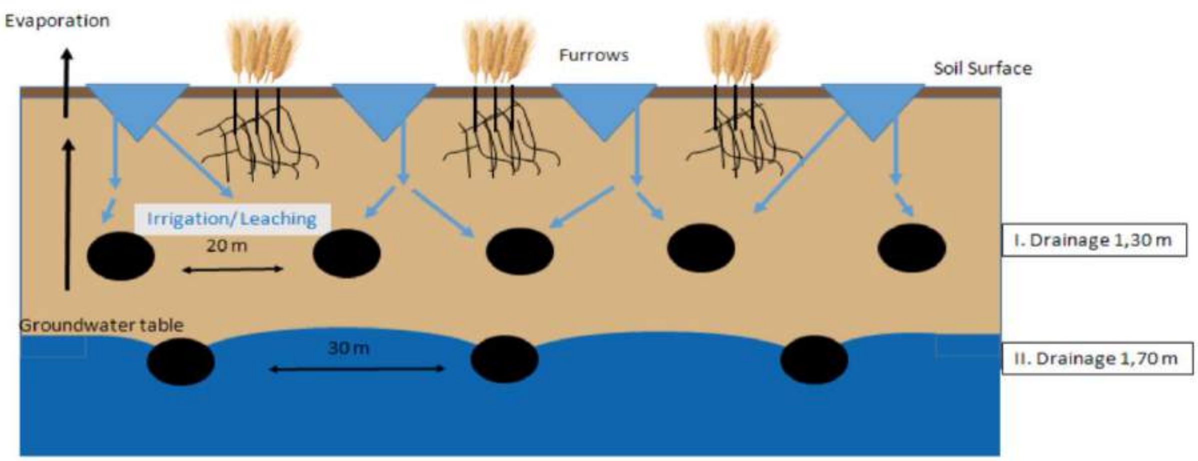


Figure 6: Furrow irrigation (wheat crops) and subsurface drainage on saline soil with saline groundwater (first: dewatering/ second: leaching)

Resulting drainage water within upper soil layers will be less saline over time (as desalination of the soil took place due to efficient irrigation and leaching). Hence, drainage effluents from shallow drainage outlets (1,30 m) can potentially be reused directly without treatment for reuse strategies like the use of salt-tolerant crops or directly discharged into rivers. Highly saline waters should be kept separated from the less saline water supply, to be disposed of in a salt sink.

As the groundwater level will be kept lower (Drainage II) throughout the year and the irrigation/ leaching and precipitation effluent will be drained by System I (leading to less soil moisture), the evaporation rate will be much lower which affects water use efficiencies positively.

Further solutions related to drainage redesign is the establishment of **ring drainage systems** or to install **open ring channel** (moats) systems combined with subsurface drainage. Also here, the saline soil can be leached and drained successfully as no salinisation occurs in the long run and the soil´s salt balance can be lowered significantly over time.

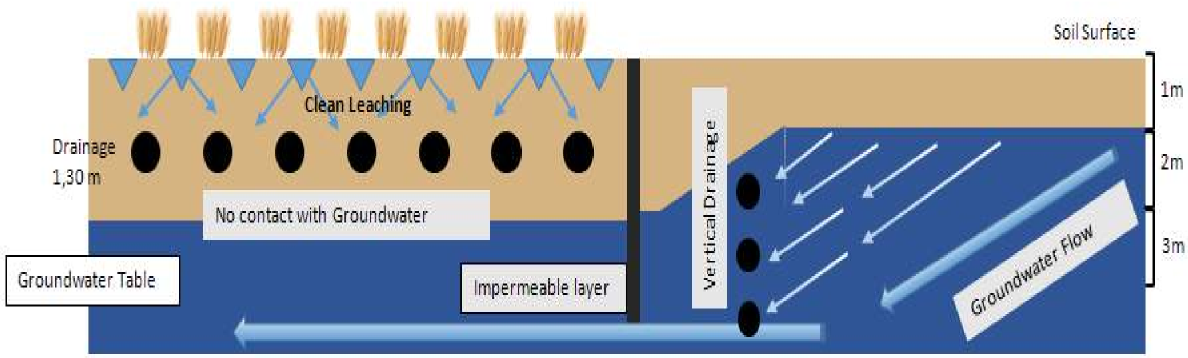


Figure 7: Vertical drainage solution

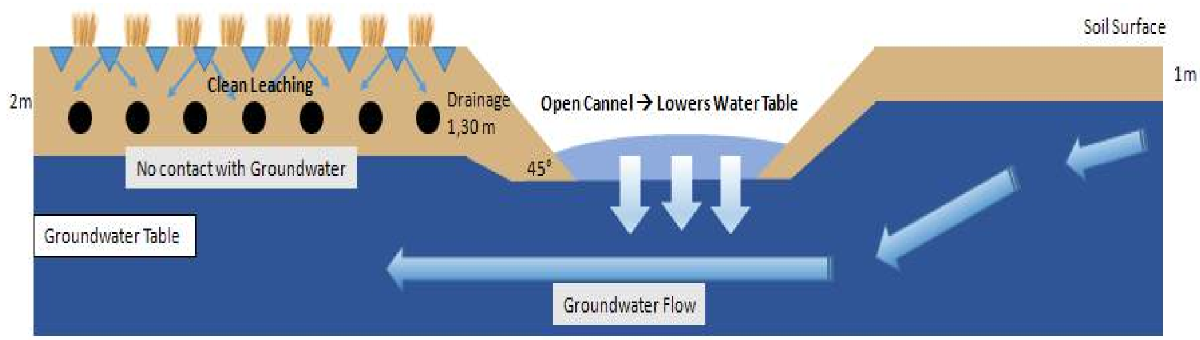


Figure 8: Open ring channel solution

Note: To validate the functionality of the proposed systems at different depths, further data collection and field testing are required. Calibrating and evaluating the subsurface drain flow in order to simulate effective soil and water balances are further important measures to take as part of detailed drainage design planning. Effective simulation should be based on flow data such as saturated and unsaturated hydraulic conductivity, effective porosity and spatial variability in soil and groundwater properties among other factors. Based on such results it can be decided which system would be effective, or if cheaper alternatives are more effective.

Establishing drainage water control systems (long term solution)

Amount of drainage water in Khuzestan

In order to establish valuable long term solutions, a discharge control system in all relevant main drains should be implemented. To fulfil this task, automatisation and control systems in all relevant drainage pump stations/ outlets have to established. Moreover, the establishment of institutions responsible for drainage quantity management, e.g. a Dispatching and Control Centre, as part of the drainage water management by KWPA has to be established. It is of highest importance and a very basic requirement for sustainable IWRM to have full control of pumps and other forms of outlets in order to be able to directly influence discharges and indirectly river and drainage water quality.

As modern irrigation and drainage systems are complex units that are interrelated by the interaction at various levels, systematic modelling is necessary to provide sufficiently accurate information for evaluating drainage water management scenarios. Changes in quantity (and quality) of reused drainage water cannot be predicted merely from historical data. Water management, cropping patterns, climate change are interrelated processes that all affect drainage water management. Therefore, the modelling of allowed drainage water amount discharges into wetlands, based on weekly evaporation rates and other relevant data (2005-2014), is an absolute necessity.

Quality of drainage water (long-term)

As described earlier, water monitoring involves quantity and quality and has to be performed on a regular basis, both at the field level by the farmer and at the catchment level by the water authorities. Management for safe reuse and disposal requires an understanding of the qualitative characteristics of the drainage water, and a matching of those characteristics to the environmental protection needs of the reuse or disposal area. Drainage water is no different from any other water supply and is always usable for some purpose within certain quality ranges. Beyond these limits, drainage water must be disposed of in a manner that safeguards the usability or quality of the receiving water for present established and potential uses (FAO 1997). Hence, quality parameters should be frequently monitored and evaluated. Within the drainage water quality control system, especially salinity values (like EC) should be monitored in all relevant main drains. Regarding the biological filter function of a soil, subsurface drainage water in Khuzestan is not expected to have high levels of pesticides or micro-organisms. It is mainly salt that is captured by a subsurface drainage system. Hence drainage effluents are often highly concentrated with the major cations and anions. These are common non-toxic elements that only become problematic when concentrated in the soil.

Only by quality control of drainage water further reuse options can be assessed. As it is the case for irrigation control, drainage water control systems can be realised by Web GIS and should be evaluated within the near future.

An example of an integrated ADW modelling approach under arid/ semi-arid climate conditions is given with the SIWARE model package. SIWARE stands for Simulation of Water Management in the Arab Republic of Egypt. It has been developed as a decision-support system in 1984 for the Irrigation and Planning Sectors of the Egyptian Ministry of Public Works and Water Resources. SIWARE segments the irrigation and drainage system networks and evaluates all the hydrologic, hydraulic, soil, and crop input data. Hence, various water management scenarios can be calculated. (Anonymous 1995)

Note: In addition to river and drainage water quality assessment, groundwater quality conditions in terms of salinity have to monitored.

Reuse of drainage water

Reuse options are highly variable and differ in terms of geography and quality. Several ways of how to reuse drainage water exist. Realistic reuse solutions for Khuzestan could be:

- Reuse for salt tolerant crops
- Reuse as water for irrigation (either directly or in conjunctive use)

The quality of the drainage water decides which process could be used. Hence, to assess appropriate reuse options, drainage quality monitoring has to be implemented.

If salinity levels don´t exceed certain thresholds several reuse possibilities arise. If, for instance, at certain drains, the ADW has a salinity of less than 3 mS/cm, it can be directly reused for irrigation. If at other parts, salinity levels are higher than 3mS/cm and less than 10-20 mS/cm, the water could be used for irrigating salt tolerant crops or blended with fresh water sources to create water for irrigation. If ADW discharges exceed certain salinity thresholds, treatment or disposal options can be considered.

If ADW is hygienically unsafe, it should not be used for agricultural production without treatment. Hence, drainage water management involves flexible integration of several reuse strategies and eventually treatment if the drain outlet quality is too low for direct reuse.

In terms of crop substitution for drainage water reuse, further investigation has to be made in order to select currently available species for areas within Khuzestan. Salt tolerant trees and bushes for fuel and forage production, for instance, can be irrigated with highly brackish waters (e.g. 19 dS/m). Where irrigation water is too saline to grow conventional agricultural crops, halophytes might be a valuable option. Integrated Seawater Energy and Agriculture Systems (ISEAS) that integrate salt tolerant species and aquaculture could be another way to reuse saline drainage water in Khuzestan.

A key strategy to prevent major overflow scenarios due to high discharge volumes of drainage water is to combine certain drainage water management strategies. Along main drains several methods can be installed in order to use or discharge drainage water flows. These strategies can be perfected in ways that not only total discharge volumes can be significantly reduced, but also important reuse strategies can be implemented (e.g. aquaculture, salt tolerant crops). Figure 7 shows examples of how to combine reuse and discharge solutions within discussed areas.

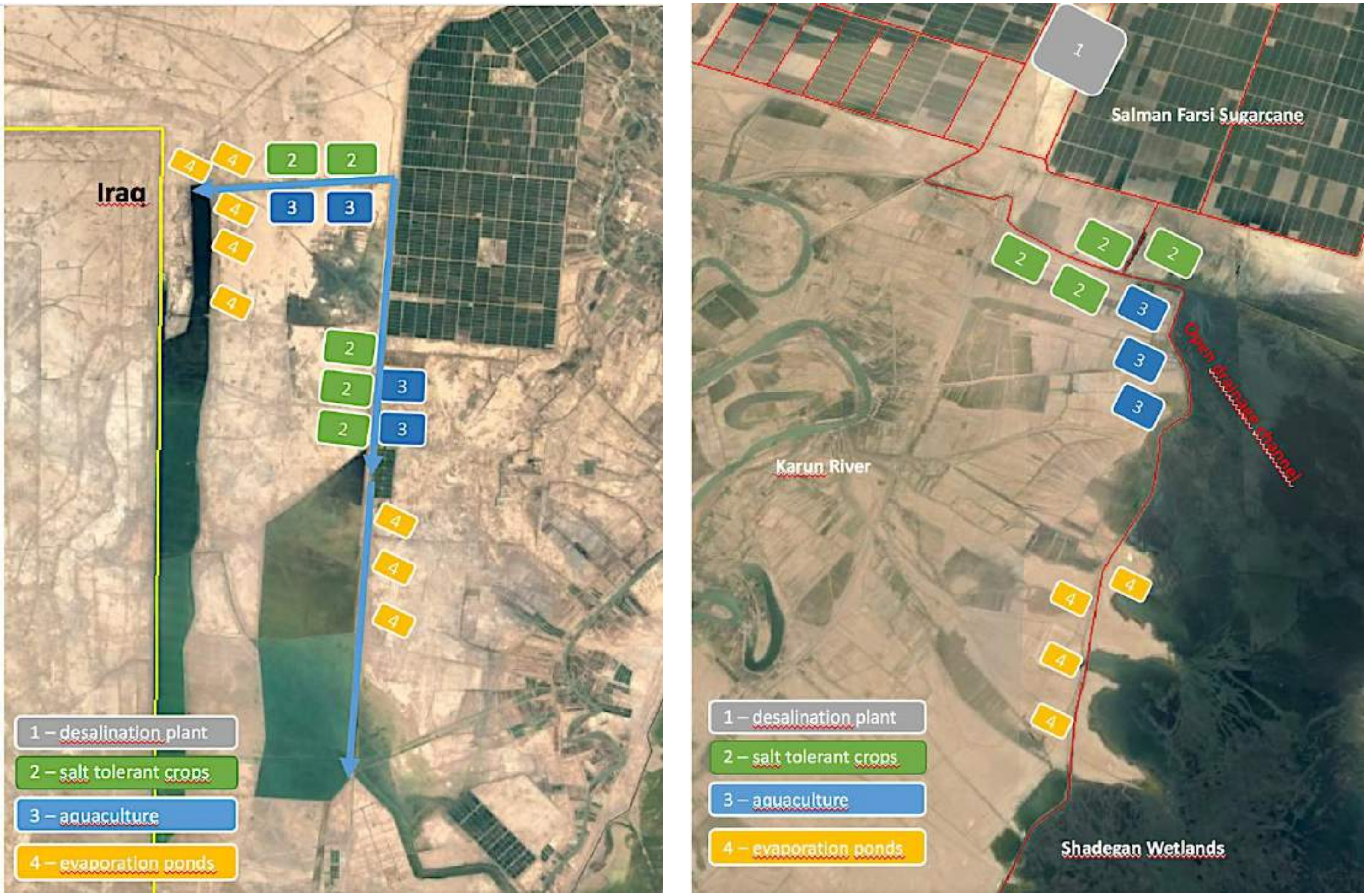
Note: Changing quantity and quality of drainage water directed into wetlands has the potential to affect environmental and social functions of wetland ecosystems. Flora, fauna, flood control and tourism are examples for areas that might be affected. This has to be taken into account in particular for the Shadegan Wetlands, an UNESO Ramsar convention listed site.

Discharge solutions (Arvand River)

Potential discharge solutions for untreated drainage water within Khuzestan are mainly evaporation ponds and wetlands. As already mentioned, it is important to incorporate several reuse and discharge options along main drains that are currently directed into wetlands.

Clearly ADW can be a valuable resource which should be reused in some way if somehow possible (Qadir 2015). One strategy to gain economic benefits from disposing ADW inland would be to use untreated ADW in solar ponds before final disposal. Solar ponds involve constructing deep ponds that allow collection and storage of heat energy in hypersaline water for direct use (e.g. drying ovens) or generating electricity (e.g. using heat-exchange systems to drive a Stirling cycle engine coupled with an AC generator) (Degens 2009). Salt harvesting by evaporation dynamics presents a further potential option that combines discharge and reuse options in a sustainable manner. Regarding the intrinsic necessity of water within southern plain areas of Khuzestan, it should always be of highest priority to reuse drainage water. In order to reduce discharge amounts into wetlands, evaporation ponds should be integrated along main drains. The effect of evaporation dynamics of saline water on surrounding environments (soil, surface water) has to be assessed before construction starts.

Another possible solution is to discharge drainage water into the tidal river Arvand, flowing along the border to neighbouring Iraq. The discharge of drainage water into the saline Arvand River is possible, but highly influenced by the border demarcation (Iran – Iraq). The border situation has to be considered carefully and resulting diversions of main drains planned accordingly. Figure 8 shows a former proposal to discharge the drainage effluent into the Arvand River in close proximity to the border. As political circumstances and regulations about discharging drainage water into neighbouring states can be a very sensitive topic, another solution should be considered. Figure 9 shows the proposed solutions. In this case, drainage water is directed via open drainage channels parallel to the Karun River before it gets discharged into the Arvand River. This would put less pressure on the wetlands of bordering Iraq. Due to high volumes of drainage water, piped solutions would technologically and economically not be feasible. In terms of discharging drainage water into the Arvand River, the best possible outlet location has to be defined. In the solution proposed (Figure 9), the main drain will be directed far enough away from the border in order to prevent political confrontation between Iran and Iraq.



Data Source: Google Earth 2016

Figure 7: Examples of integrating drainage water management solutions in study areas

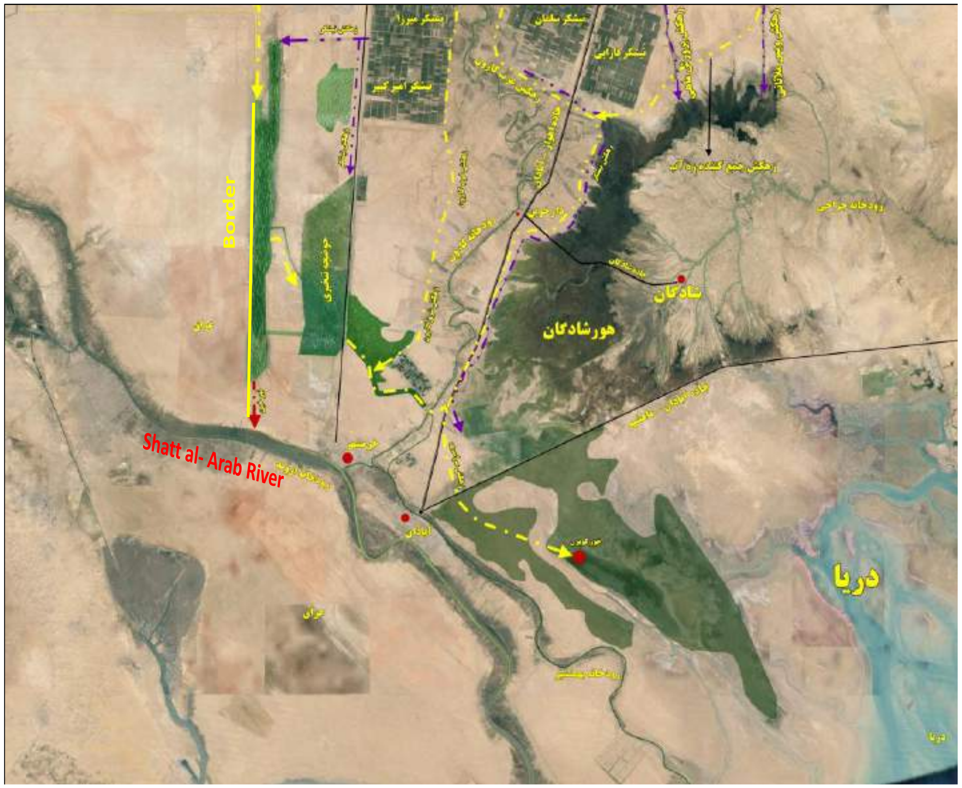


Figure 8: Proposal to divert drainage water into Arvand river via open drainage channel

Figure 9: Proposal for diversion of open drainage channel into Arvand River parallel to Karun

Desalination

Feed water for desalination can be sourced from a range of locations including seawater, brackish/ fresh ground or surface water as well as waste water. The quality and consistency of the feed water is important, as it will affect the performance of the downstream treatment processes (UNESCO 2008).

Table 6: Different concentrations of TDS in forms of raw water

Description	Dissolved solids (mg/l)
Drinking Water	< 1.000
Mildly brackish	1.000 - 5.000
Moderately brackish	5.000 - 15.000
Heavily brackish	15.000 - 35.000
Seawater	35.000

(Data source: Clayton 2015)

All desalination engineering processes underlie the same principle: a stream of saline water is fed to the process equipment, a specific form of energy (heat, water, pressure or electricity) is applied and two outlet streams are produced: a stream of desalinated water (product) and a stream of concentrated brine (retentate or concentrate) which has to be disposed of (Clayton 2015).

Around the globe, more than 99-percent of the technologies used for desalination of feed water can be divided into few approaches, namely membrane and thermal technologies (Dietrich 2013). Membrane desalination plants produce potable water by separating molecules, while thermal desalination plants work by breaking bonds between water molecules (UNESCO 2008).

In Khuzestan, desalination plants could potentially be incorporated into already existing industries and other forms of energy-dependent infrastructures. Here the process could be set up by using wasted heat or open power capacities as energy sources. Examples are petrochemical plants, refineries, off-shore facilities, power plants, pharmaceutical and food industries, inorganic and metal industries, textile, pulp and paper and drinking water producers along the Karun-Dez River network. Resulting product water could be directly reused for internal processes or sold as fresh potable water. This possibility needs to be investigated further.

Moreover, renewable energy sources like wind and solar power, maybe in form of off-grid systems, can be combined with desalination facilities. This possibility presents a viable option towards decentralised structures which implies a higher degree of independence from public energy

networks. Regarding Khuzestan´s climatic conditions, renewable energy potential coupled with desalination technologies could be economically and environmentally interesting for future scenarios.
Hereby Pilot and Demonstration Projects (PDP) would be a good option for respective field testing in remote areas that are located further away from existing energy infrastructures.

Current desalination processes within Khuzestan are mainly focussing on purifying river water (especially from the Karun). It is argued, that respective water quality is decreasing making water treatment processes very challenging. Installing desalination plants along main drains instead might be a better option. In particular ADW is naturally filtered to some extend by infiltrating the soil. The soil´s biological filtration function reduces contaminants stemming from microorganisms, pesticides or bacteria (FAO 1997). Treating drainage water that has already been partially filtered by the soil instead of river water containing a variety of pollutants could be beneficial as technological, economic and energy requirements might be lower. Hence treating and reusing drainage water instead of other water sources might entail energy and water saving potentials which in turn have positive environmental effects. Key data regarding technological requirements and drainage water quality (e.g. salinity parameters) for establishing effective desalination concepts have to assessed within pre-feasibility studies.

Connecting desalination plants with singular drains within Khuzestan would facilitate the integration. Within this strategy monitoring drainage water quality and quantity would be easier if compared to an approach that integrates desalination along main drains that are subject to multiple drain inlets (all affecting water quality and quantity). Directly connected to the drains of single producers, it can be expected that the feed water input can be controlled more effective.

At the present time, drainage structures located in the Karkhe, Dez and Karun River basins mainly discharge into wetlands and evaporation ponds of western and central Khuzestan, whereas drainage structures located in the Maroon and Zoreh River basin, discharge via eastern Khuzestan into wetlands connected to the Persian Gulf. No drainage water reuse strategies are currently implemented and vast amounts of water are lost on a daily basis. Especially cities like Ahvaz will face difficulties in meeting fresh water demands in the near future. Climatic changes, population, industrial and urban growth all lead to a steady deterioration of surface water quality and quantity. Treating and reusing drainage water will help to improve this situation.

As far as desalination presents viable potentials within the study region, occurring limitations such as further R&D requirements, high capital and operation costs and the necessity of operator expertise have to be considered. Moreover, the disposal of brine is highly cost intensive. It is argued, that if a desalination plant is further than 80km away from the ocean, or if treated water has to be piped over a compelling distance, the economic as well as environmental costs become too high for the technology to be viable (Weidler et al. 2009). Following this argument, for vast parts of the study region the concentrate management dilemma would arise. Brine discharge inland can affect the physical and mechanical properties of the soil (e.g. structure, the degree of dispersion of soil particles, permeability, and stability of aggregates) which in turn can have detrimental effects on plants and other parts of the ecosystem.

In general, the question about the ratio of desalination costs and costs of drinking water, related to water pricing, has to be examined further.

Note: Integrating desalination and other treatment systems by coupling multiple units can be also done within and not solely at the end of a drain. Deciding which flows will need treatment and when will help in deciding which treatment approaches might be needed (Degens 2009).

Conclusion: Concept of an all-functioning Integrated Drainage and Wastewater Management System for Khuzestan

The main factors responsible for high amounts of saline ADW within Khuzestan´s plain region were identified:

- inefficiencies within irrigation management: the use of water for irrigation and leaching at a rate greater than the evapotranspiration rate leads to higher amounts of drainage water than necessary
- high salinity of Karun River water, which is the main source of irrigation within respective parts of the study region
- heaviness of soil texture and improper soil drainage conditions (insufficient natural drainage)
- over-drainage due to deep drains that continuously pump saline groundwater; 70% of agricultural farm land in the Khuzestan plain is confronted with shallow and saline groundwater levels
- if groundwater levels are higher than 2 m under surface, saline groundwater + irrigation water + leaching water all contribute to increasing the amount of drainage water with high salinity
- saline soils: irrigation and leaching washes out soluble salts, which in turn lead to ADW with high salinity
- lack of waste water treatment and reuse solutions for drainage water
- lack of control structures for water extraction and return flows in terms of quality and quantity; e.g. monitoring, modelling
- municipal, industrial and agricultural pollution sources (drains into river)

Resulting discharges of saline drainage water are likely to exceed the EC threshold of 3 mS/cm by multiple times and can´t be redirected into the river system. Currently, no water reuse or treatment facilities exist. Hence, main drains are being either directed to Western wetland structures in close proximity to bordering Iraq or to Shadegan Wetlands in close proximity to the Persian Gulf.

Figure 10 illustrates and locates recommended strategies in order to implement a sustainable Integrated Drainage and Wastewater Management System in all its entirety. As can be seen, the first and most urgent step is to manage present drainage water flows in order to overcome current environmental dangers and social conflicts. The next step is to strategically think about how to manage future drainage flows in order to prevent further environmental/ socioeconomic conflicts and to enhance water reuse strategies. Last but not least, it is important to manage agricultural water supply, namely irrigation. Respective tasks can be seen as the base of the integrative management system as water input by irrigation and leaching is one of the biggest factors determining drainage water output. The three spheres important to embed in every IWRM system are science, technology and policy. Only policy itself can guarantee safe and effective technology and knowledge transfer, whereas the prerequisite for all systemic parts is a well-rounded academic approach that facilitates the R&D process. Hence further investigation in order to facilitate hollistic IWRM approaches is urgently required.

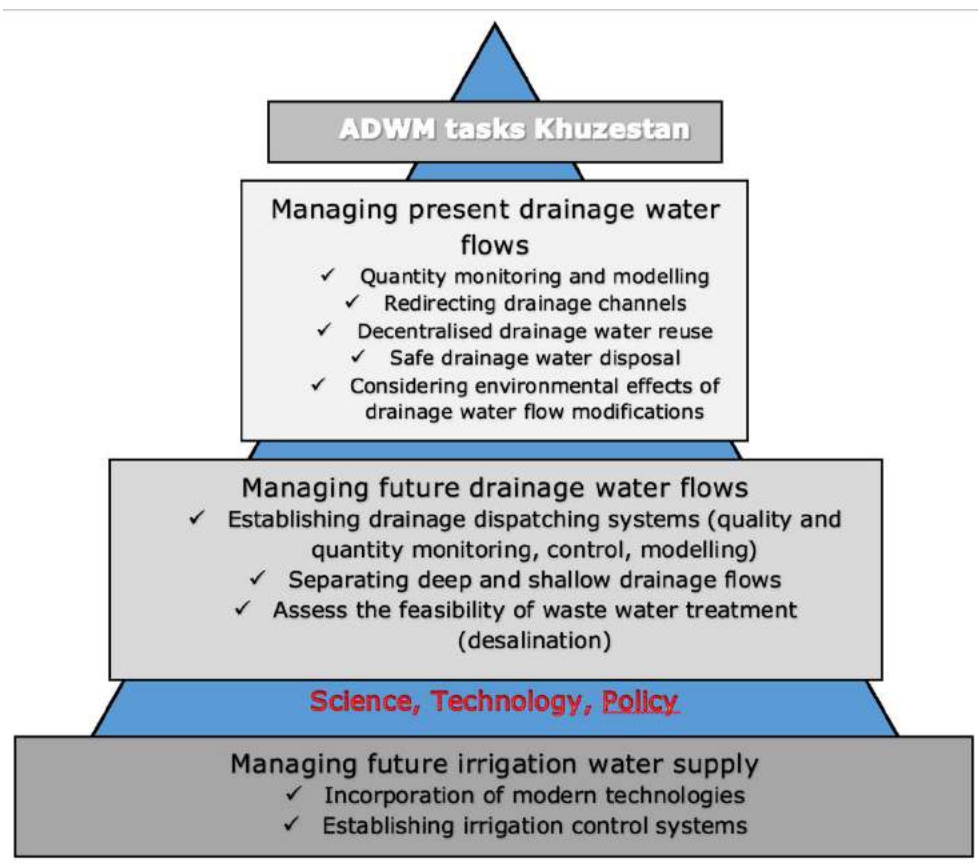


Figure 10: Integrated Drainage and Wastewater Management System Khuzestan

A) Managing present drainage water flows

- Quantity monitoring and modelling based on climatic data:

  In order to assess the amounts of drainage water that can be directed into existing evaporation ponds and wetlands, respective thresholds (based on weekly PET-rates) have to be defined. Assessing maximum discharge allowances will help to overcome current discharge excesses and should be a first step in order to achieve an improvement of the present drainage water excess.

- Redirecting main drains into the Arvand River while taking care to avoid potential political conflict due to the river´s geographical proximity to the Iraqi border:
  A rough outline was given but construction of discharge points and channel systems require detailed planning based on field visits.

- Integrating decentralised drainage water reuse and disposal options in close proximity to drainage systems:
  Evaporation ponds and salt tolerant crops are potential solutions to minimise drainage water discharge amounts into wetlands. They can be installed easily and offer a cost effective management solution. Feasibility studies and PDPs within drainage systems can assess important factors regarding climatic data, drainage water quality, evaporation rates, salt harvesting options and suitable salt tolerant cropping patterns that make use of the soil´s biological filter function.

- Considering environmental effects of drainage water flow modifications:
  Wetlands will be especially affected by drainage water management. Consequences could be far reaching and involve several groups such as environmental conservation organisations (e.g. bird conservation) reaching international levels.

B) Managing future drainage water flows

- Establishment of an intelligent automation dispatching system (drainage), facilitated by modern technological solutions:
  - Quality monitoring and modelling of suggested parameters is of highest importance as the quality of drainage water determines possible reuse options (with and without treatment).
  - Quantity monitoring and modelling: Amounts of current and estimated future discharge with the possibility of efficient automation and control

  - Control system for all pumping stations and outlets

- Separating deep and shallow drainage flows:
  Highly saline groundwater conditions require a dewatering system facilitated by solutions such as double drainage. If saline groundwater is taken out of the drainage effluent, reclamation of saline soils will be more effective as capillarity will be decreased. Hence, leaching and irrigation will be effective processes of desalination and automatically enhance crop yields. The resulting drainage effluent will contain further reuse or discharge possibilities. Highly saline waters should be kept separated from the less saline water supply, to be disposed of in a salt sink. Here PDPs will contribute further information about how to proceed in the future.

- Assess the feasibility of waste water treatment solutions, namely desalination:
  Thermal processes, connected to existing power plants, using wasted heat could be a viable option. The product water is of high quality and has a variety of beneficial usages. Within ADW management, high quality product water could be blended with untreated ADW and/ or river water for conjunctive irrigation use. RO technology should be further examined and tested for local conditions. Renewable energy sources (wind, solar etc.), potentially off-grid, should be integrated. Treating saline drainage water instead of heavily polluted river water might be benefical in orde to meet Khuzestan´s potable water demands. Feasibility studies and PDPs are highly recommended in order to assess probabilities of realisation.

C) Managing future irrigation water supply

- Incorporation of modern pressurised irrigation technologies in order to increase water use efficiencies:
  If investment required for new systems is too large, investigations into the possibilities of modernisation of prevailing surface irrigation systems should be done. Planning requires field visits, which could be conducted as part of PDPs.

- Establishing irrigation control systems based on variable factors (climate, crops etc.):
  Web GIS and IRRIGAMA are suggested methods. PDPs and further investigations will clarify possible ways to incorporate intelligent, web-based control systems. Extensive and frequent quality and quantity control of existing pumping stations used for irrigational purposes is highly recommended.

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A CONCEPTUAL FRAMEWORK OF KHUZESTAN INTEGRATED WATER RESOURCE MANAGEMENT (KIWRM) FOR THE BEST OF SUSTAINABLE AGRICULTURAL AND SOCIO-ECONOMIC DEVELOPMENT (CASE OF KHUZESTAN PROVINCE, IRAN)

Frank Riesbeck[1,*], Md Zillur Rahman[1], Simon Dupree[1], Hamid Reza Khodabakhshi[2], Arash Mahjoubi[2]

Abstract

The main objective of this paper is to present a conceptual framework (model) of holistic integrated management approach for improving the water use efficiency and agricultural development in Khuzestan, a south-western province of Iran. Given the observable impacts of rapid economic development in Khuzestan and climate change-based extreme conditions (in arid and semi-arid regions), there is a significant demand for a new strategy for sustainable soil/water resource management, agricultural and socio-economic development in Khuzestan. To address these needs a holistic management approach has been designed in this paper, which is based on contemporary literature review from the local and from examples of global contexts as well as collected data and factors of an ongoing empirical research project jointly with Humboldt University in Berlin and Khuzestan Water and Power Authority (KWPA). The main focus of the model is to emphasize the need of multiple approaches and inclusion of all relevant aspects (e.g. social, economic, environmental, policy, agri-crop pattern and technological), which affect the sustainable agricultural development in the province.

The framework is divided into four sub-models to cover broader aspects of agricultural development such as 1) Integrated River Water Management (IRWM), 2) Integrated Irrigation and Drainage System Management (IIDSM), 3) Integrated Drainage Wastewater Management (IDWM) and 4) Integrated Aquaculture and Fish Firm Management (IAFFM). The KIWRM model presented in this paper, is getting implemented through Pilot and Demonstration Projects (PDPs) on several 'Irrigation and Drainage Networks' KWPA. It is to emphasise that one way solutions for agricultural management hardly exist. Instead different strategies, timely adjusted and integrated into one system, are needed for sustainable management and to control the quality and quantity of water stabilizing Khuzestan´s agricultural and socio-economic development. Finally, an example of sub-model IDWM in Karun-Dez River area is presented in a separate paper to demonstrate how this sub-model is an integrated part of the complete (holistic management framework) sustainable water management in the province.

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KEY WORDS: Conceptual framework, Holistic Modelling, Integrated Water Resource Management, Social, Economic, Environmental, Policy, Agri-crop Pattern and Technological Aspect, River, Wastewater, Fish Farm, Irrigation and Drainage, Khuzestan, Iran.

Introduction

In global context, the impacts of climate change are posing huge challenges for water resource management and risking on the sustainability of natural resources (IPCC, 2014; Barros et al., 2015; Chen et al., 2015; Wood and Mendelsohn, 2015) and thus adaptation and mitigation have become the core issues in many countries (Havlík et al., 2014; Makkonen et al., 2015; Gelfand and Robertson, 2015; Domínguez and Fellmann, 2015, Nam et al., 2015). However, lack of necessary capacities to protect water resources are further contributing to water pollution through urban wastewater discharging without treatment, excessive use of pesticides, fertilizers and agrochemicals for agricultural production, release of prohibited or hazardous chemicals to water body (Wooster et al., 2005; Rahman, 2014; Robson, 2014; Hassan, 2015). All of these are contributing to increase the risks of climate change and environmental adaptation as well as posing threats to human health and livelihoods. Moreover, population in urban areas around the world has grown more than four times during the past 60 years to 3.9 billion (Sun, Michelsen et al. 2015). According to UN global urbanization is progressing at an unparalleled speed (van Leeuwen and Sjerps 2015). Presently, about 50 % of people live in cities and by 2050, it will be 67 % (Lyons 2014, UN, 2012). In developed countries, this percentage is even higher (more than 86 %). This is leading to the biggest challenges to water supply, the deterioration of water quality due to pollution, changes in urban land use, drainage and sewage infrastructures in most cities (Bach, Rauch et al. 2014, Martínez and Bandala 2015, Sun, Michelsen et al. 2015, Zimmer 2015).

In the context of Khuzestan, the similar challenges are observed and Khuzestan faces a serious water crisis which will be further accelerated by the very low water use efficiencies, low water quality and increasing water demands. Reports from HU-Berlin (2015, 2016) show an increased concentration of hazardous substances and pollution loads in Karun and Dez River water. A decrease of the water quantity will worsen this situation further and lead to severe ecological and socioeconomic deficits in Khuzestan.

Varying climatic trends (higher temperatures, lower rainfall, higher PET-rates, more frequent droughts etc.), population growth and resulting changes in water management strategies and policies, such as an expansion of agricultural production and more domestic water consumption, are threats that vast parts of Khuzestan will be subjected to in the future. Occurring harmful effects will be accelerated by exposing Karun and Dez River to industrial wastewater, urban sewages, and agricultural effluents (Keshavarzi, Mokhtarzadeh et al. 2015). Built on this, it is important to incorporate a well-rounded, holistic water management approach that includes future scenarios and trends as well as strategic water management planning in order to estimate present and future water availability and quality in order to positively affect Khuzestan´s social and environmental development. Corresponding, the implementation of integrated water resource management (IWRM) approaches plays a key role for Khuzestan´s present and future progress. IWRM is defined as "*a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems*." (GWP 2000). This research paper starts by highlighting the importance of a conceptual IWRM framework for sustainable agricultural development in Khuzestan.

Developing a conceptual framework: Integrated water resource management and sustainable agricultural development in Khuzestan

Integrated water resource management (IWRM) means to combine pieces in order to achieve the best possible management and sustainable use of water resources. To do so, social, environmental and technological aspects must be considered (Viessman Jr 2011). Moreover, according to GWP (2010), IWRM is a process that promotes the coordinated development and management of water resources in order to maximise economic and social welfare. For analysts, planners, and managers it is vital to comprehend the difference of 'comprehensive' and 'integrated' as different spheres within such holistic management processes (Mitchell 2005, Khanna, Shrestha et al. 2016). Major IWRM strategies are based on the Dublin Principles which were presented at the World Summit in Rio de Janeiro in 1992 (GWP 2010), such as:

> 1. *Water is finite and a vulnerable resource: Fresh water is essential to sustain life, development and the environment.*
> 2. *Participatory approach: Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels.*
> 3. *Women´s role: Women play a central part in the provision, management and safeguarding of water.*
> 4. *Social and economic value of water: Water is a public good and has a social and economic value in all its competing uses.*
> 5. *Integrating three Es: IWRM is based on the equitable and efficient management and sustainable use of water.*

One of the main features of the IWRM approach is to combine several scopes in order to create a well-rounded management approach: hereby, land and water, surface water and groundwater, river basins and adjacent coastal and marine environments as well as up- and downstream interests should be covered within respective agendas. Moreover, the approach focuses strongly on policy-making and planning (GWP 2010, Khanna, Shrestha et al. 2016):

- *water development and management has to take into account the various uses of water and the range of people's water needs;*
- *stakeholders are given a voice in water planning and management, with particular attention to secure the involvement of women and the poor;*
- *policies and priorities consider water resources implications, including the two-way relationship between macroeconomic policies and water development, management, and use*
- *water-related decisions made at local and basin levels are along the lines of, or at least do not conflict with, the achievement of broader national objectives; and*
- *water planning and strategies are incorporated into broader social, economic, and environmental goals.*

In general, any IRWM approach focuses on three basic pillars by considering the following aspects (Figure 1.a):

- *an* ***enabling environment*** *of suitable policies, strategies and legislation for sustainable water resources development and management,*
- *putting in place the* ***institutional framework*** *through which to put into practice the policies, strategies and legislation, and*
- *setting up the* ***management instruments*** *required by these institutions to do their job.*

(GWP 2010)

Figure: 1.a: General Framework of IWRM

Box 1: Main Components of IWRM (GWP 2010)

Managing water at the basin or watershed: *This includes integrating land and water, upstream and downstream, groundwater, surface water, and coastal resources.*

Optimizing supply: *This involves conducting assessments of surface and groundwater supplies, analyzing water balances, adopting wastewater reuse, and evaluating the environmental impacts of distribution and use options.*

Managing demand*: This includes adopting cost recovery policies, utilizing water-efficient technologies, and establishing decentralized water management authorities.*

Providing equitable access: *This may include support for effective water users' associations, involvement of marginalized groups, and consideration of gender issues.*

Establishing policy: *Examples are implementation of the polluter-pays principle, water quality norms and standards, and market-based regulatory mechanisms.*

Intersectoral approach: *Utilizing an intersectoral approach to decision-making, where authority for managing water resources is employed responsibly and stakeholders have a share in the process.*

Khuzestan: In relation to existing experiences from Khuzestan (reported through different HU Study Reports for KWPA), it is important to consider various aspects such as irrigation and drainage, fish production and river water management in order to assist the creation of an holistic IWRM strategy. Built on this, four strategic sub-frameworks are identified within the specific Khuzestan-IWRM framework (Figure 1.b):

1. Integrated River Water Management Strategy,
2. Integrated Irrigation and Drainage Systems Management Strategy,
3. Integrated Drainage and Wastewater Management Strategy,
4. Integrated Aquaculture and Fish Firm Management Strategy,

In the case of Khuzestan, these four strategies are immensely interlinked. However, in this paper a focus will be put on strategy number 3 (Integrated Drainage and Wastewater Management). Within the IWRM approach, according to GWP 2010, there are several other elements to implement, such as (illustrated in the following Figure):

- Policy aspect
- Environmental aspects,
- Socio-economic aspects
- Technological aspects are examples of globally common aspects of integrated management (Sehlke 2016).
- Crop patterns

- In some situation, distribution systems and treatment process are important aspects to include.

All of these aspects are narrowed down with several other factors those influencing overall IWRM in Khuzestan. It is noted that many of them are linked to each other (dot lines in following Figure 1, b).

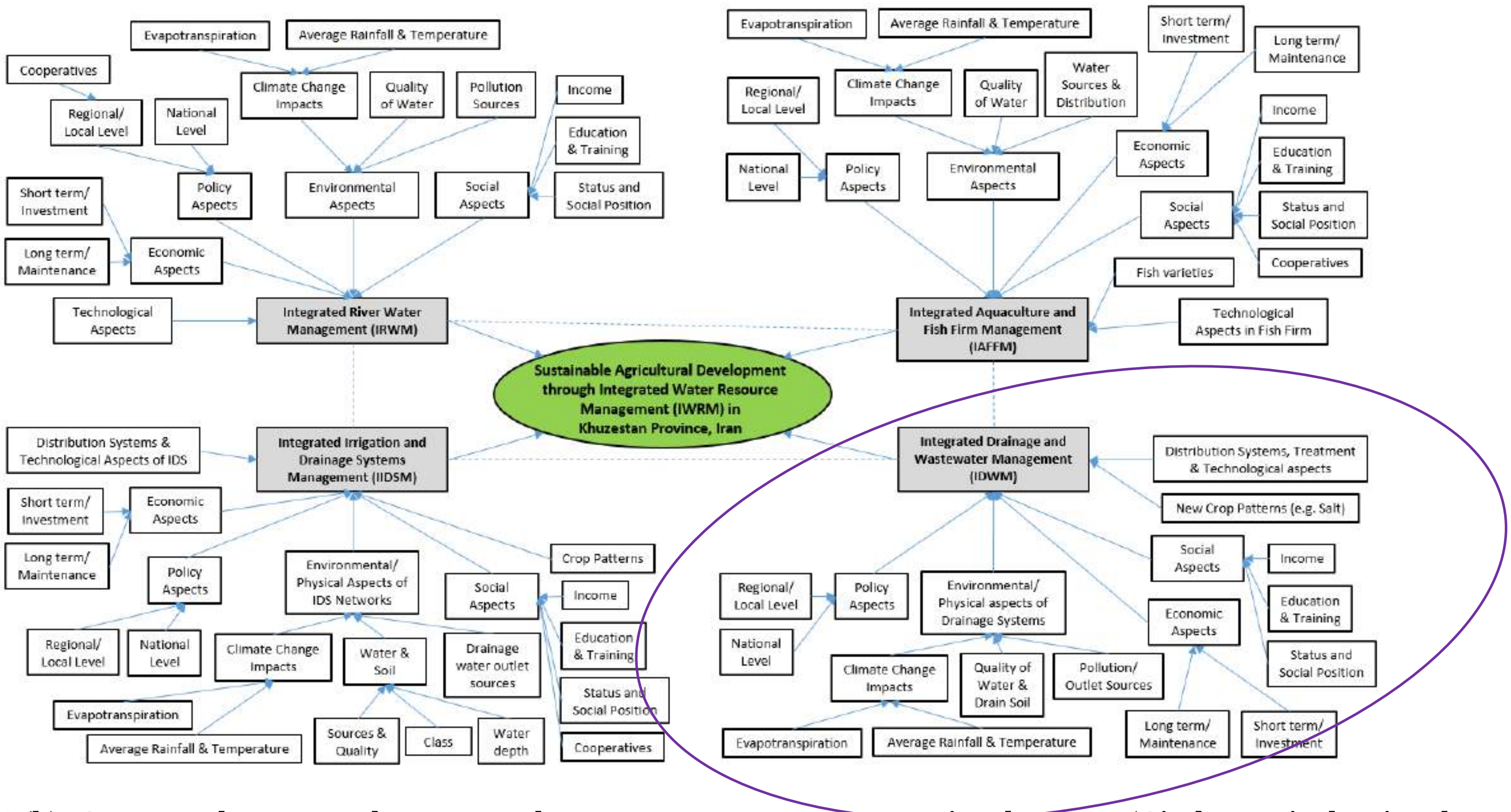


Figure 1 (b): Conceptual Framework: Integrated Water Resource Management in Khuzestan (Circle part is showing the Integrated Drainage and Wastewater Management (IDWM) the main focus for this paper).

Present and Future Challenges of Integrated Water Resource Management in Khuzestan

Present and Future Challenges Due to Impacts of Climate change

The following section is based on the official report "Iran Second National Communication to UNFCCC". The report was published in December 2010 by the National Climate Change Office at the Department of Environment on behalf of the Government of the Islamic Republic of Iran.

Iran is highly vulnerable to the adverse impacts of climate change. Most parts of the country are arid or semi-arid, prone to drought and desertification; limited forests are liable to decay; water resources are scarce; sea-level rise is a threat to very long coastal zones of the country; many urban and industrial areas are heavily polluted; and the country is mountainous with very fragile ecosystems. As a prerequisite to carry out the vulnerability and adaptation (V&A) assessment, a study on climate variability and climate modelling is essential in order to predict the future climate of Iran based on the historical record. In addition, Iran is a country whose economy is highly dependent on the production, processing and export of oil and gas and the associated energy intensive products.

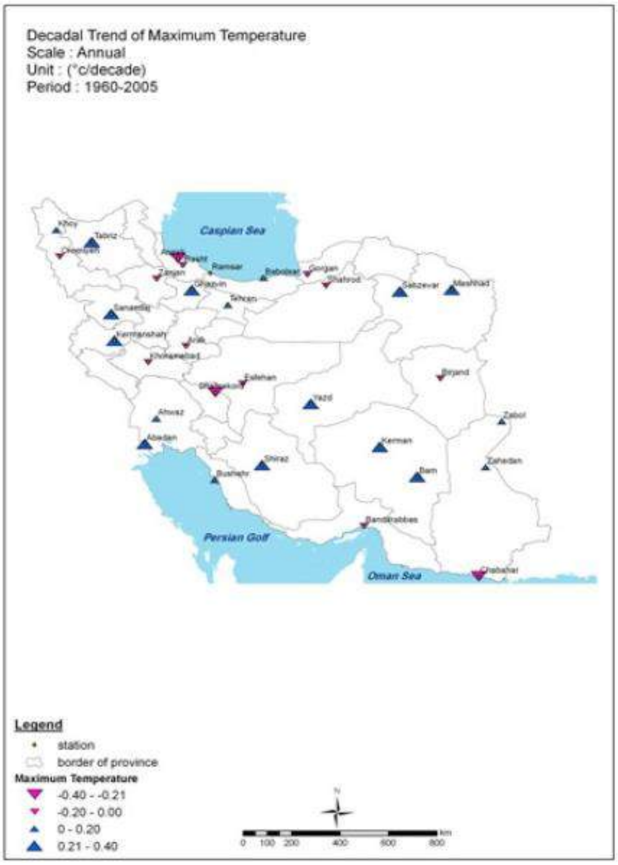


Figure 2 a: Trends in Maximum Temperatures in Selected Stations

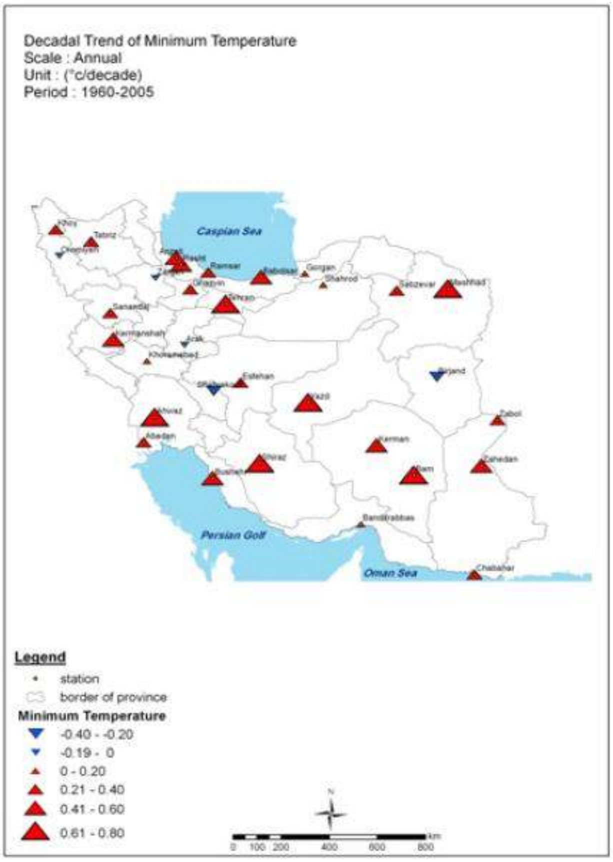
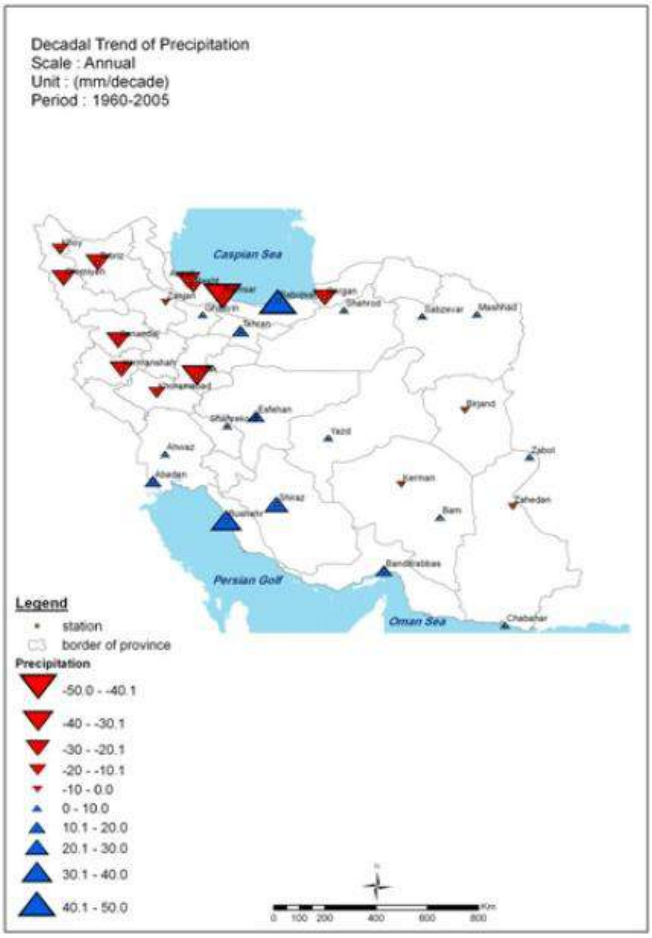


Figure 2 b: Trends in Minimum Temperatures in Selected Station

Precipitation: Following figure (3a) illustrates the changes in the amount of precipitation in selected stations. Accordingly, it could be concluded that the south-western part of the Caspian Sea, northwest and west of the country have experienced the highest rate of reduction in the amount of their annual precipitation. Study shows that the number of days with precipitation is higher than 10 mm, have reduced in the west, northwest and southeast of the country That number has increased in the other regions except in the southeast of the Caspian Sea (Figure 3b).



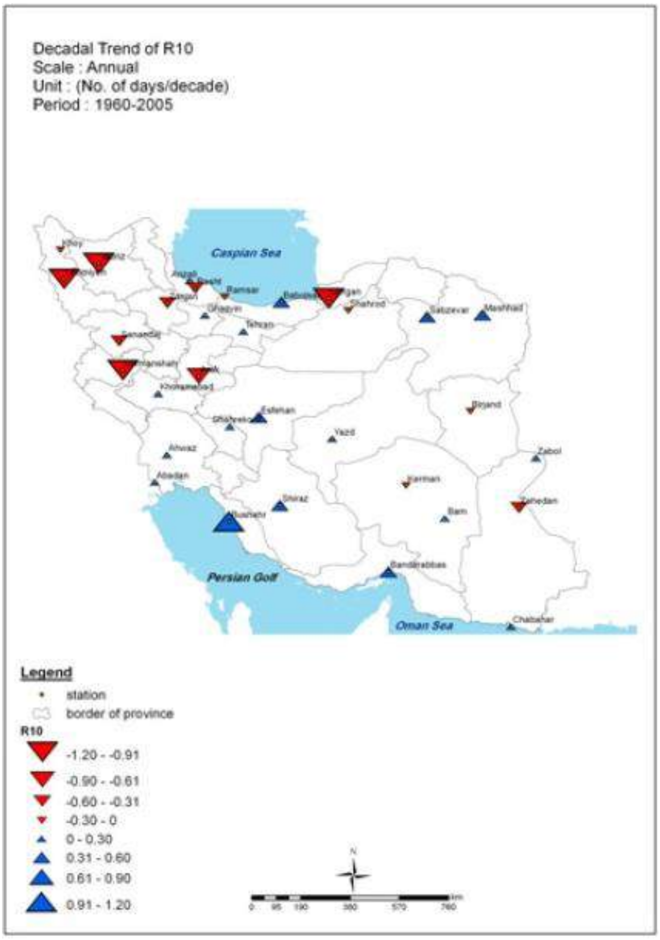


Figure 3a: Trends in Precipitation in Selected Stations

Figure 3b: Trends in Number of Days of Precipitation Higher than 10mm

Climate Change Projection: The two models MAGICC - SCENGEN, Lars - WG have been used to project future changes in the country's climate at the regional scale while the PRECIS model has been used for projection at the local scale. Climate Change Projection using MAGICG-SCENGEN (HadCM2 and ECHAM4 Models) The HadCM2 and ECHAM4 in combination with 18 available emissions scenarios have been utilized to project the changes in the country's temperature and precipitation (as the main contributors to the formation of the climate) until the year 2100. Both GCMs predict a higher temperature nationwide with very little variation. According to HadCM2, the temperature will rise between 0.4 to 3 degrees centigrade, while the results of ECHAM4 suggest that the rise will be in the range of 0.5 to 4 degrees centigrade.

The results indicate that the amount of precipitation will on average decrease throughout the country by 9% between 2010-2039 compared with the 1976-2005 period. However, the number of heavy and torrential rains will increase by 13% and 39% in the same period, respectively. Temperature projections show an average increase in the amount of 0.9 degrees centigrade and minimum and maximum temperatures will on average rise by 0.5 degrees centigrade. The rises are more pronounced during the cold season. The number of hot days in most parts of Iran will increase. The highest increase will occur in the southeast of the country by 44.2 days. The study has also revealed that the number of freezing days in most parts of the country will decrease. The highest decrease will occur in the northwest of the country with freezing days decreasing by 23 per annum. Study of the changes in the number of wet days during 2010-2039 indicates that it will increase in some areas in the northwest, center, south, east, and southeast of the country. In other parts of the country the number of wet days will decrease. The highest decrease will occur in the cold season. The study on the number of dry days shows an increase in many parts of the country. The highest rise at 36 days is expected to occur in the west and southeast of the country. Figures 3c to 3d illustrate the changes in the above-mentioned parameters in the 2010-2039 periods.

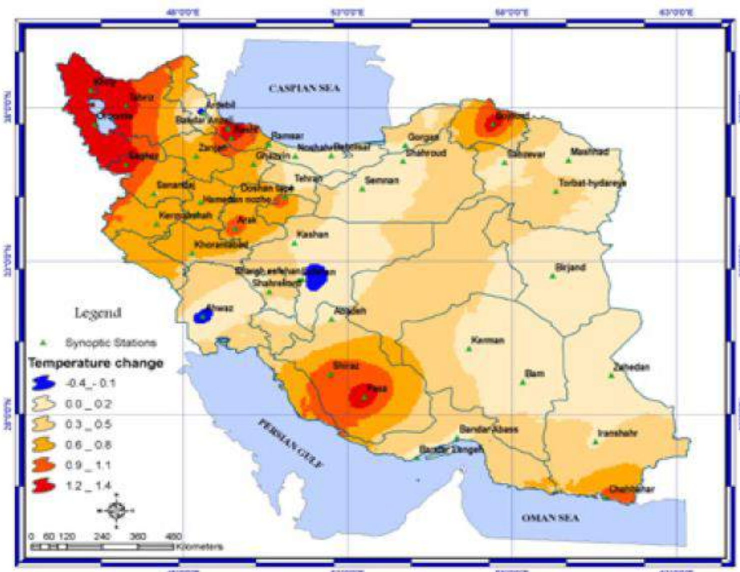


Figure 3c:Temperature Changes Projected for 2010-2039 with Respect to 1976-2005, Projected by LARS -WG

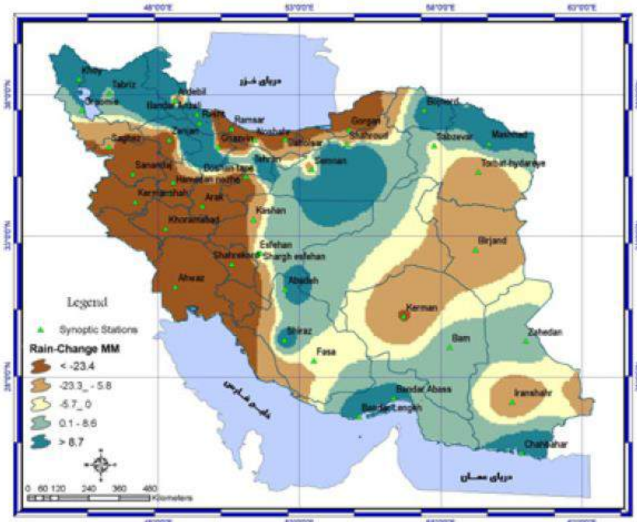


Figure 3d: Rainfall Changes Projected for 2010-2039 with Respect to 1976-2005, Projected by LARS - WG

Potential Water Resources: The Islamic Republic of Iran receives approximately 413 bcm of water from precipitation per annum, from which 296 bcm goes unutilized through evaporation and evapotranspiration. According to 2005 statistics, the resources of renewable water are 130 bcm. Water supply and consumption by different sources are shown in Figures 3e to 3f.

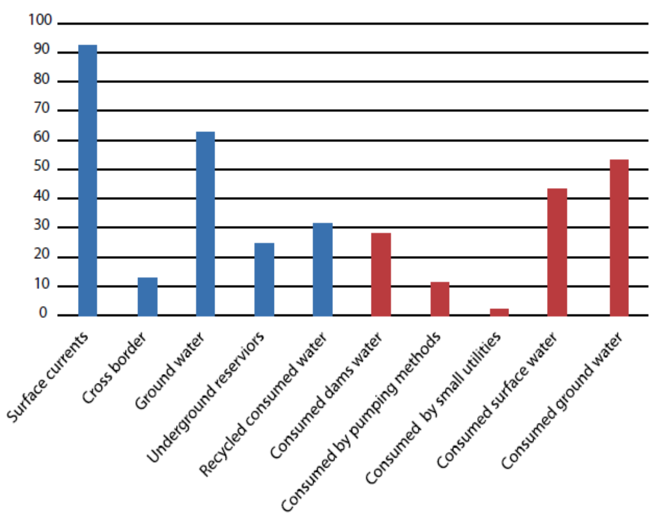


Figure 3e: Water Sources and Consumption Trends in Iran

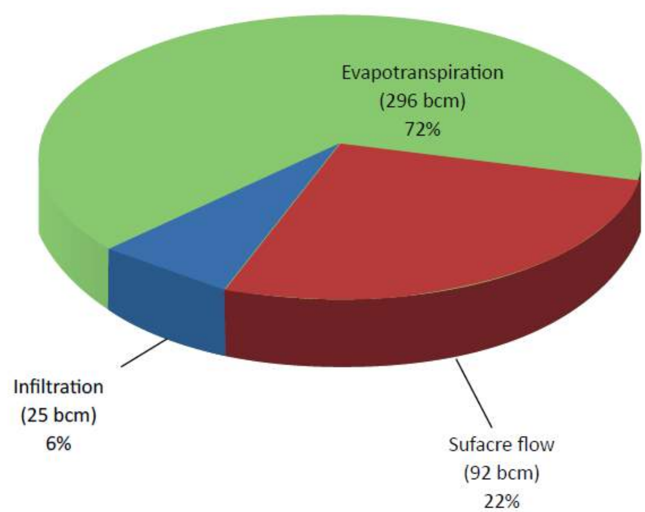


Figure 3f: Total Renewable Water Resources

Iran is located in the arid and semi-arid region of the globe with approximately 70% of the area in the dry and semi-arid region. In addition, in recent decades' climate change has also adversely affected the country's water resources.

One of the consequences of climate change is increased frequency of flood that causes severe damage to water resources and is a major problem in water management. In fact, watershed degradation is an outstanding factor in the overall water crisis that has resulted in reduced production capacity of soil and water resources. Other consequences of climate change are the occurrence of severe and frequent droughts that cause reduced water resources for various uses and the loss of some water ecosystems. Lack of updated planning and management and adaptation appropriate to present conditions has exacerbated the reduction of water resources. Average renewable water resources based on rainfall, vegetation, and other effective elements are about 130 bcm while the total accessible water with return flow is estimated about 111 bcm. Some 105 bcm of the total renewable water is contained by surface water. An estimated 25 bcm penetrates groundwater resources. At present average renewable water per capita is about 1,900 cubic meters (2009), however, due to the increasing rate of population and the impacts of climate change, it is expected that the per capita water availability will be reduced to 1,300 cubic meters per capita by 2021. Regardless of the obvious differences in the country regarding water resources and the extensive arid area of Iran, this Fgure is much lower than the average rate in the country. Furthermore, the data of average per capita of water in the coming years forecasts that Iran is entering a new stage of water stress and scarcity.

IWRM Challenges Due to Future Economic Development Activities (e.g.- More Irrigation, More Industries, Urban development, More Population in cities)

Urbanization and Industrial Development: Human activities, rather than natural forces are the major sources of the contemporary changes in the state and flow of the biosphere, land transformation due to human activities have taken many forms, starting with the urbanization including industrial expansion. Urbanization is one of the most detrimental forces affecting stream health and one of the biggest challenges facing watershed managers. However, methods to determine how large-scale changes in watersheds affect local habitats are still producing varied results. Urbanization affects "patterns of ecologic structure and function" by altering the physical landscape, increasing imperviousness, and changing channel morphology. Modification of the physical landscape by human development can exacerbate erosion, sedimentation, and bank undercutting thus reducing habitat for organisms such as fish and benthic macroinvertebrates. Urban storm water enters creeks and rivers more readily from impervious surfaces and can increase the flashiness of the flow regime. Urban runoff can also affect water chemistry by changing levels of heavy metals and nutrients like phosphorus and nitrogen. These impacts from urbanization can cause changes in the biological communities of the stream ecosystems. In addition, urban impacts are especially concerning because they can be seen throughout watersheds, and not just on a local level. As stream ecosystems are changing, it is apparent that there is a need to develop consistent methods to track these changes, and monitor the environment within streams. Impacts can be seen on multiple scales, and it is important to look

Industrial pollution sources (sewage and wastes): As a result of industrial development, there are many industries and sites in the study area of that most of 30 are important in environmental pollution studies. There are many pollutant industries in in Khuzestan. According KWPA data the industries active Pollution source is 11 at present time. In Dezful to Bamdej reach, the highest concentration of the pollution load is COD and Mollasani to South Ahvaz reach, the highest concentration of the pollution load is TDS.

IWRM Challenges Due to Future Inter-Basin River Water Transfer

According to the initial information from KWPA inside of previously handed HU reports, several projects of interbasin water transmission are in operation at the present time and many similar projects are being implemented. Therefore, in this section the influences of inter-basin river water transfer plus impacts of climate change on Karun River water discharge will be evaluated. Due to the long term inlet and outlet flow time, series to Gotvand and Dez dams were not presented, the above information were derived from Karun & Dez systemic project (DCE 2010). In this study ARSP (Acres Reservoir Simulation Program) software is used to simulate the water resources planning system of Karun and Dez catchments in various operation horizons. ARSP is a powerful tool of modelling and simulation of water resources. A major advantage of the ARSP is its inherent flexibility in defining the operating policies through a penalty structure specified by the user. The ARSP utilizes network flow optimization techniques to handle a subset of general linear programming (LP) problems for individual time intervals. The objective of the LP application is to minimize a cost function, which reflects relative benefits derived from a particular operating policy.
The locations of dams on Dez and Karun Rivers in the existing status and the inter-basin water transmission projects are described in previous sections. In summary, the following dams and water transmission projects are included in the present time.

Table 1: Dams in Karun and Dez Rivers at Present time

Dams in the present term horizon
Roodbar Dam
Dez Dam
Karun 1 Dam
Karun 3 Dam
Karun 4 Dam
Godar landar Dam
Gotvand Dam

Table 2: Water transfer projects in Karun and Dez Rivers at Present time

Scenario 3-1	scenario 3-2
Kharkheh transmission system	Kharkheh transmission system
Dez to Ghomrood	Dez to Ghomrood
Cheshmehlangan	Cheshmehlangan
khedengstan	khedengstan
Koohrang 1 tunnel	Koohrang 1 tunnel
Koohrang 2 tunnel	Koohrang 2 tunnel
Koohrang 3 tunnel	Koohrang 3 tunnel
	Beheshtabad tunnel

The summary of agricultural, industrial and urban consumptions at the present time in Karun and Dez basin are tabulated in following Table. For more information and detail, please see "Inter-basin Water Transmission Report".

Table 3: Agricultural, industrial and urban consumption in the existing status

	Annual Demand Volume (MCM)	Number of Demands
Domestic and Industrial	2382.54	24
Agriculture	12718.11	58
Fishery	1366.75	8

(Source: Karun & Dez systemic project, DCE 2010)

The water resource simulation software (ARSP) result shows that the annual average outflow of Gotvand dam will decrease 10.22% in the case of inter-basin river water transfer plus impacts of climate change, in existing status. Since this project transmits water from Karun basin to Zayandeh rood basin, it has no effect on Dez River discharge. Therefore, outflow of Dez dam is as same as decrease by 5.62 % in comparison to existing status. The influences of the inter-basin river water transfer plus impacts of climate change on Karun and Dez Rivers water quality will be evaluated in the next section. For this reason, a quality model was set-up. In the following, the model set up and simulation results will be discussed.

At the future, in addition to the climate change phenomena, the interbasin water transmission development of Karun and Dez will be implemented and the reduction in river flow will be increased more and consequently the river water quality will be worse. Therefore, in this section the influences of economic development activities plus inter-basin river water transfer plus impacts of climate change on Karun River water discharge will be evaluated. Similar to the previous scenario, the inflow and outflow of various dams are extracted from the systematic studies of Karun and Dez basins performed by Dezab Consulting Engineers. The locations of dams on Dez and Karun Rivers in the the Intermediate term horizon and the inter-basin water transmission projects are described in previous sections. In summary, the following dams and water transmission projects are included in the Intermediate term horizon up to year 2031.

Table 4: Dams in Karun and Dez Rivers at the Intermediate term horizon up to year 2031

Dams in intermediate time
Roodbar Dam
Dez dam Dam
Karun 1 Dam
Karun 3 Dam
Karun 4 Dam
Godar landar Dam
Gotvand Dam
Karun 2 Dam
Liroo power plant
Bakhtiary Dam
Khersan 3 Dam

Table 5: Water transfer projects in Karun and Dez Rivers in at the Intermediate term horizon up to year 2031

Name
Oshtorinan
Kharkheh transmission system
Sarab sefid to Galerud transmission system
Transmission system to Arak city
Sezar tunnel
Dez to Ghomrood
Cheshmehlangan
Khedengstan
Bideh dam tunnel
Koohrang 1 tunnel
Koohrang 2 tunnel
Koohrang 3 tunnel
Solkan tunnel
Shiraz water supply system
Shahid dam tunnel
Dez Environmental waterways
Beheshtabad tunnel

The summary of agricultural, industrial and urban consumptions at the intermediate term horizon up to year 2031 of Karun and Dez basin are tabulated in following. For more information and detail, please see "Inter-basin Water Transmission Report".

Table 6: Agricultural, industrial and urban consumption in intermediate term horizon

	Annaul Demad Volume (MCM)	Number of Demands
Domestic and Industrial	2741.4	27
Agriculture	13168.25	78
Fishery	1865.22	8

(Source: Karun & Dez systemic project, DCE 2010)

The water resource simulation software (ARSP) result shows, that the annual average outflow of Gotvand and Dez dams will decrease by 18.82% and 8.9 % respectively, in comparison to existing status, in the case of the economic development activities plus inter-basin river water transfer plus impacts of climate change in the horizon of year 2031.Also, the water resource simulation software (ARSP) result shows that the monthly minimum outflow of Gotvand and Dez dam will decrease by 66% and 49% respectively in comparison to existing status, in the summer time at drought years,
in the case of the economic development activities plus inter-basin river water transfer plus impacts of climate change in the horizon of year 2031.

The influences of the economic development activities plus inter-basin river water transfer plus impacts of climate change on Karun and Dez Rivers water quality will be evaluated in the next section. For this reason, a quality model was set-up. In the following, the model set up (Figure 4, more on HU Study Report for KWPA).

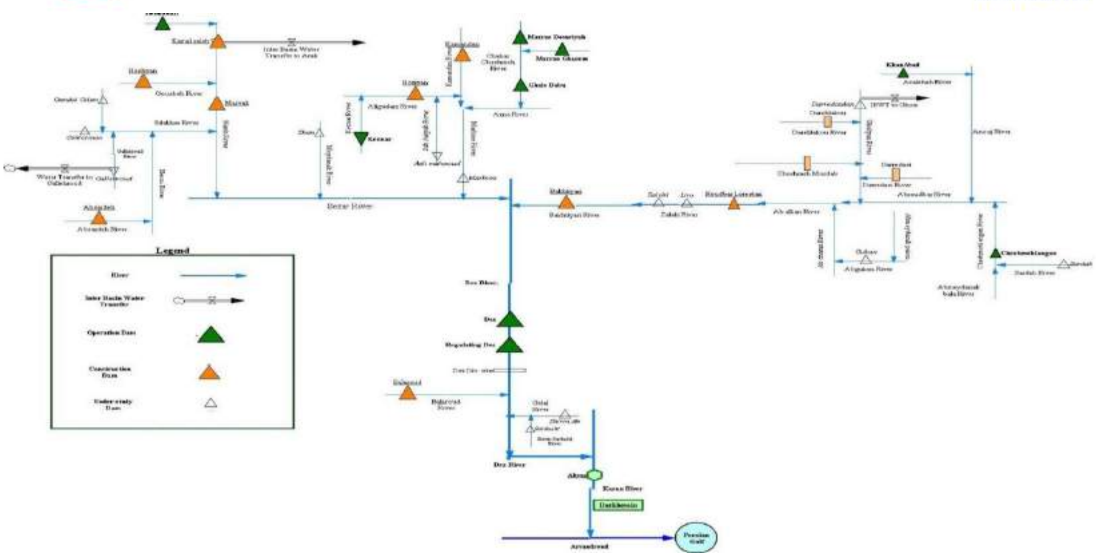


Figure 4: Scheme of Dez River Basin with Dams and Inter Basin Water Transfer (HU Study Report)

(Operational, execution and study)

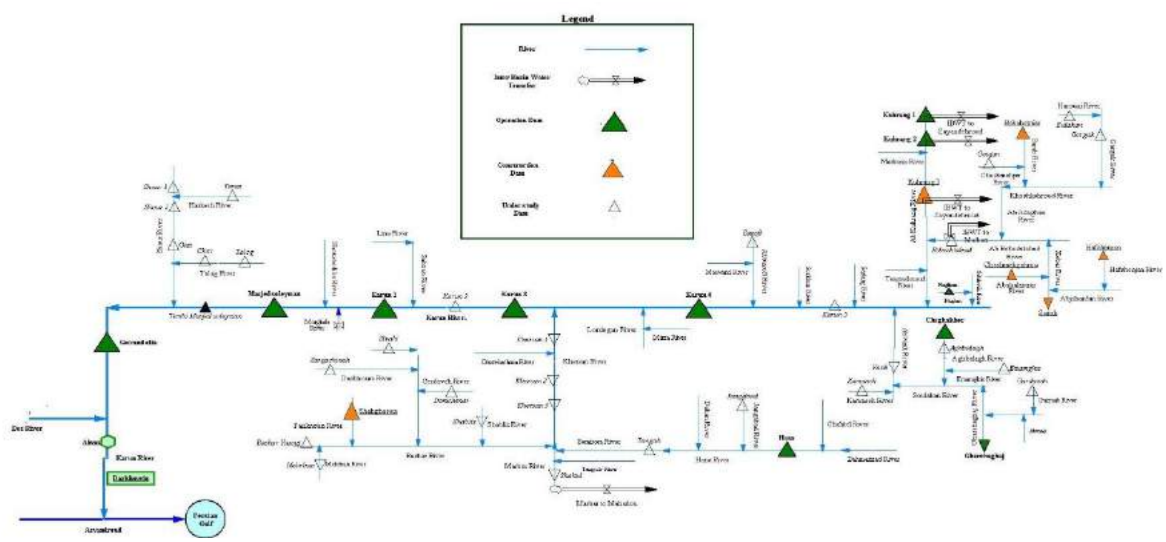


Figure 5: Scheme of Karun River Basin with Dams and Inter Basin Water Transfer (HU Study Report)

(Operational, execution and study)

Decision Support System (DSS) for the Improvement of Integrated Water Resource Management- Case: Improvement of River Water Quality in the Existing Conditions

Case: DSS for the Improvement of River Water Quality in the Existing Conditions

As it is reported about the existing status of the rivers and pollution sources, Karun river water quality is bad and it will be worse in the future due to the climate change phenomena, interbasin water transmission and future development. Thus, it is necessary to find some method of solutions such as the treatment of domestic and industrial wastewaters, improvement of the cropping pattern, improvement of the agricultural wastewater drains, monitoring network implementation, and water quality management for Karun and Dez rivers. In this regards, the salinity and quality models are provided and various method of solutions are used to study the effect of them on the water quality of Karun and Dez rivers. The simulation method (HU Study 2017) of solutions regarded to set four scenarios to improve the salinity of the water are as follows (Table below):

- Existing condition without load reduction
- Without groundwater load
- Scenario two (The second scenario in which the exit flow from Gotvandolya dam reservoir is reduced to 1000 µS/cm, the urban and industrial salinity loads are entirely eliminated is applied, the salinity levels of the agricultural drains and fishery drains are reduced by 30%).
- Scenario three (The third scenario in which the exit flow from Gotvandolya dam reservoir is reduced to 1000 µS/cm, the urban and industrial salinity loads are entirely eliminated is applied, the salinity levels of the agricultural drains and fishery drains are reduced by 50%).

Therefore, in order to improve Karun river water quality at Ahvaz city, the following implementations can be regarded respectively according to their significance. Outcome of the scenarios are presented in Table 8.

Table 7: Results of the mathematical model to calculate salinity load and TMDL of Karun and Dez Rivers

Station Name	Existing conditions-without load reduction				Without groundwater load				Second scenario*				Third scenario**			
	Discharge M^3/s	EC µS/cm	TDS Mg/lit	Salinity load	Discharge M^3/s	EC µS/cm	TDS Mg/lit	Salinity load	Discharge M^3/s	EC µS/cm	TDS Mg/lit	Salinity load	Discharge M^3/s	EC µS/cm	TDS Mg/lit	Salinity load
Ahvaz	230	2680	1876	37280	230	2130	1491	29629	230	1920	1344	26708	230	1715	1201	23856
Mollasani	238	2150	1505	30948	238	2150	1505	30948	238	1437	1006	20685	238	1226	858	17647
Arab Asad	189	1706	1194	19501	189	1706	1194	19501	189	1074	752	12277	189	1045	732	11945
Gotvand	211	1500	1050	19142	211	1500	1050	19142	211	1000	700	12761	211	1000	700	12761
Gargar_Banghir	12	4035	2825	2928	12	4035	2825	2928	12	2843	1990	2063	12	2100	1470	1524
Gargar_Shoushtar	18	1575	1103	1715	18	1575	1103	1715	18.5	1074	752	1202	18.5	1064	745	1190
End of Dez River	55	2885	2020	9597	55	2885	2020	9597	55	2100	1470	6985	55	1470	1029	4890
Bamdej	57	1844	1291	6357	57	1844	1291	6357	57	1347	943	4644	57	1028	720	3544
Harmaleh	50	1038	727	3139	50	1038	727	3139	50	768	538	2322	50	654	458	1978
Dezful	173	459	321	4803	173	459	321	4803	173	459	321	4803	173	459	321	4803

* The second scenario in which the exit flow from Gotvandolya dam reservoir is reduced to 1000 µS/cm, the urban and industrial salinity loads are entirely eliminated is applied, the salinity levels of the agricultural drains and fishery drains are reduced by 30%.

** The third scenario in which the exit flow from Gotvandolya dam reservoir is reduced to 1000 µS/cm, the urban and industrial salinity loads are entirely eliminated is applied, the salinity levels of the agricultural drains and fishery drains are reduced by 50%.

Table 8: Developing Decision Support System (DSS: Ahvaz Station: Scenarios Load (ton/day) Salinity and Germany EQS)

Parameters	**Cut-off Control Standard value** (KWPA Set-Value & Germany EQS)	**Cut-off Control Load (ton/day)**	**Ahvaz Station (4 different events)**							
			Event 1 Existing Condition-Without load reduction		**Event 2 Without ground water load**		**Event 3 Second Scenario**		**Event 4 Third Scenario**	
Discharge [m³/s] in a Ahvaz	230		230	**Load (ton/day)**	230	**Load (ton/day)**	230	**Load (ton/day)**	230	**Load (ton/day)**
EC [µS/cm]	1715		2680		2130		1920		1715	
TDS (mg/l)	(1715*0.7)= 1201	23866.2	1876	37279.8	1491	29629.1	1344	26707.9	1201	23866.2
DO (mg/l)	>8 (EQS)	158.97		158.97		158.97		158.97		158.97
BOD (mg/l)	<4 (EQS)	79.4		79.4		79.4		79.4		79.4
COD (mg/l)	<7 TOC (EQS)	139.1		139.1		139.1		139.1		139.1

Conclusion: The paper has shown an overview of the integrated water resource management in global context following the explanation of globally accepted Dublin principles of IWRM. It has also highlighted the water scarcity in Khuzestan province and has developed a conceptual framework of IWRM for Khuzestan. Different aspects and factors are considered from various studies done by HU Projects with KWPA. HU reports show the three main challenges of IWRM in Khuzestan (climate change, economic development and inter-basin water transfer). The paper has shown the linkages of these and concluded with an example of decision support system to improve water quality in Rivers in Khuzestan.

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DRAINAGE WATER MANAGEMENT PLAN OF THE SOUTH WEST KHUZESTAN, IRAN

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Abstract

The existence of four large rivers and hundred thousand flatlands have made the Khuzestan province an important agricultural area. Because of soil salinity and saline shallow groundwater, subsurface drainage is inevitable in irrigated lands of the south of Khuzestan. Drainage water disposal to receiving water bodies, usually large rivers, was a common solution for drainage water problems in the 1990s. It caused major damage, especially in the downstream sectors of rivers. Due to the development of irrigation and drainage networks (IDN) after the 2000s, it was decided to manage the drainage waters of the IDNs in the southwest of Khuzestan (with an area of 340,000 hectares) as an integrated plan. Drainage water management is dependent on environmental, economic and social conditions and also on its quality and quantity (Q & Q), which are always changing. Thus, a model for predicting drainage water Q & Q in the operation period of IDNs was developed and validated using a research field of 25 hectares. The model was executed for all IDNs to predict the discharge and salinity of drainage water during the operation period. Predicted drainage water salinity of the IDNs, was used to choose between reusing or disposing of it. Drainage water salinity of IDNs will thus be reduced during the operation period; therefore, the managerial approach will change cin line with the extent of the salinity. The IDNs construction schedule would then be estimated in tandem with the modelled predictions, and a timetable for drainage waters salinity and discharge for each of the IDNs could be provided. In the early operating period, especially in the reclamation stage, drainage water reuse would not be possible because of its high salinity, as a result it will be disposed of in evaporation ponds or the Persian Gulf. Salinity will be reduced over time and the drainage water will be reused for salt-tolerant crop farming, desert greening or will be transferred to water bodies. By applying the said time table, the discharge of the drainage waters that is to be transferred to reusing sites or disposed of, could be calculated. The maximum discharges of reuse or disposal drainage waters during the time will be the design discharge for re-use sites, pump stations, main transforming drains etc. Some on farm methods have also been considered to reduce the quantity and enhancing the quality of the drainage waters.

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KEY WORDS: Drainage water reuse, Salinity, Irrigation and drainage network, Drainage water disposal, Evaporation pond.

Introduction

Drainage disposal is a acute problem that has been reported widespreadly in different parts of the world such as Southern Asia, Eastern Asia, central Asia, Northern Africa, the Middle East, Australia and the United State of America (Tanji and Kielen, 2003). Drainage water re-use planning is considered as an effective solution to this global issue. Drainage water planning and management was not given enough attention to until the 1990s where the majority of studies in drainage became focused on project design and assessment (Snellen, 1997). After the Earth Summit conference in 1992 international irrigation and drainage communities focused chiefly on drainage water management. The Earth Summit conference manifests that not only is there a need for drainage as a complement to irrigation development in arid and semi-arid areas, but also there is a need for the conservation and water re-use in Integrated Water Resources Management (Weiss, 1992).

The re-use of drainage water is practiced worldwide, mostly in arid or semi-arid regions where irrigation water is in short supply, but it is also applied in temperate regions, where re-use is practiced during the dry summer months (Ritzema and Stuyt, 2015). Re-use can increase a country's available water resources. In irrigated agriculture, re-use can be practiced on the farm level, project level, and regional level, often as a combination of official re-use by the government and unofficial re-use by individual farmers. The official re-use of drainage water at a regional level is based on the drainage water which flows in the main drains (Ritzema and Braun, 2006).

While drainage water obtained from a particular field is usable for a particular species, which is salinity resistant up to a given level, and it must be re-used before its final disposal. (Rhoades et al., 1977, Rhoades et al., 1989). Egypt a specific example. In the Nile Delta in Egypt, farmers re-use drainage water by pumping it for irrigation directly from the drains. In the eastern part of the Nile Delta, 15% of the crop water is supplied from groundwater and on-farm re-use (Abdel Gawad et al., 1991). These re-use options have increased Egypt's water availability by 20% (Barnes, 2014). A major disadvantage of this type of re-use is the salinity of the re-used water. Drainage water can never be completely re-used, however, because the salts brought in by the irrigation water have to be exported out of the area (Ritzema, 2016; Ritzema and Braun, 2006).

Safe disposal is a final challenge to drainage having its own place as part of integrated and sustainable water management. Evaporation ponds are sometimes used for salt disposal, e.g. in Pakistan, but they are of limited use as only 13% of the salts that are left behind in the Indus Basin are deposited in the ponds which are located in the desert area outside the irrigated plain in southeast Punjab (Quereshi and Sarwar, 2009). Discharging the salts into lakes and/or rivers that eventually reach the sea or ocean seems logical, but there are consequences to these higher salt concentrations. If the receiving water cannot cope with the amount of salt laden drainage water, a separate facility with a safe outlet, usually the sea, has to be constructed (Ritzema, 2016; Skogena et al., 2014).

Two of the best-known outfall drains, especially created for the disposal of highly saline drainage water, are the Left Bank Outfall Drain in Pakistan and the Third River in Iraq. The Left Bank Outfall Drain has been constructed to drain approximately 0.5 million ha in the Sind Province of Pakistan (McCready,1987). The disposal of the drainage effluent back into the River Indus, or one of its branches, is unacceptable because of the high salinity levels it has: the effluent from subsurface drainage can vary from 4.7 to 15 dS/m and that from tube wells is often twice as saline. Disposal into the river would result into excessively high salinity levels and would make downstream use for irrigation impossible. In Iraq, the Third River, which was completed in 1993, acts as an outfall drain for the area between the Euphrates and the Tigris (Ritzema, 2016).

Thirty hundred and forty-seven thousand hectares of irrigated and drained lands have been built or are being built in the whereabouts of the lower Karun and Karkheh rivers in the Southern part of Iran. Shallow groundwater level and high soil salinity make subsurface drainage inevitable in these lands. Sugarcane agro-industrials were the first areas to have an operational irrigation and drainage network in the area. The drainage water of these agro-industrials was first disposed into the Karun River, which resulted into detrimental environmental, social and economic impacts. The main problem was caused by the high salinity of the drainage water in the first years due to heavy soil leaching in order to make these lands cultivable. Disposing of highly saline drainage water directly into the Karun River increased the river salinity in the Southern parts and made it useless for meeting different demands especially for drinking purpose. To overcome these issues, drainage water was disposed into evaporative ponds in the North of the city of Khoramshahr for years. Considering the ever-increasing volume of drainage water and ever-decreasing evaporation rate potential, due to the increasing of salt concentration, the importance of drainage water management plan becomes obvious. The first step in any drainage water management plan is to forecast the quantity and quality of drainage water yet since there there was no any available data for drainage water disposal prior to the construction of the irrigation and drainage network. The literature review on the long-term fluctuation of drainage water quality in arid and semi-arid regions reveals that an overwhelming majority of soil salinity will be disposed of in the first decade of the projects' operation span. Whatsmore, the most severe salinity disposal happens in the first 2 or 3 years of the project operation. Salt discharge and as a consequence the salinity of the drainage water shows a higher level in the first years especially when the initial salinity of the soil and salinity of the groundwater is high. Drainage water salinity tends to move towards a constant level after 15 to 20 years of the operational start date. If the initial soil salinity is high then the constant level is high too. After this phase, a decrease in drainage salinity occurs gradually (Johnston, 1993, Sharma et al., 1995). These results are consistent with those of Sharifipour et al. (2012) which show that the salinity of drainage water in the Khuzestan sugarcane agro-industrial company decreased from 70 dS/m to 7.5dS/m after 20 years of operation. Thus, the first step in the development of the drainage water management plan is to develop a simulation model which is able to forecast the quantity and quality of drainage water during the operational time span. Such a simulation is essential because it can be used as a guideline to decide whether drainage water should be disposed of or re-used.

Materials and methods

Study area

There are 18 irrigation and drainage networks to the west of the Karun River and to the south of the Karkheh River with a total area of 347,000 hectares of irrigated agricultural land. This area is considered as the spatial boundary of the study.

As Table 1 depicts, the precipitation and temperature related parameters of three synoptic meteorological stations located in the north, middle, and south of the study area, near the cities of Bostan, Ahwaz, and Abadan, respectively (Figure 1).

The prevailing soil texture of the study area is characterized by silt clay loam and soil class Entisol. Based on the Iranian land classification method (Mahler, 1970); A very small part of the argricultural lands (0.5 percent) have no salinity limitations (EC of soil saturation extract < 4dS/m); 9.3 percent have slight salinity limitations (4 dS/m < EC < 8 dS/m); 17.7 percent have moderate salinity limitations (8 dS/m < EC < 16 dS/m); 30.7 percent have severe salinity limitation (16 dS/m < EC < 32 dS/m); And 34 percent have very severe salinity limitations (32 dS/m < EC). However, 7.8 percent of the study area was not evaluated. In some cases, especially in the south of the study area, the EC of soil saturation extract exceeded 100 dS/m.

Groundwater depth is less than 1m in 4 percent of the study area. Moreover, it was reported that between 1 to 2 m in 40 percent of the study area, in 27 percent of the study area it was between 2-3m, and in 49 percent of the study area it is more than 3m. Groundwater salinity is more than 60 dS/m in more than 90 percent of the study area.

Table 1. precipitation and temperature parameters in the north, middle, and the south of the study area

Station (City)	Average annual precipitation (mm)	Precipitation percentage of each season (%)				Average temperature of warmest month; July (C°)	Average of maximum temperature of warmest month (C°)	Average temperature of coldest month; January (C°)	Average of minimum temperature of coldest month (C°)
		Winter	Spring	Summer	Autumn				
Bostan (North)	193	51	13	0	36	36.6	45.5	11.7	7.4
Ahwaz (Middle)	220	48	14	0	38	37.0	46.2	12.4	7.4
Abadan (South)	159	51	11	0	38	37.0	45.4	12.5	7.4

surface irrigation was used throughoutI all of the projects, mostly in the form of closed-end furrows and borders. The Annual need for irrigation water was reported as 4.629 billion m^3, and was supplied from the Karkheh river (2.972 billion m^3) and the Karun river (1.657 billion m^3). The annual average of irrigation water for both rivers was about 1.5 dS/m. According to the U.S. salinity laboratory water classification, the most frequent class of irrigation water samples is C3S1 followed by C3S2.

Saline soil and saline shallow groundwater, make subsurface drainage inevitable in the irrigated lands of the South of Khuzestan. PVC pipes with synthetic envelopes are being used as lateral drains which disposed the drainage water to open collectors, except for the Amir Kabir and Mirza Kouchak Khan sugarcane Agro-Industries in which concrete pipes were used as collectors. Lateral drain pipes were installed at depths of 2m in old projects, thus avoiding environmental problems; however, installation depth is limited to 1.4m in the projects under development; in addition lateral drains were spaced from 30-80m.

Among the 18 networks, three of them belonged to the sugarcane agro-industries and others belong to local farmers which had a mixed crop pattern. Eucalyptus, which is salt tolerated, is cultivated in the region and its water demand is met from the sugarcane fields' drainage water, which now after 20 years its salinity has been reduced to a level that is suitable for re-use. Table 2 demonstrates the general information of irrigation and drainage project in the study area.

In the design phase, the main drainage network to the West of the Karun river and to the South of the Karkheh river , including the main drainage channels of the projects of which the disposal end of them was considered to be bodies of water such as rivers or marshes. The mains drainage channels and their area is illustrated in figure 1.

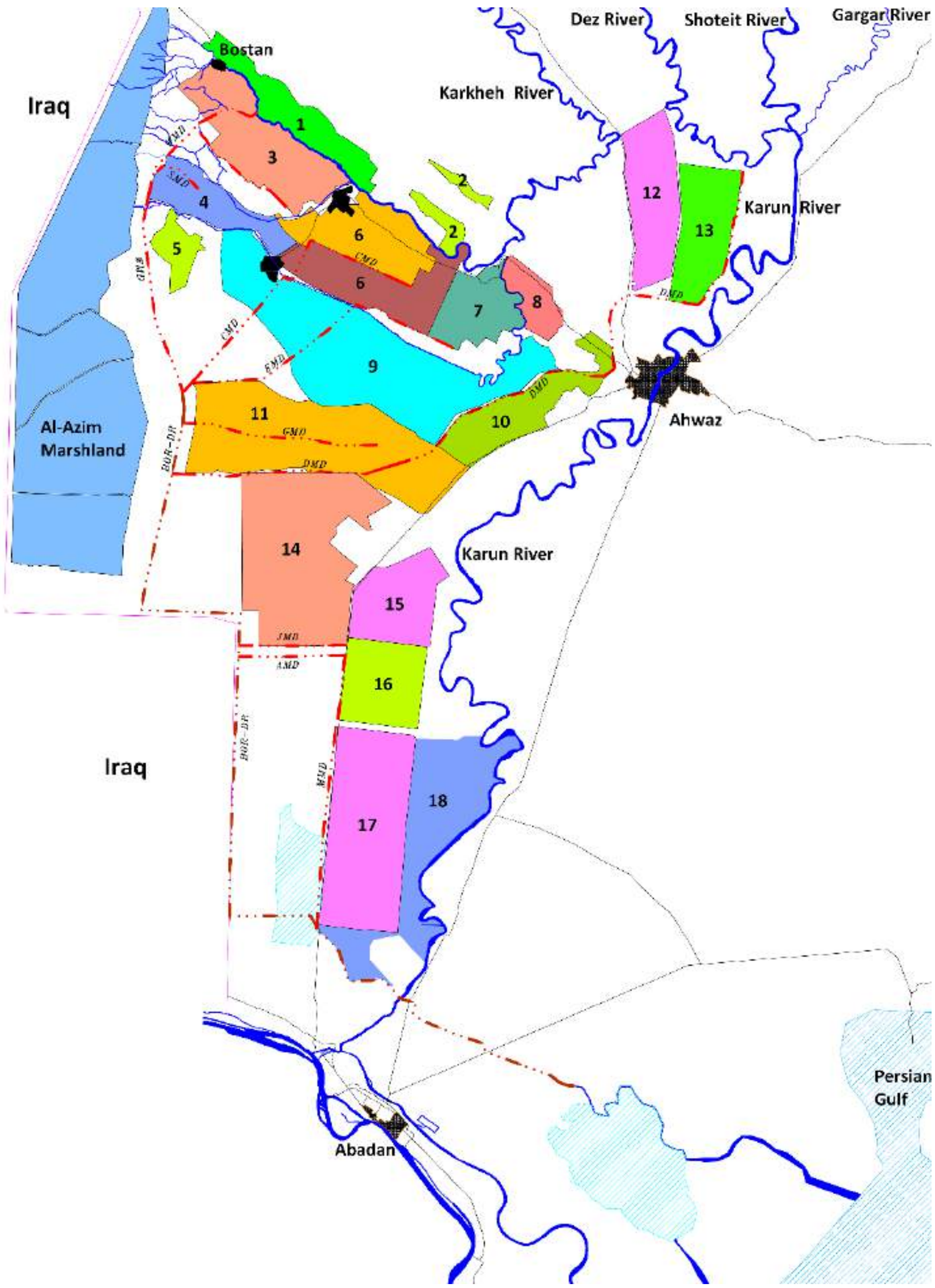

Figure 1. irrigation and drainage projects in the studied are and their main drains

WMD: Civil District 3, Azadegan plain, Civil District 4, Azadegan plain, New Yazd, Ghods and Zamzam, North of Hoofel
CMD: Civil Districts 1 and 2, Azadegan plain
EMD: Right Hamidiye, Left Hamidiye, The south of Karkhe Noor
GMD: Shahid Chamran, Development of Shahid Chamran
DMD: Dehkhoda sugarcane Agro-Industry, Kowsar
JMD: Jofeir
AMD: Amir Kabir sugarcane Agro-Industry
MMD: Mirza Kouchak Khan sugarcane Agro-Industry
KMD: Eucalyptus Agro-Industry
WKD: Western of Karun

Table 2. General information of irrigation and drainage projects in study area

Row	Project's name	Area (ha)	Row	Project's name	Area (ha)
1	North of Hoofel	10,000	10	Shahid Chamran	11,200
2	Ghods and Zamzam	4,750	11	Development of Shahid Chamran	53,805
3	Civil District 4, Azadegan plain	18,700	12	Kowsar	12,880
4	Civil District 3, Azadegan plain	13,000	13	Dehkhoda sugarcane Agro-Industry	12,000
5	New Yazd	4,580	14	Jofeir	39,645
6	Civil Districts 1 and 2, Azadegan plain	24,649	15	Amir Kabir sugarcane Agro-Industry	12,000
7	Right Hamidiye	8,502	16	Mirza Kouchak Khan sugarcane Agro-Industry	12,000
8	Left Hamidiye	6,158	17	Eucalyptus Agro-Industry	18,415
9	The south of Karkhe Noor	44,795	18	Western of Karun	40,000

Drainage water quantity and salinity simulation model

Jury et al. (2003) simulated the quality of drainage water of agricultural lands in San Joaquin Valley, California. They concluded that the salinity of discharged drainage water is in relation to the salinity of groundwater. They showed that the depth of the impermeable layer has a significant effect on the equilibrium time of the salinity of drainage water. In other words, if the impermeable layer is deep then more time is needed to reach the equilibrium time. On the other hand, the distance between drainage pipes has a significant effect on the discharge volume taken from the bottom of the drainage pipes. It means that closer drainage pipes tend to withdraw less amount of groundwater from the bottom of pipes. Therefore, the quantity and quality of discharged drainage water is a function of the depth and distance of the drainage pipes as well as the salinity profile in soil above and under drainage pipes (Wahba and Christen, 2006). In conclusion, it can be stated that if the groundwater under the drainage pipes has a high salinity level, the discharged drainage water suffers from high salinity as well.

The simulation model enjoys the benefits of system dynamics. The most important feature of system dynamics is that it helps to elucidate the endogenous structure of the system under consideration, and to demonstrate how different elements of a system actually relate to each other. This facilitates experimentation as relations within the system are changed to reflect different decisions (Elmahdi et al. 2005). Agricultural systems and their environmental effects, like many other environmental problems, constitute complex systems, the study of which requires a systemic approaches capable of explicitly managing the temporal dimension, sustainability conditions, uncertainty, and externalities (Bergh 1996). Therefore, system dynamics is a good approach to simulate such a system.

In order to simulate soil water movement and solute transport in saturated and unsaturated conditions of a drainage system the model applied the aforementioned technique. The system dynamics tool, Vensim, was used because it provides a fully integrated simulation system to conceptualize, document, simulate, and analyze models of dynamic systems. The prediction variables were drain discharge, drain water salinity, and ground water salinity behavior for different drainage densities (the depth of the drain and the drain spacing), soils, and climate.

The quantity and quality simulation model of this study consisted of two zones: a saturated zone and an unsaturated zone. The unsaturated zone was divided into four different layers ; each of them considered as a state variable. The inputs to the first layer were precipitation, irrigation water, groundwater upward flux from the sub-layer and the outputs are evapotranspiration and deep percolation. The inputs of the lower layer include deep percolation from the upper layer and upward groundwater flux and the outputs are evapotranspiration, deep percolation and the discharged amount of water from this layer to upper layers. In other words, the model traces the portion of the irrigation water that evapotranspires,and the portion that infiltrates through each layer, and finally the portion that recharges the groundwater.

The saturated layer is placed below the groundwater level. In this layer, drainage water enters the pipe drains from its entire perimeter. In saturated conditions, Hooghoudt’s equation is used to calculate the drainage outflow. Hooghoudt’s equation consists of two terms; the first term corresponds to the layer under the drain pipe and the second term corresponds to the layer above the drain pipe. Solute transport is often simulated by applying the convection-dispersion equation to field conditions. In this research, the dispersive flux is assumed to be the combination of molecular diffusion and dispersion mixing.

The concept of system dynamics is based on quantifying feedbacks and delays in the system. Therefore, the future state of the system can be calculated using a system structure and the initial value of state variables. The structure of the system is built using casual loops. There are two different casual loops in system thinking, reinforcing loops and balancing loops. Reinforcing loops represent a situation which an increase in the cause encourages an increase in the effect while balancing loops show that with an increase in the cause will result into the effect decreasing. For example, with an increase in soil moisture, deep percolation from the root zone increases and with an increase in deep percolation, moisture in the upper layer decreases and in the lower layer it increased. The causal loop diagrams are shown in Figures 2–4.

The presented simulation model uses meteorological, pedological, irrigation, groundwater, crop pattern and drainage design in order to forecast drainage water salinity and quantity.

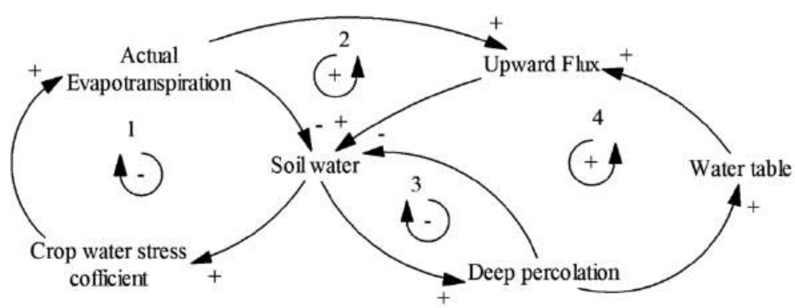

Figure 2. Unsaturated zone causal loop diagram (Nozary and Liaghat 2014)

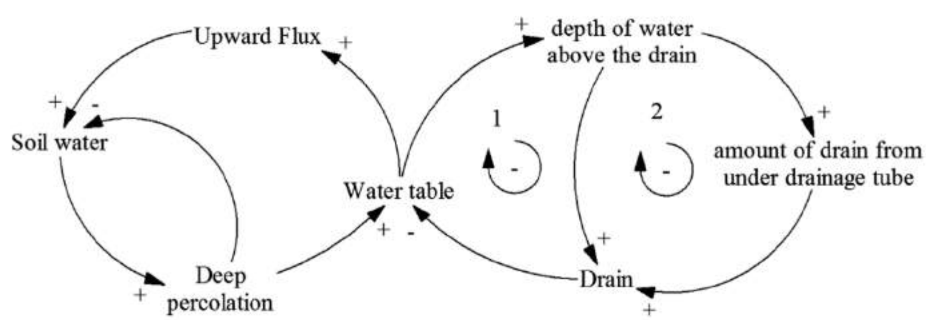

Figure 3. Drainage performance causal loop diagram (Nozary and Liaghat 2014)

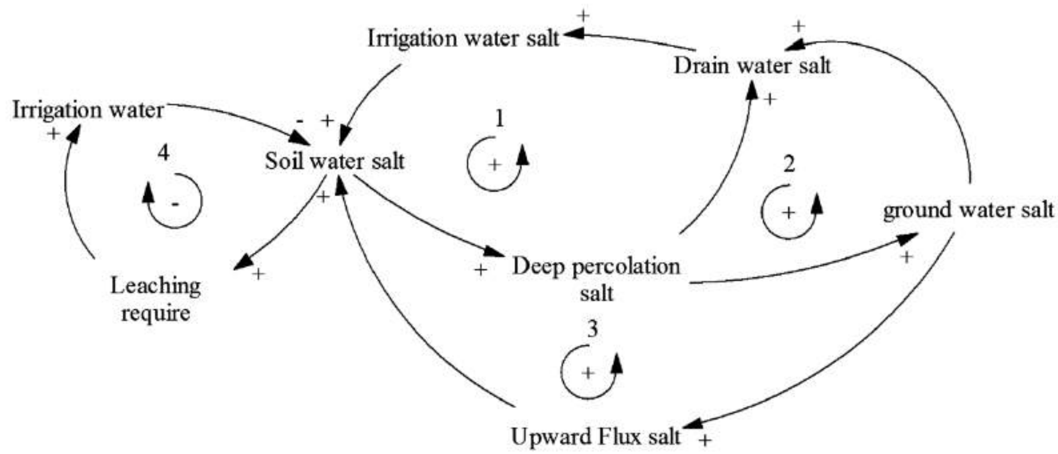

Figure 4. Causal loop diagram for dynamic salinization model (Nozary and Liaghat 2014)

The simulation model results were validated using a dataset taken from a 25 hectare field placed in the center of the sugarcane research institute of the Amir Kabir agro-industry. Three sets of piezometers were established 100, 250 and 375 meters from the collectors in order to capture the groundwater fluctuations. During the irrigation period (from March to September), fluctuations of the groundwater level, drains discharge, irrigation water salinity, groundwater salinity and drainage water salinity were measured on a daily basis.

Executing the model using the field conditions, groundwater fluctuation, drainage water discharge, drainage water salinity and groundwater salinity on a daily basis were simulated. The standard error (SE) and root square error (RSE) were calculated and the accuracy of the model was evaluated. The calculated SEs for groundwater fluctuations, drainage water discharge, and drainage water salinity were 14.4 cm, 0.43 l/s, 2.8 dS/m, respectively. The SEs of groundwater salinity in three different depths were 0.49, 0.29 and 0.36 dS/m from the surface to depths, respectively. These measures indicate relatively high accuracy. The RSEs for the mentioned variables in the same order were 8, 20, 19, 12.9, 7.5 and 8.2 percent which also indicate relatively high accuracy. The detailed description on the model development has been given by the developers (Nozary and Liaghat 2014).

On-farm techniques to reduce the quantity and enhance the quality of drainage water

Although this study was conducted in order to arrange official actions, some on-farm and project level suggestions were proposed. The Khuzestan Water and Power Authority, which is in charge of water resources and drainage water in the Khuzestan Province, has offered some design manuals for consulting engineers, and has offered some on-farm techniques for the farmers. The aim of these documents and techniques is to reduce the quantity of drainage water as well as enhancing the quality of drainage water (especially a reduction in fertilizers and pesticides concentration). These recommendations are summarized as below:

- Decreasing the depth of the subsurface drain pipes in order to reduce the groundwater proportion in drainage water salinity, especially in regions with highly saline shallow groundwater resources.
- Designing closed-end furrows, laser leveling and optimal irrigation management in the field to increase irrigation efficiency.
- Optimizing the usages of fertilizers and pesticides and replacing biological control instead of chemical control.
- Using drainage water for leaching and reclamation of saline soils (Sharifipour et al., 2015a, b).

Results and discussion

Drainage water planning and management: Dispose or Re-use?

Choosing whether drainage water should be disposed or re-used depends on the basis of its quality. In areas with shalow saline groundwater, and in which drainage water is too saline, in the first years of the operation of the irrigation and drianage network, it is necessary that drainage water is disposed of in evaporation ponds or the sea. When the quality of drainage water improves it can be used for the agriculture of salt tolerant plants, mixed with freshwater or it can be used as a replenishment source for water bodies.

In the region under study, irrigation and drainage projects are in the developmental stage. Therefore, drainage water will be produced as the projects finish and leaching begins. In other words, the speed of completing irrigation and drainage network projects shows rapid addition to the quantity of drainage water. Construction speed depends on many criteria, and thus different scenarios were developed. The results of this study are based on the most widely acceptable scenario, which indicates that 10,000 hectares of land will be added to the network annually. This study was about official practice and drainage water managements at official level usually in vicinity of the main drains. The Quantity and quality of drainage water in main drains in the study area during the operational time since the start of the project was simulated based on the aformetntioned scenario.

The simulated results of the model for WMD main drain are given in this study as an example. Figures 5 and 6 show discharge variability and salinity of the drainage water in WMD main drain, respectively. As it can be observed from these figures, the quantity of drainage increases while the salinity of drainage water decreases over months by maximizing irrigation, which is in April in the region. On the other hand, in months with no irrigation, the lowest amount of drainage water with the highest amount of salinity is disposed of . The Long-term trend shows that the quality of drainage water is getting better as the duration of operations continues. The model has been calibrated with the quantity and quality of drainage water data during the operational time span, should such data be available.

The Maximum calculated discharge using the model will be used for the hydraulic design of drains. For instance, a maximum discharge of drainage water in WMD main drain will occur in April 2057. The annually weighted average salinity of drainage water determines which management options (dispose or re-use) will be used. It is of note that as the drainage water quality increases during the operational time span, management options will adapt. The threshold of drainage water salinity at which it should be disposed or re-used is 8 dS/m for annually weighted average. For example, the annually weighted average of salinity on a WMD main drain is above 8 dS/m up to 2040, so it must be disposed of.

In this study the following receiving sources for drainage water disposal were considered.

- Evaporative ponds
- Evaporative ponds in dried parts of marshes of the region
- The Persian Gulf

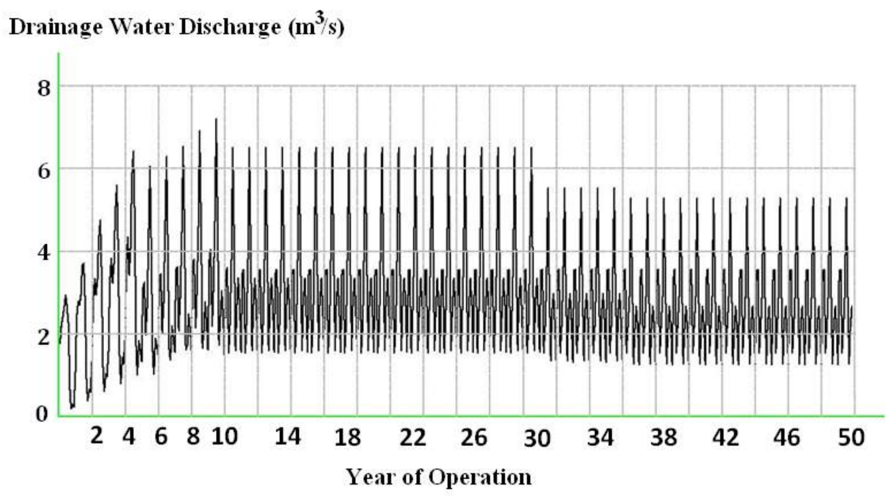

Figure 5. Drainage water discharge during the operational time in WMD main drain

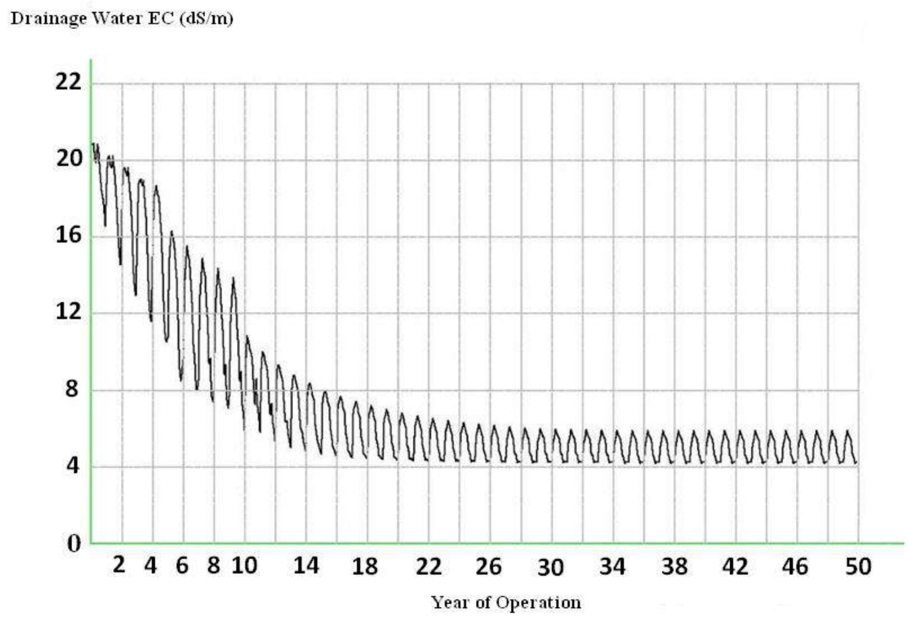

Figure 6. Drainage water Salinity during the operational time in WMD main drain

After sufficient time (approximately 20 years) since operations began, the following options are considered as the quality of drainage water which will allow the re-use of such water.

- Recharge marshes in the region
- Using drainage water for leaching and land reclamation
- Using drainage water for cultivating salt tolerant plants
- Using drainage water for natural resources conservation and desert degradation
- Recharging Arvand River
- Recharging the downstream region of the Karun River

According to the model results, the annually weighted average salinity of the CMD in the main drain will reach 7.98 dS/m in 2035 and will further reach 6 dS/m in 2050. A similar simulation for the EMD main drain shows that it will be 8 dS/m in 2047, and for the GMD main drain will be 9 dS/m in 2078 and for the DMD main drain it will be 7.34 dS/m in 2068. The Salinity of the MMD and AMD main drains are already below 7.5 dS/m, therefore it can be used for Eucalyptus agro-industry in northern Khoramshahr. The annually weighted average salinity in the JMD, WKD, and KMD main drains will never be better than 14.66 dS/m. Thisis due to the fact that the drainage water of the Eucalyptus agro-industry is highly saline because it is irrigated using the drainage water of the Amir Kabir and Mirza Kouchak Khan projects. Thus, it is obvious that, at least up to the next 20 years, the salinity of drainage water from projects placed in the South of the Karkheh river and West of the Karun river, except for the sugarcane fields of Amir Kabir and Mirza Kouchak Khan, will be high and needs to be disposed of.

The most suitable disposal method: Disposal to the sea and evaporative ponds

Disposal into the sea and evaporative ponds has the least effect on the environment. The regions main drain collects drainage water from the farthest northern end (e.g. WMD main drain) to the farthest south end of the study area (e.g. WKD main drain) to the south which there is a disposal point into the Persian Gulf and evaporative ponds. Evaporative ponds can not cope with the huge amount of the areas drainage water, but they can act as reducers for the drainage water discharge; the salt load; and the pollution.

In some main drains, drain water already has a suitable EC for re-use. Some drain water in some project will reach 8dS/m in different years. Beside the general long term trend in the quality changes of drain waters, which is inclined to salinity reduction, there is some monthly changes. For example, it is predicted that in 2030 drainage water salinity of DMD main drains, which transfer drainage water of the Kowsar project and the Dehkhoda sugarcane fields, will be more than 8 dS/m in November, December, January and February. These months are when no irrigation is applied for sugarcane. During the rest of the year, DMD's salinity is less than 8 dS/m and can be re-used. Therefore, a dual main drain is designed for transporting the areas drainage water; one to dispose saline drain water; and another one for transporting drain water with less salinity to re-use sites.

As per the results of the study, drainage water quality in main drains will be higher than 8 dS/m (except in MMD and AMD main drains) up to 2035, therefore, the drainage water in these drains must be disposed through the regional main drain (BOR-DR main drain). The final discharge for the regional main drain at the end of 2042 will reach approximately 90.07 m^3/s, but the salinity of some of the main drains will be suitable enough to be considered for the re-use. Considering the re-use, the final disposal of drainage water discharge will be 67 m^3/s, which will be disposed into the Persian Gulf.

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WATER MANAGEMENT AND FARMING SYSTEM TECHNOLOGIES WITHIN THE INDONESIAN RECLAIMED LOWLANDS FOR FOOD SECURITY OF THE NATION

Robiyanto H. Susanto[1,*], Adang Saf Ahmad [2], Ngudiantoro[3], Jarot Widiatmoko[4]

Abstract

Indonesians have been using lowlands nearby the rivers for food production for decades. Local indigenous people had developed paddy field with shallow intensive drainage systems within the tidal range. Paddy and coconut were planted. The Government of Indonesia since 1970 has been developing additional new settlement area for food production and transmigration up to 1.8 million ha mostly in Sumatera and Kalimantan islands. The total paddy field in combination of other crops within the lowlands of Indonesia so far is around 4.2 million ha. This paper will focus mainly on the reclaimed lowlands within the transmigration areas in South Sumatera, Jambi, South Kalimantan, West Kalimantan, East Kalimantan and North Kalimantan provinces. Water management consideration and farming systems technologies for paddy, corn and soy bean production have improved the yield. Rainfall, drainage, water retention and supplemental tidal irrigation are able to fulfill paddy water requirements at the farm level in November to March (first planting season of the year). Application of farming systems technologies have improved yield of paddy from 3-4 tons grain/ ha to 5-6 tons/ ha. In the second planting season of March-June, the use of ratton paddy and water melon for example will be benefited to adapt to the water regime during this period. In the drier months of June – September, corn is planted with the yield of 7-8 tons grain/ ha. Consideration of the water management and farming systems technologies has to be made depend on the site specific condition exits. Prospective uses of this approach has been implemented to around 500.000 ha of reclaimed lowlands within the transmigration areas in Sumatera and Kalimantan with an estimate of cost around Rp 3-4 million/ha. Knowledge transfer and empowering the local institutions have to be done simultaneously during this process.

KEY WORDS: Integrated lowland development, Water management, Farming system technology, Propagation development tdal lowland.

Introduction

The Government's economic development strategy places strong emphasis on rural and regional development. It includes interventions on key areas of the agricultural sector. The objective of this

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strategy has been to enchance food production especially rice, corn, and soybean; to meet increasing domestic demand; to provide rural employment; and to achieve balanced regional development. Direct Government interventions in the food sector has included :

1. Large investment in, and control and operation of, physical infrastructure for irrigation, drainage and flood control;
2. Massive farm input and farm support progress, including expansion of institutional credit arrangements, to promote the adoption of new production technology and assure farmers an acceptable income;
3. Expansion of research and extension networks, including the training program for human resources development: and
4. Establishment and operation of BULOG (the agency for national logistic administration) to co – ordinate and implement policies aimed at maintaining a nation – wide balance between the supply and demand of major food crops ensuring food security.

The Food Crop Sector has had a high priority since REPELITA I, and the government has achieved remarkable success in this regard. With the recent – on going economic crisis and recovery, the food security is one of the important issue. There is increasing awareness that the principal needs are :

1. To put strong emphasis on production of primary food crop to support food security;
2. To continue to improve the return from economic efficiency of the previous investment in irrigation and drainage, by rationalizing and strengthening system operation and maintenance, and increasing the level of cost recovery with regard to cultivation of secondary crops;
3. To continue exploitation of the currently untapped potential for major increases in land productivity by prudent expansion of the irrigation and drainage base, with special emphasis on small to medium – scale, quick – return investment;
4. To continue in improving the effectiveness of agricultural support program

Problem Definition

Indonesia avails over large lowland areas with an estimated acreage of about 33.4 million ha, out of which about 20 million ha is tidal lowland. About 8 million ha of the tidal lowlands is suitable for food crop production, implying that 12 million ha is not suitable (Figure 1). The other 13.4 million ha concern predominantly non-tidal lowlands along rivers and inland swamp areas. This discussion focuses on the about 4 million ha of the tidal lowlands that have been reclaimed, partly by spontaneous settlers (about 2.5 million ha) and partly by the Central Government (about 1.8 million ha). While the reclaimed areas mainly consist of clay and especially the government schemes have a rational lay out. These areas generally have a good potential for agriculture. Dependent on the local topographic situation, in the wet season the conditions are suitable for a rice crop and in the dry season for a second rice crop, or a dry food crop (Suryadi, 1996). However, production levels are generally low in many areas (1.5 – 2.0 tons/ha) with exceptions, especially in South Sumatra (4 – 5 tons/ha). The low production levels are caused by a variety of limitations but a major cause is the absence of an adequate water management infrastructure. For successful tidal lowland development and management there is a need for an integrated approach, based on effective water management in combination with the application of adequate farming systems technology and post harvest activities (Hartoyo Suprianto et al., 2009).

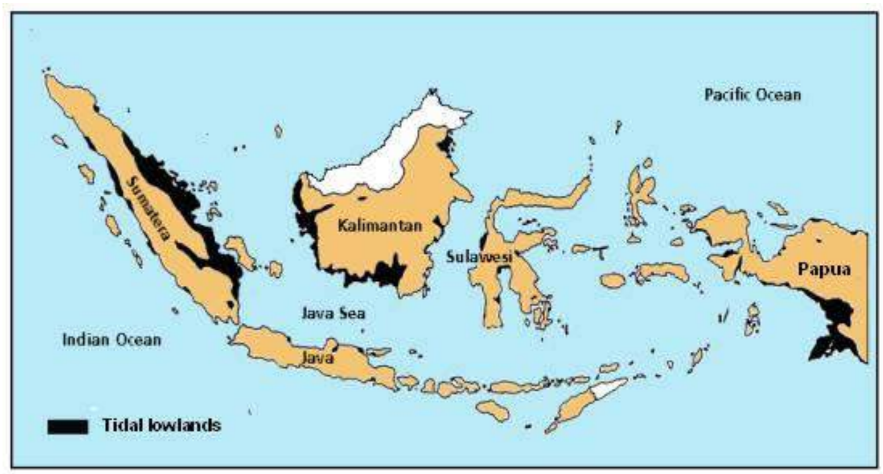

Figure 1. Tidal lowlands in Indonesia

Materials and Methods

Water management strategy which determined by the cropping pattern does not operate fully at the field even though the implementation has been anticipated. Cropping pattern which is an input to the water management action depends on the water availability and other agricultural inputs such as seed, fertilizer, labor and mechanization. Improvement of the water availability does not guarantee that the water will uniformly available at a tertiary block. And more importantly, the other agricultural inputs should be made available under the farmer's capacity. Water related issues on the tidal land can not be used to motivate farmers to start working on their farms as it is on a technically irrigated dry lands. Water management approach at the tidal land should be conducted differently as it is on a technically irrigated areas. Farmers would not be willing to work at the farm level unless the agricultural inputs also be made available. Integrated approach on food production in the reclaimed lowlands need to be done (Susanto, 2010)

Tidal Reclamation Scheme. The reclamation started with the introduction of primary canals connection two nearby bordering rivers. In addition, pairs of secondary canals known as village canal (SPD) and main drainage canals (SDU) were excavated. Farmers home lots and village roads situated along pairs of village secondary canals (SPD) (Figure 1 and 2). Tertiary canals bordering on tertiary block of 16 ha. One tertiary block designated 8 farmers having 2 ha of farm lots, first and second holding.

Water management units. As limited by the structures (canals and water gates) and actual field condition, a water management unit can be considered as 'secondary water management unit (SWMU)', 256 ha (128 farmers' households), and 'tertiary water management unit (TWMU)', 16 ha (8 farmers' households). A secondary block is bordered by secondary, tertiary canals and equipped with secondary gates as water in-outlets. Within a SWMU there are 16 TWMUs of 16 ha. A tertiary water management unit is bordered by secondary canals (part of SPD and part of SDU) and pair of tertiary canals equipped with tertiary gates. The TWMU is 8 ha for 8 farmers family (see Figures 1 and 2).

Approach. Water management will be conducted at secondary unit ('meso-level') by operating the secondary gates and at tertiary unit (micro level) by operating the tertiary structures, digging the quartenary canals and on farm water and soil management. Since the agricultural activities strongly depends on these water management units, the integrated agricultural development has to considered these water management approach. Agricultural development unit which covers 4 SWMU's 94 x 256 ha = 1024 ha) consists of at least 512 families. This family size is within the ratio of one field extension worker.

Scenarios. Cropping system development and management within the secondary or tertiary blocks level will consider several different water management strategies as flood protection, tidal irrigation, free drainage and quality or hydro-topography of the areas. First of all, quantity and quality of yield within a unit of cropping intensity from one crop to two or more crops per year need to be achieved. Project's components and sub components for the integrated development as shown on Table 1 and 2. There are three key factors to start with: Water management improvement, farming system technologies, and empowerment of the communities. During the first year of project, at least one cycle of the season, dry season, soybean-corn crops, and wet (rainy) season, rice crop, has to be achieved. In addition to the on-farm activities, the related off-farm activities will also be conducted. The outcomes will be evaluated for the following year's plan of works.

Results and Discussion

Experiences in the pilot areas integrated approach to tidal lowland development

As said, for successful tidal lowland management there is a need for an integrated approach, based on effective water management in combination with adequate farm inputs, farming systems technology and post harvest activities. In order to develop, analyze and promote such an integrated approach the project Land and Water Management Tidal Lowlands (LWMTL) was implemented from 2004 to 2006. The project aimed at improvement of the existing agricultural exploitation to increase cropping intensity and yields, in order to obtain indicators on the potential of the tidal lowlands to contribute to governments' objective with respect to self-sufficiency in rice and to a certain extent in maize. It was a bilateral cooperation between Indonesia and the Netherlands that was based on three pillars: a) assessment needed water control infrastructure; b) familiarization and implementation of farming systems technology; c) operation and maintenance with water users associations.

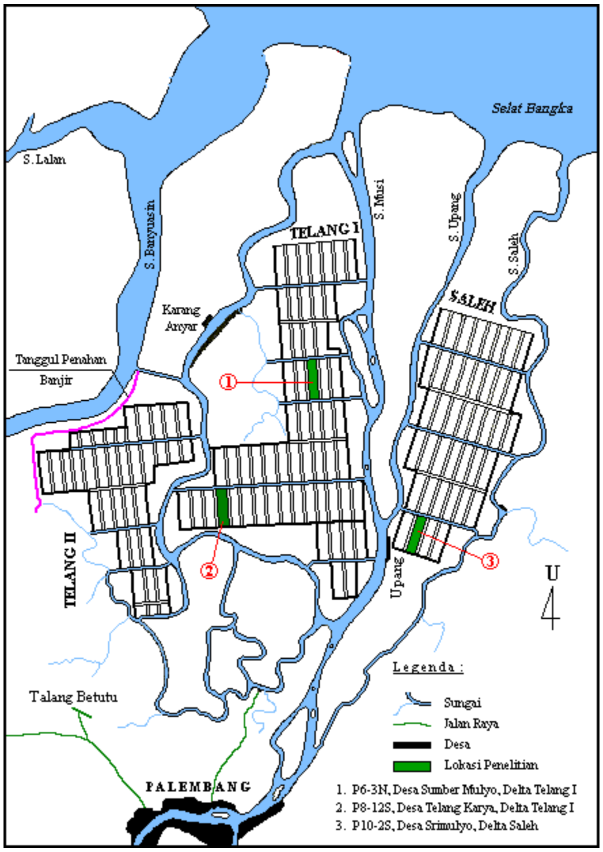

Figure 1. Telang and Saleh schemes, Musi delta, District Banyuasin, South Sumatra with the location of the three pilot areas (Hartoyo Suprianto et al, 2009)

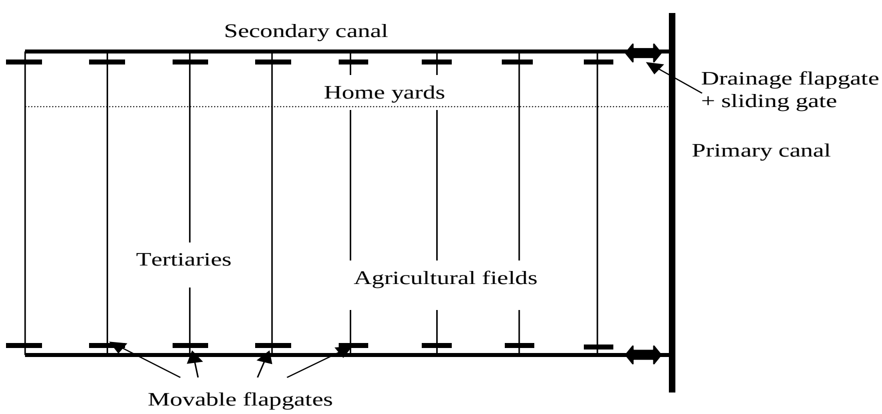

Figure 2. Example of a secondary block with water control structures

The approach that has been developed was applied in three pilot areas (representing category A, B and C areas) - each covering a secondary block of about 250 ha - in the Musi Delta, South Sumatra (Figures 1) (Hartoyo Suprianto et al., 2009).

In January 2007 the LWMTL project was followed up by the project Strengthening Tidal Lowland Development (STLD) where further experience has been obtained in the same three pilot areas in South Sumatra and their surrounding areas and in two new pilot areas in the Districts Pontianak and Sambas in West Kalimantan. In addition experience has been obtained with modern mechanized maintenance of secondary and tertiary canals. Completion of this project was by the end of July 2008. The proposed Propagation Development of Tidal Lowlands (PDTL)to disseminate the success of LWTL and PDTL results was then proposed.

Water management consideration and farming systems technologies for paddy, corn and soy bean production have improved the yield. Rainfall, drainage, water retention and supplemental tidal irrigation are able to fulfill paddy water requirements at the farm level in November to March (first planting season of the year) in Telang I and Telang II, Banyuasin areas. Application of farming systems technologies have improved yield of paddy in Telang I Banyuasin areas from 3-4 tons grain/ ha in 2003 to 5-6 tons/ ha in 2008 (Hartoyo Suprianto et al, 2009). In the second planting season of March-June, the use of ratton paddy and water melon for example will be benefited to adapt to the water regime during this period in Telang II in 2015. In the drier months of June – September, corn is planted with the yield of 7-8 tons grain/ ha in Telang II area (Bappeda Banyuasin 2015). Consideration of the water management and farming systems technologies has to be made depend on the site specific condition exits. The three key components: water management, farming system technologies, and empowerment of communities have given significant results of food production and farmers welfare. There are still a lot of components need to be considered and implemented (see Table 2). Related research and development are needed in this integrated approach (Direktorat Rawa dan Pantai 2009; Susanto, 2009, 2010, Sartika et al 2010, Rahmadi et al, 2010, Megawati et al 2012, Husin Adam et al 2013, Erry Korianti et al 2016).

Adoption and spreading over of the best practices to other provinces

Prospective uses of the integrated approach has been implemented to around 500.000 ha of reclaimed lowlands within the transmigration areas in Sumatera and Kalimantan with an estimate of cost around Rp 3-4 million/ ha. Knowledge transfer and empowering the local institutions have to be done simultaneously during this process. The selected interest local governments in 8 provinces to apply the integrated approach on lowland development are shown on Table 1.

Table 1. Selected Sites being used for an Integrated Lowland Development for Crops in 8 lowland provinces Indonesia

No	Name of provinces	**Districts** Sites	Hydro-topography	Present Yield and cropping pattern
1.	South Sumatera	**Banyuasin** Muara Sugihan	B/C	3-4 tons/ ha one crop per year
2.	Jambi	**Tanjung Jabung Timur** Berbak Delta	B	3-4 tons/ ha one crop per year
3.	Riau	**Indragiri Hilir** Pulau Palas	B	3-4 tons/ ha one crop per year
4.	South Kalimantan	**Barito Kuala** Danda Jaya	A/B	3-4 tons/ ha one crop per year
5.	West Kalimantan	**Kubu Raya** Bintang Mas	B/C	3-4 tons/ ha one crop per year
6	East Kalimantan	**Penajam Paser Utara** Sebakung	B/C	3-4 tons/ ha one crop per year
7.	North Kalimantan	**Bulungan** Tanjung Buka	A/B	3-4 tons/ ha one crop per year
8.	Central Kalimantan	**Seruyan**	A/B	3-4 tons/ ha one crop per year

Table 2. Integrated Lowland Development for Food Crops Components

No.	Project's component	Description
1.	Management Information System	Agro institutional profile, price information, market need assessment, data base, mapping, of soil-water constrains-farm-crops-yield-market-product, pest monitoring and control.
2.	Hydraulic Infrastructures Development and Improvement	Flood controls, river embankments, upgrading of the main and secondary canals, water retention structures, operation and maintenance
3.	On-Farm Soil-Water Management and Mechanization	Land clearing, ploughing, puddling, tertiary canals maintenance, on-farm quaternary canals and gates, field leveling, water distribution and uniformity, fertilization.
4.	Cropping System Management and Development	Crop selection, crop variety, seed, planting, crop protection and weed control, fertilization, cropping intensity, crop diversification, yield increase, technology demonstration.
5.	Harvest and Post-harvest Handling	Harvesting, threshing, seed sorting and screening, packing, transportation, drying, fumigation storage.
6.	Agroprocessing and Agroindustry Development	Sorting, washing, grinding, cooking, processing (home-industry), fermentation, quality assurance, marked oriented research, packing, labelling
7.	Agricultural Waste Management	Organic fertilizers (manures), utilization of agricultural waste for chicken-ducks pellet, composting, green fertilizer, mulching, ash for liming.
8.	Marketing	Market needs assessment, packing, and labeling, product and price information, KUD, credit system
9.	Agricultural Transportation System	On-farm road-bridge systems, earthen road compaction, motored-wheeled carts, water transport utilization, docking system
10.	Training-Extention and Community Development	Training for the trainer (TOT), training for the farmers, institutional integration, group activity studies, (mobile) training unit, brosur, booklet, comparative studies.
11.	Domestic Water Supply	Rainfall utilization and storage, communal water system, deep groundwater utilization, water treatment, water related desease extension and awareness
12.	On-Farm Farmers Oriented Research (Client Oriented Research)	Market information service, water management, soil improvement, vegetable research, cropping system development, fruit tree improvement, mechanization, seed production, pest monitoring and control, institutional affairs

The roles of multi stake holders. Implementation of integrated components need to be shared to multi stakeholders working on the same targeted areas. This will include the local government, academician/ researcher, private sector, community and politician. Continuous approaches and efforts have to be done.

Integrated Lowland Development Components for Welfare of the Community. The tree main components of integrated development as explained before is not sufficient and has to be coupled with a more comprehensive efforts as shown on Table 2 above. Role sharing and road maps are needed.

Conclusion

Application of farming systems technologies, water management practices, and community empowerment have improved yield of paddy at the first growing season from 3-4 tons grain/ ha to 5-6 tons/ ha. Other related suppoting factors are still needed simulatenously. In the second planting season of March-June, the use of ratton paddy and water melon for example will be benefited to adapt to the water regime during this period. In the drier months of June – September, corn is planted with the yield of 7-8 tons grain/ ha. Consideration of the water management and farming systems technologies has to be made depend on the site specific condition exits. Prospective uses of this approach has to be implemented to around 500.000 ha of reclaimed lowlands within the transmigration areas in Sumatera and Kalimantan.

Implementation of integrated components need to be shared to multi stakeholders working on the same targeted areas. This will include the local government, academician/ researcher, private sector, community and politician. Continuous approaches and efforts have to be done.

Prospective use of the integrated approach has been implemented to the the reclaimed lowlands within the transmigration areas in Sumatera and Kalimantan with an estimate of cost around Rp 3-4 million/ ha. Knowledge transfer and empowering the local institutions have to be done simultaneously during this process.

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SIMULATION STUDY ON THE PERFORMANCE OF AN IMPROVED SUBSURFACE DRAINAGE SYSTEM

Yuan Tao[1] , Shaoli Wang[2,*], Di Xu[3]

Abstract

New requirements have been put forward for agricultural drainage systems due to frequent floods and shortage of cultivated land in China. The improved subsurface drainage is a more efficient drainage system due to the laying of high permeability materials as filters above the drains based on conventional subsurface drainage whose function is limited by soil hydraulic conductivity. The HYDRUS model was used to evaluate the impacts of the filters' hydraulic conductivity, in addition to the filter width and height, drain spacing and depth on improved subsurface and drainage discharge with constant ponding depth to support the subsequent design. In addition water table depths at different distances from the drain pipe for improved and conventional subsurface drainage were simulated under initial conditions of saturated soil and no surface ponding. The results indicated that the improved subsurface drainage had a real-time drainage function due to the fact that the cumulative outflow had increased by about 45% more than the conventional subsurface drainage within 12h after the beginning of the draining of the field soil. Improved subsurface drainage lowered the water table to an appropriate depth faster than conventional ones and provided a more favourable soil moisture condition for crop growth. Furthermore, through daily water balance analysis of improved and conventional subsurface drainage with different rainfalls and initial water table depths, the results showed that subsurface drainage could reduce surface runoff effectively, especially for improved subsurface drainage. Suitable drain ability of improved subsurface drainage was beneficial in the decreasing of the amount of soil water storage after rainfall and helped to shorten subsequent draining time during water table drawdown. The research results provide a scientific basis for improved subsurface drainage design and lay a good foundation for its application. Meanwhile, it would be beneficial to enrich agricultural drainage technologies and promote the development of agricultural drainage in China.

KEY WORDS: Hydrus, Improved subsurface drainage, Conventional subsurface drainage, Discharge, Water table, Runoff reduction.

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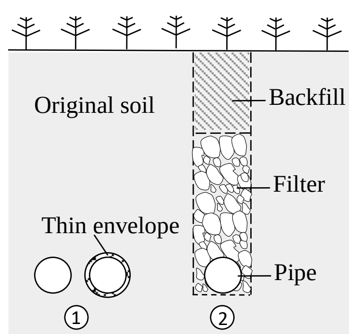
Introduction

Abnormal climate change increases the probability of heavy and intense rainfall events in some areas which causes floods frequently (Das et al., 2013; Groisman et al., 2005; Panagoulia, 2009). In China, most farmlands are in monsoon regions where floods happen more frequently influenced by monsoon climate (Loo et al., 2014). So there are higher demands for farmlands drainage facing flood threat.

Subsurface pipe drainage was widely used all over the world for the removal of excess water from soil profile to maintain favorable unsaturated condition in the root zone and improve the crop growth(Atfy et al., 1991; Darzi-Naftchali et al., 2013; Ghumman et al., 2013). Subsurface drainage systems not only reduce peak flows when compared with surface systems on similar soil, but also decrease soil erosion and sediment transport and improve agricultural water environment (Grazhdani et al., 1996). With the development of China's economy and technology, the issues of farmland shortage and agricultural pollution are getting more and more attention. Subsurface pipe drainage has great potential with characteristics of less land occupied and environmental friendly. Conventional subsurface drainage has limited discharge due to small soil hydraulic conductivity. The conventional subsurface drainage by increasing drain discharge and improving drainage efficiency will accelerate ponded surface water infiltration and removal effectively, which also will be beneficial for waterlogging control. Referring to the structure of conventional subsurface drainage and open ditches, Tao et al. (2016) proposed an improved subsurface drainage by using high permeability materials (gravels or wood chips or crop stalks et al.) as filter to replace the soil above the drains and backfilling 30~40cm original soil as a plow layer, shown in Figure 1. Larger discharge of improved subsurface drainage than conventional ones has been proved by soil column experiment, roughly. It might be difficult to evaluate the improved subsurface drainage performance comprehensively only by experiment. The numerical simulation could be a good



1.Conventional subsurface drainage.
2.Improved subsurface drainage

choice for more detailed study.

Fig.1 Sketch of two subsurface drainage patterns

Recently, DRAINMOD and SWAP (Soil-Water-Atmosphere-Plant) and HYDRUS have been widely used to simulate subsurface pipe drainage performence and its ability to control the water table. DRAINMOD and SWAP are one-dimension models based on hydrological process (Dam et al., 1997; Kroes et al., 2000). Skaggs et al. (2012) calibrated DRAINMOD with two years of field data for a sub-surface drained agricultural field in eastern North Carolina and validated the model by data of another two additional years to state the validity of DRAINMOD on predicting discharge and water table of subsurface drainage system. Wang et al. (2006) simulated the water table and surface runoff and subsurface drainage based on data of Eugene F.Whelan plots using DRAINMOD and demonstrated that DRAINMOD has a good simulation performance for hydrology and can be a useful tool for the design of the drainage system. Singh et al. (2006) designed subsurface drainage systems for Iowa' tile landscapes based on calibration and validation of DRAINMOD. Kelleners et al. (2000) predicted subsurface drainage water salinity for a long time using SWAP. Sarwar and Feddes (2000) applied SWAP model to compute the effects of land drainage (12 combinations of drain depth and spacing) on soil moisture conditions in the root zone and their effect on crop yield and soil salinization.

However, HYDRUS is a windows-based model, which can simulate two-dimensional and three-dimensional water flow situations. HYDRUS is used to simulate water, heat, and solute movement in variably saturated media. Especially, HYDRUS can handle flow domains delineated by irregular boundaries. The flow region itself may be composed of nonuniform soils having an arbitrary degree of local anisotropy (Šimůnek et al., 2006). TEKİN (2002) has predicted the relationship of drain discharge and water table depth by simulating water flow into subsurface pipe drains for a layered soil profile based on HYDRUS-2D model. Ebrahimian and Noory (2014) have applied HYDRUS-2D model to simulate water flow under subsurface drainage in a paddy field for various drain depths and spacing, surface soil textures and crack conditions. Filipović et al. (2014) has used HYDRUS-2D/3D to evaluate three subsurface drainage systems of pipe drains, pipe drains with gravel trenches, pipe drains with gravel trenches and mole drains under a given high intensity rainfall and a real case scenario, and discussed the effects of three subsurface drainage systems on water table control. The results has demonstrated that pipe drains with gravel trenches and pipe drains with gravel trenches and mole drains were more efficient on waterlogging control, runoff reduction and drainage management than single pipe drains.

The main objective of this paper was to numerically evaluate the performance of improved subsurface drainage by HYDRUS-2D model based on calibration and verification by field experiment data. (ⅰ) The drainability of improved subsurface drainage was analyzed with variable factors of filter hydraulic conductivity, filter width and height, drain depth and drain spacing in saturated soil with constant ponding water depth. (ⅱ) Under initial saturated soil and no ponding water conditions, the water table dynamics under improved subsurface drainage was studied to explain the effect of water table control by comparing with conventional subsurface drainage. (ⅲ) Daily water balance was calculated to demonstrate the capacity of surface runoff reduction for improved subsurface drainage with variable initial water table depths and different rainfalls.

Materials and methods

Field experiment

The field experiment was conducted at Xinmaqiao experiment station in Huaibei plain, China(117°22′ E, 33°09′ N). The climate of Huaibei plain belongs to warm temperate and semi-humid monsoon climate with an average annual precipitation of 760mm~920mm(Qi, 2009), occuring mostly from June to September. It is prone to surface and subsurface waterlogging. Field experiments were carried out in 2015 and 2016. It consists two of conventional and improved subsurface drainage plots, each 18m wide by 17m long, with an area of 306 m^2. Each plot contained three 75mm diameter tile drains. Drains were installed at 0.80m depth and 6m spacing and the gravel filter width and height of the improved subsurface drainage were 0.4m and 0.5m. The drain outflows from each plot flowed directly into observation wells and cumulative discharges were recorded using digital water meters. Tests were conducted when surface ponding was generated or water table was close to the surface after rainfall. Furthermore, the hydraulic conductivities of soil in each plot had been measured by double loop infiltration experiment. The average values of conventional and subsurface drainage plot were 0.805m/d and 0.916m/d. The average saturated and residual water content were 0.31cm^3cm^{-3} and 0.05cm^3cm^{-3}, measured by laboratory test. Water table and the water contents in unsaturated soil were measured before testing (Table 1).

Due to the natural spatial heterogeneity of soils in the field, expected lack of uniformity of soil hydraulic properties, experimental data were used with the inverse option available in HYDRUS-2D to estimate the other effective soil hydraulic parameters characterizing (Kandelous and Šimůnek, 2010).

Table 1 Water table and content before drainage tests

Date	Ponding depth (cm)	Water table depth (cm)	Water content(cm^3cm^{-3})
August 12, 2015	7cm	-	-
August 13, 2015	-	25cm	0.25
October 18, 2015	1cm	-	-
June 5, 2016	-	5cm	0.28
June 7, 2016	-	5cm	0.28
June 24, 2016	-	20cm	0.255

Numerical modeling theory

The governing flow equation for two dimensional isothermal Darcian flow of water in variably saturated rigid porous medium is given by the following modified form of Richards equation:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x}(K_x \frac{\partial h}{\partial x}) + \frac{\partial}{\partial z}(K_z \frac{\partial h}{\partial z}) + \frac{\partial K_z}{\partial z} - S \qquad (1)$$

Where θ is the volumetric water content [L^3L^{-3}], t is time [T], x and z are the spatial coordinates [L], h is the pressure head [L], S is a sink term [T^{-1}], K_x, K_z are components of K at x and z directions and K is the unsaturated hydraulic conductivity function [LT^{-1}] given by

$$K = K_s K_r \tag{2}$$

Where K_r is the relative hydraulic conductivity and K_s is the saturated hydraulic conductivity [LT^{-1}].

The van Genuchten(VG) model was used to describe soil hydraulic functions. The expressions of VG model were given by

$$\theta(h) = \begin{cases} \theta_r + \dfrac{\theta_s - \theta_r}{[1+|\alpha h|^n]^m} & h < 0 \\ \theta_s & h \geq 0 \end{cases} \tag{3}$$

$$K(h) = K_s S_e^l [1-(1-S_e^{1/m})^m]^2 \tag{4}$$

$$S_e = (\theta - \theta_r)/(\theta_s - \theta_r) \tag{5}$$

$$m = 1 - 1/n \qquad n > 1 \tag{6}$$

Where θ_r and θ_s denote the residual and saturated volumetric water contents [L^3L^{-3}], respectively; S_e is the effective saturation [-], α [L^{-1}] and n [-] are retention curve shape factors, and l is a pore connectivity parameter [-].

Model calibration and validation

The HYDRUS-2D was firstly used to calibrate unknown parameters of field soil according to observed drain process on August 13, 2015. The parameters of gravel describing filter hydraulic properties adopted the values suggested by (Filipović et al. (2014)). The final estimates of soil hydraulic parameters for soil and gravel were shown in Table2.

Table 2 Hydraulic parameters of soil and gravel for VG model

	θ_r($cm^3\ cm^{-3}$)	θ_s($cm^3\ cm^{-3}$)	a(cm^{-1})	n	K_s($cm\ min^{-1}$)	l
Soil in conventional plot	0.05	0.31	0.014	1.8	0.0560	0.5
Soil in improved plot	0.05	0.31	0.014	1.8	0.0636	0.5
Gravel in improved plot	0.005	0.42	0.1	2.1	2	0.5

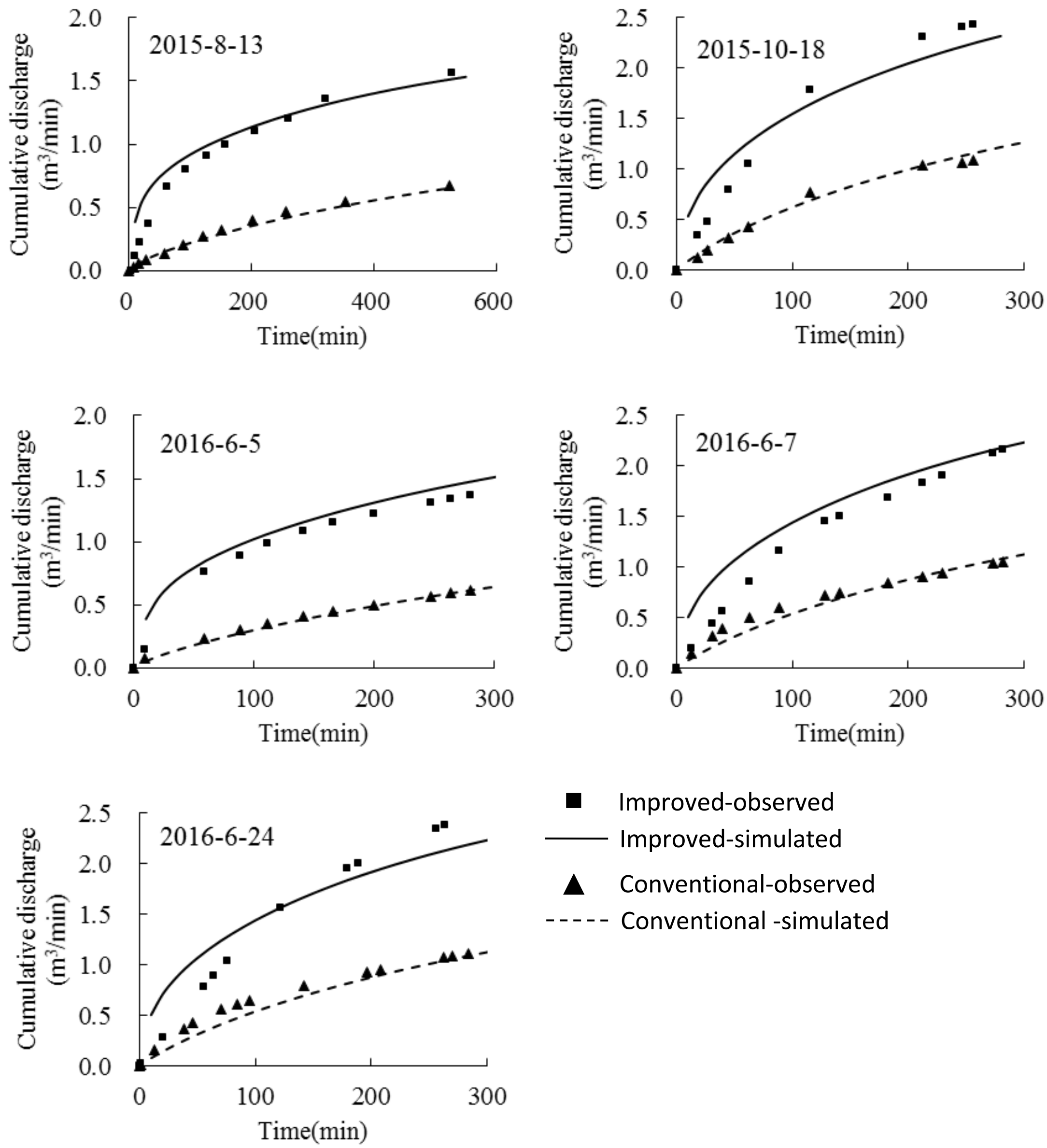


Fig.2 A comparison of observed and simulated drain process for the field experiment

On August 12, 2015, the drain test was conducted under the condition of surface ponding. The observed discharge were 0.0135cm^3 min^{-1} and 0.0116cm^{3}min^{-1} for conventional subsurface drainage and 0.0292cm^{3}min^{-1} and 0.0255cm^{3}min^{-1} for improved subsurface drainage with 7 and 1cm surface ponding depths, respectively. Correspondingly, the simulated discharge were 0.0131 cm^3 min^{-1} and 0.0121cm^{3}min^{-1}, 0.0296 cm^3 min^{-1} and 0.0262 cm^{3}min^{-1} for conventional and improved subsurface drainage. It could be easily seen that the observed and simulated discharge matched well under the condition of surface ponding. In addition, the improved subsurface drainage discharges were over 2 times of conventional ones with same ponding depth.

The comparison of observed and simulated cumulative discharge for conventional and improved subsurface drainage plot at other times were shown in figure 2. To evaluate the effect of calibration and validation, three statistical parameters of coefficient of determination (R^2), relative error (*RE*), and Nash-Sutcliffe efficiency coefficient (Nash and Sutcliffe, 1970; Saleh et al., 2000) were selected. Table 3 showed the evaluation of the model calibration and validation. In validation period, the statistical parameters R^2/*RE*/Nash-Sutcliffe efficiency coefficient were respectively 0.975/-4.6%/0.97 overall, which reflected an excellent performance of the model.

Table 3 Evaluation of the model calibration and validation

	Date	Coefficient of determination	Relative error (%)	Nash-Sutcliffe efficiency coefficient
calibration	August 13, 2015	0.948	8.7	0.93
validation	October 18, 2015	0.955	3.6	0.95
	June 5, 2016	0.985	6.1	0.97
	June 7, 2016	0.974	1.6	0.97
	June 24, 2016	0.977	-4.6	0.96
	Overall	0.975	-4.6	0.97

Simulated scenarios

The largest difference between improved and conventional subsurface drainage is that improved subsurface drainage uses high permeability material as filter laid from the drains to plough layer (seeing Figure 1). Gravels or rice husk or wood chips or crop stalks or cinders were commonly used as filter materials (Stuyt and Dierickx, 2006). These materials have different hydraulic conductivities. And even the permeability of a material will be changed after working for a long time. For an example, the hydraulic conductivity of rice husk will be reduced to half when pressure increases from 0kPa to 5kPa (Ebrahimian et al., 2011). In shallow groundwater areas, the water table can reach the ground surface within a short time after heavy and intense rainfall and surface ponding occurs subsequently, which will make the soil fully saturated. In this case, the effect of filter hydraulic conductivity on drainability of improved subsurface drainage in saturated soil with ponding water is worth to be discussed. Besides, filter width and height influence the drainability directly as well. Although the discharge of improved subsurface drainage with larger filter size will be larger, we also have to consider the installation cost of drains. Furthermore, drain depth and spacing are still the factors affecting the discharge of improved subsurface drainage. After surface ponding fading away, the main goal of drainage is to lower water table to an appropriate depth in a given number of days better for crop growth and yield (Claire et al., 2008; Jackson, 1990). So the ability of water table control was simulated to examine the function of the improved subsurface drainage.

Scenario 1 and 2 were developed to study the factors affecting the drainability of improved subsurface drainage with constant ponding depth in a saturated soil. In scenario 1, the effects of filter permeability on the removal of ponding water were discussed for improved subsurface drainage. Then in scenario 2, variable factors of filter width and height, drain depth and spacing were considered.

In scenario 3, the drain discharge and water table dynamics under improved subsurface drainage with initial saturated soil and no ponding water were studied. Compared with conventional subsurface drainage, water table depths at different distances away from the drain pipe were calculated to illustrate the function of lowering water table level by improved subsurface drainage. In scenario 4, daily water balance for improved subsurface drainage was analyzed to explain the capacity of surface runoff reduction under rainfall of 25mm, 50mm and 100mm per day with initial water table depth of 0cm, 10cm and 30cm respectively.

Simulated scenario input

Drainage model using HYDRUS was built based on the above-mentioned four scenarios, showed in figure 2 in which S1 and S2 stand for hydraulic conductivities of the soil and filter, b_0 stands for filter width, h_0 is filter height, h is drain depth, B represents drain spacing and T represents the depth of impermeable layer. In the scenario 3 and 4, the geometric parameters were chosen by taking subsurface drainage practices of Huaibei plain as reference. Geometric parameters are assumed as follows: b_0=40cm, h_0=70cm, h=1m, B=40m, T=10m(Wen et al., 2000). Furthermore, the hydraulic conductivity of the soil and diameter of the pipe were assumed the same as that of improved plot in field experiment. For scenario 1 and 2, the parameters were varied as showed in table 4 based on aforementioned ones.

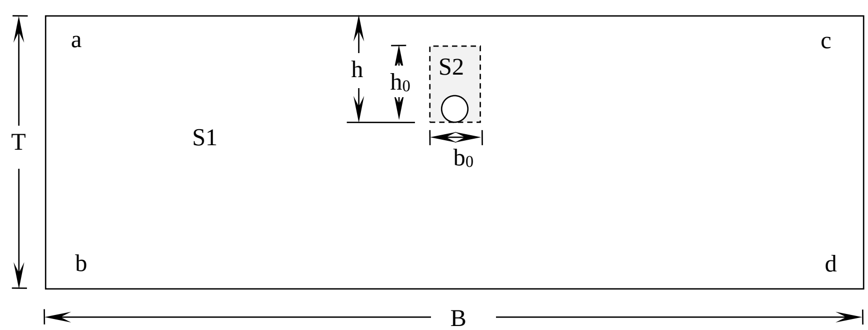


Fig.3 Sketch of improved subsurface drainage model

Table 4 Geometric parameters and filter hydraulic conductivity of scenario 1 and 2

Factors	Variable parameters
Filter hydraulic conductivity	$S2/S2_f$=0.1,0.3,0.5,0.8,1,1.2,1.5,1.8,2,3
Filter width	b_0=0,0.1,0.2,0.3,0.4,0.5,0.6m
Filter height	h_0=0,0.1,0.2,0.3,0.4,0.5,0.6,0.7m
Drain depth	h=0.8,0.9,1,1.1,1.2m, h_0=0.5m
Drain spacing	B=5,10 ,20, 30, 40, 50, 60 m

$S2_f$ stands for hydraulic conductivity of the filter in the field abdc was a no-flux boundary (Figure 3), drain pipe was assigned seepage boundary, and surface boundary ac was variable in different scenarios. The boundary ac was set to be constant head boundary of 7cm in scenario 1 and 2, and seepage boundary in scenario 3. While in scenario 4, atmospheric boundary was used to describe surface boundary ac where evaporation was ignored and rainfall was 25mm, 50mm and 100mm per day respectively. Besides, the pressure head in unsaturated soil were assumed to be -100cm when initial water table was lower than ground surface. VG model was also used to describe the soil hydraulic properties.

Results and discussion

Removal of ponding water

Effect of filter hydraulic conductivity

Effects of filter hydraulic conductivity on improved subsurface drainage discharge per unit length were shown in Table 5. Generally speaking, the improved subsurface drainage discharge increased with the increasing filter hydraulic conductivity, while the increased percentage of per unit hydraulic conductivity decreased gradually. When the ratio of filter and soil hydraulic conductivity was about 10 which was the minimum allowed ratio in usual filter design criteria, the discharge was about 1.9 times of that in conventional subsurface drainage. Next, when hydraulic conductivity of improved subsurface drainage filter was about 30~40 times of the soil's, the improved subsurface drainage discharge could be increased about 10% again based on the minimum allowed ratio aforementioned. However, the subsequently increased hydraulic conductivity of the filter would have small impacts on the increase of discharge.

In another words, there will be little influence on improved subsurface drainage discharge until filter hydraulic conductivity reduces to about 30~40 times of the soil after filters of gravels or rice husk or wood chips or crop stalks working for a long time in practice. Fortunately, there were still obvious larger discharge of improved subsurface drainage than conventional ones even when the ratio of filter and soil hydraulic conductivity reduced to 10.

Table 5 Discharges per unit length with different filter hydraulic conductivities

S2(m/d)	0.916	2.88	8.64	14.40	23.04	28.80	34.56	43.20	51.84	57.60	86.40
$S2/S2_f$	0.03	0.1	0.3	0.5	0.8	1.0	1.2	1.5	1.8	2.0	3.0
S2/S1	1.0	3.1	9.4	15.7	25.2	31.4	37.7	47.2	56.6	62.9	94.3
discharge(m^2/d)	1.51	2.40	2.87	2.95	3.01	3.04	3.06	3.09	3.10	3.12	3.15
Times of conventional drain	1.00	1.59	1.90	1.95	1.99	2.01	2.03	2.05	2.05	2.07	2.09

Effect of filter width and height

Figure 4 showed the effects of filter width and height on improved subsurface drainage discharge per unit length. It could be seen that wider and higher filter size could obviously increase the drain discharge before filter width and height reached critical values. When filter height kept constant, the relationship between improved subsurface drainage discharge per unit length and filter width could be estimated as a second degree parabola. The discharge increased about 76% when filter width varied from 0 to 0.2m and subsequently the discharge only increased 10% on the basis of current value every 0.1m increase in width when filter width changed from 0.2 to 0.6m. Similarly, when filter width remained constant, the discharge increased about 67% when filter height increased from 0 to 0.2m, and only 7% every 0.1m increase in width when filter width changed from 0.2 to 0.6m. Additionally, filter size is an important factor for influencing improved subsurface drainage discharge, larger filter size usually means larger discharge but higher cost. Four types of improved subsurface drainage with the same filter cross sectional area were further simulated(b_0=0.2m/ h_0=0.6m, b_0=0.3m/ h_0=0.4m, b_0=0.4m/ h_0=0.3m, b_0=0.6m/ h_0=0.2m). The discharges were 2.555,2.559,2.699,2.751 m^2/d respectively in order. It could be seen that bigger filter width made larger drain discharge when filter sectional area was a constant. However, filter width usually affects engineering excavation quantity. No matter in design or practice, it is critical to optimize drain layout considering the relationship between investments and drain effect with maximum benefit as the target.

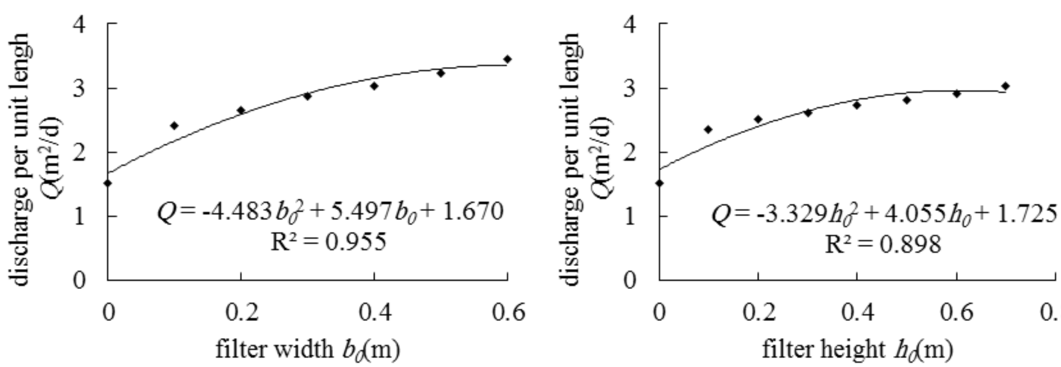


Fig.4 Effects of filter width and height on discharge per unit length

Effect of drain spacing and depth

With fixed filter size and drain depth, the total drain volume was close to be stable when drain spacing exceeded an effective control distance. For improved subsurface drainage, the discharge per unit length increased obviously with the increasing drain spacing within a drain spacing of 10m. After drain spacing exceeded 10m, the discharge changed slowly (left in figure 5). While for conventional subsurface drainage, the effective control distance was about 5m which was smaller than improved subsurface drainage. In another word, improved subsurface drainage could control larger drainage areas. Besides, the ratio of improved and conventional subsurface drainage discharge rose gradually within 10m drain spacing and was almost in a stable value 2.02 when drain spacing was larger than 10m. The effect of drain spacing on drainage discharge per unit area which is an important drainage index in design was also shown in figure 5 (right). We could easily found that the relationship between conventional and improved subsurface drainage discharge per unit area and drain spacing was power function distribution.

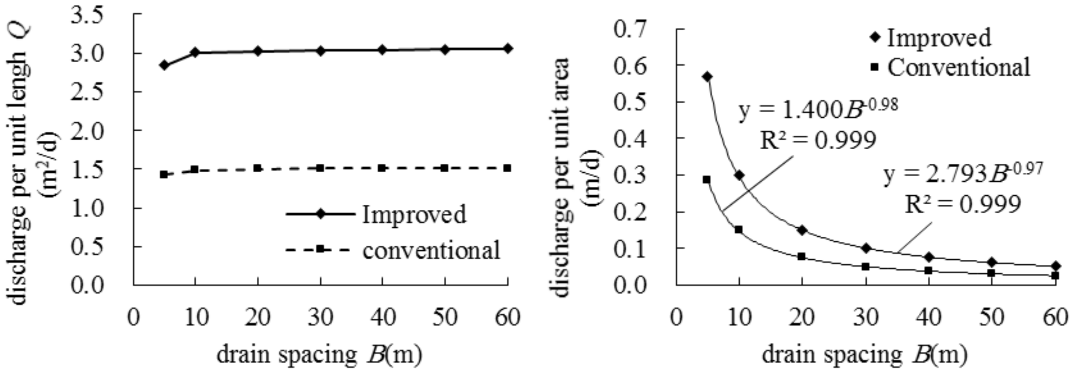


Fig.5 Effect of drain spacing on improved and conventional subsurface drainage discharge

In figure 6, the effect of drain depth on improved subsurface drainage discharge per unit length was given. The simulation results showed that the relationship between improved subsurface drainage discharge and drain depth satisfied linear positive correlation well when filter size and drain spacing kept constant. The variation trends of drain discharge with drain spacing and height were almost the same as that of conventional subsurface drainage obtained from Kirkham (1949) formula.

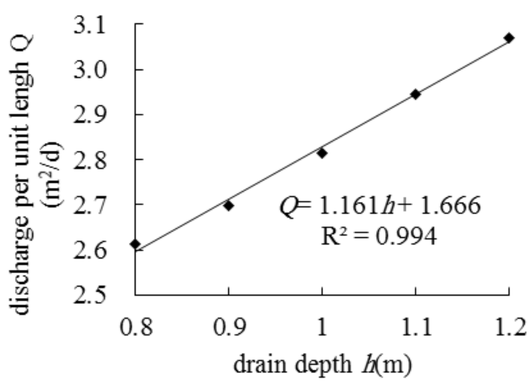


Fig.6 Effect of drain depth on improved subsurface drainage discharge

Water table control

Drain discharge and cumulative outflow

Figure 7 displayed improved and conventional subsurface drainage discharges and cumulative outflow per unit length within 72h after beginning drainage. With draining time going on, water table declined and discharge of improved and conventional subsurface drainage decreased gradually, but improved subsurface drainage discharge was larger than that of conventional subsurface drainage all the time. The improved subsurface drainage had a larger discharge as soon as the drainage began due to weak water holding capacity within the filter. Subsequently soil water around the filter was drained. As time continued, water table continuously decreased and contact zones between groundwater and filter narrowed gradually. Ultimately, the improved subsurface drainage discharge was close to conventional ones, as shown in the left side of figure 6. Meanwhile, it was easily found that the relationship between the discharge and draining time accorded with power function and presented a good correlation both for improved and conventional subsurface drainage.

For the right side in figure 7, conventional subsurface drainage had cumulative outflows of 2869, 4627, 7173 and 9028cm^2 per length at 12h, 24h, 48h and 72h after beginning drainage. While the cumulative outflows of improved subsurface drainage were 4173, 6205, 9053 and 11066cm^2 per length, resulting in a corresponding increase of 1303, 1578, 1880 and 2039 cm^2 than conventional ones respectively. From the view of cumulative outflow, the effect of improved subsurface drainage was remarkable within 12h after beginning drainage during which there was 45% cumulative outflow increasing than conventional subsurface drainage. That is to say, the improved subsurface drainage had obvious effect for real-time drainage and could lower water table to waterlogging tolerance more quickly to produce a more favourable soil moisture condition for crop growth.

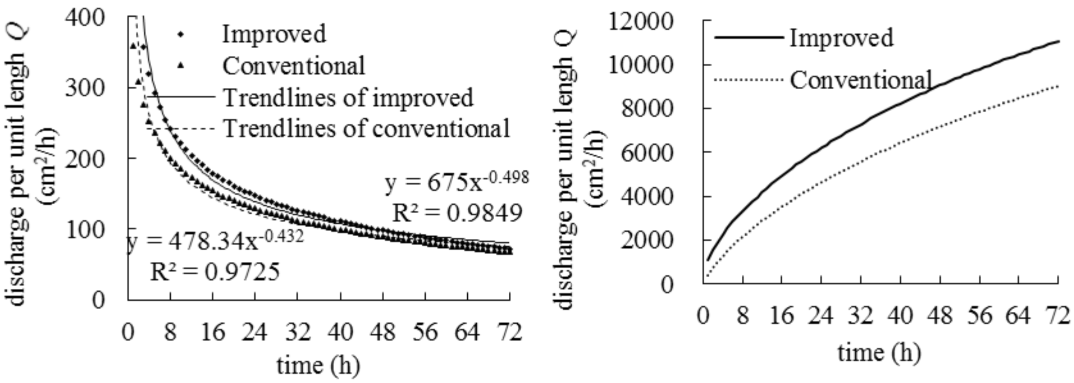


Fig.7 Dynamic processes of drain discharge and cumulative outflow

Water table dynamics

Under drain spacing of 40m, water table depths at distances of 20m(B/2), 10m(B/4) and 5m(B/8) away from the drain pipes under improved and conventional subsurface drainage respectively were shown in Figure 8.

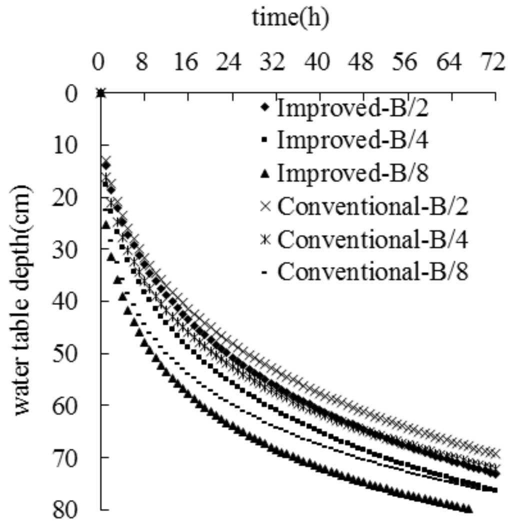


Fig.8 Water table depth in improved and conventional subsurface drainage

With the increase of draining time, water table declined and the ability of lowering water table of improved subsurface drainage was weakened because of decreasing discharges. In China, waterlogging control standard of agricultural drainage requires that water table should drop to 40~60cm below the soil surface within 3~4 days during waterlogging sensitive period for drought crops or within 3~5 days during drying period for paddy field. Hence, the time required to lower the water table to 50cm below the soil surface has been selected as a study target. Numerically, the times of water table drawdown at distances of 5m, 10m and 20m away from the drain pipes were 10h, 17h and 24h separately for improved subsurface drainage and 13h, 22h and 28h for conventional subsurface drainage. It could be seen that water table dropped more slowly at farther distance from drain pipes. In addition, the draining time of improved subsurface drainage lowing water table to 50cm below the soil surface decreased over 14% than conventional subsurface drainage. It was shown that improved subsurface drainage was more beneficial to control water table and helpful for drainage water management.

Drain process under high intense rainfall

Table 6 gave daily water balance of improved and conventional subsurface drainage corresponding to rainfall of 25mm, 50mm and 100mm per day under initial water table depth of 0cm, 10cm and 30cm respectively. The water contents in the unsaturated zone were set as 0.25 cm^3cm^{-3} and 0.28 cm^3cm^{-3} respectively with initial water table depth of 10 and 30cm according to field experiment. There were three ways to go for the rainfall: surface runoff, subsurface drainage and storage in soil. Generally, from table 6, we could see that surface runoff remarkably increased with the increasing rainfall when initial water table depths were equal, while the amount of subsurface drainage and soil water storage appeared small increase limited by soil hydraulic conductivity.

Under conditions of initial saturated soil, corresponding to 25mm, 50mm, 100mm rainfall per day, cumulative outflows were 19.4mm, 23.2mm and 27.5mm per length and the percentages of surface runoff reduction were 73%, 45% and 27% by infiltration for conventional subsurface drainage.

Depending on larger discharge, the cumulative outflows of improved subsurface drainage were 1.2, 1.2 and 1.3 times of conventional subsurface drainage discharge respectively and the percentages of surface runoff reduction also increased 12.6%, 16.4% and 21% than conventional ones, accordingly. It could be seen that the effect of improved subsurface drainage on surface runoff reduction was larger than conventional subsurface drainage, especially for large intense rainfall.

Table 6 Daily water Balance for high intense rainfall

	Water table depth (cm)	Rainfall (mm)	Infiltration (mm)	Runoff (mm)	Drain (mm)	Soil water variation (mm)
Improved subsurface drainage	0	25	20.6	4.4	24.1	-3.5
	0	50	26.3	23.7	28.9	-2.6
	0	100	32.9	67.2	34.9	-2.1
	10	25	21.5	3.5	23.3	-1.9
	10	50	27.3	22.7	28.2	-0.9
	10	100	34.6	65.4	34.8	-0.2
	30	25	24.3	0.7	18.0	6.3
	30	50	32.8	17.2	25.2	7.6
	30	100	41.0	59.0	32.8	8.2
Conventional subsurface drainage	0	25	18.3	6.7	19.4	-1.1
	0	50	22.6	27.4	23.2	-0.6
	0	100	27.2	72.9	27.5	-0.4
	10	25	19.3	5.7	18.9	0.4
	10	50	24.0	26.0	23.0	1.0
	10	100	28.5	71.5	27.2	1.3
	30	25	23.4	1.6	14.0	9.4
	30	50	29.9	20.1	19.9	10.0
	30	100	35.9	64.2	25.6	10.2

With the increasing of initial water table depth, less water were drained and more water were stored in soil which would accelerate the infiltration. The soil water storage in rainy day would directly influence the subsequent draining. For improved subsurface drainage, there was less increased soil water storage than conventional ones when other conditions were equal. Taking 50mm rainfall per day as an example, the soil water storages were 17.2 mm and 20.1mm for improved and conventional subsurface drainage separately when initial water table depth was 30cm. In addition, runoff decreased with the increasing of initial water table depth. Taking 50mm rainfall per day as an example, compared with conditions of initial saturated soil, there were 4.2%, 27.4% runoff reduction for improved subsurface drainage and 5.1%, 26.6% for conventional subsurface drainage under initial water table depth of 10cm and 30cm respectively.

To sum up, under same initial water table depth and rainfall, improved subsurface drainage had better drainability and more effect in reducing surface runoff than conventional subsurface drainage, which was better to satisfy agricultural drainage and waterlogging control requirement.

Conclusion

Numerical experiments have been performed for improved subsurface drainage, (ⅰ) the drainability of removing ponded surface water with variable filter hydraulic conductivity, filter height and width, drain spacing and depth, (ⅱ) the capacity of water table control, (ⅲ) drainability and surface runoff reduction under different rainfalls and initial water table depths. The main conclusions were as follows. Firstly, under saturated soil and constant ponding water depth conditions, the value of 30~40 was a transition ratio of filter and soil hydraulic conductivity. Improved subsurface drainage discharge increased obviously when the ratio was less than 30~40. But the increase of discharge tended to be small when the ratio exceeded 30~40. Fortunately, the discharge of improved subsurface drainage was significantly larger than conventional ones even when the ratio of filter and soil hydraulic conductivity reduced to 10. Filter width and height had a good relationship of second degree parabola with improved subsurface drainage discharge respectively. The effect of drain spacing and drain depth almost met the same rules as that in conventional subsurface drainage except for larger effective control distance. In practices, the factors aforementioned should be chosen carefully, considering the costs and benefits comprehensively. Secondly, improved subsurface drainage had better effect on water table control than conventional subsurface drainage. The draining time of improved subsurface drainage lowering water table to 50cm under surface decreased over 14% than conventional subsurface drainage. Finally, subsurface drainage could reduce runoff effectively, especially for improved ones under high intense rainfall. The effect of improved subsurface drainage was more significant with the increasing rainfall which also reduced more surface runoff. At the same time, the increase of soil water storage for improved subsurface drainage was smaller than conventional subsurface drainage, which alleviated subsurface waterlogging degree and was beneficial for subsequent water table control. In addition, the improved subsurface drainage played more advantage than conventional ones in shorten draining time for the selected soil texture.

Acknowledgement

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THE EFFECT OF CANAL WATER RETENTION ON THE FLUCTUATING WATER TABLE AT THE RECLAIMED LOWLANDS FARM AT TANJUNG LAGO, BANYUASIN, SOUTH SUMATERA

Warsito[1,*], Robiyanto H Susanto[2], Edward Saleh[3], Novia Sumardi[4]

Abstract

The reclaimed lowlands of Indonesia, respective of one 16 ha tertiary block within a 256 ha secondary block consisting of 16 tertiary blocks, are used for food production. The Paddy is planted during the rainy season of November to February followed by water melon cultivation in March to May, and corn in June to September. The fluctuation of the water table in the farm is very crusial in determining the cropping calender. Water management applying a free drainage approach is influenced by tidal water movement into the tertiary canals bordering the farmers fields. A constant water retention -10 cm below the canal bank increased the water table in the farm from -10 cm to +20 cm. Water retention (controlled drainage) mode was applied by farmers especially during the rice growing period. The release of water in the canal to a depth of -50 cm below the canal bank lowered the water table level to -20 cm. Over the 200 day experiment, soil and water samples are taken 16 times to be analyzed in relation to the fluctuating water table. The NO_3^-, NH_4^+, pH content of the water sample corresponded to the the fluctuating water table. Preliminary research results related to the water table fluctuation are discussed in this paper.

KEY WORDS: Water table fluctuation, Drainage, Reclaimded tidal lowland, Controlled drainage.

Introduction

Development of tidal lowland in South Sumatra has been conducted by government since 1969 through transmigration program. Conserved and improved tidal lowland land of South Sumatra are approximately covered 2.92 million ha (Euroconsult, 1995). It is reported that 60 percent rice production in South Sumatra of 2.8 million tons is currently produced from lowland areas (Prov. Agricultural Office of South Sumatra, 2015). The reclaimed lowland is frequently experience lack

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of fresh water supply due to low tidal irrigation that incapable reaching into the land and less rainfall. Moreover, porous soil condition results in high value of soil hydraulics conductivity caused in very high losses of water due to percolation and lateral seepage. It is caused that rainfall water is difficult to be retained. This made a sharp drawdown of the shallow water table in the farm (Susanto, 2007). The water table depth, especially in dry season, is lower than the depth of pyrite layer depth which results in oxidation process.

Water management is one of important factor for land management at reclaimed tidal lowland area (Suprianto et al. 2009). This management is not only to reduce or to add surface water availability, but also to reduce acidity, to minimize land acidity due to phyrite layer oxidation, to minimize salinity hazards and flooding risks, as well as to reduce toxic chemical compounds as a result of phyrite layer oxidation (Imanuddin and Susanto 2005). In order to establish the above conditions, water management operation is geared toward aspects of water table management that is always located above phyrite layer and land leaching through a controlled drainage systems (Skaggs, 1991).

In term of the above potential and constraint, tidal lowland development needs a proper planning, management, and utilization of land as well as proper technology application, especially water management aspect (Susanto, 2003). This soil has a good potential for agricultural development through proper management. Proper planning of water management is certainly need data of daily soil water status, thus yearly monitoring of that data is essential. Water table dynamics within the crop root zone has highly significant to influence water availability for crops. Therefore, a field study to monitor water status at tertiary blocks is needed in order to develop water management and land utilization planning. The study objective is to investigate the water table dynamics within tertiary blocks in order to determine correlation between water level in the canal and withn the soil at the farmers field during drainage. Daily water level fluctuation in the canal and water table fluctuation within the soil are observed

Materials and methods

Study and field investigation have been conducted at tidal lowland reclamation area. The demonstration plots (demplot) of 16 ha is located at Primer 17-6S, Banyu Urip, Tanjung Lago, Banyuasin District (Figure 1). Study and field monitoring are conducted within two growing seasons consisting of wet and dry seasons. Observation period (water table monitoring) in the field is carried out from January to June 2015. Soil and water samples were taken and analyzed 16 times during this periods.

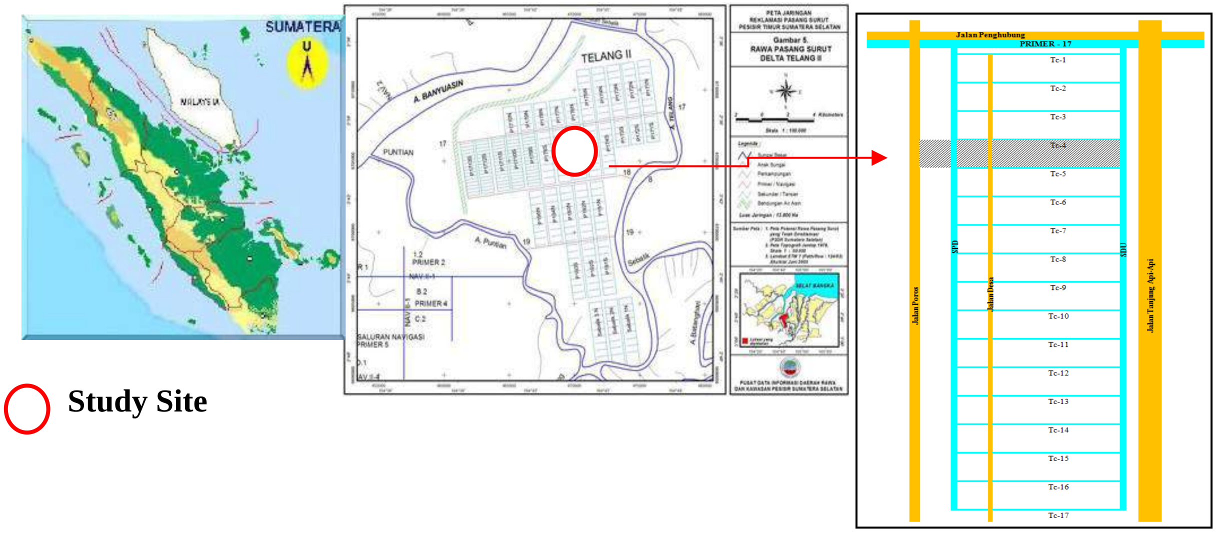

Figure 1. Study site at Primer 17-6S, Banyu Urip-Tanjung Lago, Banyuasin District

The water table fluctuation measurement at farmers field conducted by using observation wells made from perporated PVC pipes. Observation wells are placed midway between tertiary canals spacing of 200 m. The distance od the wells are 100 m, 50 m, 25 m, 12.5 m and 2.0 m from the tertiary canal. Water table fluctuations were observed daily as well as the water level at the tertiary canals. In addition, daily rainfall is observed by direct measurement from rainfall tipping buckets for every 07.00 a.m time. Soil survey is carried out to determine the physical characteristics of soil such as texture, bulk density, total pores volume, soil hydraulics conductivity, and acid sulphate layer depth. Potential of tidal water penetration within the canals and water table fluctuations at tertiary block are observed daily within two growing seasons (wet and dry seasons). Results of field observation data were analyzed and compared with observation of the critical value of soil water depth that is needed to grow the crops. The cropping pattern for this area is rice, ratton rice or water melon, and corn.

Results and discussion

General Condition for Study Site in Tanjung Lago, Banyuasin, South Sumatera

This reclaimed low land is classified into agroclimate type C1 based on Oldeman classification with monthly average temperature of 32^0C and yearly average rainfall of 2500-2800 mm. Rainy season is occured from November to April, whereas the dry season is occured from March to October (Figure 2). Rainfall is relatively low and ineffective to fulfill the crop water requirement at the dry season. This fresh water deficit problem is combined with the inflow of seawater or salt water during high tide. Based on high tide water that overflow into the land, Tanjung Lago lowland area in general is classified into B/C type overflow which means that it is not flooded during high tide or low tide. The land is not overflow by tide water, but the tide water penetrate into the primary, secondary and tertiary canals, affecting the fluctuating water table in the farm. The available water is mostly from rainfall water because tide water can not enter the land which results in rain-fed characteristics of the land. Quality of this land is characterized by unripe physical soil characteristics, high total pores volume (60-70 percents), low bulk density (0.90 – 1.0 grm/cm3), and light texture at the upper layer of 0-30 cm, and medium texture at the depth of 30-60 cm. Soil hydraulics conductivity is about 9-12 cm/h. This condition creates high water losses at this area. Hardpan layer is not develop in this land due to low intensity of soil tillage.

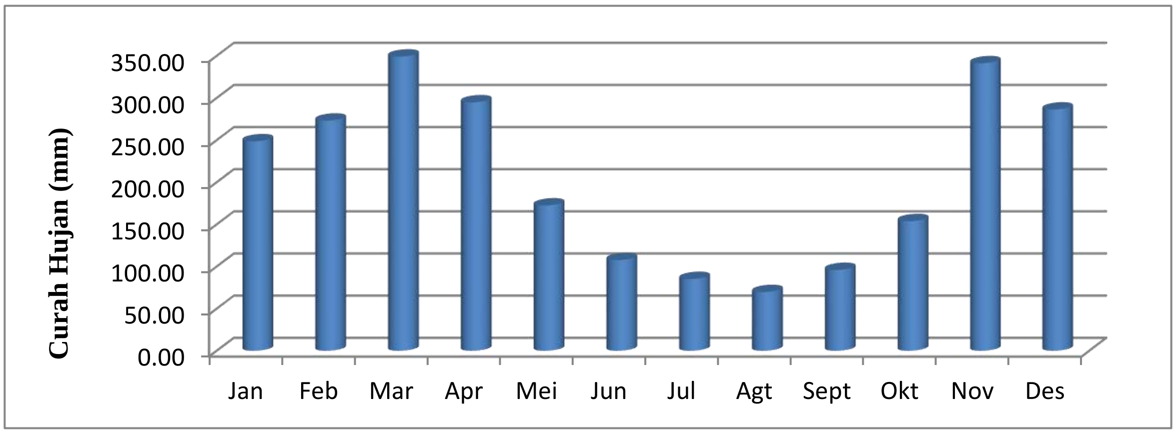

Figure 2. Average Monthly Rainfall in Tanjung Lago, Banyuasin, South Sumatera

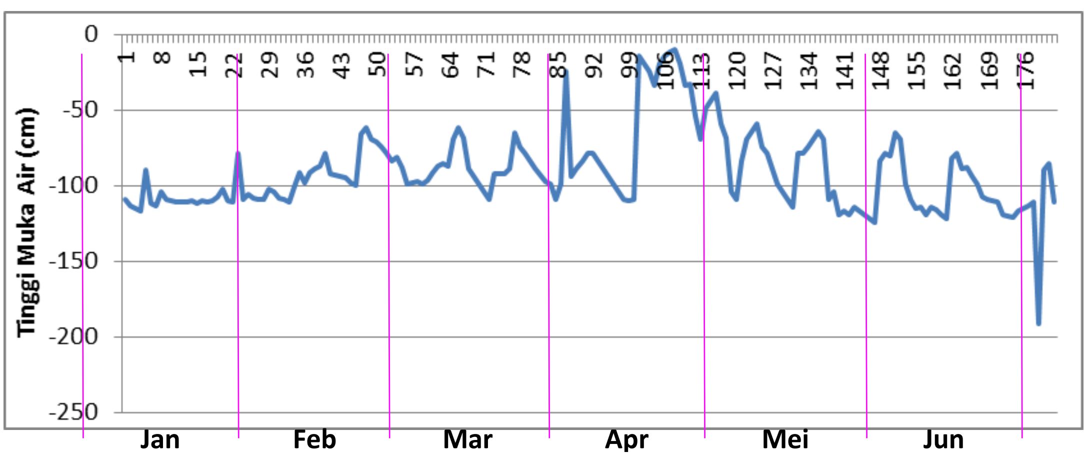

Figure 3. Water level fluctuation downstream of the tertiary canal Tc4 gate

Water level fluctuation downstream of the tertiary gate TC4

Observed water level downstream of the tertiary gate TC4 showed the effect of tidal water movement. The water level fluctuates according to the tidal water conditions. The water level downstream of the TC3 gates are always below the soil surface. It has several water level of peaks which varies during the rice growing season starting December up to April.

Water Level Fluctuation at Tertiary canal TC-4 upstream of the tertiary gate

Results of observation showed that yearly rainfall is 2500-2800 mm/year. This rainfall magnitude is actually sufficient to support paddy water needs. The effective rainfall is not optimal due to porous soil and high hydraulics conductivity as well as insufficient water management facilities. This condition is exaggerated by insufficient tidal water penetration. Free drainage mode applied by the farmers has to be changed to controlled drainage mode in this case as shown at Figure 4.

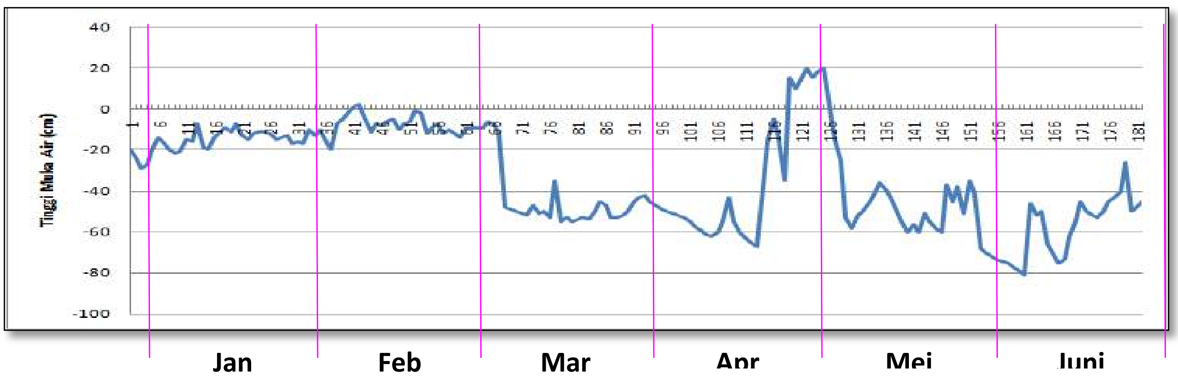

Figure 4. Water level fluctuation at tertiary canal (TC-4) with controlled drainage (water retention)

As shown on Figure 4, water is retained within the tertiary canal TC4 in January to February to almost 10-20 cm below the soil surface. This effort is to make full rainfall water retention in the paddy field during the vegetatif growth of rice planted at the end of Decmber 2015. Lateral seepage from the land into the tertiary canals as well as surface runoff will be reduced with a high water level position within the tertiary canals bordering the farm. Rainfall in January and February can be stored effectively with water retention at the TC4. The water at canal TC4 was release to average almost -50 cm during March and May to overcome the drying of farm land for rice harvest. Lowering the water level at TC4 will lower the water level in the farm. Another water retention at the end of April is due to land preparation for corn growing season. Free drainage mode applied at TC4 during May June onward for the corn growing season.

The Effect of TC4 water retention on Water table fluctuation within the soil at the observation Well 1 (near the tertiary canal TC4)

Results of daily water table analysis near the tertiary canal showed on Figure 5. Water table fluctuation within the soil near the canal TC-4 following the same trend with the fluctuating wate level inside the TC-4. In the months of January and February when the water was retained inside the TC-4, the water table at well 1 started to increase from less then 10 cm below the surface upto 3-7 cm above the soil in January and to about 10 cm above the soil in February and mid of March. The increased water table on the land with water retention in the TC4 follow the rainfall pattern during the same period. Lowering water level inside TC4 to -50 cm (Figure 4) has lowered the water level in the farm to -20 cm (Figure 5).

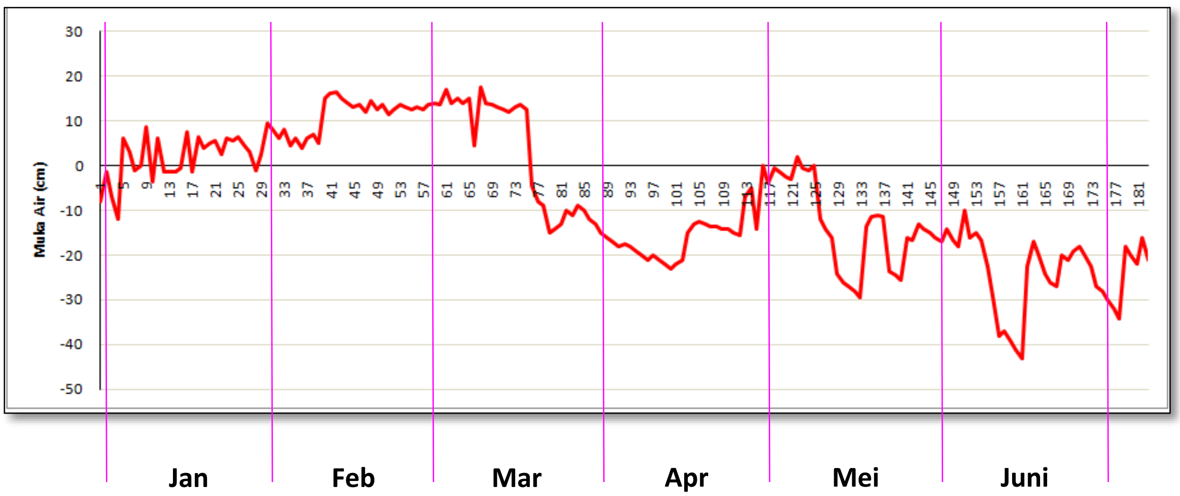

Figure 5. Water table fluctuation in well 1 during the observation periods (Well 1 is 2 m from the tertiary canal TC4)

Water table in Well 1 start to decrease with the release of water in the canal TC4 following the less rainfall in April. This water table fluctuated with free drainage applied following the rainfall in May onward.

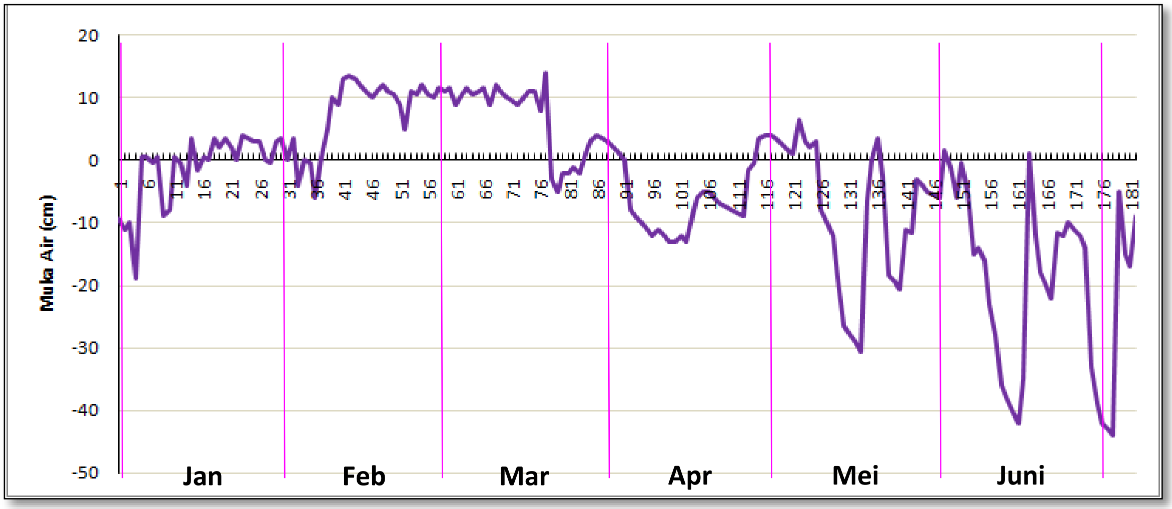

Figure 6. Water table fluctuation midway between tertiary canals, Wells-5, (100 m from the tertiary canals or midway between 2 tertiary canals)

Slightly difference respon observed at Well 5 about 100 m from the tertiary canal. Water table in January and February still just about at the soil surface while at Well 1 near the tertiary ist is about 10 cm above the ground. Water table near the filled tertiary canal will rise quickly compared to the area away from the tertiary canal. During March until Mid of April, the level of water table near (Well 1) and away (Well 5) from the canal TC4 is almost the same of 10 cm above the ground. It is clearly showed that water retention in the bordering tertiary canal with the existing rainfall, will help to retain water in the farmers fields. Paddy growing season in staring end of December 2015 until April 2016 will really need water retention in the tertiary to make the rainfall effective to support high water tabel at the farmers field

During almost 200 days experiment, soil and water samples are taken 16 times to be analyzed in relation to the fluctuating water table. The content of NO3-, NH4+, pH of the water sample will be related with the fluctuating water table.

Land and water management systems is a key factor in guarantee the success of food crops development at tidal lowland area. Agrophysical of land variations result in diversity of management systems within an area that need different approaches. Water management in tidal lowland is absolutely different than that of irrigated lands. Soil physical conditions, rainfall pattern, and tidal water effects are predominant factor in planning of the on farm water management. Some of important soil physical characteristics are total pores volume, texture, and soil hydraulic conductivity. Pore volume of soil layer within crop root zone varied in term of their forms, numbers, and sizes. The water availability within these pores are affected by soil, climate, crops, as well as land or water management practices.

Water management approach at the on farm level (free drainage, controlled drainage or water retention, and subirrigation) have to be applied differently depend the water regime needs at the on farm level. Cropping pattern of crops planted at the farmers field certainly related with the water table fluctuation. It is clearly show that paddy is best grwing when the water table near the soil surface. Corn is certainly need a lower water table for the development of depper root zone.

Conclusions

Characteristic of porous soil at the study site create relatively high water losses. Therefore, the main objective of water management for paddy field at this area is to hold rainfall water as much as possible. On the other side, during the corn growing season, is to release the water from the root zones.

A constant water retention -10 cm below the canal bank, in February and March 2016, has increased the water table in the farm from -10 cm in January 2016 to +20 cm at the end of February and beginning of March 2016. Water retention (controlled drainage) mode applied by the farmers especially during the rice growing period which need a high water table condition. The release of water in the canal to a depth of -50 cm below the canal bank lowered the ground water level in the farmers field to -20 cm. During almost 200 days experiment, soil and water samples are taken 16 times to be analyzed in relation to the fluctuating water table. The content of NO3-, NH4+, pH of the water sample will be related with the observed fluctuating water table.

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6

Topic 6:
Drainage
Special Issues

THE EFFECT OF LONG TERM TIDAL IRRIGATION AND DRAINAGE ON FORMATION OF IMPERMEABLE LAYER (CASE STUDY: ABADAN ISLAND, KHUZESTAN, IRAN)

Shahram Ashrafi[1,*], Fouad Tajik[2], Mojtaba Akram[3]

Abstract

Abadan palm date plantations have long been irrigated under tidal effects. Rivers flowing down to the sea have been and still are the water source for irrigation. During high tides, river water flows into the ditches and make subsurface irrigation possible while during low tides ditches act as the drains and water discharges out of the plant root-zone. Recently parts of the plantation has gone under traditional drainage due to rising of river water salinity and surprisingly failed to work efficiently. In order to find the cause, hydraulic conductivity of soil layers were measured using parallel ditch drains. Saturated hydraulic conductivity of the top soil (up to depth 95 cm) shows that, soil is very permeable up to 70 cm depth, but from the depth of 70 cm to 95 cm below the soil surface, it is impermeable. Piezometric measurements also have shown impermeability of the subsoil as well. Based on the piezometric measurements, soil layer located between depths of 70 to 130 cm is impermeable. Soil profile study showed three distinguishable layers in the experimental field. Although soil texture in the first layer (up to 75 cm depth) have been classified as a clayey texture, biological activities, mostly live and thick roots holes have changed the magnitude and the size of the pores in this texture. Value of saturated hydraulic conductivity of the top soil varies from 34 m/day at the top soil to a very low conductivity at the depth of around 70 cm. It was concluded that in tidal subsurface irrigation, only the upper part of the soil which has been under the root spread can be assumed permeable and deep drains laid below cannot work properly.

KEY WORDS: Date plantation, Drain ditch, Hydraulic conductivity, Piezometer, Recharge ditch.

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Introduction

Abadan Island was developed as a tidal mudflat formed by sedimentary deposition in the delta of the Karun and Arvand river systems. In the long past time, continuous and gradually sedimentation during the regularly occurred flooding along with tidal effects of the river and sea water, eventually raised the mudflat to the level where it became vegetated. The total date palm plantation area in the Abadan Island is around 28000 ha. The width of the orchard strips are between 1 and 3 kilometers along the Arvand and Bahmanshir rivers (Figure 1).

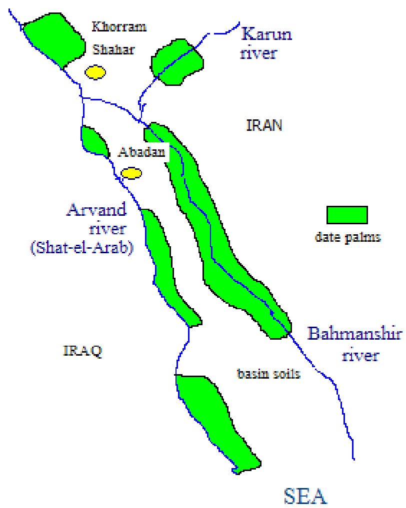

Figure 1. Sketch of the Abadan Island showing rivers and date palm plantations

The soil water condition in the palm date plantation of Abadan is controlled by tidal irrigation and drainage ditches in the neighboring Arvand and Bahmanshir rivers.
Tidal Irrigation is the subsurface irrigation of levee soils in coastal plains with river water under tidal influence. It is applied in (semi) arid zones at the mouth of a large river estuary or delta where a considerable tidal range (some 2 m) is present. The river discharge must be large enough to guarantee a sufficient flow of fresh water into the sea so that no salt water intrusion occurs in the river mouth. The irrigation is effectuated by digging tidal canals from the river shore into the main land that will guide the river water inland at high tide. At low tide, the canals and the soil drain out again, which promotes the aeration of the soil.

So far, the ditches were designed and constructed by farmers themselves, based on their experiences. The ditches with a depth of 70 to 80 cm and spacing of 10 to 12 meters, depending on the permeability of the top soil, receive their water from the tidal canals (Figure 2). In most cases tributary channels are also dug to ensure that the subirrigation is able to bring the whole area to the near saturation stage (Figure 3).

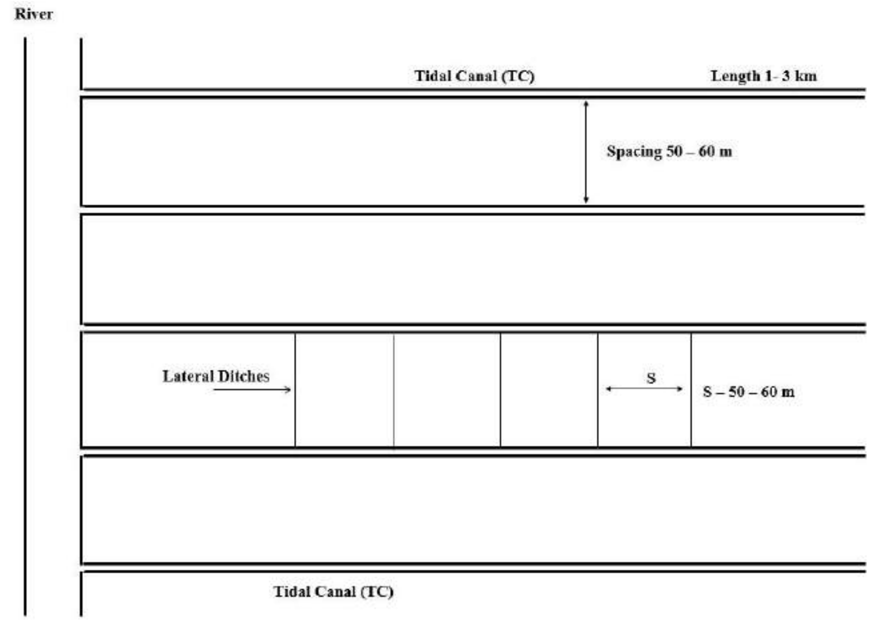

Figure 2. Sketch of the Abadan Island tidal canals and drains

The permeability of the top soil should be high enough to let the top soil between the parallel ditches becomes almost saturated during around 6 hours between high tide and normal water level, while it could drains out once in every near 6 hours between normal water level and low tide. In such a case trees have two times irrigation and two times drainage in a day.

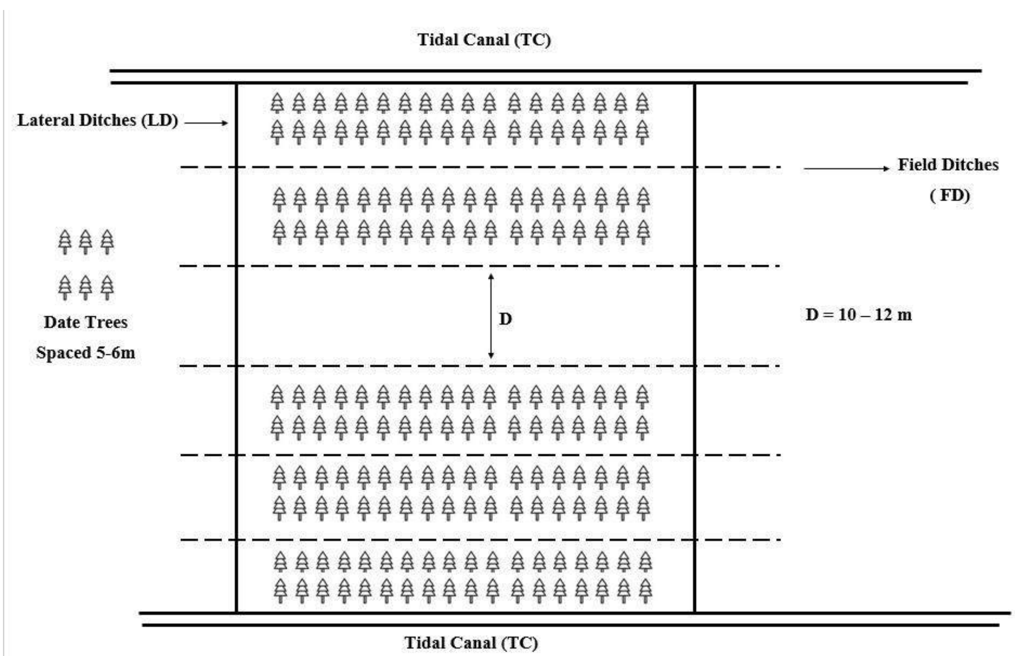

Figure 3. Sketch of the auxiliary field channels

Proper and efficient work of the system in the last few decades indicates the sustainability of the system. It also shows that farmers have been familiar with proper irrigation and drainage design of their orchards. They have also been well aware of the permeability of their topsoil.

Recently due to rising of river water salinity caused by reduction of river flows, parts of the plantations have gone under traditional drainage and surprisingly failed to work efficiently in some parts. The purpose of this research is to find the reasons behind and make the new drainage developments in tidal areas more effective, if possible. The hypothesis of this research is that drainage of the soils in this area is constrained by the impermeability of the subsoil.

Investigations conducted in last five decades by many researchers on the soil profile of Abadan Island showed that there are three distinguished soil layers in this area (Ashrafi et. al., 2015).
Soils of up to 75 cm depth are clayey textured brown colored with live roots and microorganisms without any sign of waterlogging. Soils between 75 and 180 cm are clayey textured brown colored with few roots, mostly narrow, with few mottles and gley with the signs of fluctuating to persistent water table. Soils below 180 cm are silty clay texture with many gley signs, brown mottles and few roots, green to grayish brown color which demonstrates mostly saturated soils.

Hydraulic conductivity

Hydraulic conductivity K-value in the soil profile can be highly variable from place to place and also can be variable with a different depth, what means spatial variability. Because of many factors such as uneven distribution of plant roots and agricultural activities, K-values can be variable not only in connection with different soil layers, but also within a one soil layer. Hydraulic conductivity is one of the most important factors in water management and design of subsurface drainage, while it is indispensable for the control of salinity in date palm orchard water regime. It must receive more attention in areas with tidal irrigation because of a long watering and dewatering time of the topsoil, while the other layers have much lower contribution, if any. Since the roots cannot stay alive in saturated zone, their spreading as well as their activities are limited to the topsoil, hence there is a significant difference between the hydraulic conductivity of the topsoil and other layers.
Hydraulic conductivity or K-values, is one of the principal and most important soil hydraulic characteristic parameter and it is an important factor in water transport in the soil profile and is used in all equations for subsurface water flow. Saturated hydraulic conductivity of Abadan Island soil had been investigated by many researchers but still there is a doubt on the location of impermeable layer in the soil profile (Ashrafi et. al., 2015).

There are many methods for measuring hydraulic conductivity of the soils. So far most of the measurements applied here have been based on small-scale field methods. Small scale field methods are not suitable for strongly layered soils or for soils with irregular pore space distribution. The Auger hole method has been the sole method used in previous studies. The depths of the holes have been between 1.5 and 2.0 meters. So, investigators have reached to an average hydraulic conductivity which could be much different from the hydraulic conductivity of each layer.

The large-scale fields' methods guarantee the representative K-values, where the problem of variation is eliminated as much as possible. But the large-scale field's methods are rather expensive and time-consuming, than the small scale methods. The advantage of the large-scale determinations is that the flow paths of the groundwater and the natural irregularities of the K-values along these paths are automatically taken into account in the overall K-value found with the method. It is then not necessary to determine the variations in the K-values from place to place, in horizontal and vertical direction, and the overall K-value found can be used directly as input into the drainage formulas. A second advantage is that the variation in K-values found is considerably less than those found with small-scale methods (Oosterbaan and Nijland, 1994). Among different methods of large scale field methods of hydraulic conductivity measurement, parallel drains ditch is more accurate as well as representative of the all area of groundwater flow to the drains (Ritzema, 2006).

Generalized table with the ranges of K-values for certain soil texture is presented in Table 1 (Ritzema 2006). The subsoil of Abadan is a poorly to nonstructured soil mostly with no cracks. So, one cannot expect a rather acceptable hydraulic conductivity to drain water.

Table1. K-value range by soil texture (Ritzema, 2006)

Texture	**Hydraulic conductivity K (m.day^{-1})**
Gravelly coarse sand	10 – 50
Medium sand	1 – 5
Sandy loam, fine sand	1 – 3
Loam, clay loam, clay (well structured)	0.5 – 2
Very fine sandy loam	0.2 – 0.5
Clay loam, clay (poorly structured)	0.002 – 0.2
Dense clay (no cracks, pores)	< 0.002

Preferential flow

Preferential flow may have drastic effect on the hydraulic conductivity of the soil and severely limits the applicability of standard flow models. Models are mostly based on Richards' equation (Gerke, 2006). The pore network, especially pore size distribution and connectivity, is believed to control soil hydraulic properties. Preferential flow pathways in this intact structured soil consist of a complex network of earthworm burrows, root channels, interaggregate macro pores, and meso pores or even micro pores in the soil matrix (Lou et al., 2008). Permeability problems on irrigated soils may be alleviated by root systems that increase water flow by creating macro pores. Infiltration rates have been shown to increase where plant roots decay and serve as preferential flow paths. Earthworm channels were also not stable. However, decaying roots of alfalfa produced stable macro pores, while wheat produced no such macro pores (Mitchell et al., 1995). Therefore, it depends on the shape and pattern of the roots. Root systems create networks of preferential flow and thus influence water pressures in soils which may alter subsurface flow. Preferential flow of water occurs in the following types of root channels: (a) channels formed by dead or decaying roots, (b) channels formed by decayed roots that are newly occupied by living roots, and (c) channels formed around live roots. Conceptual examples are presented to illustrate how root architecture and properties (e.g., diameter, length, orientation, topology, sinuosity, and decay rate) affect the creation of root channels and thus affect preferential flow (Ghestem et al., 2011). Furthermore, Bargues Tobella et al. (2014) demonstrated that trees have a positive impact on soil hydraulic properties influencing groundwater recharge. In order to model water flow through the soil, a relatively simple dual-porosity flow was introduced combining Richards' equation with composite (double-hump type) equations for the hydraulic properties to account for both soil textural (matrix) and soil structural (fractures, macro pores, peds) effects on flow (Simunek et al., 2003).

Material and Methods

In this study the saturated hydraulic conductivity of the different soil layers were measured using auger hole and inverse auger hole methods at 16 stations. At each site, a trench was dug to approximately 2 m depth to study the soil profile. Three points were chosen next to each profile in order to measure the saturated hydraulic conductivity of the soil layers each with three replications at the depths of 50, 100, 150 and 200 cm approximately. Results obtained from the study have shown, even soil layers at a specific depth in each station had different values of saturated hydraulic conductivity. Comparisons of the value of hydraulic conductivity in different sites at same soil layer showed significant differences in different places as well (Ashrafi et. al., 2015).

It seems that preferential flow is responsible for such a variation. Thus, the experiments continued in research date palm field of Shalheh with large scale field method named parallel drain ditches method in order to obtain more accurate and reliable values of saturated hydraulic conductivity of the soil layers in Abadan Island.

In order to combat shortcomings of small scale methods used in the past by engineers and researchers worked in Abadan which apparently reached to false values of hydraulic conductivity; it was decided to examine large scale method to reach to a hydraulic conductivity which could be representative of the region.

An experimental field was selected in the palm date plantations of Abadan, at Shalheh Haj Hossein village near to the Arvand river (approximately 500 meters far from Arvand). Soil description for 16 profiles distributed in the orchards was done in the summer 2015. In each profile, soil color and its layers were examined in the field and soil samples were taken to the laboratory to determine other soil properties. Profile no. 2 located in the experimental field was the representative profile of the region as shown in figure 4.

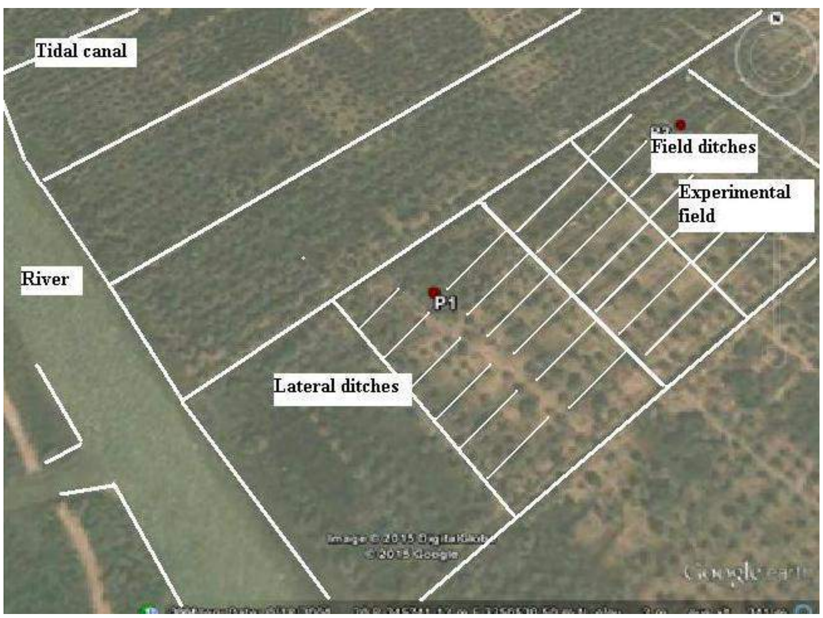

Figure 4. Location of the profile no 2 in Shalheh Haj Hossein

The experimental field was isolated in two sides by two open deep drains and the other two sides by using poly ethylene plastic rolls to a depth of around 1.5 meters. The irrigation water was recharged by a ditch laid in the middle of the two drains. Water surface was remained level both in irrigation and drainage ditches. Inflow and outflow was measured by WSC flumes.

Calculation of the value of hydraulic conductivity was measured from the ditch recharge rate and ground water table level (W.T.) midway between the middle ditch and drain ditch as shown in figure 5 from the readings of the observation well located there.

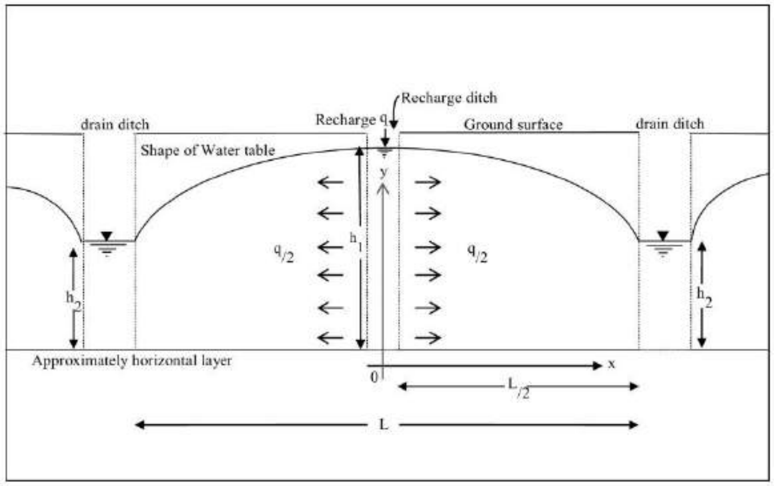

Figure 5. Schematic view of the steady state flow to the open ditches, placed on relatively horizontal layer

In the method used in this research, a system of open drain ditches, placed on relatively horizontal very low permeable layers, under the steady state drainage flow conditions, where recharge rate, q, was equal to drainage discharge q. Drain ditches spacing is L, free water level in the ditches is h_2 and the maximum of W.T. at the middle ditch between the drain ditches is h_1 as shown in Figure 2. Soil porous medium is assumed to be homogenous isotropic with one value of hydraulic conductivity K. The origin of x-y axis is selected to be on the middle of the bed of the irrigation ditch. Horizontal axis is positive to the right direction which extends on the very low permeable, approximately horizontal layer. Vertical axis is positive to the upward direction. All the process of steady state drainage flow is symmetrical with axis of symmetry, y-axis, placed at the midway between the drain ditches. Based on the Darcy's Law and Dupuit- Forcheheimer's assumptions, equation 1 is used for the calculation of saturated hydraulic conductivity of the soil at different water levels of the drain ditches.

$$q = \frac{\left(h_1^2 - h_2^2\right)}{2L} * K \qquad (1)$$

Available ditch drain in the experimental field was excavated to the depth of 100 cm. The distance between the two drain ditches was 12 meters, equal to the width of the experimental field. The width of the experimental field was divided to two equal parts (each 6 m) and a ditch excavated to the depth of 100 cm at this point. This ditch was called recharge ditch in this study as shown in figure 5. The width of the recharge ditch was 40 cm with a length of 16 m which is equal to the length of the drain ditches. For measurement of the recharge rate during the experiments, WSC flumes (Washington State College Flume, type II) were installed at the upper and lower ends of the recharge ditch in the soil surface. For measuring the water table (W. T.) at the all ditches (drain ditches and recharge ditch) a scaled indicator was installed in the midpoint of the each ditch.

Small water tight dam was constructed at the lower end of each drain ditch as shown in figure 6. In order to maintain required water level at each drain ditch, 10 PVC pipes (approximately 0.7 meter long and 10 cm diameter) was installed horizontally in the body of the dams with a 10 cm incremental steps from bottom to the top of the dams.

Figure 6. Small water tight dams at lower ends of the drain ditches

For measuring the W.T. in the field, 6 observation wells in the right, and 6 in the left side of the recharge ditch were placed (at the midpoint of the field) to a depth of 130 cm. All of the observation wells were equipped with perforated 10 cm PVC pipe. Experimental field also was equipped with 8 piezometer batteries at the midpoint of the field with different distances from the recharge ditch. The depth of each piezometer battery in the soil was 40, 50, 60, 70, 90 and 130 cm from the soil surface. Piezometer batteries were installed parallel to the ditches.

Initial W. T. in observation wells and piezometers were measured before starting the experiment. Required level of the W.T. for measuring the saturated hydraulic conductivity of the each soil layer was maintained by plugging of the lower PVC pipes at the body of the dams. Experiment for each level of the W.T. (at the drain ditches) was started by recharging the middle ditch. Inflow and outflow from the middle ditch were measured by WSC flumes. Each experiment continued until reaching to equilibrium condition. This condition was obtained when water level or outflow from the lower end flume became a constant rate. In this condition, W.T. at each observation well reaches to a constant value. Reading the W.T. in the observation wells and piezometers were done approximately at 1 hour time interval. W.T. in the recharge ditch was kept at a constant level in all experiments and different levels of W.T at the drain ditches were examined. In each experiment, W.Ts at the drain ditches was approximately identical. In order to have a description from current situation of the soil layers at the experimental field, a profile was excavated to the depth of approximately 2 m. Soil color and layering examined in the field and soil properties determined in laboratory. Soil sampling was done with auger and soil properties determined at the soil laboratory of the Agricultural Engineering Research Institute (AERI) in Karaj.

Results and discussions

Soil description

The description of profile excavated adjacent to experimental field (UTM coordinates: 245750N; 3350537 E) is given in table 2.

Table 2. Soil description of profile 2, located adjacent to the experimental field

Depth (cm)	Soil description
0 - 20	Clayey texture with live roots, brown color.
20 - 75	Porous clayey texture with many live and thick roots and macro organisms, brown color.
75 - 100	Clayey texture with a few gley signs, few brown mottles, few live roots, hard digging.
100 - 140	Clayey texture with a few gley signs, few brown and black mottles, thin live roots, and fine sand lode.
140 - 160	Clayey texture with a few gley signs, many brown and black mottles, few live roots
160 - 180	Clayey texture with many gley signs and many brown mottles, few roots
180 - 200	Silty clay texture with many gley signs, brown mottles and few roots, green to grayish brown color

The results showed that the soil could be classified as Gleysols with 3 distinct layers. The first brown layer with less than 80 cm thickness is distinguished with plant root and biological activity, and has relatively high hydraulic conductivity and salinity in some regions. This layer is sensitive to soil management and must be regarded carefully in any development project. The second 100 cm layer has redoximorphic properties with visible mottling signs and slaking behavior. This layer needs special attention for drainage systems planning and design. Laying drains in this thick very low permeable reduced soil may result in a total failure. The third layer is permanently saturated and has green to grey color which behaves as sticky gley.

The soils of Abadan are mostly similar and classified as Typic Aquicambids (USDA, 2014) but better method of classification is the World Reference base for Soil Resource (FAO, 2014) which serves the best definition of characteristic and behavior of Abadan soils. Considering this classification, the soils could be classified as Gleysols. To determine the principal and supplementary qualifiers, detailed land classification and evaluation of Abadan soils must be done in the near future.

As other 15 profiles studied by Tajik et al. (2015) which showed that all have more or less the same characteristics, the first layer with less than 80 cm thickness is clayey textured, ML in US NRCS classification, EC = 12 dS/m; SAR = 14 (meq/lit)^0.5; pH = 8, calcium carbonate = 47.2 percent, and organic carbon = 1.3 percent. This layer with perceptible biologic activity is important in crop management and must be protected carefully.

The second layer has less than 110 cm thickness with clay texture, CL in US NRCS classification, redoximorphic properties and mottling, EC = 12 dS/m; SAR = 13(meq/lit)^0.5; pH = 7.9, calcium carbonate = 44.7 percent and organic carbon = 0.8 percent. This layer is important because installation of drainage lateral in many regions might ends in a total failure. It also has a very important role in sea water transmission to the land in moderate to high tides. The vertical cracks and slaking after wetting can be observed almost everywhere. This again brings preferential flow into consideration.

The third layer begins in 190 cm with clay texture and green to grayish color, CL in US NRCS classification, EC = 19 dS/m; SAR = 21(meq/lit)^0.5; pH = 8, calcium carbonate = 40 percent and organic carbon = 0.5 percent. This layer is permanently saturated and very sticky in top and slimy in bottom. The roots of reed were observed.

Determination of the location of impermeable layer in the soil profile

In the first step of experiment, it was required to determine the location of impermeable layer in the soil profile. For this purpose, W.T. in the drain ditches was kept at the lowest elevation until subsurface drain flow reached to the steady state condition. This experiment was repeated for different levels of W.T. in the drain ditches, up to the level of about 9 cm to the soil surface. Results of this experiment showed that, maximum rate of recharge/discharge is happening when W.T. in the drain ditches is at the lowest elevation (96.5 cm below the soil surface). This rate of recharge/discharge remains constant for other levels of 81 and 68 cm. This clearly shows that the flow contribution of this soil layer is almost zero. From the depth of 68 cm, as the elevation of the W.T. in the drain ditches increased, the value of recharge/discharge decreased as shown in figure 7. The equation obtained from the fitted line to the measured data was used and relationship between the recharge/discharge and W.T. in the ditches was calculated for different W.T.s in the ditches. Table 3 represents the role of different soil layers of depth increments in drainage rate.

Again it shows that the contribution of the upper depths are much more than the lower ones. It also demonstrates that the hydraulic conductivity of the lower strata (lower than 68 cm) is almost zero and could be assumed a real barrier to flow.

Table 3. The role of different soil layers of depth increments in drainage rate

Depth to ground surface (cm)	Discharge rate (L/S)	Layer depth (cm)	Contribution of the layer in drainage (L/S)	
			Based on data	Based on best fit
96.5	0.55198	96.5	0.000	-0.01434
81	0.55198	81-96.5	0.000	0.01391
68	0.55198	68-81	0.000	0.04751
52.5	0.46425	52.5-68	0.087735	0.05129
42	0.43343	42-52.5	0.030816	0.05283
33.5	0.40324	33.5-42	0.030198	0.09180
21.5	0.31903	21.5-33.5	0.084208	0.11706
9	0.18913	9-21.5	0.129895	0.17713

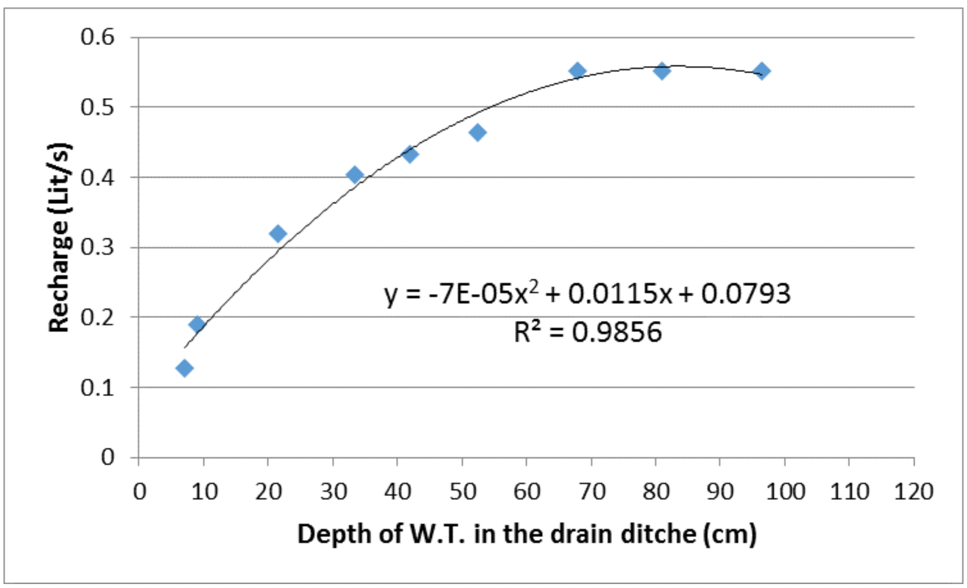

Figure 7. Relationship between the recharge/discharge and depth of W.T. in the drain ditches.

In this study, recharge measurements showed that, subsurface flow to the drain ditches remains constant when W.T. in the drain ditches being at the depths of 96.5, 81 and 68 cm. In this condition, it is very difficult to determine exact location of the impermeable layer in the soil profile. Therefore, lots of field experiments required for different levels of W.T., as well as accurate measuring instruments. The foregoing field data based on the subsurface flow or recharge measurement in this study showed that, top of the impermeable layer in the experimental field at Shalheh Haj-hossein should be around the depths of 65 to 70 cm and it extends at least to the depth of 96.5 cm which the data is collected from.

Piezometric study

Piezometers were used for measuring the potential of water in different soil layers. In order to have completely saturated condition of the soil profile from top to deep soil in the experimental field, the highest W.T. in the drain ditches was used for piezometric study. Before starting the experiments for any W.T.in the ditches, it was required to measure initial condition of the W.T.in the experimental field. As experiments were conducted continuously every day early morning and lasted to evening, soil layers had approximately 12 hours to discharge the water which had been remained from the previous experiment.

Before starting the experiment, initial condition of the W.T., which was measured in the 12 observation wells were more or less at the same elevation of 145 cm as shown in figures 8 to 13. At the end of experiment, final condition of the W. T. in the soil profile (between drain ditches) varies between depths of 21 and 6 cm in the vicinity of the drain ditch and in the recharge ditch, respectively as shown in figures 8 to 13. Results obtained for different depths of piezometers installed in soil profile (40, 50, 60, 70, 90 and 130 cm) are shown in figures 8, 9, 10, 11, 12 and 13 respectively.

Initial condition of the W. T. in the piezometers installed at the depths of 40 and 50 cm, showed that, there is no saturated water in soil profile, but initial W.T. in the observation wells, were approximately at the elevation of 145 cm as shown in figures 8 and 9. At the end of experiments, W.T. in the piezometers 40 and 50 cm are approximately identical with levels of the W.T. in the field at each point.

Initial condition of W.T.s in the 60 cm piezometers showed that, out of 8 piezometers, 3 piezometers still having water from the last experiment (12 hours before), but the other 5 piezometers are empty. Elevation of the W.T. in these 3 piezometers had not been significantly changed at the end of experiment as shown in figure 10. Initial condition of W.T.in the 70 cm piezometers showed that, all 8 piezometers still have water at the average depth of 65 cm which had been remaining from the last experiment (12 hour before), but the final condition of the W.T. in these piezometers have not been significantly changed at the end of experiment. Although average W.T. in the field at the end of experiment is 14 cm below the soil surface, but the average depth of W.T. in these piezometers has been remained at 62 cm below the soil surface at the same time, as shown in figure 11. Comparing average elevation of the W. T. in the field with the final elevation of the W. T. in the piezometers installed at the depth of 70 cm indicate that, movement of water from the soil to these piezometers is very slow. The average change of W.T. in these piezometers was only 3 cm during the experimental time. This indicates that, compare to upper layers, the permeability of the soil at the depth of 70 cm is very very low.

Initial and final conditions of the W.T. in the piezometers installed at the depths 90 and 130 cm are shown in figures 12 and 13. Almost all initial and final conditions of the W.T. have not been changed during the experimental time. This means that, soil layer located between 90 and 130 cm depth is not permeable at all.

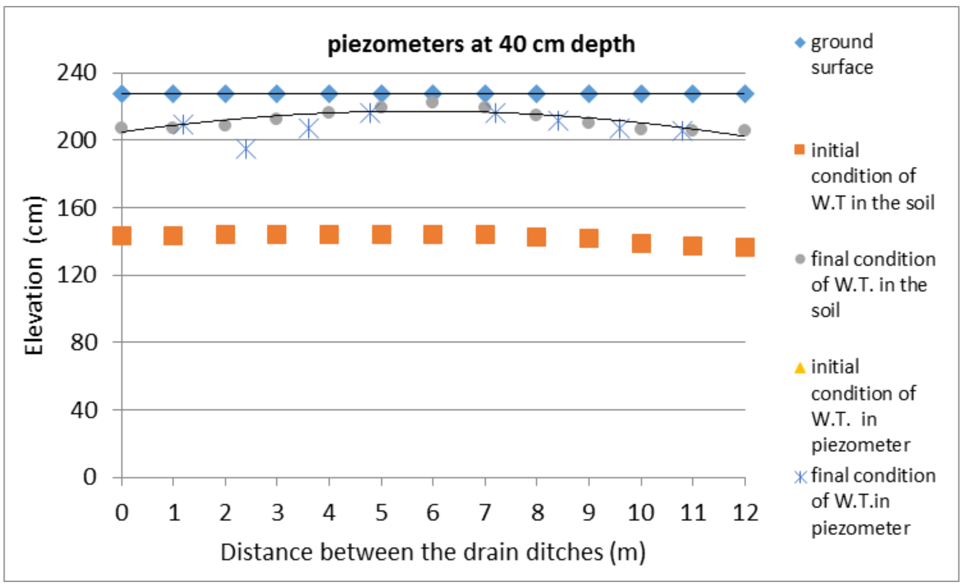

Figure 8. Initial and final conditions of the W.T. in the soil profile and piezometers istalled at the depth of 40 cm

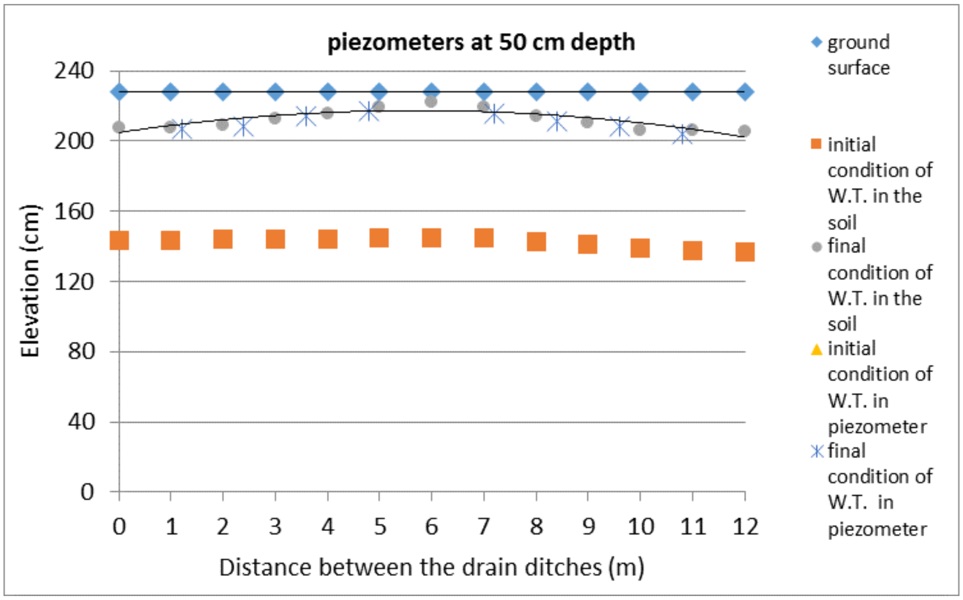

Figure 9. Initial and final conditions of the W.T. in the soil profile and piezometers istalled at the depth of 50 cm

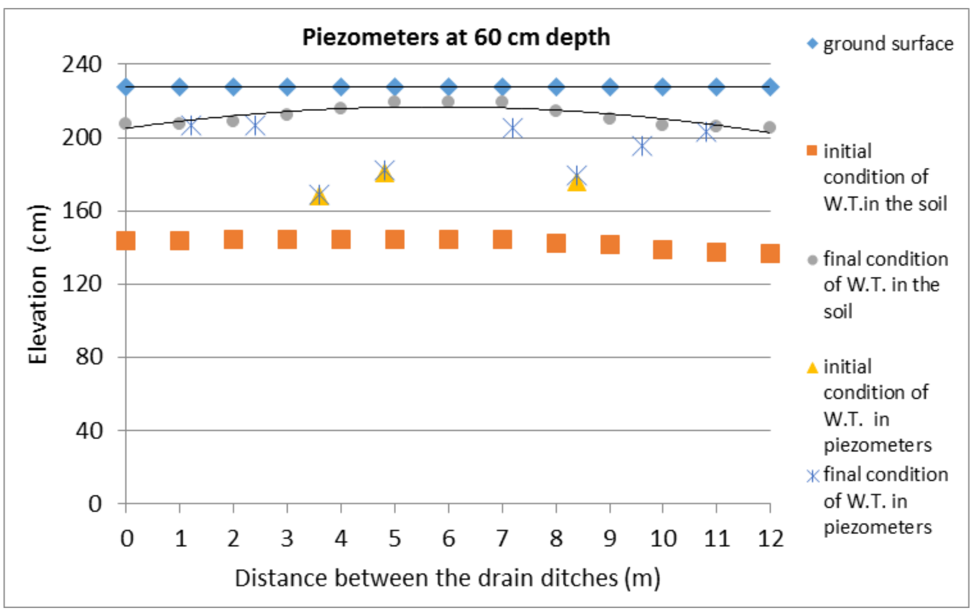

Figure 10. Initial and final conditions of the W.T. in the soil profile and piezometers istalled at the depth of 60 cm

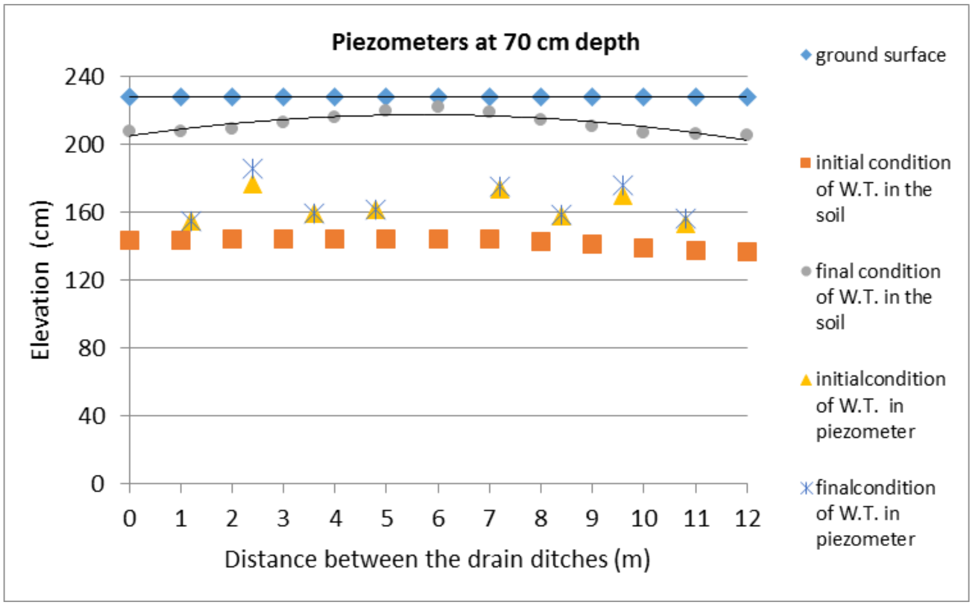

Figure 11. Initial and final conditions of the W.T. in the soil profile and piezometers istalled at the depth of 70 cm

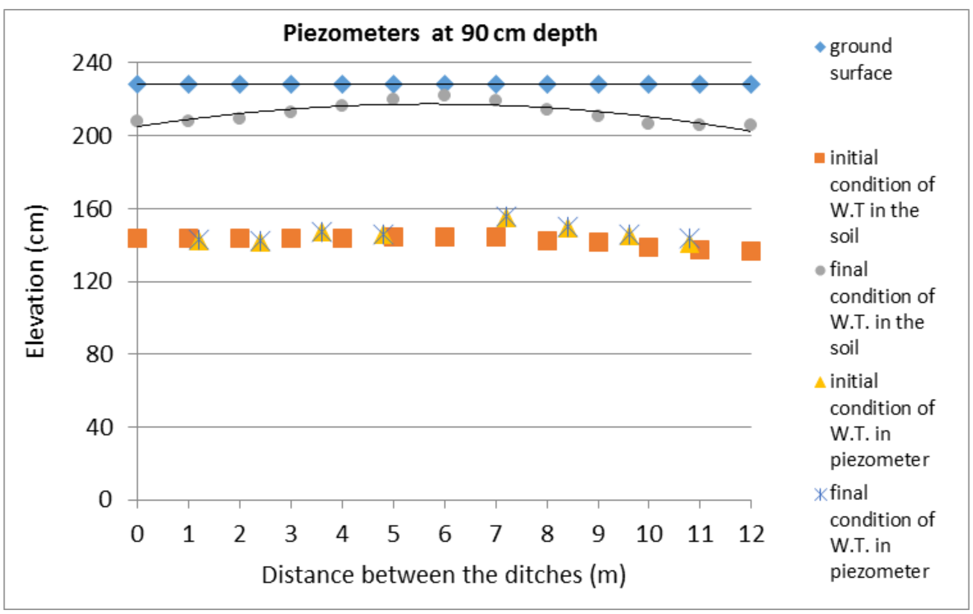

Figure 12. Initial and final conditions of the W.T. in the soil profile and piezometers istalled at the depth of 90 cm

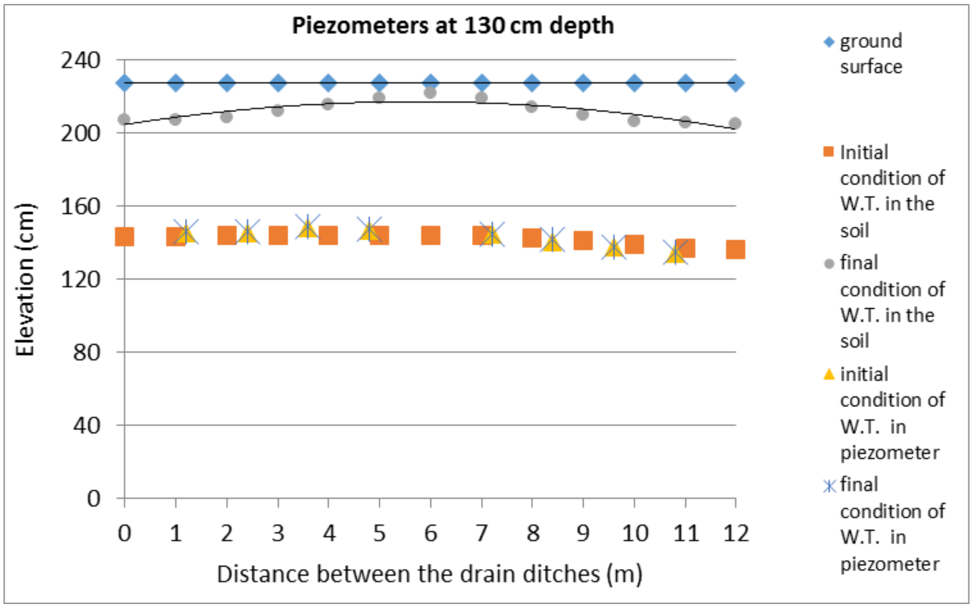

Figure 13. Initial and final conditions of the W.T. in the soil profile and piezometers istalled at the depth of 130 cm

Hydraulic conductivity calculation

Results achieved from measurements of recharge flow in this study have shown that, soil layer which is located at the depths of 68 to 96.5 cm is not permeable. This means soil layer located between elevations of 131.5 and 160 has no contribution to the drainage flow. Also, results which were taken from piezometric study have shown that, impermeability of the soil in the experimental field starts from elevation 158 cm (70 cm below the soil surface) and it extends to elevation 98 cm (130 cm below the soil surface) in soil profile. So, the foregoing results and equation 4 were used for hydraulic conductivity calculation. The K-value was calculated based on the concerning boundary condition of the flow in the field and ditches for each soil thickness. Then, the value of the hydraulic conductivity of the soil at each point in the soil profile was calculated using primary K-value which was calculated for each water table in the drain ditches and shown in figure 14. The equation obtained from the fitted line to the measured data was used and relationship between the soil depth and its hydraulic conductivity was calculated and shown in figure 15.

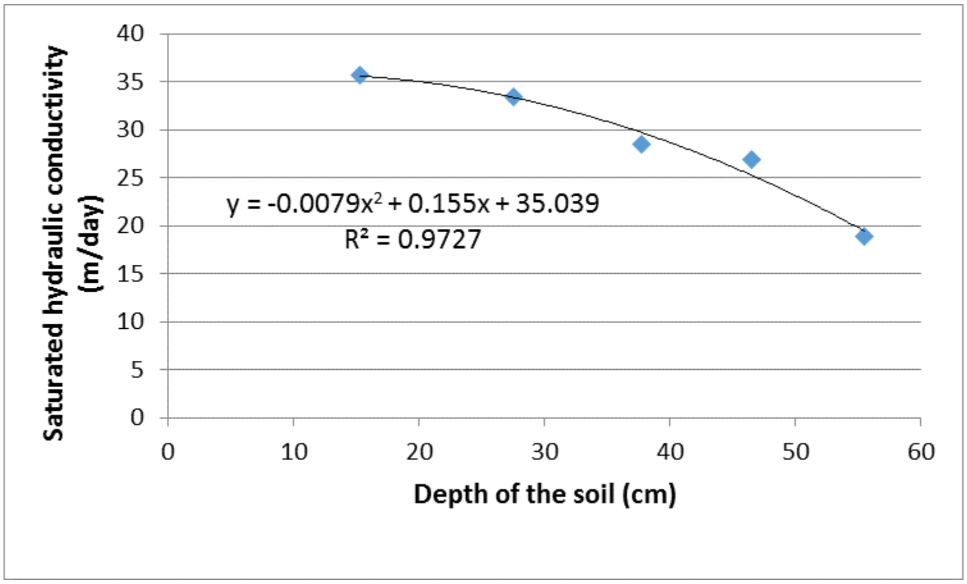

Figure 14. Relationship between depth of the soil and its hydraulic conductivity (Based on field measurements)

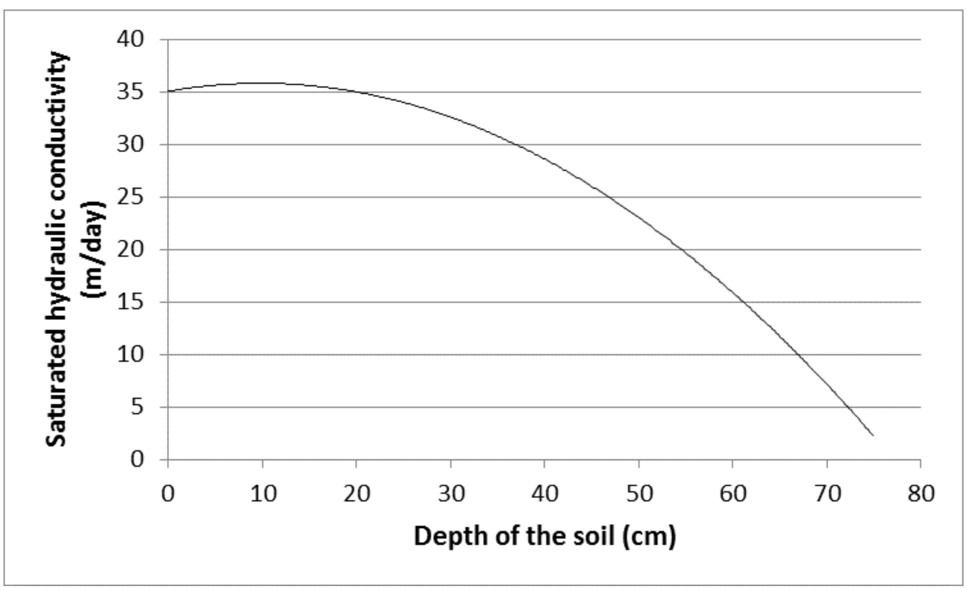

Figure 15. Relationship between depth of the soil and its hydraulic conductivity (Based on equation obtained from the fitted line to field data)

Soil profile description in this study have shown, out of three distinguished layers, most of the biological activities concentrated in the first layer which thickness is less than 80 cm. the results which was taken from hydraulic measurements completely matches with the soil description specially for the first 75 cm depth. Although soil texture in the first layer have been classified as a clayey texture in the first 75 cm layer, but biological activities mostly live and thick roots have changed the magnitude of the pores. The value of the saturated hydraulic conductivity of the experimental field shows that, in the first 60 cm layer, soil is very permeable and based on the classification in table 1 soils behaves like a gravelly coarse sand. As presented in table 2, texture of the this soil is porous clayey texture, so its saturated hydraulic conductivity should be less than 0.2 m/day, based on the classification presented in table 1. This diversity in saturated hydraulic conductivity can be interpreted only by addressing to the description of soil profile in table 2. As presented in table 2, live and thick roots and macro organisms (all biological activities) are concentrated in the first 75 cm depth of the experimental soil. As mentioned by different researchers like Lou et al., 2008 and Mitchell et al., 1995, preferential flow pathways consist of a complex network of earthworm burrows, root channels, inter aggregate macro pores, and meso pores or even micro pores in the soil matrix that increase water flow of the soil. Also, decaying roots of different plants makes preferential pathways and consequently causes high hydraulic conductivity of such a soil.

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A NEW DRAIN PIPE-ENVELOPE CONCEPT FOR SUBSURFACE DRAINAGE SYSTEMS IN IRRIGATED AGRICULTURE

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Abstract

In irrigated lands, drain pipes are equipped with envelopes to safeguard the subsurface drainage system against the three main hazards of poor drain-line performance: high flow resistance in the vicinity of the drain, siltation, and root growth inside the pipe. A wide variety of materials are used as envelopes, ranging from mineral and synthetic materials to mineral fibres. The challenge is to match the envelope specifications with the soil type. As soils are rather variable, the design of envelopes is not straightforward as illustrated by the numerous norms and criteria that have been developed worldwide. These norms and criteria have been mainly developed in Western Europe and the USA and often lead to disappointing results when applied in other countries where their specifications and effectiveness have not been proven in field trials. In irrigated lands, problematical factors which are evident are that as compared to rainfed agriculture, the hydraulic function of an envelope is less important than the filter function moreover, the root growth inside the drain pipe is a major problem. To tackle these problems, an innovative envelope design concept, based on optimizing the geometry of the pipe and the envelope, has been tested in a 50 ha pilot area in Haran Province, Turkey. The new concept, Hydroluis®, consists of a corrugated inner pipe with two rows of perforations at the top and an unperforated outer pipe that covers about 2/3 of the inner pipe leaving the bottom part of the inner pipe in contact with the soil. The main advantage of the new concept is that it is less dependent on the soil type than the existing envelope materials. The new concept was tested and compared with a geotextile, a sand-gravel envelope and a control with no envelope material. All three envelope types had a lower sediment load as compared to the control and the sand-gravel and Hydroluis® envelopes had a considerable lower entrance resistance as compared to the geo-textile, which showed the best drain performance and showed no signs of root growth. It can be concluded that the Hydroluis® envelope is a good alternative for a sand/gravel or synthetic envelope in irrigated lands.

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KEY WORDS: Subsurface drainage, Envelope materials, Entrance resistance, Drain performance.

Introduction

Pipe drains are equipped with envelopes to safeguard the subsurface drainage system against the three main hazards of poor drain-line performance: siltation, high flow resistance in the vicinity of the drain pipe and root growth inside the pipe. A wide variety of materials are used as envelopes for drain pipes, ranging from organic and mineral material, to synthetic material and mineral fibres (Cavelaars et al., 2006). Organic material is mostly fibrous, and includes peat - the classical material used in Western Europe - coconut fibre, and various organic waste products like straw, chaff, heather, and sawdust. Mineral materials are mostly used in a granular form; they may be gravel, slag of various kinds (industrial waste products), or fired clay granules. Synthetic materials may be in a granular form (e.g. polystyrene) or in a fibrous form (e.g. nylon, acryl, and polypropylene). Glass fibre, glass wool, and rock wool, which all are mineral fibres, are also used. A drain envelope has three functions (Ritzema et al., 2006):

- Filter function: to prevent or restrict soil particles from entering the pipe where they may settle and eventually clog the pipe;
- Hydraulic function: to constitute a medium of good permeability around the pipe and thus reduce entrance resistance;
- Bedding function: to provide all-round support to the pipe in order to prevent damage due to the soil load. Note that large diameter plastic pipes are embedded in gravel especially for this purpose.

Apart from these conflicting filtering and hydraulic functions, the formulation of functional criteria for envelopes is complicated by a dependence on soil characteristics, mainly soil texture, and installation conditions (Stuyt and Dierickx, 2006; Stuyt and Willardson, 1999). Vlotman et al. (2001) reviewed the simultaneous development of theory and practical experience in Europe and North America. Traditionally, the required envelope around the drain pipe consisted of locally available materials like stones, gravel or straw. In arid areas, the technique of using gravel envelopes has been further developed to such a degree that effective gravel envelopes can be designed for most soils (United States Bureau of Reclamation, 1978). In practice, gravel envelopes are often expensive due to the high transport costs, while their installation is cumbersome and error prone, and requires almost perfect logistic management during installation (Ritzema et al., 2006). Moreover, gravel cannot be used when installation is done with trenchless equipment. Subsequently, pre-wrapped envelopes of synthetic material have been under development for some decades, but only limited research has been done on locally made synthetic envelopes for subsurface drainage in irrigated lands (El-Sadany Salem et al., 1995; Kumbhare and Ritzema, 2000). Specialized machines have been developed to pre-wrapped sheet and loose-fibre envelopes around the drain pipes, not in the field but in the factory, ensuring a better quality and easier quality control (Nijland et al., 2005). Pre-wrapped synthetic envelopes are presently used almost everywhere in Europe, in some areas of the United States, and in the countries in the Middle East. Since the specifications of envelopes are very soil specific and soils are rather variable, the specifications and effectiveness of envelopes have to be proven in field trials in the areas where they are to be applied (Vlotman et al., 2001).

The life of subsurface drainage systems can be hundred years if no blockage, deformation nor siltation occurs (Jahn et al., 2006; Stuyt et al., 2005). Blockage of the pipes generally occurs due to sanding, siltation, chemical and biological settlement, penetration of plant root into the pipe, accumulation of compressed filling soil in drainage trenches (in very wet environments) or improper installation of individual pipes (Eggelsmann, 1987). A common practice to prevent penetration of plant roots into the pipes is to increase installation depth. To prevent entry of sediments into drain pipes, pipes are wrapped with envelopes selected according to the characteristics of the soil in which they will be installed. In soils that are problematic in terms of siltation, it is important to prevent penetration of soil grains into the drain pipe (Zaslavsky, 1978). The envelope material wrapped around the pipes to prevent sediment penetration into pipes must have characteristics that does not increase entrance resistance (Wesseling and Homma, 1967). Head losses that occur due to the compression during the entering of water into the drains reduce efficiency of the systems. Increasing the size of the perforations and consequently the total area of holes in plastic drain pipes decrease entrance resistance (Cavelaars, 1965). In an experiment conducted in a horizontal sand tank with a fine sand loamy soil, Chiara and Ronnel (1987), who tested different envelope options, achieved the greatest flow rate and lowest siltation in the pipes wrapped with geotextiles.

Although there are many studies and publications that suggest that there is no need for envelopes in matured, structurally developed, stable soils that contain certain amount of clay (Vlotman, 1998), in Turkey drain pipes in these type of soils are generally equipped with envelopes (Bahçeci et al., 2001). The envelope material that has the best performance under these conditions is gravel obtained from natural sand gravel pits. These envelopes, however, are very expensive and often the particle-size distribution of these natural sand gravels doesn’t match the design specifications. More recently geotextiles are used but they have the twin problem of clogging and root penetration.

A new concept, the **Hydroluis®** pipe-envelope system has been developed to overcome these shortcomings. It is designed in such a way that penetration of plant roots and soil particles into the pipe is prevented. The new concept consists of a corrugated inner corrugated pipe with two rows of perforations at the top and an unperforated outer pipe that covers about 2/3 of the inner pipe leaving the unperforated bottom part of the inner pipe in contact with the soil (Figure 1). The outer pipe has an egg-box profile to ensure that there is an open space between the two pipes through which the water can flow upward to the perforations in the inner pipe. The distance between the two pipes determines the flow velocity. The new concept has recently been certificated by the Turkish Bureau of Standardization (Türk Standardlari Enstitüsü, 2016). The two pipes are transported in roles to the field and put in place during installation using a specially developed extension on the trench box of the trencher. Another special punching device has been developed that is also mounted on the trench box to perforate the inner pipes during installation to ensure that the holes are in the correct position.

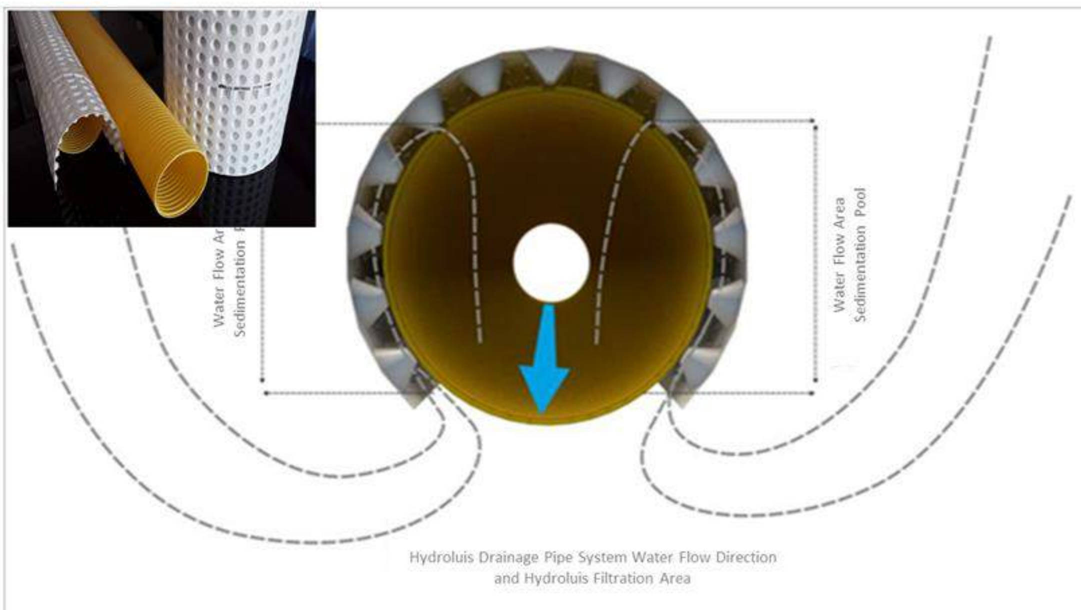

Figure 1. Hydroluis® pipe-envelope combination and working principle

The concept is based on the assumption that about 70% of water entering the drain pipes takes place with radial flow from underneath the pipes (Cavelaars et al., 2006). In a 'traditional' drain envelope system, water velocity increases when the water flows toward the perforations, increasing the risk of soil particle movement that results in either clogging of the envelope or sediment entering the pipe. In irrigated agriculture, this is particularly risky after irrigation when the water table rises well above drain level and consequently increases the hydraulic head. In the new concept, the velocity of the water decreases when it flows upward between the two pipes, significantly reducing the movement of the soil particles and thus the risk that these particles enter the inner drain pipe. The lighter and smaller particles that will stay in suspension during this upward movement, will stay in suspension when they enter the inner pipe eliminating or minimizing clogging and sedimentation.

A second problem for subsurface drains in irrigated agricultural lands is that root penetration is a major risk when the water table falls below drain level, because of the favourable humid conditions in the drain pipe (air & water). In the new concept, root penetration will be eliminated as the space between the inner and outer pipe is either saturated (when the water table is above drain level) or filled with air (when the water table is below drain level). Both conditions prevent root penetration. The objective of this study was to test the new concept under field conditions.

Materials and methods

The field study was conducted at the GAPTAEM research station (50 ha) near Harran (36° 56’44 N, 38° 54’44 E), located in south eastern Turkey 30 km south of city of Şanliurfa, at an altitude of about 400 m (Figure 2). The area is representative for the Şanliurfa Harran Plain, an area of about 150 000 ha that is already under irrigation. Water is mainly supplied from the Atatürk Dam with two tunnels (General Directorate of State Hydraulic Works, 2003).

Figure 2. Location of Harran pilot area

The climate in the Harran Plain is arid, hot in summer and cold and rainy in winter (Table 1). The average annual precipitation is 365 mm, the average temperature 17°C and open water surface evaporation 1849 mm. The distribution of the precipitation over the seasons is 56% in winter, 30% in spring, 1% in summer and 13% in autumn. The average number of rainy days is 70 and number of days covered with snow is 3.

Table 1. Meteorological data in the Harran plan (monthly averages).

	Precipitation (mm)	Temperature (°C)	Relative Humidity (%)	Evaporation (Class A - pan) (mm)	Wind speed (m/s)
Jan	66	5	69	-	1.6
Feb	63	6	64	-	1.7
Mar	60	10	58	52	1.6
Apr	27	15	58	117	1.6
May	23	22	42	199	1.9
Jun	4	28	33	315	2.4
Jul	0	31	34	376	2.3
Aug	0	30	40	338	1.9
Sep	1	25	38	250	1.5
Oct	20	18	45	152	1.0
Nov	42	10	60	51	0.9
Dec	61	6	72	-	1.2
Year	365	17	51	1849	1.6

The pilot area has a flat topography and deep alluvial soil profile with A and C horizons (Table 2). Soil texture is clayey with a clay content of more than 50–60%, the lime content is about 30% and the soil pH between 7.1–8.0. Soil samples were collected from different soil layers and their respective total porosity and effective porosity were determined in the laboratory by standard procedures (Braun and Kruijne, 2006).

Table 2. Soil properties in Harran Pilot Area

Treatment	Depth (cm)	Sat. Cap. (%)	Texture (%)			Class	pH	EC_e dS/m	Lime (%)
			Sand	Clay	Silt				
Control (no envelope)	0-30	78	24	56	20	Clay	7.6	0.7	30
	30-60	74	24	58	18	Clay	7.7	0.9	30
	60-90	70	22	58	20	Clay	7.8	1.2	30
	90-120	74	22	58	20	Clay	7.7	1.2	30
	120-150	68	32	44	24	Clay	7.8	0.9	30
	150-180	74	26	48	26	Clay	7.8	0.8	30
	180-210	77	24	54	22	Clay	7.8	0.7	30
Geotextile	0-30	71	24	66	20	Clay	7.6	0.8	31
	30-60	70	24	56	20	Clay	7.7	1.1	29
	60-90	71	20	58	22	Clay	7.7	1.4	30
	90-120	73	20	60	20	Clay	7.6	1.7	30
	120-150	74	22	58	20	Clay	7.6	1.6	32
	150-180	83	22	56	22	Clay	7.8	1.0	32
	180-210	79	22	58	20	Clay	7.9	0.8	29
Gravel	0-30	70	22	56	22	Clay	7.6	0.8	30
	30-60	71	24	56	20	Clay	7.7	0.9	29
	60-90	69	24	56	20	Clay	7.7	1.0	29
	90-120	70	22	58	20	Clay	7.7	1.0	35
	120-150	69	26	54	20	Clay	7.6	1.1	42
	150-180	74	24	56	20	Clay	7.7	0.9	43
	180-210	75	20	60	20	Clay	7.5	0.9	43
Hydroluis	0-30	72	22	60	18	Clay	7.7	0.9	30
	30-60	70	20	58	22	Clay	7.6	0.9	31
	60-90	70	20	60	20	Clay	7.6	0.9	32
	90-120	71	22	60	18	Clay	7.7	0.9	33
	120-150	72	18	60	22	Clay	7.6	1.0	35
	150-180	73	20	62	18	Clay	7.6	1.0	33
	180-210	78	22	56	22	Clay	7.6	0.8	44

Experimental site layout

In the test plot, plastic drain pipes were installed at an average depth of 1.50 m, with a 0.1% slope, with a length of 200-250 m and 25-60 m spacing. Four combinations were tested:

1) Sand-gravel filter envelope around the drain pipe
2) Pre-wrapped geotextile
3) Hydroluis® pipe-envelope combination
4) No envelope material (control)

For each combination, three field drains were connected to a collector drain through a manhole (Figure 3). Hydraulic heads were measured in three rows of observations wells: midway between the drains, adjacent to the drain pipe just outside the drain trench and inside the drain pipe (Figure 3 & 4). The head differences were used to assess the entrance resistances for the four drain/envelope combinations based on the classification proposed by (Cavelaars et al., 2006) (Table 3). Measurements were repeated 3-4 times a day to obtain data for different hydraulic heads. Water samples of the drain outflow were collected for pH, EC and silt-load analyses. The monitoring programme started in 2015, but only a limited number of data could be collected, thus the monitoring programme was repeated in 2016. At the end of each season, root growth was manually checked using a video system.

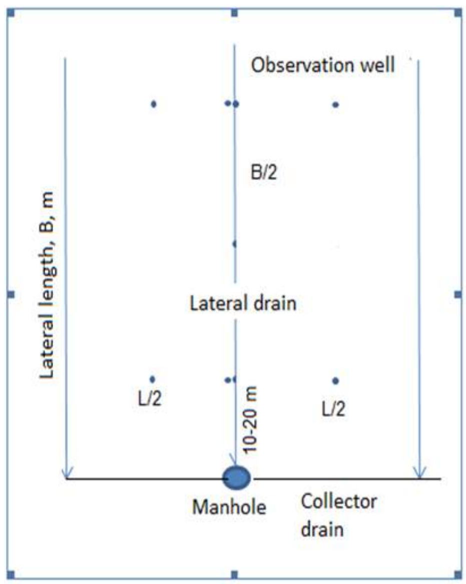

Figure 3. Measurement and observation network: each combination consists of three field drains connected to a collector drain through a manhole.

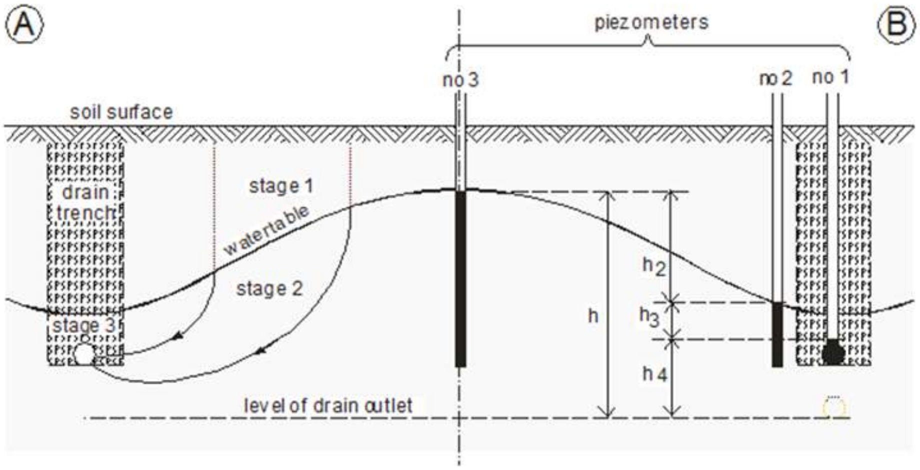

Figure 4. Principle of drainage testing: (A) Four stages of water flow towards and inside the drains; (B) Head losses in the four stages (Cavelaars et al., 2006).

Table 3. Drain performance criteria for different drain envelope combinations (Cavelaars et al., 2006)

$h_3/(h_2+h_3)$	Entre resistance	Drain performance
< 0.2-0.3	normal	good
0.3 – 0.6	high	moderate to poor
> 0.6	excessive	very poor

Results and discussion

The results of the monitoring programme in 2015 are presented in Table 4. The drain performance of the Hydroluis® pipe-envelope combination and the gravel envelope was good, but the performance of the geotextile was moderate to poor. The entrance resistance in the control plot was not measured, thus the drain performance could not be established. The sediment load was measure in all four combinations. The control plot had the highest sediment load (46 g m^{-3}), the sediment load in the drains with geotextile was 24% lower (35 g m^{-3}), the Hydroluis® combination had about the same reduction 26% (34 g m^{-3}), but the sediment load of the gravel envelope (26 g m^{-3}) was with 43% significant lower.

Table 4. Drain performance values for different drain envelope combinations (2015)

Envelope pipe combination	$h_3/(h_2+h_3)$ (-)	Drain performance	pH	EC (dS m^{-1})	Silt (g m^{-3})
Gravel	0.25	Good	7.2	0.96	26
Geotextile	0.38	Moderate to poor	7.5	0.99	35
Hydroluis®)	0.28	Good	7.0	0.97	34
Control	-	-	7.2	1.03	46

There is no significant difference between pH and EC values of drainage discharges and the siltation values are not high when they are evaluated in terms of irrigation water.

The results of the monitoring programme conducted in 2016 are presented in Table 5 to 8 for respectively the Hydroluis® pipe-envelop system, the gravel envelope, the geotextile and the control plot.

Table 5. Groundwater levels, hydraulic heads and entrance resistance for the Hydroluis® pipe-envelope system in 2016

No.	h (cm)	h_2 (cm)	h_3 (cm)	h_{pipe} $(h-h_2-h_3)$ (cm)	h_{trench} $(h-h_2)$ (cm)	Entrance Resistance $h_3/(h_2+h_3)$ (-)
1	16.0	12.7	1.7	1.6	3.3	0.12
2	15.7	12.6	1.6	1.5	3.1	0.11
3	15.2	12.6	1.2	1.4	2.6	0.09
4	16.0	12.7	1.7	1.6	3.3	0.12
5	15.7	12.6	1.6	1.5	3.1	0.11
6	15.5	12.7	1.2	1.6	2.8	0.09
7	15.2	12.6	1.2	1.4	2.6	0.09
8	15.2	12.8	1.1	1.4	2.5	0.08
9	14.9	12.9	0.6	1.4	2.0	0.05
10	14.7	12.7	0.6	1.3	1.9	0.04
11	14.7	12.7	0.6	1.3	1.9	0.04
12	14.3	12.2	0.7	1.4	2.1	0.06
13	14.2	12.3	0.5	1.4	1.9	0.04
14	14.2	12.3	0.5	1.4	1.9	0.04
15	14.2	12.3	0.5	1.4	1.9	0.04
16	14.3	12.2	0.7	1.4	2.1	0.05
17	14.3	12.2	0.7	1.4	2.1	0.05
18	14.1	11.9	0.7	1.4	2.1	0.06
Average	14.9	12.5	1.0	1.4	2.4	0.07
St. Dev.						0.03

In the plot equipped with the Hydroluis® pipe-envelope system the average drain discharge was 0.062 l/s or 2 mm/day. This value is lower than the design drainage coefficient used in the project. The average hydraulic head midway between the drains was 14.9 cm, the head just outside the drain trench (h_{trench}) was 2.4 cm and the head just outside the pipe 1.4 cm (Figure 5). Based on the criteria presented in Table 3, the entrance resistance, with an average of 0.07 and a standard deviation of 0.03, can be classified as "normal" and the drain performance as "good".

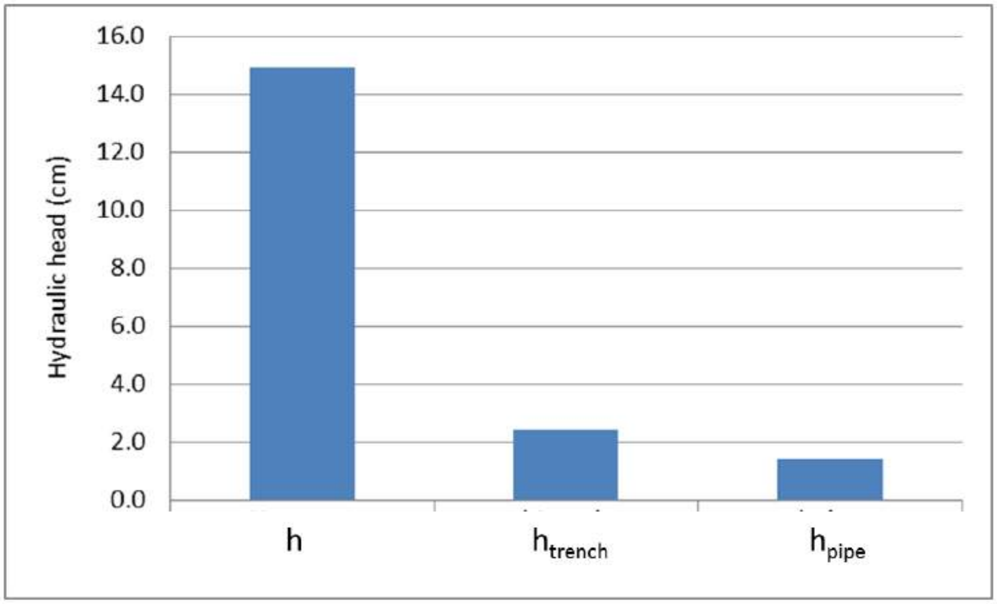

Figure 5. Average hydraulic head in the Hydroluis® pipe-envelope system

Table 6. Groundwater levels, hydraulic heads and entrance resistance for the sand gravel envelope in 2016

No.	h (cm)	h_2 (cm)	h_3 (cm)	Entrance resistance $h_3/(h_2+h_3)$ (-)
1	17.7	8.4	4.4	0.34
2	13.7	9.4	6.4	0.41
3	11.7	8.4	4.4	0.34
4	12.2	7.4	5.9	0.44
Average	13.8	8.4	5.3	0.38
St. Dev.				0.04

The entrance resistance of the gravel envelope, with an average of 0.38 and a standard deviation of 0.04, can be classified as "high" and the drain performance as "moderate".

Table 7. Groundwater levels, hydraulic heads and entrance resistance for the geotextile envelopes in 2016

No.	h	h_2	h_3	Entrance Resistance $h_3/(h_2+h_3)$
	(cm)	(cm)	(cm)	(-)
1	19.8	9.3	5.9	0.39
1	8.6	3.6	7.0	0.66
2	8.0	4.0	6.0	0.60
3	7.1	7.1	4.0	0.36
6	17.3	4.4	13.0	0.75
7	8.1	3.8	6.5	0.63
8	13.8	3.4	11.0	0.76
9	9.6	2.6	6.5	0.71
10	8.6	3.1	5.0	0.61
11	8.6	3.6	7.0	0.66
Average				0.61
St. Dev.				0.14

The entrance resistance of the geotextile was significantly higher and with an average of 0.61 and a standard deviation of 0.14 can be classified as "excessive", subsequently the drain performance is "very poor".

Table 8. Groundwater levels, hydraulic heads and entrance resistance for pipes without envelopes (control plot) in 2016

No.	h	h_2	h_3	Entrance resistance $h_3/(h_2+h_3)$
	(cm)	(cm)	(cm)	(-)
1	8.5	2.0	2.0	0.49
2	12.2	-0.2	9.0	1.03
3	25.0	26.5	19.5	0.42
4	8.0	25.0	14.0	0.36
5	5.2	23.8	12.5	0.34
6	4.0	23.5	11.5	0.33
Average				0.49
St. Dev				0.27

In the control plot, the average entrance resistance was 0.49 and can thus be classified as "high" and the drain performance as "moderate to poor".

When we compare the four drain-envelope combination for both years, we can concluded the Hydroluis® drain-envelope combination had a normal entrance resistance and a good drain performance (Table 9). The gravel envelope scored second with a normal entrance resistance and moderate to good drain performance. Both performed much better than the geotextile and the drain without envelope in the control plot. The performance of the geotextile envelopes in 2016 was significantly poorer compared to 2015, suggesting a clogging problem of the envelope.

Table 9. Classification of the entrance resistance and drain performance for the four drain-envelope combinations

Pipe - Envelope combination	2015			2016		
	$h_3/(h_2+h_3)$	Entrance resistance	Drain performance	$h_3/(h_2+h_3)$	Entrance resistance	Drain performance
Gravel	0.25	normal	good	0.38	normal	moderate
Geotextile	0.38	normal	moderate	0.64	high	very poor
Hydroluis®	0.28	normal	good	0.07	normal	good
Control	-		-	0.49	high	moderate to poor

The silt content was only measured in the plots with the Hydroluis® pipe-envelope system and the gravel envelopes (Table 10). In both plots the silt load of the drainage water is low and it will not create a risk of clogging the pipelines.

Table 10. Electric Conductivity (EC), pH and sediment load of the drainage effluents for the drains with Hydroluis® and geotextile in 2016

No.	Solid matter (%)	EC (dS/m)
Hydroluis:		
1	0.07	0.78
2	0.07	0.78
3	0.07	0.78
4	0.06	0.79
Average	0.07	0.79
Geotextile:		
1	0.07	1.01
2	0.07	1.00
3	0.08	0.95
4	0.07	1.03
Average	0.07	1.00

On 14 June, 2016 a visual inspection of the four drain-envelope combinations was done using a video camera (Figure 6). The drain pipes were also excavated for a visual inspection of root growth (Figure 7). Although root growth was limited, probable because the crops were still in their initial stage of development, it is clearly visible that the Hydroluis® combination didn't have any sedimentation inside the pipe nor any signs of root growth.

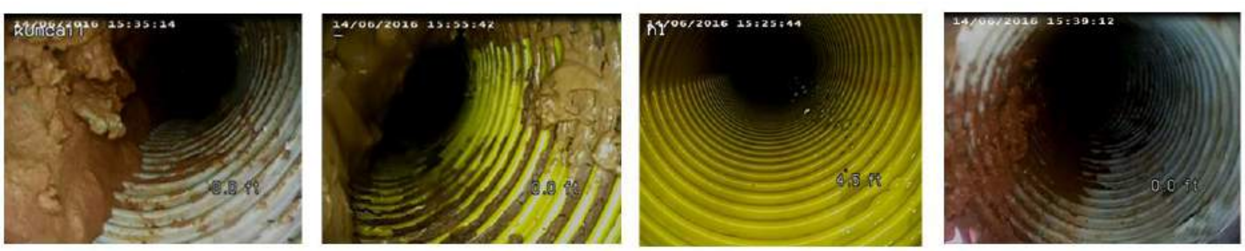

Figure 6. Visual inspection of the four drain-envelope combinations: from left to right: gravel – geotextile - Hydroluis® combination - control. (Note: vertical orientation of the photos is not correct because of the moving camera).

Figure 7. Visual inspection for root growth after excavation of the drain pipes with a geotextile (left), no envelope (middle) and Hydroluis® combination (right).

Conclusion

Three drain-envelope combinations of subsurface drainage systems were tested in a field plot and compared to a control plot with no envelope. Based on the two-year monitoring programme, it can be concluded that the Hydroluis® drain-envelope combination performed good with a normal entrance resistance and a good drain performance. The gravel envelope scored second with a normal entrance resistance and moderate to good drain performance. Both performed much better than the drains with a geotextile envelope and the drain without envelope in the control plot. The performance of the geotextile envelopes was significantly poorer in 2016 compared to 2015, suggesting a clogging problem of the envelope as the sediment load in the drainage water was comparable to the sediment load of the drainage water from the Hydroluis® plot. Another advantage of the Hydroluis® pipe envelope combination is that no sign of penetration of plant roots into the pipe were visible. Furthermore, the Hydroluis® pipe envelope combination has features that prevent or reduce deformation of the pipes by providing mechanical support through the egg-box profile of the outer pipe. The production costs are comparable to the cost of a pre-wrapped synthetic envelope (personal communication, PipeLife Nederland, 24-08-2016) and transportation and installation costs are lower than for a gravel envelope. Although the new concept looks promising, it is recommended to do more research to verify the long-term resistance to root growth and the performance under other soil, hydrological and agricultural conditions.

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CLOSED DRAINAGE ON HEAVY SOIL: THEORY AND PRACTICE IN RUSSIA

I. G. Bondrik[1,*], G. G. Guluyk[2]

Abstract

Maintaining, rehabilitation, and rational use of fertile agricultural lands are still urgent problems at present. High-quality improvement of agricultural land areas and natural agrolandscapes on the basis of multipurpose land reclamation is one of the quidelines of the activities of the Ministry of Agriculture, water management, designing and research organizations. One of the most important and effective methods of preventing lands from over wetting and bogging is closed drainage. Currently, there are 9.3 million ha of reclaimed lands in the Russian Federation, of which 4.8 million ha are drained; the balance cost of systems of all the forms of ownership totals 307 billion roubles. Out of the total area of drained lands 3.0 million ha, or 62 %, are represented with closed drainage systems, including 2.6 million ha in 29 subjects of the Russian Federation located within the Nonchernozem Zone, the remaining land areas are located in the regions of Siberia and Far East. The goal-oriented federal target program «Development of agricultural land reclamation of Russia for the period until 2020» was aimed at developing the system of rational agro-ameliorative practices for long-term operation of reclamation systems, in particular on heavy soils with the use of drainage and rehabilitation of the humid zone soils polluted as a result of human activities. This problem was successfully solved. The assessment of theoretical findings, experimental works and results of their practical use were carried out in some land reclamation project areas of the Nonchernozem Zone.

KEY WORDS: Close drainage, Land reclamation, Wetland, heavy soil, Adaptive landscape tillage.

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Introduction

According to the existing practice in the Russian Federation, in case of drainage of over wetted soils using the closed drainage system the recommended drain spacing varies within the limits of 15-40 m depending on the type of bogging and soil properties. As to the world practice of drainage construction, the closed drain spacing in slightly permeable soils varies from 6 to 15-17 m; this value varies from 20-25 to 50 m and more in well permeable soils. For example, the drain spacing in silty clay soils of Poland equals 8 m; it varies from 6 to 18 m in Germany, from 8 to 15 m in Austria and Switzerland, and averages 25 m in England.

The efficiency of heavy soil drainage is also achieved through regulation of the depth of drain laying. The depth of drain laying in heavy soils of the Russian Federation is assumed to be 1.0-1.2 m. The depth may be increased to 1.5-2.0 m under the condition of intense feeding with pressure water.

The efficiency of closed drainage operation depends not only on its parameters but also on constructional features of drainage pipes.

During the period of 2014-2020, it is planned to reconstruct drainage systems covering the area of 1000 000 ha, to implement a large volume of other works aimed at improving drained land areas, soil fertility and enhancing the efficiency of drained land use.

Experimental site layout

The Nonchernozem Zone covers a vast area and is referred to the regions of low biological productivity of lands caused by the fact that the greater part of agricultural land areas is located in the regions of increased wetting and overwetting. In addition to this, pollution of soils, surface water and groundwater with chemicals exceeding the ultimate permissible concentrations is observed in some areas of this zone, the pollution being caused by the impact of industry, municipal utilities, and other factors.

Large-scale work related to the agrarian transformation in this zone was carried out over the period of 1974-1990. These transformations were based on multipurpose land reclamation. The lands of this zone needed drainage, removal of brush and stones, liming, cultivation; it was necessary to construct roads, dwelling facilities and to provide production and social infrastructure. Great volumes of works were implemented over the period in question. The Government was responsible for financing of transformations stipulated by the programme.

Drainage developments in the zone were mainly accomplished at that period; nearly all land reclamation systems currently used in agricultural production were constructed at that time. It was the period, when closed drainage was universally put into practice, main designs of drainage systems and conditions of their use were studied and developed, the technologies of all the main types of land reclamation operations were worked out.

The principal objects of drainage were overwetted boggy podzolic soils widely spread in the zone under study; the productivity of such soils could be rather rapidly increased through regulation of their water and air, nutritive and thermal regimes. Drainage complete with the system of cultivation and enrichment of soil with organic matter, liming of acidic soils and other measures permit the optimization of fertility of low-productive lands. Another, less topical and having limited spreading, object of land reclamation was peat soil of lowland type. Such soils are rich in organic matter and are referred to potentially fertile lands.

Results and discussion

Heavy soils of different degree of bogging referred to the podzolic and boggy podzolic types are widespread in northwest and central regions of the Nonchernozem Zone and in the Republic of Byelarus as well. The agricultural use of these soils is possible only after their drainage. However, it is worth mentioning that drainage of heavy soils is a complicated problem because of the specific physical properties of a soil profile. This is particularly true, when the object of drainage are dense, structure less and gleyed soils with a waterproof subsoil layer ($K_{seepage}$<0.1-0.01 m/day). The problem of drainage of such kind of soils is also observed in other countries.

The drainage of heavy soils is aimed at dropping the groundwater level and disposal of surface water. The main method of land drainage is closed drainage using tile or plastic pipes. The drains should be laid only with protective filtering envelope. The efficiency of the closed drainage system operation depends on the reliability of choosing the design parameters in the course of drainage system planning (depth of drain laying, drain spacing, etc.), which provide the necessary degree or rate of drainage according to crop demands for water regime.

Many famous scientists specialized in land reclamation (Kostyakov, Aver'yanov, Pisar'kov, Ivitskii, Dubenok, Volkonskii, Rozova, Shkinkis and other researchers) were involved in studying the theoretical principles of drainage operation and in engineering calculations of drainage in heavy mineral soils. Provision was made for substantiation of the impact of soil factors and human-induced (engineering) factors on the drainage capacity. In particular, the problem concerning the role of top soil and subsoil layers as well as drainage filling in formation of drainage runoff was discussed. Opinions differ in interpretation of these problems. For example, A.N. Kostyakov has revealed that in clayey slightly permeable soils groundwater runs to drains mainly along the plough sole of the top soil layer and the smaller part of it runs along the subsoil layer. Kh.A. Pisar'kov has found that the insignificant runoff through the subsoil layer is often more important than the greater runoff through the top soil, in other words, the runoff through the subsoil decreases the top soil overwetting. A.I. Klimko has revealed that under the condition of the Kaliningrad Region, where drains are laid at a depth of 0.85 m and spaced at 12-14 m, more that 40 % of water enters the drains through the top soil, 28 % of water runs along the surface of the top soil though the drainage filling, and 29 % of water comes from the subsoil layer. Ts. N. Shkinkis thinks that under the condition of deep drainage, less that 10 % of the total amount of excess water runs to drains through the heavy top soil layer. The studies carried out by I.M. Krivonosov in the Leningrad Region have shown that the runoff from drains is observed, when the level of groundwater is only in the top soil layer, i.e. the runoff is formed in the top soil layer and in more porous drainage filling. At the same time, the experiments performed by I. Dwob and R. Lamsodis did not reveal any difference in water permeability of trench filling material and intact ground. The efficiency of closed drainage operation in heavy, regularly overwetted soils was also studied by some other researchers.

The closed drainage is known to be more efficient under the condition of levelled surface, properly cultivated soils, and structural top soil rich in humus. The drainage effect of closed drainage systems depends on many natural and designing factors: permeability of soils and soil-forming rocks, meteorological conditions, relief of the area to be drained, depth of soil freezing, and drainage system parameters. In addition to this, the efficiency of tile drainage in loamy soils fed by atmospheric precipitation greatly depends on the location of drains on the surface to be drained, drain spacing, drain length, depth of drain laying, design of the conveying part of the system of structures.

According to the existing practice in the Russian Federation, in case of drainage of overwetted soils using the closed drainage system the recommended drain spacing varies within the limits of 15-40 m depending on the type of bogging and soil properties. As to the world practice of drainage construction, the closed drain spacing in slightly permeable soils varies from 6 to 15-17 m; this value varies from 20-25 to 50 m and more in well permeable soils. For example, the drain spacing in silty clay soils of Poland equals 8 m; it varies from 6 to 18 m in Germany, from 8 to 15 m in Austria and Switzerland, and averages 25 m in England.

The efficiency of heavy soil drainage is also achieved through regulation of the depth of drain laying. The depth of drain laying in heavy soils of the Russian Federation is assumed to be 1.0-1.2 m. The depth may be increased to 1.5-2.0 m under the condition of intense feeding with pressure water. In slightly permeable soils, when the line of seepage is not formed in subsoil layers, the depth of drain laying is decreased to 0.7-0.9 m and drain filling with filtering material is provided. As for the foreign experience, the following depth of drain laying is practiced in different countries depending on soil and climatic conditions: 0.8-1.6 m in arable lands and 0.7-1.3 m in grasslands of Austria, 1.2 m in Finland; at the rate of drainage equaling 0.6-0.9 m, the depth of drain laying varies from 0.75 to 1.37 m in the USA; it varies from 0.9 to 1.3 m in England and from 0.9 to 1.5 m in Poland.

The efficiency of closed drainage operation depends not only on its parameters but also on constructional features of drainage pipes.

Over a long period of time, drains for closed drainage systems were made of tile pipes in Russia. Beginning in 1975, corrugated PVC and polyethylene pipes 50 and 63 mm in diameter are used. Roll synthetic nonwoven materials are used as filtering materials. Drains in moderately and slightly permeable soils are also covered with local bulk filtering material (sand, wood chips, slag, etc.) and then backfill of trenches with excavated earth is performed.

To speed up water disposal from the top soil in very compacted heavy soils (the seepage factor being less than 0.1 m/day) it is recommended to practice permeable filling of drainage systems (up to the ground surface or up to the top soil) with the use of gravel and crushed stone or to supplement drainage with a complex of agro-ameliorative measures, which contributes to more rapid inflow of excess water into drains.

In draining lands of heavy mineralogical composition, the use is made of granulated material of high permeability (sand, gravel, ash and slag wastes, etc.) for filling trenches.

During the operation period, compacted layers are formed in the soil profile under the impact of agricultural machinery. Deep ameliorative soil loosening to the depth of occurrence of the compacted layer sole is capable to restore the soil profile permeability and design regime of drainage operation.

Thus, it can be concluded that only the application of a complex of agro-ameliorative measures can provide normal operation of drainage in heavy soils and enhance the efficiency of drained land use.

Land reclamation systems were constructed in the Russian Federation in the 1960s-1980s. Over the period of reforms, the insufficient financing from budgets of different levels and other sources resulted in dramatic decrease of volumes of works related to reconstruction and rehabilitation of land reclamation systems, the volume of necessary repair and maintenance operations also decreased. As a consequence, the technical level of these systems decreased along with the condition of reclaimed lands, particularly in farm systems belonging to agricultural commodity producers or assigned to them.

Currently, the condition of nearly 1.4 million ha of drained lands (29% of the total drained area) is unsatisfactory. High groundwater table and intolerable delay in surface water disposal are observed in this area. The total of 1.6 million ha of drained land systems need reconstruction and rehabilitation.

The condition of about 30% of areas under drainage systems with tile drains is unsatisfactory; secondary bogging is observed in some places. Silting of drains, collecting drains, and discharge canals is recorded as a result of long-term exploitation of these systems. Moreover, because of the lack of financing and special equipment, canals got overgrown with wood and brush vegetation. The cleaning of canals from vegetation and sediments goes on slowly.

To ensure long-term functioning and more efficient operation of drainage systems with the use of tile and other type of drainage the following measures are necessary: regular cleaning of drainage systems (particularly, outlets of discharge collecting drains) from sediments with application of up-to-date methods and use of drain-flushing machines; reconstruction, repair, and cleaning of canals from vegetation and sediments. This will need considerable enlargement of the fleet of excavators, cutters, and other special machines in water management organizations. Some steps in this direction have been already taken.

Scientific analysis of these data shows, that yield of agricultural crops on the heavy mineral soils drained by subsoil pipes, essentially raises at carrying out of agro- and land reclamation actions in different variations. On land improvement systems for efficiency of subsoil drainage it is offered to apply a complex of agro-technical and agro-ameliorative actions. On heavy soils the most effective reception of improvement of their fertility is application of subsoiling.

Efficiency of functioning of the close pipes also is defined by a technical condition of the drainage system including pipes, canals network and constructions. As it would be noticed, that with increase in period of validity of a drainage its working capacity worsens, in concerning to silting and ferrites deposits process.

It is necessary to understand, that the ecological substantiation of efficiency of drainage systems on heavy cespitose-podzolic soils in depending on term of its action and operation conditions is not enough elaborate. Also the question on change of soil conditions depending on period of validity of drainage system on the base of application of agronomy actions is insufficiently known.

In the conditions of the Central area of the Nonchernozem zone of the Russian Federation more than half of drained lands are used under forage crops (perennial and annual grasses, root crops). E.I.Lopukhin (1974) specifies, that on the drained lands expediently expansion of the areas under perennial grasses that promote increase of fertility of soils.

On heavy mineral drained soils It is possible to give a high yields of grain, a potato and root crops. However a high crop yields depends of drainage efficiency, its technological parameters and a design.

In the conditions of the Moscow and Vladimirovsky Districts it was estimated, that the yield of grain cultures and perennial grasses depends of drainage parameters: with reduction of distances between drains and increase in their depth. Deep subsoiling on the base of a drainage with spacing from 22 to 30 meters has allowed a grain yield increase in comparison with the control (a drainage without subsoiling) on 10-20 %.

Considerable volumes of work related to reconstruction and rehabilitation of drainage systems have to be fulfilled in accordance with the approved Federal target program «Development of agricultural land reclamation of Russia for the period until 2020». During the period of 2014-2020, it is planned to reconstruct drainage systems covering the area of 100 000 ha, to implement a large volume of other works aimed at improving drained land areas, soil fertility and enhancing the efficiency of drained land use.

Conclusion

The Government of the Russian Federation accepted the federal target program «Development of agricultural land reclamation of Russia for the period until 2020». The purpose of the program is improvement of the competitiveness, profitability and stability of agricultural output. It requires to emplement complex land reclamation measures along with the methods of adaptive landscape tillage for ensuring food security and preserving future generations of natural resources. Federal target program for the development of land reclamation aimed to solving the problem of food security by means of sustainable innovation development of agriculture and the creation of mechanism for effective use of agricultural land and natural resources with methods of integrated land reclamation measures, irrespective of climate change and abnormalities.

During the period of 2014-2020, it is planned to reconstruct drainage systems covering the area of 1000 000 ha, to implement a large volume of other works aimed at improving drained land areas, soil fertility and enhancing the efficiency of drained land use.

Acknowledgement

The authors wish to express our sincere thanks and appreciation to the Ministry of agriculture of the Russian Federation for support the Program.

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DRAINAGE SYSTEM DESIGN FOR COASTAL POWER PLANT: OPTIMIZATION OF LIMITED RESOURCES

Chawalit Chanamai[1,*], Narin Phaowanich[2]

Abstract

The southern part of Thailand plays an important role in tourism and economic development; thus, growth in electricity demand increases steadily. To ensure stability of supply, it was decided that a base load power plant is to be developed to provide reliable and dependable electricity supply. Thepa Coal-fired Power Plant is located near the coastal area at Pak Bang Sub-district, Thepa District, Songkhla Province, Thailand. The project has an area of around 4.736 km^2. The Thepa Power Plant Project covers the construction of the power plant complex, bearth and jetty facilities, as well as the construction of high voltage 500 kV transmission line.

Geographically, the Thepa District deals with both floods and droughts every year. The Office of Disaster Prevention and Mitigation proposes a plan to prevent flood and drought in the area to reduce the impact of such events on residents and the local agricultural sector. The change in land use is one factor that increases flood risk by reducing water permeability and increasing water surface runoff. To minimize the environmental impacts of developed land area, Sustainable Urban Drainage System (SUDS) techniques have been used as a tool for integrated water resources and water management. SUDS techniques are internationally adopted as an effective tool for sustainable design philosophies aiming not only to protect natural resources, but also to maintain good public health. In addition, the SUDS technique also preserves biological diversity by minimizing environment impact from developed land area over the long term.

This study focuses primarily on the sustainable and environmental-friendly design of drainage system for the new coastal power plant. The drainage system has been design using the Storm and Sanitary Analysis (SSA) two dimensional mathematical model which is for hydrology and hydraulics in a project. The study quantifies the criteria of the drainage system of the Power Plant. After identifying a suitable area for constructing a power plant, hydrological data including flood area, temperature, rainfall, runoff, soil properties and geometry were collected to be used as the basis for drainage design preventing flood area problems. One of the key principals in the design is to try to avoid any conflicts with the local community. After examining all relevant aspects, the criteria of drainage design and the criteria of sustainability design are set up to fully utilize

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available resources, not only for drainage, but also for power plant usage during construction as well as operation.

Flood prevention of the power plant is mandatory for reliable plant operation. Accordingly, the flow velocity should be designed for self-cleaning velocity. The velocity is then defined as the rate between 0.6 to 3.0 m/s to prevent sedimentation and to prevent erosion of pipe, gutter and channel. The maximum flow velocity is then quantified by the return period of rainfall at the project area. The drainage system planning is considered based on (i) Rational Method, (ii) Time of Concentrate (TOC), and (iii) Flood Routing.

The results of the study through the application of SUDS techniques show that the drainage system is composed of a 5.00 x 3.65 m 1.50 km main drain channel ., 2 retention ponds of total capacity 6,900,000 m^3, and a run-off canal. This system will effectively utilize the surface runoff while providing a reliable flood prevention system to the power plant.

KEY WORDS: Drainage design, Power plant, SUDS, SSA, Storm Drainage, Sustain Urban Drainage System.

Introduction

Electricity Generating Authority of Thailand (EGAT) is a state enterprise of power sector under the supervision of the Ministry of Energy of Thailand. The main objectives of EGAT are production electricity for supplying the usages of all sectors. The southern part of Thailand is important area of economic activities and tourism, thus the electricity demand rate keep increasing steadily. Some power plants need to shut down for maintenance as power plant management plan. Moreover, some of power plants in the south did not operate to the maximum capacity. EGAT seriously concerns about electricity reserving and suppling power generation for the future. That is the reasons why EGAT need to construct new power plant (COT, 2015).

The main problems of Thepa District are flood and drought (Buenoi, 2016). Not only residents suffer from these problems, but also plants and wildlife are affected from flood and drought. Water is more difficult to percolate to ground because land area surface is covered by building materials. The effect of land developing increases of runoff surface. Therefore, EGAT’s engineers shall consider both on environmental factors; pollution impact and preventing the flood and also engineering sector.

To reducing the environmental impact of developed land area, SUDS is introduced to design land area development (Zhou, 2014). Moreover, The study of Royal Haskoing illustrated that the capital cost of SUDS in terms of maintenance decrease around 2.5 – 8.0 percent from the traditional drainage system per property at UK (Royal Haskoing, 2012).

In this paper focuses primarily on how to design the drainage for new power plant near the coastal by sustaining water resources. The two mathematical dimensions of hydrology and hydraulics model is used to design drainage system by SSA in project. The study quantifies the criteria of drainage system of Power Plant.

Study Area

Thepa Coal-fired Power Plant which has capacity 1,100 MW is located near coastal area at Pak Bang Sub-district, Thepa District, Songkhla Province, Thailand. The project area is around 4.736 km^2. The Thepa Coal-fired Power Plant is going to construct birth and jetty for importation of bituminous coal and sub-bituminous coal. Moreover, the project includes the electrical line 500 kV around 70-80 km for connection with Hat Yai 3 high voltage power station (COT, 2015). The location of study area is showed in the Figure 1.

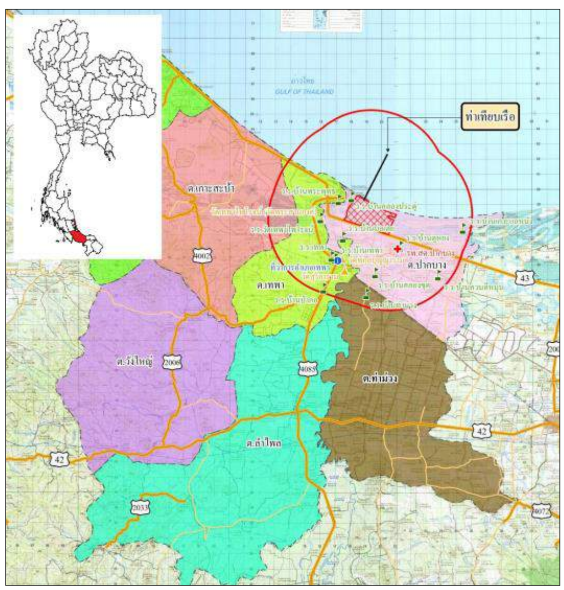

Figure 1. Thepa Coal-fired Power Plant

Previous Studies

In 2007, the European Flood Risk Directive presented the flood risk management plans by applied USDS method (Boogaard and Stockel, 2011). According SUDS, the drainage plan can reduce flood at the beach resort Egmond aan Zee in the north-west of the Netherland during extreme rainfall events.

Elliott and Trowsdale discuss about capability and relevance of 10 models to sustainable drainage systems. The paper presents insights into the advantages and disadvantages of the reviewed models in response to different requirements of the various SUDS devices (Elliott and Trowsdale, 2007).

According to Modelling of Sustainable Urban Drainage Measurement, Vergroesen et. al. found that the models for SUDS for green roofs, swale filter drainage system and infiltration transport drainage system are reasonable (Vergroesen et. al., 2014). The results from the mathematic model can present physical behavior of each system.

Methodology and Data

Methodology of Design

The overall methodology of drainage design for a new power plant is shown in Figure 2. After identify the proper area for construction of power plant. The designer shall collect data including flood area, temperature, rainfall, runoff, soil properties and geometry to prepare drainage design and prevent flood area problem. The local people shall allow to express their thoughts and have metting with designer team for reducing misunderstands about the project. Moreover, the designer shall understand their demand to reduce conflicts of community. After examining the engineering proposes, the criteria of drainage design and criteria of sustainability design are set up to design and analyze the drainage model for multi proposes. The submission of drainage of project will be considered by EHIA which is an indicator of the impact in environment and health. The agreement of city council is the final process for construction.

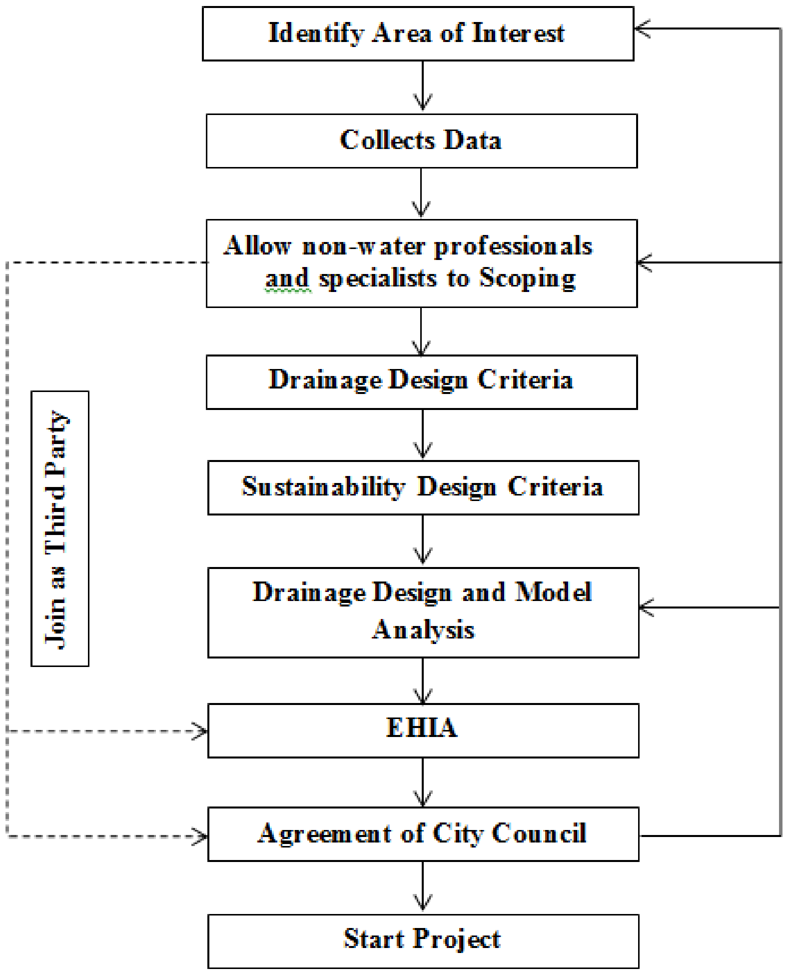

Figure 2. Framework of Drainage Design for Power Plant near Coastal

SUDS

Sustainable land development challenge engineer to improve amenity by balancing environment and health with changing land use. SUDS is techniques to manage runoff attenuation and mitigation with considering about pollutants reduction and amenity construction (Zhou, 2014). SUDS has approaches to manage water quantity (drought and flooding), water quality (pollution), amenity (new construction) and biodiversity (wildlife and plants) in a long term. The SUDS applied to the new project design has many techniques (Wilson et, al, 2011). There are many ways to present the components. This study focuses on only 4 elements of SUDS as follows:

Filter Strips

The filter strips refer to grass or other plant strips to collect mass of water or sheet flow and to remove pollution from it. The minimum length of covering plants and grass should be around 900-

1,200 mm with minimum top soil depth 150 mm. The filter strips prevent flood by infiltration and remove silt or small particular in water for preventing pollution.

Detention Basin

Generally, Detention basin refers to open and flat area covering with grass that are normally dry. If it rain heavily, these areas are used to store excess water in short term. Sometimes, they are used for multi proposes such as play areas.

Swale

Swale is a very shallow channel with side slope is not more than 1 in 3 for collecting runoff and removing pollution. Plants and grass can cover on both slope and bottom surface along the channels for preventing flood by infiltration. The flow rate for swale is not more than 1 – 2 m/s to prevent erosion. Normally, grass swales height should be 75 – 100 mm to prevent grass lodging and falling over due to the wind and runoff.

Retention Pond or wetland

The retention pond and wetlands are proposed to provide temporary storage for excess rainfall. They are designed as the open areas of shallow water. The water level will rise if it rain. Ponds and water land have the same concept that they provide the benefits of environment by removing pollution from surface water. The different between pond and wetland is that the pond consider to storing excess water, while wetlands focus on treatment pollution.

SSA

SSA is hydraulics, hydrology and water quality model which developed by Autodesk in 2010. Many projects and case study use SSA as a tool to design and analyze drainage system including stormwater, retention pond, outlet structure and water quality. The model is used worldwide because the results of model can be exported and analysized to AutoCAD and ArcGIS. SSA analysis is based on USEPA SWMM 5.0, NRSC (SCS) TR-55, NRSC (SCS) TR-20, HEC-1, rational method and unit hydrograph (Autodesk, 2013). SSA can quantify SUDS for storage volume requirement for the peak flow attenuation in project area, by determining the volume of runoff to extent storm durations for examining the critical storm duration. The model computes the volume of runoff by the storm duration time step method. The Figure 3 showed the software display the calculation of SUDS storage dialog box. The latest version of SSA is 2016. However, in this study use SSA version 2012 to design and analysis drainage system.

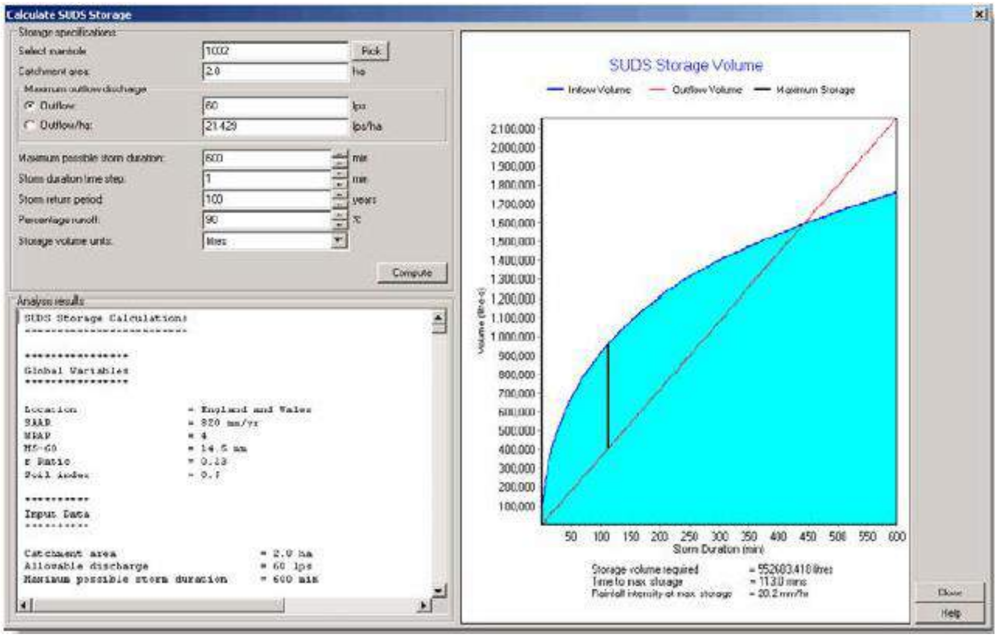

Figure 3. The example calculation SUDS storage (Autodesk, 2013)

Design Criteria

The new power plant needs a good drainage system design. The flow velocity should be designed with self-cleaning velocity. The velocity should be between 0.6 to 3.0 m3 for preventing sedimentation and preventing erosion of pipe, gutter and channel (NHI, 2001). The maximum flow velocity can be quantified by return period of rainfall at the project area. The drainage system plan based on following criteria:

Rational Method

The idea of Rational method is calculated from the maximum discharge by the rainfall excess in catchment area (NHI, 2001). The equation of rational method showed in Equation 1.

$$Q = 0.278CIA \qquad (1)$$

Where Q is the peak flow (m/s), C is the coefficient of runoff, I is intensity of precipitation (mm/hr) and A is drainage area or catchment area (km^2). The runoff coefficient is showed in Table 1.

Table 1 Runoff Coefficient (Autodesk, 2013)

Type of Drainage Area	Runoff Coefficient
Business:	
Downtown areas	0.70-0.95
Neighborhood areas	0.50-0.70
Residential:	
Sigle-family areas	0.30-0.50
Multi-units, detached	0.40-0.60
Multi-units, attached	0.60-0.75
Suburban	0.25-0.40
Apartment dwelling areas	0.50-0.70
Industrial:	
Light areas	0.50-0.80
Heavy areas	0.60-0.90
Parks, cemeteries	0.10-0.25
Playgrounds	0.20-0.40
Railroad yard areas	0.10-0.30
Unimproved areas	
Street:	
Asphaltic	0.70-0.95
Concrete	0.80-0.95
Brick	0.70-0.85
Drive and walk	0.75-0.85
Roofs	0.75-0.95

Time of Concentrate (TOC)

TOC refers to the time from all area in drainage catchment flow through outlet. TOC shall be considered from the longest point of drainage system. According to SSA, TOC is consists of TOC of catchment area to drainage system and TOC of drainage system. The method is calculated by the equation 2 (NEH, 2010).

$$T = \frac{L}{V} \tag{2}$$

Where T is travel time (min.), L is the flow length (m.) and V is the average velocity (m/s).

Flood Routing

Flood routing of drainage system is determined by mass conservation and momentum equations in variety cases. There are three different models in SAA to solve these equations (Autodesk, 2013). Steady flow, kinematic wave and dynamic wave routing are selected to calculate flood routing depending on the purpose of the simulation. In this study, SSA must show a balance between preserving water and attenuating flooding risk. That is the reason why the kinematic wave model was selected to solve these equations.

Manning's Equation

The stromwater discharge of variety drainage shape of pipe, channel and culvert can be calculated by Manning's equation. SSA support to the calculation of any types of pipe and irregular natural cross-section. The Manning's equation (Equation 3) was select for this study (Autodesk, 2013).

$$Q = \frac{1}{n} A R^{2/3} \sqrt{S} \tag{3}$$

Where Q is flow rate (m^3/s), n is Manning roughness coefficient, A is cross section area (m^2), R is hydraulic radius (m.) and S is energy slope. For Manning roughness coefficient is showed in Table 2 (Autodesk, 2013).

Table 2 Manning's Roughness Coefficient for Channels and Overland Flow (Autodesk, 2013)

Land Surface Type	Manning n
Concrete, Asphalt or Gravel	0.005-0.015
Rural Residential (1-10 acre lots, maintenance or grazing assumed)	0.40
1-3 building units/acre	0.30
3-10 building units/acre	0.20
>10 building units/acre	0.15
Commercial/Industrial (effects of landscaping, driveways, roofs included in combined value)	0.11
Average Grass Cover	0.40
Poor Grass Cover, Moderately Rough Surface	0.30-0.40
Light Turf	0.20
Dense Turf	0.17-0.80
Dense Grass	0.17-0.30
Bermuda Grass	0.30-0.48
Dense Shrubbery and Forest Litter	0.40

Data and Sources

SAA in this study is calculated using data from various sources. The list of data requirement is showed in Table 3.

Table 3. Data and sources in this study

Data	Sources	Period
Weather parameters (temperature, rainfall, humidity, Sun hour and wind speed)	Thai Meteorological Department (TMD)	๑๙๖๑-๒๐๑๐
Geology and soil properties	EGAT	2015-2016
Runoff and sea level	Royal Irrigation Department, Thailand (RID) and Marine Department of Thailand(MD)	1970-2010

Drainage Design and Discussion

The conceptual master plan of power plant is showed in Figure 4. The power plant zone is located at the west side of the project area. For the east side of the project, EGAT plans for providing the public area such as garden, observation, market, waterpark opening sport fields, community center and agricultural demonstration area. The drainage system in this zone is designed as swale flow to wetland which locates near waterpark. The water will be collected at a retention pond (capacity around 5,000 m3) for planting at agricultural demonstration area. Storm water from retention pond 1 (power plant zone) is preparing for waterpark. Stromwater is collected from green zone around market, garden and Java bird competition area to retention pond of public area (capacity around 8,000 m3) is located at observation. At the center of the sought east part of the project area, there is opened sport area (football, volleyball and cycling) which is designed as detention basin around 130,000 m2 to infiltration to the ground. In case of high rainfall excess, the excess of water will flow to waste water treatment tank checking and improving quality before release to Tu Yong Channel.

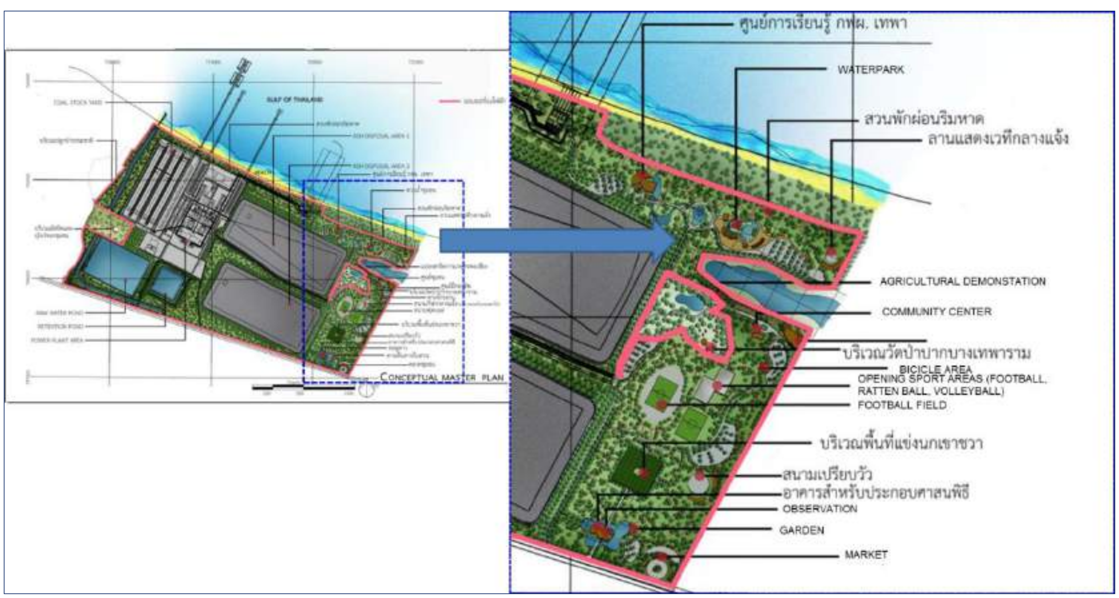

Figure 4. The Conceptual Master Plan

According to the project location, flood plain always across the main road to resident and project area in rainy season. The channel is improved by concrete lining and construction embankment for preventing flood event. The flood direction and channel were showed in the Figure 5. The trapezoid channel has 5 meters width with average slope 1:3. The capacity of this channel is 63 m^3/s, while the 100 years return period of flood plain is around 58.10 m^3/s.

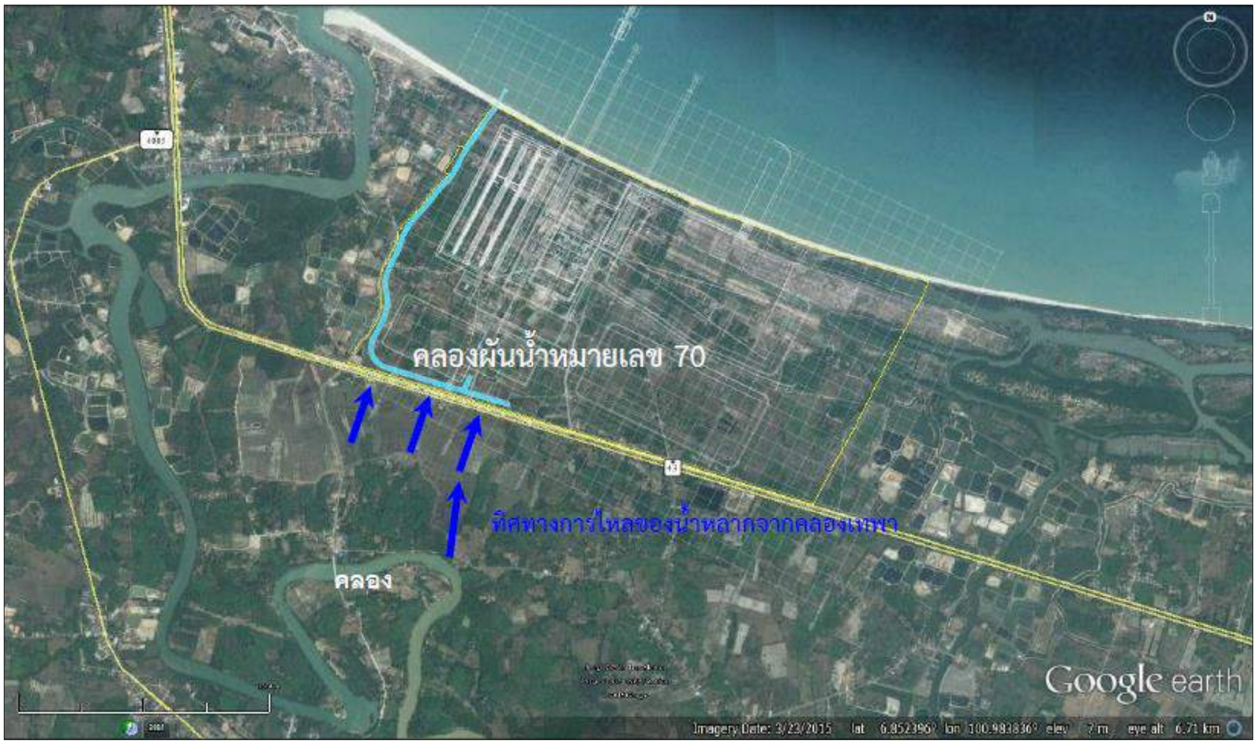

Figure 5. The Conceptual Master Plan

According to Table 2, the main drainage which has size of 5.00 x 3.65 meter is designed to collect stormwater base on 10 years return period of rainfall duration 15 minutes the safety factor 1.30. The capacity of this main drain is 35.25 m^3/s. There is clearance around 15 meters both sides of main drain with filter strips removing particles from water. All of stromwater is collected at the retention ponds with capacity 6,900,000 m^3 by main drainage system. The retention pond consists of clay blanket and HDPE sheet to prevent water infiltration and preventing sea water dissolve to water system. Water is prepared for gardening, washing equipment, spreading coal and public area.

Table 4 Calculation of Main Drain

From	To	Increment Length of Gutter m.	Total Length of Gutter m.	Total Catchment Area m².	Area for C		I mm/hr	Qp m³/s	Drainage System Design						Depth of Channel m.	Qmax m/s	vmax m/s	Safety Factor
					0.30	0.80			Bed Width m.	y m.	A m².	P m.	R m.	n Manning				
1	2	3.25	3.25	193,619	0	193,619	150	6.45	5.00	0.80	7.50	8.00	0.94	0.015	2.35	15.15	2.02	2.35
2	3	212.80	216.05	280,170	0	280,170	150	9.34	5.00	1.03	8.63	8.45	1.02	0.015	2.35	18.43	2.14	1.97
3	4	178.46	394.51	297,650	4,980	292,670	150	9.82	5.00	1.06	8.80	8.52	1.03	0.015	2.56	18.96	2.15	1.93
4	5	21.53	416.04	428,320	4,980	423,340	150	14.17	5.00	1.37	10.33	9.13	1.13	0.015	2.74	23.63	2.29	1.67
5	6	114.07	530.11	445,200	9,790	435,410	150	14.64	5.00	1.40	10.48	9.19	1.14	0.015	2.76	24.10	2.30	1.65
6	7	85.89	616.00	526,987	9,790	517,197	150	17.36	5.00	1.58	11.38	9.55	1.19	0.015	2.88	26.95	2.37	1.55
7	8	49.77	665.77	556,037	20,200	535,837	150	18.11	5.00	1.62	11.61	9.64	1.20	0.015	2.96	27.70	2.39	1.53
8	9	222.64	888.41	573,257	37,420	535,837	150	18.33	5.00	1.64	11.68	9.67	1.21	0.015	3.01	27.91	2.39	1.52
9	10	13.50	901.91	584,417	48,580	535,837	150	18.47	5.00	1.65	11.73	9.69	1.21	0.015	3.23	28.07	2.39	1.52
10	11	14.00	915.91	766,027	48,580	717,447	150	24.52	5.00	2.02	13.60	10.44	1.30	0.015	3.25	34.20	2.51	1.39
11	12	103.65	1,019.56	788,197	48,580	739,617	150	25.26	5.00	2.06	13.82	10.53	1.31	0.015	3.26	34.91	2.53	1.38
12	13	150.00	1,169.56	900,917	48,580	852,337	150	29.02	5.00	2.29	14.95	10.98	1.36	0.015	3.36	38.72	2.59	1.33
13	14	306.80	1,476.36	1,007,867	112,170	895,697	150	31.26	5.00	2.42	15.58	11.23	1.39	0.015	3.51	40.84	2.62	1.31
14	15	42.35	1,518.71	1,007,867	112,170	895,697	150	31.26	5.00	2.415	15.575	11.23	1.38691	0.015	2.42	42.97	2.65	1.30

The ash disposal ponds are located at the center of project area. The cross-section of ash disposal pond is showed in Figure 6. The bottom of disposal pond is covered by sand layer and under drain system. The under drain collect water around 65 m^3/day from initial filter particles in sand layer to waste water treatment area. The HDPE sheet is used to prevent stormwater mixing with ash emit to environment. The waste water system will be treated and reused for electrical production process which is about 600 m^3/day. As a result of the simulation of water level in Figure 7, the capacity of ash disposal pond is available to store both stormwater and ash for 15 years.

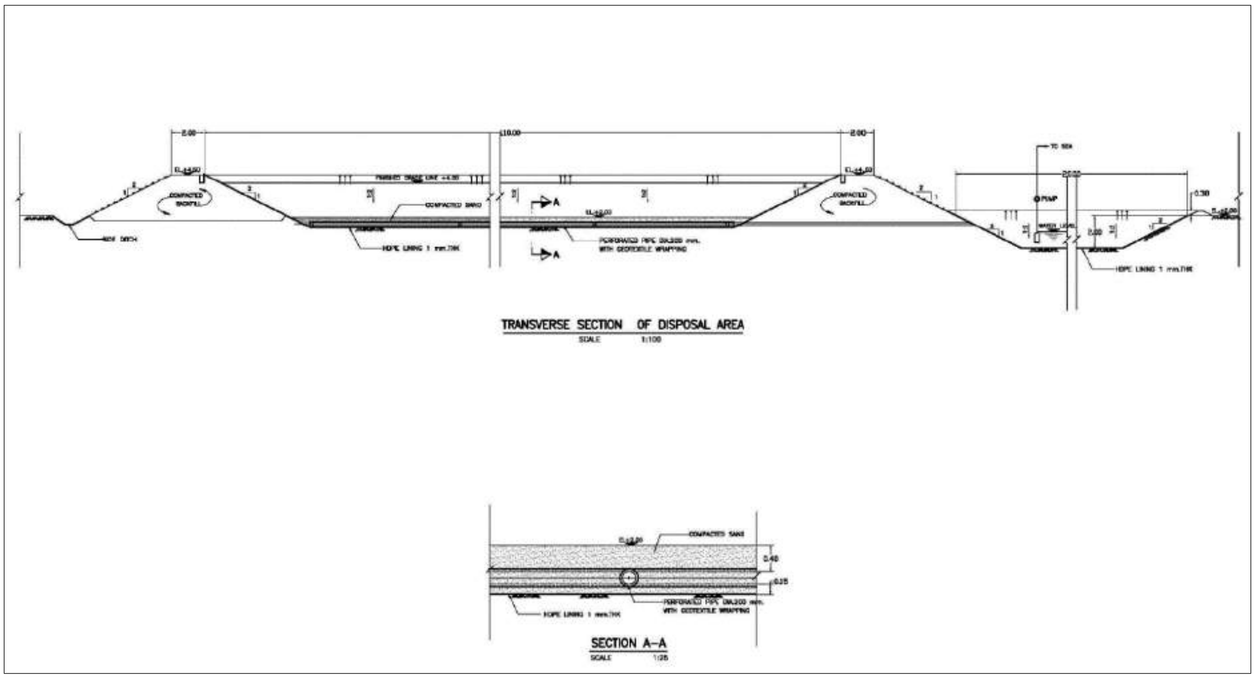

Figure 6. Ash Disposal Section

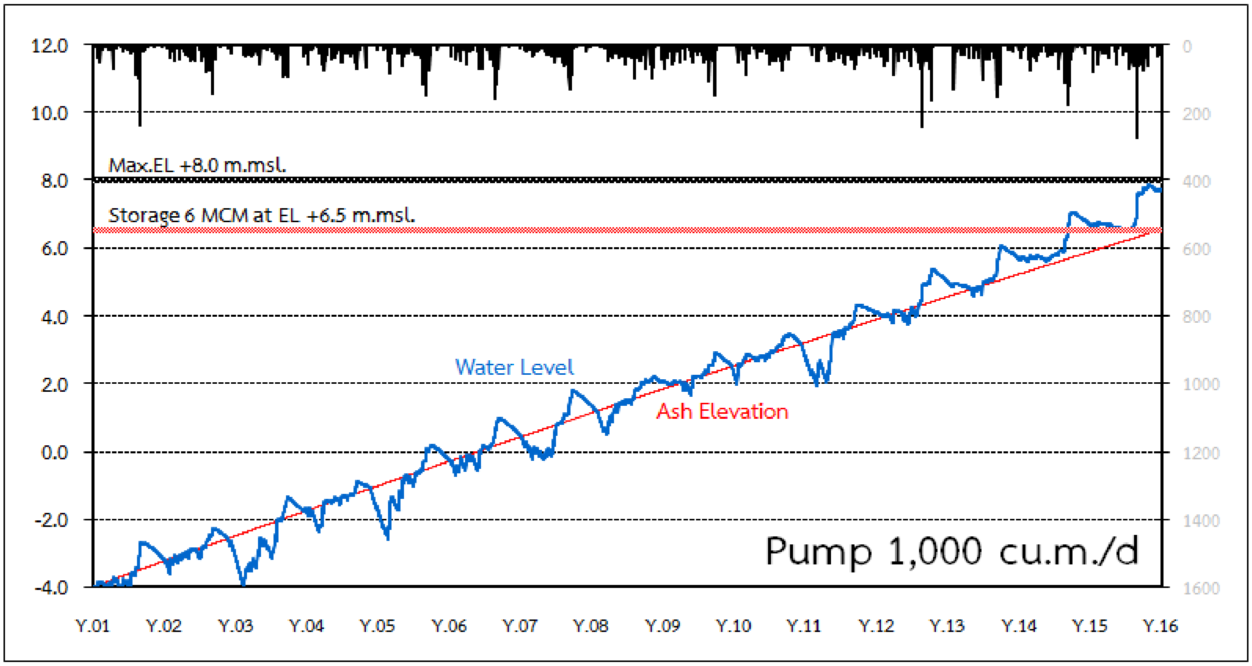

Figure 7. Water Management at Ash Disposal

Conclusion

This case study has shown that EGAT concerns about sustain water. The drainage system designed for coastal power plant in Thailand which gets along well with environment and community. According to SUDS techniques, the new power plant which is located near the coastal will effectively prevent 100 years return period of flood from the site project and out site project area for people around Thepa Power Plant. Swale, filter strips and detention pond are used as to improve water quality in drainage system. According to reusing water in power plant activities such as gardening (412 m^3/day), washing ash and equipment (200 m^3/day), and utilizing in the public area zone, rainfall in the project area is used up. It means that there isn't stromwater that mixes with pollutant such as sediment and oil releasing to public channel or river. The rainfall assess in rainy season shall store in retention ponds for using in dry season in both power plant project and public area.

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MODELING STORM WATER MANAGEMENT FOR WATER SENSITIVE URBAN DESIGN USING SUSTAIN

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Abstract

In an attempt to transit South Australia to a water sensitive State, a plan named Water for Good was launched in 2012 which is a guide for urban and regional development of South Australia. One of the main objectives of this plan is to reduce the negative impact of urbanization on the water cycle of the cities. In order to reduce the hydrological impact of urbanization, best management practices have been proposed. Determining the topology of such structures (number, size and placement) is the key element of any urban storm water management plans. Several models have been proposed which are based on hydrologic, hydraulic or combination of both properties of the catchments. This paper addresses some of the most important models and then introduces SUSTAIN as a suitable model for the optimization of best management practices in South Australia. The selection of the appropriate model was based on the desired condition of the study. In order to study the potential of SUSTAIN for storm water management, a part of the Paddocks area located in Para hills, South Australia was selected which is 15.95 acres in size and was broken into five sub- catchments. The hydrologic parameters of the model were derived from a calibrated model which was developed using EPA SWMM. Three types of BMPs i.e. rain garden (bioretention), rainwater tank (cistern) and detention tank (bioretention as a surrogate) were studied. After designing the study area, defining data layers, placement of BMPs, specifying routing network and the setting of parameters for each sub catchment and BMPs, SUSTAIN was run for a minimum of six months leading up to the 2 or 5 year ARI event. A total of 15 out of 50 scenarios result into an optimized solution which can be classified in three groups according to the type of used BMPs. SUSTAIN successfully produced results for preserving peak flow rate within the catchment, producing data regarding the least cost solution for the size and placement of

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retention or detention storages. In the retention scenario, levels of demand (or disposal) greater than 450 L/day of retained water were required to produce an optimum result for the 2 years ARI storm event, and greater than 5000 L/day flow to preserve the existing peak flow of the 5 year ARI storm event. For detention systems, an orifice 25 mm was successfully used for preserving both the 2 years ARI and 5 years ARI. However, there did not appear to be any clear pattern in the placement of retention or detention tanks, with results varying each time a successful scenario was rerun. Further optimization with multiple outcomes is recommended to produce a pattern of optimal tank arrangement.

KEY WORDS: Water Sensitive Urban Design, Storm Water Management, SUSTAIN, BMP.

Introduction

There have been recorded an increasing attempt to improve peak flood quantile estimation in the world over the recent decades (Jenkinson, 1955; Dalrymple, 1960;Benson, 1962; Greenwood et al., 1979; USWRC, 1981; Kuczera, 1982; Adamowski, 1985; Hosking et al., 1985; Hosking and Wallis, 1988; Jin and Stedinger, 1989; Burn, 1990; McKerchar and Pearson, 1990; Madsen et al., 1997; Penning-Rowsell et al., 2000; Handmer, 2001; Reiss and Thomass, 2001; Katz et al., 2002;Reis et al., 2004; Zhang and Singh, 2006;Borga et al., 2011; Chavoshi et al., 2012; Castellarin et al., 2012; Silva et al., 2012; Brodie, 2013; Yongfei et al., 2013; Chavoshi et al., 2013a,b; Bezak et al., 2014; Zhang et al., 2014; David and Davidova, 2014). One of the main goals of such studies is to provide reliable estimation of peak flood values with different return period for designing flood control structures.

Several studies have investigated the impact of WSUD features to manage flow rate, volume and flooding from developed catchments. The studies include a wide variety of techniques for simulating the impact of WSUD systems on the flow volume, peak flow rate and flood volume. The EPA SWMM was most widely applied for predicting flow rate, volume and flooding, however few studies assessed the impact of WSUD on peak flows over a truly continuous simulation period, which is required to capture the variability of rainfall and the impact of antecedent catchment conditions (which are influenced by the filling and emptying of storages).

In order to investigate the potential of SUSTAIN in WSUD projects, it was employed for a small urban catchment. The main objective of this study is to find the appropriate BMPs combination (type, size, number and location) to reduce overland flood peak with different ARI to a desired level according to the least cost.

Materials and methods

Case Study

To demonstrate the potential of SUSTAIN for the optimization of BMPs for storm water management, a case study was developed based on a sub-catchment of the Paddocks catchment area located in Para hills, South Australia (Figure 1). This catchment is 6.46 hectares in size and was broken into five sub- catchments (Table 1). It includes four landuse types, namely pervious area (45.39%), road (19.65%), roof (23.85%) and other impervious area (11.12%). Table 2 shows the ratio of current landuse types in each of the sub-areas

Figure 1. An aerial view of the study area and its sub-catchments

Table 1. Sub-catchments properties in the study area

Parameter	Sub-catchment				
	C1	C2	C3	C4	C5
Area (ha)	0.53	2.15	0.17	2.12	1.49
Slope (%)	7.5	7.5	7.5	7.5	6.25
Width (ft)	445.45	1800	141.52	1775.52	1250.25

shown in Figure 1. As this table shows, impervious area (directly connected and indirectly connected) covers almost 55.10 percent of the catchment.

Table 2. Landuse types and percent in each sub catchment

Sub-catchment	C1	C2	C3	C4	C5
Forest_Pervious	44.09	46.00	22.05	44.76	48.54
Road_Impervious	14.50	21.54	58.50	19.95	13.93
Rooftop_Impervious	30.96	23.79	0.00	23.96	23.93
Low Density Residential	10.46	8.67	19.45	11.34	13.61

The impervious condition in both predevelopment and post development scenarios are shown in Table 3.

Table 3. Distribution of impervious and pervious area in the region

Sub catchment	Area (hectare)	Pre development		Post development	
		Impervious (%)	Routed (%)	Impervious (%)	Routed (%)
C1	0.53	44.7	55	62.6	32.3
C2	2.15	47.4	39	70.5	18.8
C3	0.17	44.7	24	66.1	1.8
C4	2.12	44.7	41	63.7	19.2
C5	1.49	43	55	56.5	32.3

A total of 46 houses each with one rainwater tank exist in the study area. According to Australian Building Codes Board (2013) each new house to be build must have one rainwater tank. So, in order to simulate the post development condition, a total of 50% impervious surface increment due to new infill development was considered. It means that a total of 50% of new tanks were considered for post development scenario.

It was assumed that 1 in 3 houses was demolished and replaced with 2 new homes on the same allotment. Each allotment was assumed to be in accordance with Table 4. It was assumed that each new house was constructed with one LID unit. IN all cases, the connected roof area was assumed to be 100 m2 (Table 4).

Table 4. New allotment properties

Houses	2
Roof (m2)	400
Paving (m2)	70
New connected imp (m2)	470
new indirect imp (m2)	30
Total impervious (m2)	500
Connected impervious per allot (%)	54.20
Total (%)	0.57

Model Setup

The hydrologic parameters of the model were derived from a calibrated model which was developed using EPA SWMM. These parameters include soil infiltration characteristics (using the Horton infiltration model, including minimum and maximum infiltration rate, a decay constant, a maximum infiltration volume and drying time), Manning's coefficient for overland flow over the pervious and impervious part of the basin, depth of depression storage on the pervious and impervious part of the basin, percent of the impervious area with no depression storage, percent of routed runoff, pipe roughness coefficient, surface depression storage and monthly mean evapotranspiration. The values of the model parameters are listed in the Appendix 1 and 2. In the model, all runoff from indirectly connected impervious area was assumed to run over the pervious area before reaching the catchment outlet (drain). Other required information was collected including spatial data (GIS maps, catchment properties, landuse) and climate data (6-minutes precipitation and average monthly evaporation from the BOM gauge at Parafield Airport, 023013).

Water Sensitive Urban Design Measures

Three types of BMPs i.e. rain garden (bioretention), rainwater tank (cistern) and detention tank (bioretention as surrogate) were studied. Rainwater tanks were simulated using the 'cistern' node in SUSTAIN, while rain garden and detention tanks were studied by applying the bioretention node with different properties to suit (Figure 2).

The properties of assumed on site detention tanks (simulated by adapting the bioretention node as a surrogate), rain garden (simulated using the bioretention node) and on site rainwater tanks (simulated using the cistern node) are shown in Appendix 3 to 5.

In the first class of scenarios, each new house was equipped to one cistern and a uniform steady rate for water usage (cistern release) was considered. In this case, the size of the cistern was considered as a model variable while other parameters were pre-specified in SUSTAIN.

In the second class of scenarios, one rain garden was allocated to each new house and the length and width of tanks were considered as evaluation factors.

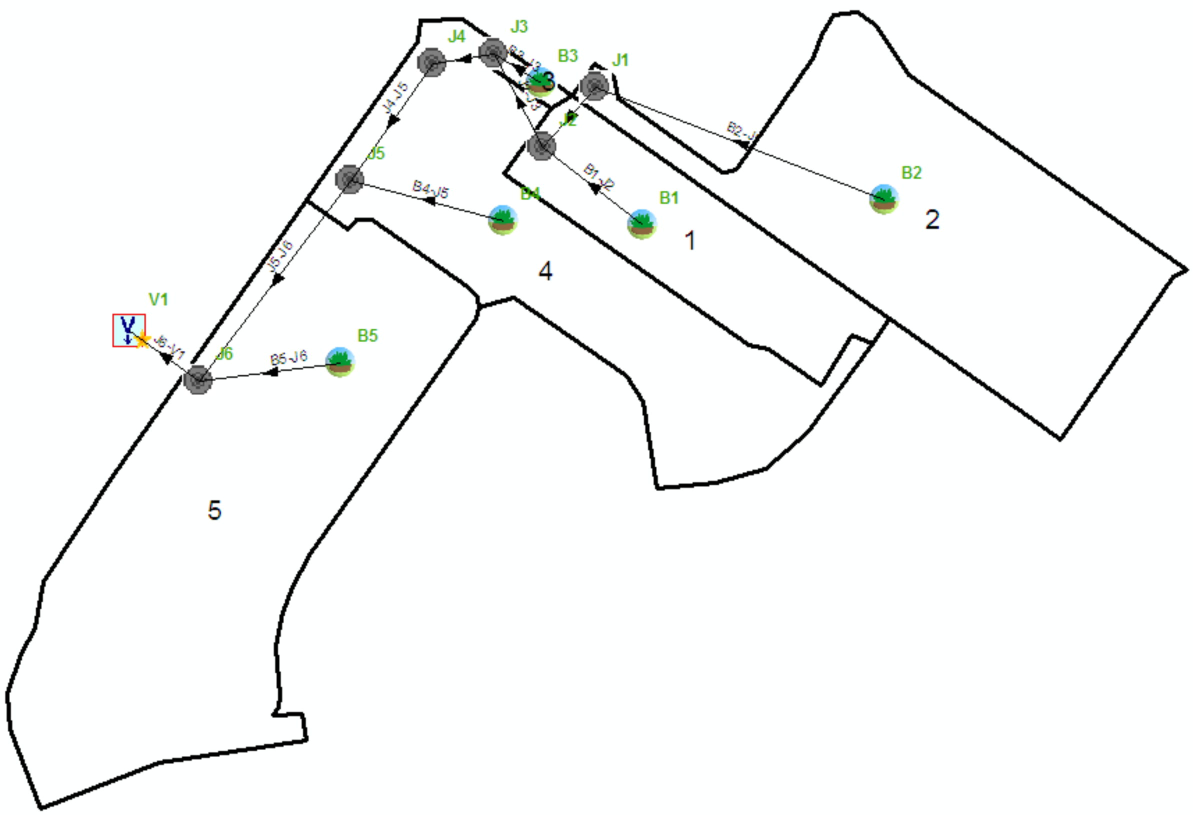

Figure 2. The schematic view of the sub-catchments and BMPs network in the study area

As the last class of scenarios, one detention tank was attributed to each new house and the size of tank (length and width) as well as orifice parameters (diameter and height) were selected as evaluation factors.

The cost of implementation

The assumed cost for rainwater tanks included a fixed cost of AUD$2546 for the purchase of each rainwater tank as well as AUD$3.34 for each cubic foot of tank storage (Marsden and Associates, 2007). Detention tank cost includes AUD$1907 as the fixed cost and AUD$3.34 per square feet of each bioretention system.

The cost of bioretention systems (rain garden and detention tank) was estimated by the following equation (EWATER, 2010):

$$\text{Cost} = 387.4 * \text{A}^{0.7673} \quad (1)$$

Where, A is the plan surface area (m2)

Determination of peak flow with different return interval

The methodology proposed by Ghafouri (1996) was used to estimate the peak flow of runoff from the catchment (Table 5).

Table 5. The estimated peak discharge with different return period in the study area

ARI	1	2	5	10	20
Pre-infill	5.67	7.89	10.84	13.06	15.29
Post-Infill	10.40	13.57	17.77	20.95	24.12

The recorded peak discharge events on 26 March 2004 and 15 January 1997 were selected as 2 and 5 ARI values, respectively, because these values have the closest value to estimated 2 and 5 ARI events in the pre-development flow time series at the end of the catchment. These values were selected to represent the threshold flows for optimization in SUSTAIN. Therefore a period of rainfall was selected for each threshold which included one of these events. This period was selected so as to not include any peak discharge events greater than the defined threshold. Table 6shows the selected 2 and 5 ARI peak discharge as well as their rainfall periods. The period was selected so that the simulation was less than one year to reduce model simulation times.

Table 6. Selected 2 and 5 ARI peak discharge

ARI	2	5
Threshold	5.71	6.8
Date and time of occurrence	26th March 1984, 12:12	15th January 1977, 17:30
Rainfall Period	1st April1983 to 28th March1984	15th January 1976 to 16th January 1977

Figures 3 and 4 show the comparison of pre-infill and post-infill scenarios in terms of 2 and 5 years ARI, respectively.

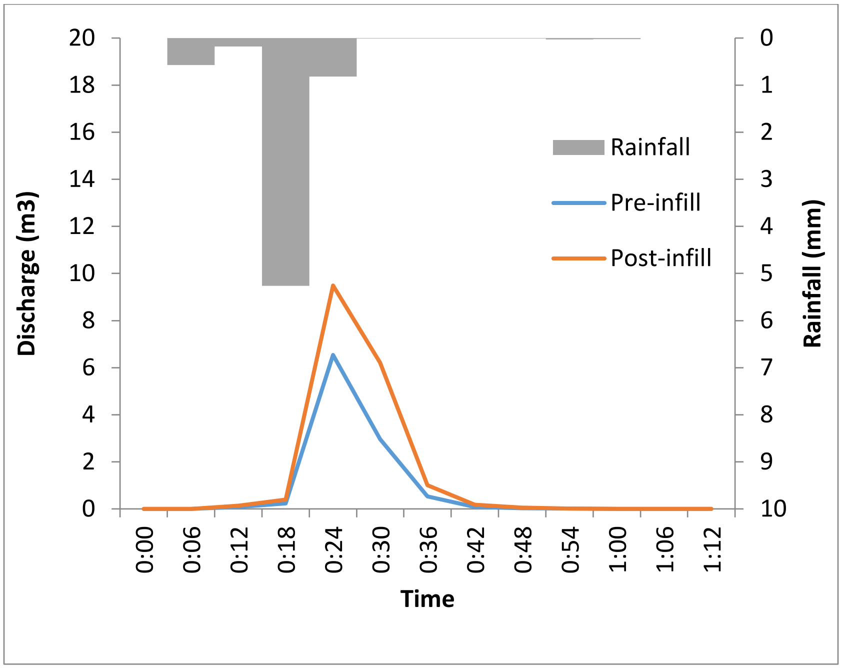

Figure 3. A sub-section of 2- years ARI flow hydrograph (26th March 1984)

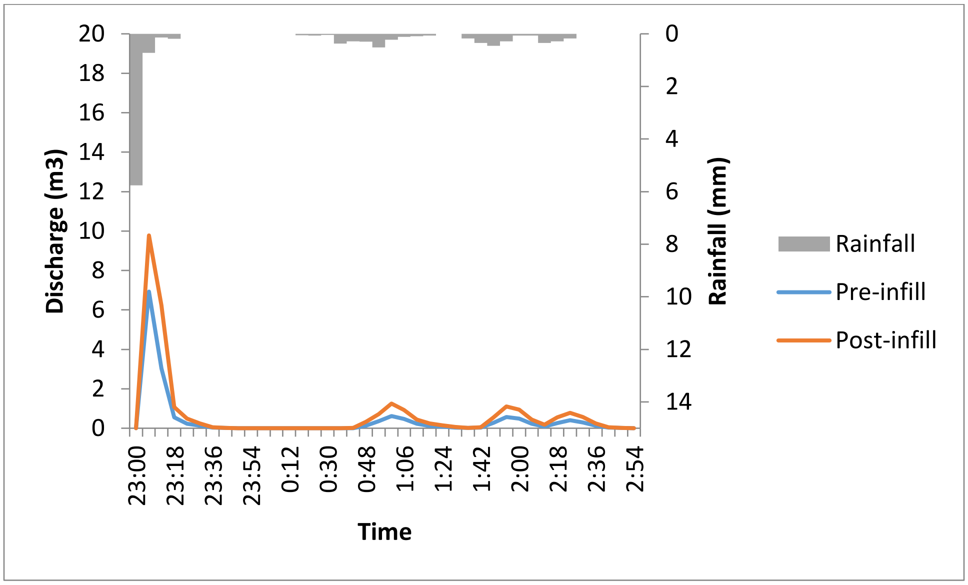

Figure 4. A section of 5- years ARI flow hydrograph (14th January 1977)

Defining scenarios

After designing the study area, defining data layers, placement of BMPs, specifying routing network and setting parameters of each sub catchment and BMPs, SUSTAIN was run for a minimum of six months leading up to the 2 or 5 year ARI event. As the first step, landuse was simulated using the internal simulation option to generate the runoff time series for each sub catchment. Then the assessment process was initiated by defining the assessment point where flow rates are used to measure the effects of WSUD. In this study the outlet of the catchment was selected as the assessment point for all of the scenarios. The assessment process was based on minimizing cost and the evaluation factor was the peak discharge at the assessment point. The peak discharge was set to equal the 2 or 5 Year ARI prior to infill development. The number of near optimal solutions for output was set to 1, and the model was instructed to stop searching when it could not optimize cost more than $2000. Depending on the catchment area, number of sub catchments, the complexity of BMPs network and assessment parameters, several iterations were calculated and compared by SUSTAIN to find the optimum solution. The following sections describe the modeling approach to optimize the placement of rainwater tanks, bioretention systems and detention tanks on redeveloped allotments in the model.

Results and discussion

A bar chart showing the evaluation factor values of four different conditions, i.e. pre-development, post-development, existing and best solutions was generated for each scenar-

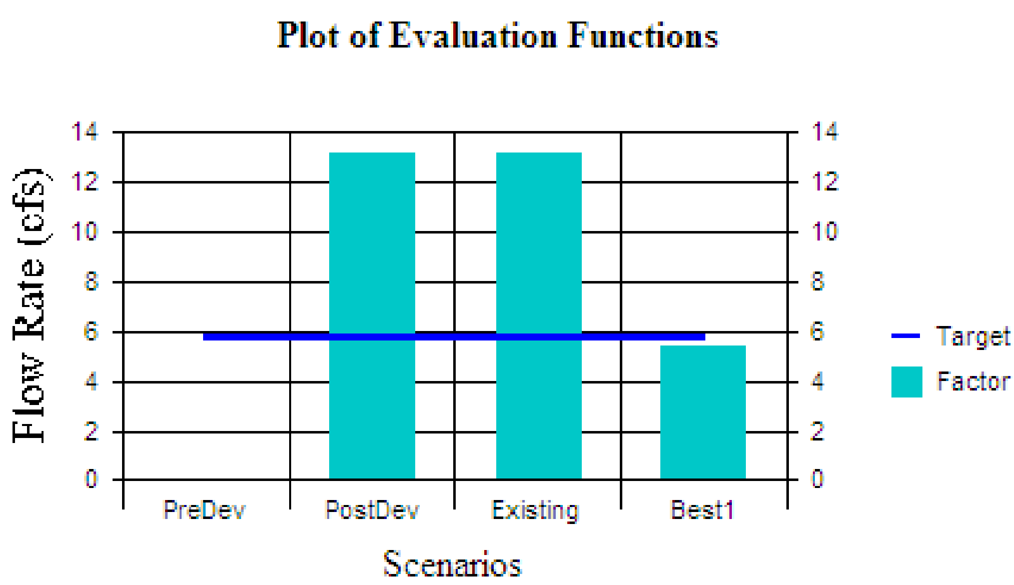

Figure 5. Results of evaluation in different condition

-io. An example of this output is shown in Figure 5 which corresponds to the results of scenario number 44. In this graph, pre-development refers to the condition prior to development; post-development and existing deal with developed condition without and with BMPs, respectively; and the best solutions show (e.g. Best1) shows the optimal solutions determined during the optimization process. Figure 5 shows fully optimized results as the solution Best1 is below the target flow rate. It should be noted that this may not always be possible. The solution Best1 may be above the target value if the WSUD options considered cannot be arranged to achieve the target flow rate (pre-infill development ARI).

To calculate the total volume of runoff intercepted by BMPs in each scenario, the volume of flow water was measured and multiplied by the number of BMPs in each sub catchment.

A total of 15 out of 50 scenarios tend to an optimized solution which can be classified in three groups according to the type of used BMPs. The topology (number and placement) of BMPs in the catchment which caused to a proper solution in both 2 and 5 ARI were studied. This result can help to program for a sustainable water resources management in the region. The effect of different BMPs on flood reduction can be seen in some scenarios (Figures 6 to 8).

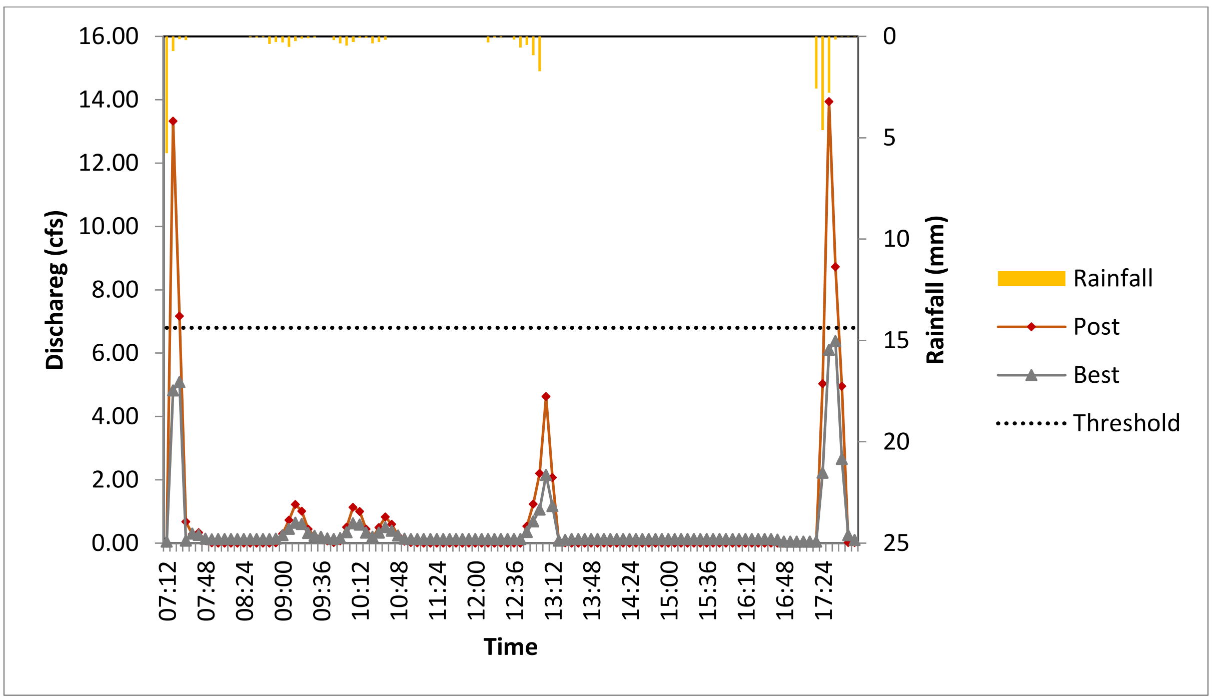

Figure 6. The flow hydrograph of rainwater tanks (cistern) in post development and best solution condition (15.1.1977)

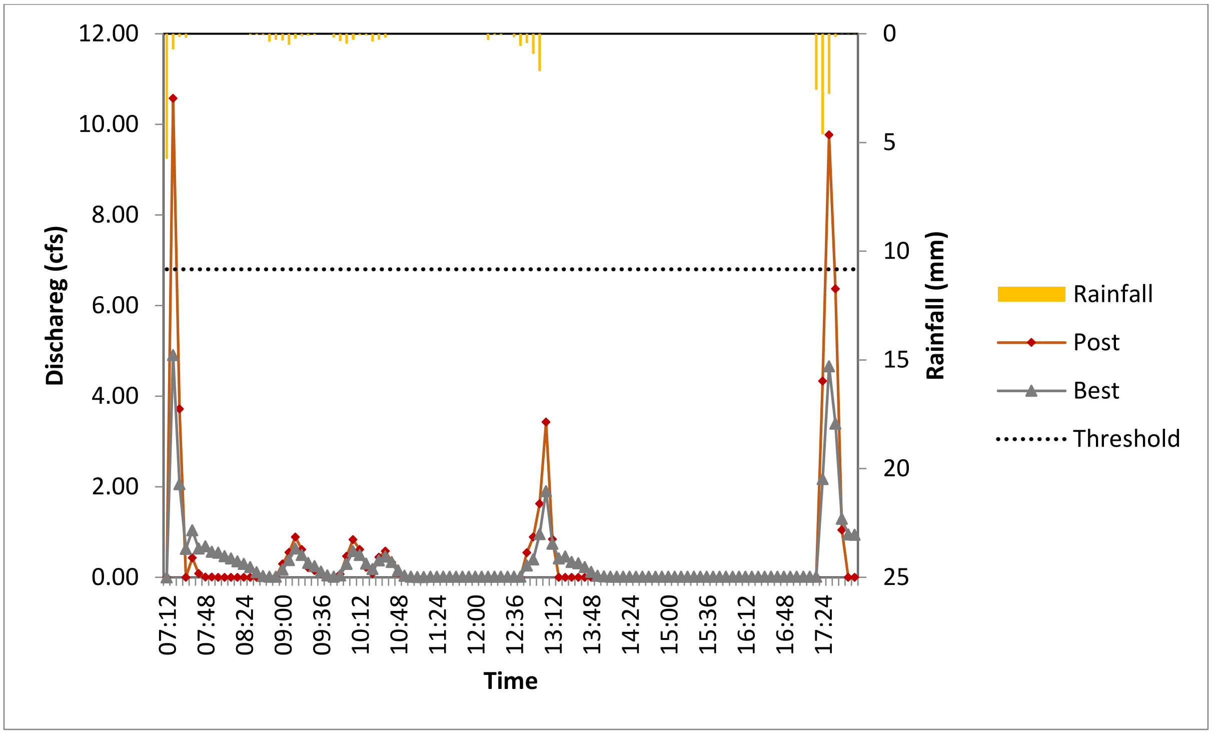

Figure 7. Flow hydrograph of detention tanks in post development and best solution condition (15.1.1977)

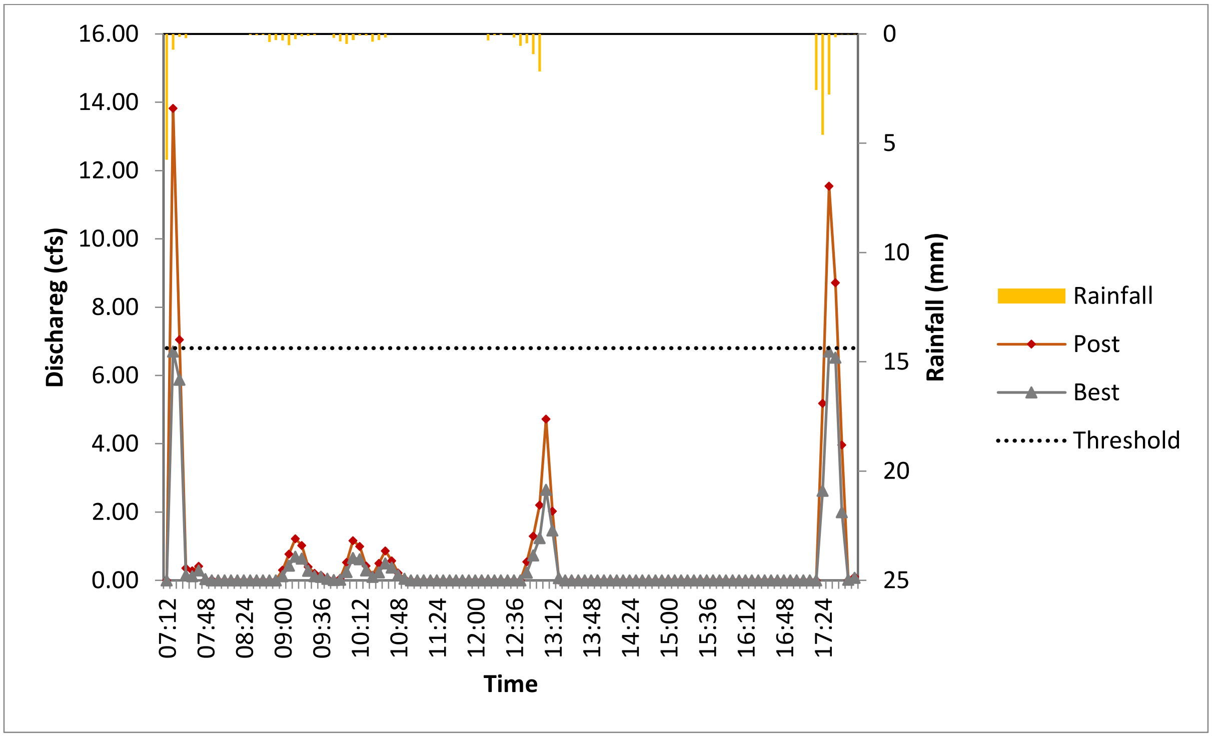

Figure 8. Flow hydrograph of rain garden in post development and best solution condition (15.1.1977)

Conclusion

The US EPA SUSTAIN software tool was used to optimize the placement and design of both a retention and detention scenario in a collection of sub catchments of the Paddocks catchment in Para Hills. SUSTAIN successfully produced results for preserving peak flow rate within the catchment, producing data regarding the least cost solution for the size and placement of retention or detention storages. In the retention scenario, levels of demand (or disposal) greater than 450 L/day of retained water were required to produce an optimum result for the 2 year ARI storm event, and greater than 5000 L/day to preserve the existing peak flow of the 5 year ARI storm event. For detention systems, an orifice 25 mm was successfully used for preserving both the 2 year ARI and 5 year ARI. However, there did not appear to be any clear pattern in the placement of retention or detention tanks, with results varying each time a successful scenario was rerun. Further optimization with multiple outcomes is recommended to produce a pattern of optimal tank arrangement.

It is recommended that further research is undertaken with more urban catchments of smaller and greater size to verify the findings of this research hold true on a broader scale. Also, one reason for the limited effectiveness of the retention and detention systems was the limitations assumed for the contributing impervious area. In this research, the connected impervious area was based on what may reasonably be assumed to be connected to an above ground tank. An underground tank may be a suitable alternative, where higher impervious areas can be connected. Further research is recommended to explore the effectiveness of assumed tank systems in this research with greater connected impervious area.

The current approach to providing acceptable drainage in existing urban catchments where the storm water system is under stress is to design and construct upgraded drainage systems. However, this research demonstrated that a complete catchment retrofit with retention or detention, or even to a limited extent the construction of street scale rain gardens, was effective at maintaining peak flow rates at pre-infill development levels. Based on these outcomes, it is recommended that the economic costs and benefits of retention, detention and rain gardens are assessed with respect to a typical design and upgrade scenario to determine which arrangement provides the most cost effective means of preserving peak flows in catchments subject to infill development.

Further to this, there was little difference between the impact of applying retention or detention for a fixed tank size. This result indicates that the potential peak flow rate and flooding benefits under the conditions simulated in this paper may be discounted when selecting one option in favor of another for a developing catchment. However, these results should be explored on a much larger catchment to investigate the occurrence of any lagging flow issues which were not apparent in the situations examined in this report.

Detention systems with an orifice size between 20 mm to 40 mm were most effective at reducing peak flows. However, this may be expected to vary depending on the size of the catchment. It is recommended that the methodology in this study is repeated for a very large catchment, where the ideal orifice size may differ.

Acknowledgement

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SUSTAINABLE URBAN DRAINAGE (SUD) AND NEW URBAN AGENDA (NUA)

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Abstract

This paper addresses the need to reduce the impact of city development of flooding on residents and in other places, and the worsening of the water quality in streams, rivers and lakes caused by the expansion of cities. The most appropriate current solutions involve Sustainable Urban Drainage Systems (SUDS) but SUDS can only be implemented where good policies, supportive stakeholder groups and partnership working exist in order that these new ideas, which cut across existing methods and practices, will be accepted; moreover it goes on to discuss how the New Urban Agenda (NUA) shall be supporting and addressing these challenges.

Sustainable Urban Drainage Systems require several changes in thinking and practice in city planning and there are many barriers to progress including the perceived costs added to the development itself, and the increased maintenance activities required, in addition to the attractiveness of big infrastructure projects to politicians ;whereas, drainage projects are very often just ‘normal work’. The inertia of planning systems also tends to discourage the good new ideas involved. However, the perceived additional costs need to be set against the costs of losing habitats and fish, food and other ecosystem services which follow, and the damage to properties and the danger to people caused by flooding which frequently results from development. The barriers to more sustainable drainage are high but a whole portfolio of potential ‘Green’ infrastructure solutions are available to be applied to any city in the world. There are no particular problems for high cost, or high value developments since the additional costs of drainage are small and green space is normally an integral element.

However, for most urban developments where money is tight, drainage solutions on a development site are likely to be hard concrete with no financial allocation for maintenance. Consequently, to achieve a more widespread use of sustainable drainage principles, greater integration into Green Infrastructure is necessary, and multiple benefits need to be clear. Otherwise the total operational life costs will not be properly recognized. Major developments and redevelopments give the opportunity for the reallocation of open space to improve its use through multiple functions. Sustainable drainage has the potential to provide habitat improvements which provide places for

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breeding, and to provide connectivity between SUDS and natural areas, in addition to linking directly to zones of natural habitats thus providing more sustainable solutions and greener solutions to drainage problems.

The New Urban Agenda (NUA) aims at enhancing effective urban planning and management, efficiency, and transparency through e-governance, information and communications technologies assisted approaches, and geospatial information management. Further, New Urban Agenda underscores the need to promote adequate investments in accessible and sustainable infrastructure and service provision systems for water, hygiene and sanitation, sewage, solid waste management, urban drainage, reduction of air pollution, and storm water management, in order to improve health and ensure universal and equitable access to safe and affordable drinking water as well as access to adequate and equitable sanitation and hygiene for all; and end open defecation, with special attention to the needs and safety of the fairer sex and those in vulnerable situations. NUA seeks to ensure that this infrastructure is climate resilient and forms part of an integrated urban and territorial development plans, including housing and mobility, among others, and is implemented in a participatory manner, taking into account innovative, resource efficient, accessible, context specific, and culturally-sensitive sustainable solutions.

NUA also recognizes that urban centers worldwide, especially in developing countries, often have characteristics that make them and their inhabitants especially vulnerable to the adverse impacts of climate change and other natural and man-made hazards, including extreme weather events such as flooding, subsidence, storms, including dust and sand storms, heat waves, water scarcity, droughts, water and air pollution, vector borne diseases, and sea level rise that particularly affects coastal areas, delta regions, and small island developing States, among others.

NUA also commits to promote the creation and maintenance of well-connected and well-distributed networks of open, multi-purpose, safe, inclusive, accessible, green, public spaces with high quality to improve the resilience of cities to disasters and climate change, reducing flood and drought risks and heat waves, and improving food security and nutrition,in addition to physical and mental health, household and ambient air quality, noise reduction, and promoting attractive and livable cities and human settlements and urban landscapes, prioritizing the conservation of endemic species.

KEY WORDS: Policies and Planning Systems, Effective urban planning and management, Impacts of climate change and other natural and man-made hazards, quality public spaces to improve the resilience of cities to disasters and climate change.

Introduction

With fast urbanisation there is an urgent need of city development and to reduce the impact of flooding on residents and in other places, and the worsening of the water quality in streams, rivers and lakes caused by the expansion of cities. The best way to reduce surface water drainage charges is to prevent surface water entering the public sewer. Sustainable Urban Drainage Systems (SUDS) provide a natural approach to managing drainage in and around sites. SUDS work by slowing and holding back the run-off from a site, allowing natural processes to break down pollutants. SUDS deal with run-off close to the source, rather than transporting it elsewhere via the public sewer system. Sustainable drainage systems have several benefits which include:

- Slow down surface water run-off from the site to help reduce the chances of flooding
- Reduce the risk of sewer flooding during heavy rain
- Recharge ground water to help prevent drought
- Provide valuable habitats for wildlife for built up areas
- Create green spaces for people in urban areas
- Help reduce surface water drainage charges

Sustainable Urban Drainage Systems (SUDS) are the most appropriate current solutions but SUDS can only be implemented with good policies, supportive stakeholder groups and partnerships so that these new ideas, which cut across existing methods and practices, can be accepted. The New Urban Agenda (NUA) adopted at the HABITAT-III Conference in Quito last October is also supportive to address these challenges.

Sustainable Urban Drainage Systems require several changes in thinking and practice in city planning. There are many barriers to progress including the perceived costs added to development, the increased maintenance activities required, the attractiveness of big infrastructure projects to politicians whereas drainage projects are very often just 'normal work'. The inertia of planning systems also tends to discourage the good new ideas involved. However, the perceived additional costs need to be set against the costs of losing habitats and the fish, food and other ecosystem services which follow, and the damage to properties and danger to people caused by flooding which frequently results from development. The barriers to more sustainable drainage are high but a whole portfolio of potential 'Green' infrastructure solutions are available to be applied in any city in the world. There are no particular problems for high cost, high value developments since the additional costs of drainage are small and green space is normally an integral element.

However, for most urban developments where money is tight, drainage solutions on a development site are likely to be hard concrete with no financial allocation for maintenance. Consequently, to achieve more widespread use of sustainable drainage principles, greater integration into Green Infrastructure is necessary, and multiple benefits need to be clear. Otherwise the whole life costs will not be properly recognised. Major developments and redevelopments give the opportunity for the reallocation of open space to improve its use through multiple functions. Sustainable drainage has the potential to provide habitat improvements which provide places for breeding, give connectivity between SUDS and with natural areas, and, link directly to zones of natural habitats thus providing more sustainable solutions and greener solutions to drainage problems.

Sustainable Urban Drainage Systems (SUDS) in cities and towns are required as part of local development. Use of SUDS contributes towards the city governments' aim of seeking to achieve sustainable development. SUDS are physical structures built to receive surface water run-off and provide a drainage system that:

- Deals with run off as close to source as possible
- Seeks to mimic natural drainage
- Minimises pollution and flood risk resulting from new development; and
- Provides an alternative to conventional drainage systems.

Traditional systems move rainwater as rapidly as possible from where it falls to a point of discharge e.g. watercourse. This causes a number of problems;

- Increased flooding
- Poor water quality as run off can contain a variety of pollutants
- Less infiltration to ground leading to poor groundwater recharge
- Poor biodiversity and amenity of urban watercourse, many of which are hidden underground;

(i) Therefore, using SUDS is most important for sustainable development. All developments must carefully consider appropriate sustainable surface water drainage options. Careful design of drainage systems and/or the provision of treatment facilities prior to discharge will assist in reducing the environmental impact of new development. These range of techniques are known as SUDS. They can be successfully applied to most development and can even be fitted to existing development. As stated above, there are considerable environmental and economic benefits of incorporating SUDS techniques in local development. These include:

(i) Reduced cost by not constructing expensive underground structures
(ii) Reduced cost from simpler maintenance
(iii) Increased amenity and education value
(iv) Improved visual and environmental quality of development and therefore increased economic value
(v) Increased biodiversity
(vi) Reduced pollution
(vii) Recharging of groundwater
(viii) Reduced flood risk

SUDS can be applied to large or small developments due to the variety of techniques available. Use of SUDS on a series of smaller sites can have a significant cumulative effect on minimising harm to water quality and flood risk in an area.

The impact of development on surface water flow and the fact that its disposal is a material planning consideration needs to be acknowledged. All built development tends to extend the area of impermeable ground, from which water runs off rather than percolating into the ground. This can increase both the total and the peak flow from built-up areas, resulting in increased flows downstream and thus increasing the risk of flooding.

There has been growing interest in the use of "soft" sustainable drainage systems to mimic natural drainage. As well as reducing total and peak flows of run-off, these systems can contribute substantially to good design in improving the amenity and wildlife interest of developments, as well as encouraging natural groundwater recharge.

Development should be satisfactorily serviced in terms of water supply, drainage, sewerage, energy supplies. Development which would pose unacceptable risks to the quality and quantity of the water environment both groundwater and surface water, should not be permitted unless suitable mitigation measures are taken to reduce the risk to an acceptable level. Developments which will generate additional foul, combined and/or surface water drainage should only be permitted where arrangements are made for their satisfactory disposal. Positive surface water drainage systems separate from foul drainage systems are required for new development unless it is demonstrated that soak away disposal will be satisfactory under all seasonable conditions.

Cliff stability

The objective of using SUDS is to secure and promote new development. However, there may be areas in close proximity to the cliff top where the use of SUDS may not be appropriate. In such situations, cliff stability must be maintained and it will be more appropriate to use the local piped drainage system to dispose of surface water for new development. The cliff top locations do not preclude the use of measures to recycle water or reduce runoff at source e.g. use of water butts and green roofs (roofs incorporating vegetation).

Policies need to be framed so that proposals for development or redevelopment within certain areas (say 200/500 meters) of cliffs and chines, or in proximity to steep embankments, will incorporate the measures necessary to demonstrate that such development will have no adverse effect upon existing cliffs, chines or steep embankments. Proposals for major developments in these areas may be required to submit a development impact assessment to show the proposal will have no adverse effect on land stability. Developers also need to be advised that they will be required to comply with the requirements of Planning Policy

Nearly one-half of cities are in locations susceptible to flooding. Assessment of the 136 largest world coastal cities, predicts costs resulting from flood events triggered by climate change may exceed USD1 trillion a year.

Building Regulations

Incorporation of SUDS should be reinforced as part of the development process by changes to Building Regulations. Such regulations may stipulate that, in order of priority, rainwater run-off should discharge into one of the following:

a) an adequate soakaway or some other adequate infiltration system; or where that is not reasonably practicable;
b) a watercourse; or where that is not reasonably practicable;
c) a sewer

Methods of Sustainable Urban Drainage Systems

Permeable surfaces and filter drains

Filter drains and permeable surfaces are devices that have a volume of permeable material below ground to store surface water. Run-off flows to this storage area via a permeable surface. Examples of this are: grass, reinforced grass; gravelled areas, solid paving blocks with large vertical holes filled with soil or gravel, solid paving blocks with gaps between the individual units, porous paving blocks with a system of void within the units, continuous surfaces with inbuilt system of cavities. Car park drainage does not have to go to sewer. Infiltration is where surface water is directed via cavities within areas of solid paving. With a porous surface, water is drained directly through the surface.

Permeable surfacing encourages surface water to permeate into the ground. Materials such as porous concrete blocks, crushed stone/gravel or porous asphalt can be used. Depending on the ground conditions, the water may infiltrate directly into the subsoil, or be stored in an underground reservoir (e.g. a crushed stone layer) before slowly soaking into the ground. If necessary, an overflow can keep the pavement free of water in all conditions. Pollutant removal occurs either within the surfacing material itself, or by the filtering action of the reservoir or subsoil.

Infiltration Devices

Infiltration devices drain water directly into the ground. They may be used at source or the run-off can be conveyed in a pipe or swale to the infiltration area. They include soakaways, infiltration trenches and infiltration basins as well as swales, filter drains and ponds. Infiltration devices can be integrated into and form part of landscaped areas. Soakaways and infiltration trenches are completely below ground, so water should not appear on the surface. Infiltration basins and swales for infiltration store water on the ground surface, but are dry except in periods of heavy rainfall.

- **Soakaway** is an underground chamber lined with a porous membrane and used to store surface water, and then allow its gradual infiltration into the surrounding soil. Although soakaways have been traditionally used in more remote locations away from public sewers or where sewers have reached capacity, they may be used as an alternative to connection to the piped system. They are used to dispose of storm water and are typically circular pits with a honeycomb arrangement of bricks to allow water to permeate through them into the ground.
- Gravel drive is an example of permeable surfacing encouraging surface water to permeate into the ground.

- Swales and Basins are dry channels or ditches and basins are dry "ponds". Both can vary in size. They can be created as features within the landscaped areas of the site, or they can be incorporated into ornamental, amenity and screen planted areas where they would be maintained as part of a normal maintenance contract. They provide temporary storage for storm water, reduce peak flows to receiving waters, facilitate the filtration of pollutants and microbial decomposition as well as facilitating water infiltration directly into the ground. Swales and basins are often installed as part of a drainage network connecting to a pond or wetland prior to discharge to a natural watercourse. They may be installed alongside roads to replace conventional kerbs, therefore saving construction and maintenance costs.
- Infiltration trenches and filter drains: Infiltration trenches are stone filled reservoirs to which stormwater runoff is diverted and from which the water gradually infiltrates into the ground. Filter strips, gullies or sump pits can be incorporated at inflow points to remove excess solids. This lengthens the life of the trench.
- Filter Strips: An area of gentle sloping, vegetated land through which surface water run-off is directed. Filter drains are similar to infiltration trenches but have a perforated pipe running through them. They are widely used by highway authorities for draining roads and help to slow down runoff water on route towards the receiving watercourse. They allow storage, filtering and filtration of water before the discharge point. Pollutant removal is by absorption, filtering and microbial decomposition in the surrounding soil.

Basins and Ponds - how they work

Basins are areas for storage of surface run-off that are free from water during dry weather conditions. These structures include: flood plains, detention basins, extended detention basins, Ponds contain water in dry weather and are designed to hold more when it rains. They include:

- Balancing and attenuation ponds
- Flood storage reservoirs
- Lagoons
- Retention ponds
- Wetlands

Basins and ponds store water at the ground surface, either as temporary flooding of dry basins and flood plains, or permanent ponds. These structures can be designed to manage water quantity and quality.

Ponds and Wetlands can be particularly beneficial during time of storm due to their capacity to hold large amounts of water and therefore reduce flood risk. They are most widely used on larger sites. Ponds and wetlands also help with grit removal. Algae and plants in wetlands can significantly assist with filtering and nutrient removal. The ponds and wetlands can be fed by swales, filter drains or piped systems. Use of inlet/outlet sumps assist in reducing sedimentation and reeds planted at these points will cleanse water as it enters and leaves the pond.

Choosing the right SUDS

Of the various methods, large ponds and wetlands are generally more appropriate for larger sites in excess of 5ha. Infiltration trenches, swales and porous pavements are suitable for both large and small sites. Many large sites may incorporate a mix of different mechanisms.

The choice of SUDS depends on a number of factors:

- The pollutants present in runoff (in part dependent on type of development)
- The size of and drainage strategy for the catchment area
- The hydrology of the area and infiltration rate of the soil

Large sites may incorporate a mix of different techniques. SUDS can be incorporated into areas where there is clay subsoil or there is a fairly steep gradient. Soil permeability can have a significant effect on the selection of SUDS techniques. Infiltration techniques for example may not be effective if the infiltration rate is below 10mm/hr for the upper soil layers. Swales and ponds, working by a combination of filtration and infiltration, are more tolerant of poor soils. In highly permeable soils wet ponds need to be lined.

SUDS and Planning

It is important that developers establish the soil conditions and hydrology of the site (storm water run-off, water table height, water quality) and consider appropriate SUDS at an early stage in the site evaluation and design process. This will ensure that the best drainage solution for a particular site is found and incorporated into the layout, development costs and timetable for implementation. SUDS should be incorporated into the detailed project reports (DPRs) of development proposals with detailed design. The adoption and future maintenance of SUDS should also be incorporated at the design stage.

It would be appropriate to link SUDS on new development sites to existing green space and amenity areas. Planning conditions or legal agreements should be used to secure implementation of SUDS where appropriate.

New Urban Agenda (NUA)

At the Habitat-III Conference in Quito in October 2016, New Urban Agenda (NUA) was adopted which aims at enhancing effective urban planning and management, efficiency, and transparency through e-governance, information and communications technologies assisted approaches, and geospatial information management. Further, New Urban Agenda underscores the need to promote adequate investments in accessible and sustainable infrastructure and service provision systems for water, hygiene and sanitation, sewage, solid waste management, urban drainage, reduction of air pollution, and storm water management, in order to improve health and ensure universal and equitable access to safe and affordable drinking water for all; as well as access to adequate and equitable sanitation and hygiene for all; and end open defecation, with special attention to the needs and safety of women and girls and those in vulnerable situations. NUA seeks to ensure that this infrastructure is climate resilient and forms part of integrated urban and territorial development plans, including housing and mobility, among others, and is implemented in a participatory manner, considering innovative, resource efficient, accessible, context specific, and culturally-sensitive sustainable solutions.

NUA also recognizes that urban centers worldwide, especially in developing countries, often have characteristics that make them and their inhabitants especially vulnerable to the adverse impacts of climate change and other natural and man-made hazards, including extreme weather events such as flooding, subsidence, storms, including dust and sand storms, heat waves, water scarcity, droughts, water and air pollution, vector borne diseases, and sea level rise particularly affecting coastal areas, delta regions, and small island developing States, among others.

NUA also commits to promote the creation and maintenance of well-connected and well-distributed networks of open, multi-purpose, safe, inclusive, accessible, green, and quality public spaces to improve the resilience of cities to disasters and climate change, reducing flood and drought risks and heat waves, and improving food security and nutrition, physical and mental health, household and ambient air quality, reducing noise, and promoting attractive and livable cities and human settlements and urban landscapes, prioritizing the conservation of endemic species.

SUDS should be part of local economic development strategies which also coordinate land use, infrastructure and investment planning. Financing and investment planning are also important driving concerns. Coordinated decisions about land use are essential. Urban Local Bodies (ULBs) should identify set of policies that will allow cities and their surrounding regions to reap the benefits of economies of urbanisation and localisation, attract and leverage private investments while minimising risk hazards. New Urban Agenda also underscores the need for urban planning, rules and regulations together with sound financial planning. To be successful, SUDS has to be an integral part of the local and regional urban planning and strong building bye-laws.

Conclusions

Available evidence indicates that in low and middle income countries, urban drainage sector is among few other sectors including sanitation and solid waste management that has made little progress in addressing the need for institutional reform and financial sustainability. New approaches are needed in urban drainage sector in delivering services to the informal settlements.

The whole life costs of the systems of drainage infrastructure can be correlated to the pattern of urbanization, with compact cities providing the most cost-effective solutions to drainage infrastructure investments.

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TRENCHLESS TECHNOLOGY FOR EXECUTION OF DRAINAGE SYSTEM FOR TA PROHM TEMPLE COMPLEX, SIEM REAP, CAMBODIA

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Abstract

Built in 1186 in Siem Reap (Cambodia) and originally known as Rajavihara (Monastery of the King), Ta Prohm was a hindu temple dedicated to the mother of Jayavarman VII. Ta Prohm is a temple of towers, closed courtyards and narrow corridors. Many of the corridors are impassable, clogged with jumbled piles of delicately carved stone blocks dislodged by the roots of long-decayed trees. Bas-reliefs on bulging walls are carpeted with lichen, moss and creeping plants, and shrubs sprout from the roofs of monumental porches. Trees, hundreds of years old, tower overhead, their leaves filtering the sunlight and casting a greenish pall over the whole scene.

The temple has deliberately been left in a state of un-repair; for the tourist to experience "the harmony between man and nature". The decay of the structure partly due to the entwining forestation and partly due to its frequent inundation by rains has resulted in deterioration of many of its walls, floors and the roof.

The whole of the Angkor heritage area had been under study and research for a long time, particularly with regard to the problem of water management and preservation of heritage and its environment. These problem were urgent and unusual mainly because of its essential characteristics of harmony between nature with man had to be retained.

During the rainy season, the water level in the moat closer to the North Eastern side, is higher by about 1 m, than the level in the other moat. Also the rain-water accumulated within the temple complex doesn't get drained and remains standing for 3 to 4 days. The temple complex experiences standing water up to 1m and at times up to floor level within most of the structures which affects tourism during the monsoon season.

To solve the problem of water logging in the enclosures of the temple, the Archaeological Survey of India (ASI) entrusted WAPCOS Ltd., a Government of India Undertaking under the Ministry of Water Resources, River Development and Ganga Rejuvenation to prepare and execute a drainage plan. Due to the fact that the Temple complex is a world heritage site, it was a difficult task to implement the drainage system in an open form. Therefore, a Trenchless method was used to prepare an underground drainage system.

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For the preparation of the Implementation plan, Ground Penetration Radar (GPR) survey was carried out in the Temple complex to determine the actual location, depth and spreading of the tree roots. The laying of pipe lines was decided to be carried out at a lower depth than that of the tree roots to avoid any damage. The findings of the GPR Survey ensured that the Drainage pipe lines could be laid below 2m depths safely without harming the Tree roots.

The execution of the drainage system started in March, 2014 and was completed in March 2015. The drainage system comprises 16 main lines, connecting sinks to chambers and chambers to the Inner Moat, laid by using Trenchless Technology. The Drainage System also envisages 8 mainlines from the Inner Moat to the Outer Moat. The complete network comprises 25 Sinks, 11 Sink cum collection chambers and 1 chamber located in Enclosures II & III.

This drainage system, a unique in its own kind, the first ever implemented at Angkor World Heritage Area and successfully completed within the scheduled time frame. During the execution Year 2014-2015 the work was inspected twice by the Experts of ICC- ANGKOR (International Coordinating Committee for the Safeguarding and Development of the Historic Site of Angkor). The experts of ICC-ANGKOR from France, Japan and Kingdom of Cambodia appreciated the technology adopted by WAPCOS and the way it has been implemented on site. The work was also visited by Higher Dignitaries of Royal Government of Cambodia and India and other prominent persons from India and has been well appreciated.

KEY WORDS: Entwining forestation, Water logging, Ground penetration radar (gpr), Cambodia

Introduction

Siem Reap, which literally means the "Defeat of Siam", referring to the victory of the Khmer Empire over the army of the Thai Kingdom in the 17th century was the most prosperous region of contemporary Cambodia. Its close proximity to the Angkor Wat Temple Complex (Figure 1) has turned the city into one of the world's premier tourist destinations. More than two million tourists visit Siem Reap every year to explore over a thousand years of Khmer heritage built near Tonle Sap Lake.

Figure 1: Angkor Wat, Siem Reap, Cambodia

The primary attraction for visitors to Siem Reap is the Angkor Wat Temple Complex, a UN Heritage Site which has hundreds of structures from the 9th to the 14th century which include partially renovated temples, pagodas, imperial residences and recently discovered ruins which are virtually untouched for the last 500 years.

Siem Reap also has the 12th Century Ta Prohm Temple (Figure 2) which has numerous towers, closed courtyards and narrow corridors. Many of the corridors are impassable, clogged with jumbled piles of delicately carved stone blocks dislodged by the roots of long-decayed trees.

Figure 2: Ta Prohm Temple, Siem Reap

Drainage problem in temple complex

The temple has deliberately been left in a state of un-repair for the tourist to experience "the harmony between man and nature". The decay of the structure is partly due to the entwining forestation and partly due to its frequent inundation during rains.

The tree roots have found their way through spaces between blocks of sandstone and laterite thereby causing instability to various parts of the temple structure in general but have also supported them at places. The dislodged stones are strewn all around, thereby blocking not only the passage but also the drainage path of water into the tanks and moats.

The original layout of the temple and the drainage system was not traceable because of collapsed structure, growth of trees and their root system. The whole of the Angkor heritage area had been under study and research for a long time, particularly with regard to the problem of long periods of flooding during rains and preservation of heritage and its environment. These problems were unusual and challenging mainly because the essential characteristics of the temple complex and its harmony with nature that had to be retained. The only viable solution was to construct a sub-surface drainage system without in any way disturbing the foundation of structures and the complex network of roots.

Drainage Scenario in Ta Prohm Temple Complex- Before implementation of Drainage Plan

During the rainy season, the rain-water falling within the temple complex did not get drained and kept standing for 3 to 4 days (Figure 3). The temple complex experienced inundation up to 1m and at times up to floor level of the structures, which adversely affected the tourism during the monsoon season.

Figure 3: Water Stagnation between Third & Second enclosure

Drainage implementation plan

i) Challenges in Preparation of Drainage System

In order to address the problem of water logging in the temple complex, the Archaeological Survey of India (ASI) entrusted WAPCOS Ltd., a Government of India Undertaking under the Ministry of Water Resource, River Development and Ganga Rejuvenation the assignment to prepare and execute a drainage implementation plan. Following were the Challenges in the planning and implementation of the drainage system:

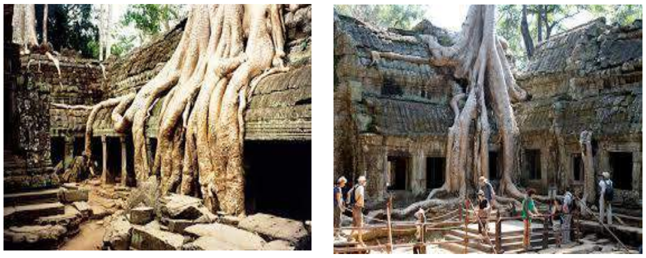

Figure 4: Roots of long-decayed trees

- **No collateral damage to any structure,** however dilapidated and unstable, was acceptable at any stage of the project. Even the collapsed parts of structure, strewn all over the place were not to be disturbed or relocated. Utmost care was to be taken not to damage any part of the root network (Figure 4) proving support to the structure above. This required extensive and precise sub-surface mapping with non-invasive state-of-the-art techniques.
- **Conservation of World Heritage Site:** The temple being a renowned world heritage site, any major or minor construction activity requires proper care and supervision as per safety norms of ICC-ANGKOR (International Coordinating Committee for the Safeguarding and Development of the Historic Site of Angkor). This organization also monitors the restoration activities of all the Historical Temples in the Angkor world heritage area.
- **Small Passages and Narrow Gates of Temple:** The narrow passage inside the temple prevented entry and movement of large sized machines/drilling rigs. Due to narrow gates/doors in most of the Enclosure in locations II & III, the machines/equipment/drilling rigs had to be moved in dismantled condition and reassembled. Drilling techniques and

placement of pipes were suitably improvised without compromising on ICC-ANGKOR norms and planned objectives.

ii) Surveys/Studies/Technology involved in Planning of Drainage System

For the preparation of Implementation plan, Ground Penetration Radar (GPR) survey was carried out in the Temple complex to determine the actual location, depth and spreading of the tree roots. The laying of pipe lines was decided at depth lower than those of the tree roots to avoid any damage. GPR surveys were conducted by moving the antennae along the planned drainage lines on the ground (Figure 5). These survey lines were selected in such a way that the entire area was represented. Through the GPR survey, it was recorded that 98% of the tree roots were located within a depth of 1m from the ground surface. No roots deeper than 2m were found. The findings of GPR Survey ensured that the Drainage pipe lines could be laid below 2m depths safely without harming the tree roots. The Geotechnical studies were also done to access the soil profile. Trial Pits (1mx1mx1m) results were used for confirmation of the soil strata. The analysis revealed that the strata essentially constituted silty sand at the surface with a layer of silty sand clay beyond 1.6m to 2m from the ground level. No hard strata were available at a shallow depth and the surface soil did not have any swelling character. The pipe line slope and depth were planned to avoid any damage to foundation and tree roots.

Figure 5: GPR Survey in the Temple Complex

Detailed Topographical survey and hydrological studies were carried out for planning and design of alignment of drainage lines and size and slope of drainage pipes.

iii) Trenchless Technology for Execution of Drainage Implementation Plan:

Drainage lines were so selected that there would be minimum interference with the critical areas of the Temple walls and Gopuras. Trenchless Technology using the Horizontal Auger Boring (HAB) method was adopted for implementation of sub-surface drainage system.

Trenchless technology is a type of subsurface construction work that requires few trenches or no continuous trenches (Figure 6). Trenchless construction includes construction methods such as Tunneling, Micro-tunneling Method (MTM), Horizontal Directional Drilling (HDD), Pipe Ramming (PR), Pipe Jacking (PJ), Horizontal Auger Boring (HAB) and other methods for the installation of pipelines and cables below the ground with minimal excavation.

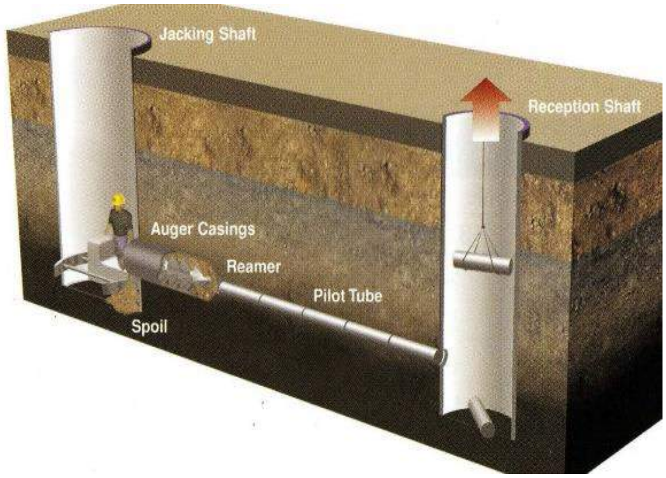

Figure 6: Trenchless Technology for Execution of Drainage

Following are some of the Trenchless techniques for different soil types.

Method	Soil Type	Remarks
Pipe Jacking	All soil types	Exception of non-displaceable hard soil and rock
Micro tunnelling (MTM)	All soil types	Very fast and reliable system
Impact Moling	Soft clays and silts	Minimum disruption
Auger Boring	Soils with sufficient stand-up time	Suitable for shallower depths
Thrust Boring	All soil types	No limitation, As to what can be achieved

Since the entire sub-surface drainage network was within 3 to 5 m below ground level, Horizontal Auger Boring Machines were used.

Execution of drainage system

The execution of drainage system started in March, 2014 and was completed in March, 2015.
The drainage system (Figure 7) comprised of 16 main lines, connecting links from chambers and from chambers to Inner Moat, laid by Trenchless Technology. The Drainage System also included 8 mainlines from Inner Moat to Outer Moat. The complete network comprised of 25 Sinks, 11 Sink cum collection chambers and 1 chamber.

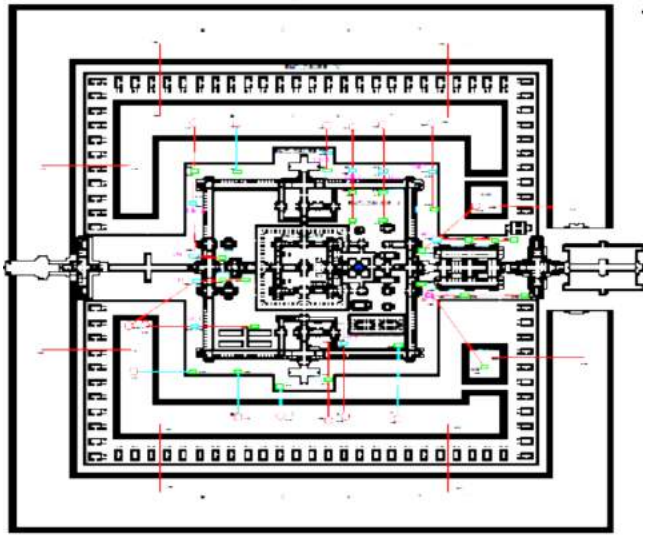

Figure 7: Drainage Plan

The Drainage Plan consisted of following main components:

- **Construction of Sinks:** Sinks were provided at the selected low-lying areas inside the temple enclosures. These were designed to collect the surface water and feed it to the network of pipes. Geo-textile filters were fixed on the top of sink, to trap silt from the surface runoff. Mechanism for periodical removal of silt has been suggested. The depths of sinks have been planned in a way to avoid damage to the tree's roots and foundation of structures. Pit for sinks were excavated for 2mx2m size. The sinks were modified into a size of 600mm x 600mm from 300mm x 300mm size to facilitate the machine to drill in the ground.

Figure 8: Fixation and Monitoring of Pipeline Levels

- **Construction of Chambers:** Collection chambers provided in Enclosures were connected to the sinks by 300 mm MS Pipes. These chambers are designed to collect the water from sink through the pipelines and also from the ground surfaces and finally drain it out into the inner moats. Pit for chambers were excavated for 2mx2m size. The chambers were modified into sink cum collection chamber by provision of silt trap. This helped to drain out the water of surrounding area of Chamber.

- **Pipe line Installation by Trenchless Technology:** A total of 1050.60m of MS pipe network was laid below the ground to drain off the Storm Water. Inner moat and outer moat were connected with 300 mm dia. MS pipes. One HAB machine was brought from India for work execution inside the temple and HDD machine was used for the Moat connections. Pipes were used in 800 mm segments and pushed into the drilled hole by HAB machine. These M.S. pipes were coated with epoxy on their outer surface and plastic paint on inner surfaces to prevent corrosion. The alignment of lines beneath the Ground Surface was fixed by Total Station, and continuous monitoring was done to ensure maintenance of levels (Figure 8).

- **Construction sequence for Trenchless Process (Figure 9)**

  The laying of drainage lines was completed in following steps:

  1. Excavation of pit
  2. Placement of HAB Machine into the pit up to required level
  3. Pilot bore drilling at a required level
  4. Removal of soil with Helical Shaped Augers (enlargement of Hole)
  5. Pipe Insertion into the drilled hole by machine
  6. Construction of Sink and Chambers
  7. Installation of Silt Traps and Covers

(Figure 9: Construction Workflow)

- **Instrumentation for Monitoring and Control of Drilling**

Following instruments were used and installed to monitor & control the drilling and behavior of surrounding structures during the work execution:

- **Directional Probe and Magnetic Field Locator with monitor**: This device was used to control the movement of the pilot inside the ground (Figure 10). The device can sense changes in soil profile and even a small stone and suitably change the direction and slope of the pilot tool. With the help of the locator, the errors in desired slope and depth were minimized and kept within permissible limits.

- **Ground Settlement Points**: Ground settlement point were used for monitoring of vertical settlement on the surface and soil mass.
- **Building Settlement Points:** Building settlement points were used to monitor the vertical settlement of structure due to nearby excavation & activities.
- **Crack Marker:** Crack markers were used to monitor the crack in vertical wall or structure due to excavation and pipe laying operations. To avoid nailing on the temple walls, sticker type crack marker was used.
- **Testing**: During execution of drainage system, random water testing of pipe lines was carried out to ensure tightness of pipe joints. Concrete cubes were also cast for each sink and chamber and got tested in recognized labs in Siem Reap.

Figure 10: Detection of Drilling tool path by Directional Probe & Magnetic Field Locator

Project completion and recognition by clients

This drainage system, a unique in its own kind was the first to be ever implemented successfully in Angkor World Heritage Area. The project was completed within the scheduled time frame. During the execution Year 2014-2015 the work was inspected twice by the Experts of ICC-ANGKOR (International Coordinating Committee for the Safeguarding and Development of the Historic Site of Angkor). The experts of ICC-ANGKOR from France, Japan and Kingdom of Cambodia appreciated the technology adopted by WAPCOS and the way it has been implemented. The work was also visited by Higher Dignitaries of Royal Government of Cambodia and India and various Experts from India and was well appreciated (Figure 11).

Figure 11: Temple Site Visit by High level Dignitaries of the Government of India, ICC-Angkor and other prominent personalities from India

References

Drainage Implementation Plan (2008), Ta Prohm Temple Complex, Siem Reap Cambodia by WAPCOS Limited

Project Completion Report (2015), Ta Prohm Temple Complex, Siem Reap Cambodia by WAPCOS Limited

Ta Prohm Temple- A Conservation Strategy by Archaeological Survey of India

APPLICATION OF HYDRUS-2D FOR PREDICTING THE INFLUENCE OF SUBSURFACE DRAINAGE ON SOIL WATER DYNAMICS IN A RAINFED-CANOLA CROPPING SYSTEM

Fatemeh Karandish[1,*], Abdullah Darzi-Naftchali[2], Jiří Šimůnek[3]

Abstract

Although subsurface drainage systems in paddy fields provide a suitable condition for winter cropping by combatting the waterlogging and ponding problems, they may alter the natural soil water dynamics. The cost and time involved in frequent field observations pertaining to quantification of such alterations lead to the use of simulation models, which are more plausible approaches. Therefore, in this research, the HYDRUS-2D model was applied to investigate the probable effects of different subsurface drainage systems on the soil water dynamics under rainfed-canola cropping system in paddy fields. Field experiments were conducted during two rainfed-canola growing seasons at the subsurface- drained paddy fields of the Sari Agricultural Sciences and Natural Resources University, Mazandaran province, northern Iran. A drainage pilot consisting subsurface drainage with different drain depths and spacings was designed. Canola was cultivated as the second crop after rice harvest. Measurements of water table depth and drain discharge were made during the growing seasons. The performance of HYDRUS2D model during calibration and validation phases was evaluated using the model efficiency (EF), root mean square error (RMSE), normalized root mean square error (NRMSE), and mean bios error (MBE) measures. Based on the criteria indices (MBE=0.01-0.17 cm, RMSE=0.05-1.02 and EF=0.84-0.96 for drainage fluxes, and MBE=0.01-0.63, RMSE=0.34-5.54 and EF=0.89-0.99 for water table depths), the model was capable enough for predicting drainage fluxes as well as the other soil water balance components. The simulation results demonstrated that water table management can be an effective strategy to sustain shallow aquifers in the subsurface- drained paddy fields during winter cropping.

KEY WORDS: HYDRUS-2D, Drainage flux, Dynamic simulation, Paddy field, Water table.

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Introduction

Subsurface drainage in poorly drained paddy fields of the Northern Iran provides suitable conditions for growing winter crops, mainly by improving soil conditions by lowering the water table below the rooting zone, creating a deeper aerobic zone, enabling faster soil drying, and improving the root zone soil conditions (Jafari-Talukolaee et al., 2016). Improved crop productivity may readily justify the installation costs of subsurface drainage systems and provide suitable conditions for the adaptation of such technology by local farmers. Although subsurface drainage provides suitable conditions for winter cropping by combating the waterlogging problem, it also alters the soil water dynamics. Therefore, further research is required to analyze such effects under different drainage systems.

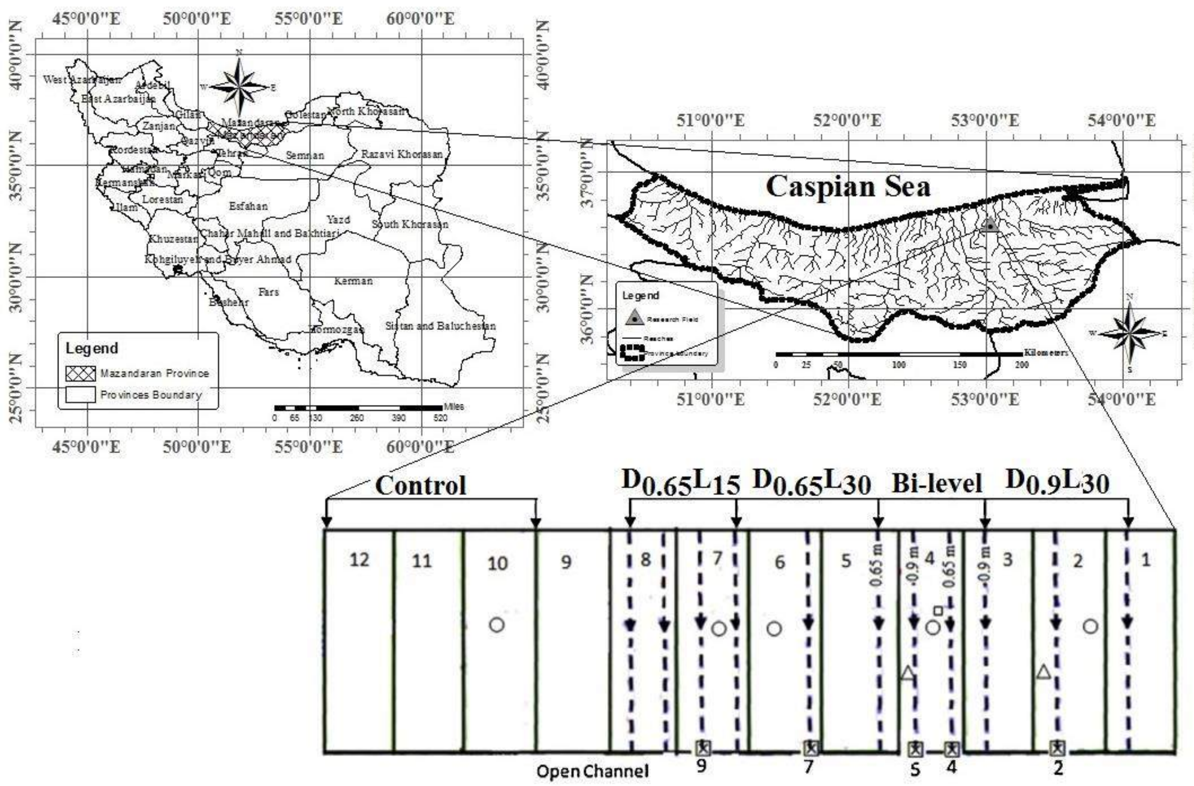
Field investigations for assessing long-term consequences of different subsurface drainage systems are usually restricted by high costs. However, some general knowledge is required in the planning and optimizing stages of drainage projects prior to their implementation at the large scale. Simulation models, which are effective tools for capturing soil-water-crop interactions, have been developed during the past decades (Wagenet and Hutson, 1987; Wessolek, 1989; Vanclooster et al., 1996; van Dam et al., 1997; Fernández et al., 2002; Cameira et al., 2003; Panigrahi and Panda, 2003; Neitsch et al., 2005; Nishat et al., 2007). Among different models, HYDRUS-2D (Šimůnek et al., 2008, 2016) is one of the most widely-used dynamic, physically-based models to simulate soil water dynamics (e.g., Cote et al., 2003; Skaggs et al., 2004; Ajdari et al., 2007; Rahil et al., 2007; Crevoisier., 2008; Lazarovitch et al., 2009; Siyal and Skaggs, 2009; Mubarak et al., 2009; Ramos et al., 2012; Tafteh and Sepaskhah, 2012, Karandish and Šimůnek, 2016ab). One of the advantages of this model is that its input parameters are closely related to soil physical properties, which could be measured either in-situ or in the lab (Karandish and Šimůnek, 2016b). Moreover, since the input parameters of HYDRUS-2D are directly related to soil, crop, and climate properties, the model often provides superior predictions than simpler soil water balance models.

Several earlier studies applied HYDRUS-2D for predicting soil-water-crop interactions in the paddy fields (Janssen and Lennartz, 2009; Garg et al., 2009; Tan et al., 2014; Li et al., 2014 and 2015). The results of these studies generally emphasized the high capability of this model to simulate water and nutrient fluxes at the field scale. However, no research has been yet conducted on the applicability of the HYDRUS-2D model to analyze the effects of drainage systems on soil water dynamics during winter cropping in poorly drained paddy fields. Therefore, this research was designed to evaluate the capability of the HYDRUS-2D model to predict daily fluctuations of drainage fluxes and water table depths during second cropping on subsurface-drained paddy fields.

Materials and methods

Field trial

A field study was conducted during two rainfed canola growing seasons (2011-12 and 2015-16) at the 4.5 ha consolidated paddy field at the Sari Agricultural Sciences and Natural Resources University in the Mazandaran province of northern Iran (Figure 1). The area is located in the coastal zone of the eastern part of the Caspian Sea. The climate of the region is alternatively influenced by cold Arctic air, humid temperate air from the Atlantic Ocean, dry and cold air associated with Siberian high pressure zones, and Mediterranean warm air. The soil on the site is silty clay and clay to a depth of 300 cm. The saturated hydraulic conductivities of different layers of the soil profile are very low.



(1 to 12 plot no, ○ :location of observation wells and open end Lysimeters for measuring evaporation+deep percolation (E-DP), Δ :location of closed end Lysimeters for measuring evaporation (E), □ :location of open end Lysimeter for measuring evapotranspiration (ET), – →–: subsurface drain lines and ⊠ :points of drain flow measurements).

Figure 1. Location of the study area in the Mazandaran province (top right) of Iran (top left) and the layout of the drainage systems (bottom).

Eleven PVC corrugated drain pipes (100 m long, with an outside diameter of 100 mm) were installed at the study site in June-July of 2011 at depths of 0.65 and 0.9 m and spacings of 15 and

30 m. Four different subsurface drainage systems were analyzed by installing drains at different depths (D_x, where subscript x indicates a drain depth in meters) and spacings (L_y, where subscript y indicates a drain spacing in meters): $D_{0.9}L_{30}$, $D_{0.65}L_{30}$, and $D_{0.65}L_{15}$. The last drainage system, denoted as *Bilevel*, has a drain spacing of 15 m and alternate drain depths of 0.65 and 0.9 m. Further details about the experimental design can be found in Darzi-Naftchali et al. (2013). Figure 1 shows the location of the research field in the country and the layout of the drainage systems in the research field.

Before crop cultivation, soil samples were taken from each treatment plot every 30 cm to a depth of 200 cm. Soil physical and chemical properties were determined on these soil samples. Soil water contents at 14 different pressure heads (from 0 to 16 bars) were measured in the laboratory using a pressure plate apparatus. The van Genuchten-Mualem model (van Genuchten 1980) was then fitted to the observed retention curves using the RETC model. Crops were then sown at November 28, 2011 and October 3, 2015. All agricultural operations followed the conventional practices of the local growers in the study area. Daily measurements of water table depths were manually made in the observation wells that were dug midway between drains. Moreover, drainage discharge was measured daily in all treatments. Drains were only plugged during the last one month of the growing seasons before the harvest. Crops were harvested on May 8, 2012 and May 3, 2016.

Simulation approach

HYDRUS (2D/3D) (Šimůnek et al., 2008) is a powerful software for simulating transient, two- or three-dimensional movement of water and nutrients in soils for a wide range of boundary conditions, irregular boundaries, and soil heterogeneities. Water flow in soils is described using the Richards equation as follows:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x}\left(K_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial z}\left(K_z \frac{\partial h}{\partial z}\right) - \frac{\partial k}{\partial z} - WU(h, x, z) \tag{3}$$

where θ is the volumetric soil water content (SWC) [L^3L^{-3}], K is the unsaturated hydraulic conductivity [LT^{-1}], h is the soil water pressure head [L], x is the lateral coordinate [L], z is the vertical coordinate (positive downwards), t is time [T], and $WU(h, r, z)$ denotes root water uptake [T^{-1}].

The van Genuchten-Mualem constitutive relationships (van Genuchten 1980) were applied for modeling soil hydraulic properties. A rectangle 200 cm deep (since the impermeable layer was at the 200 cm soil depth) and either 30 m wide for the $D_{0.9}L_{30}$ and $D_{0.65}L_{30}$ drainage systems or 15 m wide for the $D_{0.65}L_{15}$ and *Bilevel* drainage systems was defined as a two-dimensional transport domain in the model. The transport domain was discretized using unstructured, triangular, finite element mesh (FEM). A non-uniform FEM was generated by HYDRUS-2D with finite element sizes gradually increasing with distance from the drains. Six soil horizons with different soil hydraulic properties were defined for the 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm, 120-150 cm, and 150-200 cm soil depths (Table 1). An additional soil layer was considered to represent the backfilled drain trench (gravel), with a higher hydraulic conductivity above and around drains. Measured. The measured pressure head distribution was applied to define the initial conditions for flow simulations. Atmospheric boundary condition was applied at the top of the transport domain. A seepage face boundary condition was used to represent the drains during the drainage periods. All other remaining boundaries were assigned a no-flow boundary condition. Measured temporal variations of water depths (*WD*) and drainage water fluxes (*DF*) during 2011-12 growing season were used for calibrating HYDRUS-2D. The model was then validated using similar data from the 2015-16 growing season.

Results and discussion

Daily measured drainage fluxes (*DF*) as well as water table depths (*WD*) in the 2011-12 growing season were employed to calibrate the HYDRUS-2D model for all treatments. During the calibration process, the saturated hydraulic conductivity (K_s), the residual soil water content (θ_r), and the saturated soil water content (θ_s) were optimized using the inverse analysis of HYDRUS-2D and measured data, while the shape parameters α, l, and n in the van Genuchten-Mualem model (van Genuchten 1980) were kept equal to the values obtained by the RETC model. Finally, the accuracy of HYDRUS-2D was assessed based on the criteria indices including mean bias error (*MBE*), root mean square error (*RMSE*) and model efficiency (*EF*).

Temporal variations of the observed and simulated drainage fluxes (*DF*) for different drainage systems as well as the related scatter plots are displayed in Figure 2 for the calibration period. The correlation coefficients of 0.93-0.96 reveal a good agreement between observed and simulated daily *DF*s for all treatments when the optimized soil hydraulic parameters were used during the calibration period. A higher R^2 (0.96) was obtained for $D_{0.65}L_{15}$ where *DF*s were higher, while $D_{0.9}L_{30}$ with observed *DF*s in the range of 0-2.25 mmd^{-1} had the lowest R^2 (0.93). Figure 2 shows that HYDRUS-2D performed very well in simulating average *DF*s during the growing season of 2011-12. The average observed *DF* for the *Bilevel*, $D_{0.65}L_{15}$, $D_{0.65}L_{30}$, and $D_{0.9}L_{30}$ drainage systems in 2011-12 growing seasons were 1.6, 2.66, 0.69 and 1.37 mm d^{-1}, respectively, while the corresponding simulated values were, 1.61, 2.69, 0.7 and 1.38 mm d^{-1}, respectively. Although HYDRUS-2D is capable of capturing the temporal trends of *DF*s, the model slightly overestimated the peak *DF*s, especially after heavy rainfall events in the $D_{0.65}L_{15}$ treatment.

The performance of the HYDRUS-2D model in simulating *DF*s and *WD*s in terms of *RMSE*, *MBE* and *EF* is summarized in Table 1. For the calibration period, the *RMSE* values characterizing differences between observed and simulated *DF*s were 0.09 mm d^{-1} for the $D_{0.9}L_{30}$ treatment, 0.11 mm d^{-1} for the *Bilevel* treatment, 0.05 mm d^{-1} for $D_{0.65}L_{30}$ treatment, and 0.18 mm d^{-1} for the $D_{0.65}L_{15}$ treatment. Despite of a slight overestimation (*MBE*=0.01-0.02 mm d^{-1}), the *EF* values, ranging from 0.92 to 0.96, indicated that the simulated *DF*s agreed well with the observed values for all treatments during the calibration period. In addition, having *RMSE*=0.37-2.23 cm, *MBE*=-

0.01-0.25 cm, and *EF*=0.96-0.99, the HYDRUS-2D-simulated *WD*s agreed well with the observed values (Table 1). *WD*s were generally overestimated during the 2011-12 growing season for all treatments except for $D_{0.9}L_{30}$, in which *WD*s were overestimated by less than 1%. In general, higher accuracy in estimating *DF*s and *WD*s was obtained for the $D_{0.65}L_{15}$ treatment while the highest error was observed for the $D_{0.65}L_{30}$ treatment during the calibration period (Table 1).

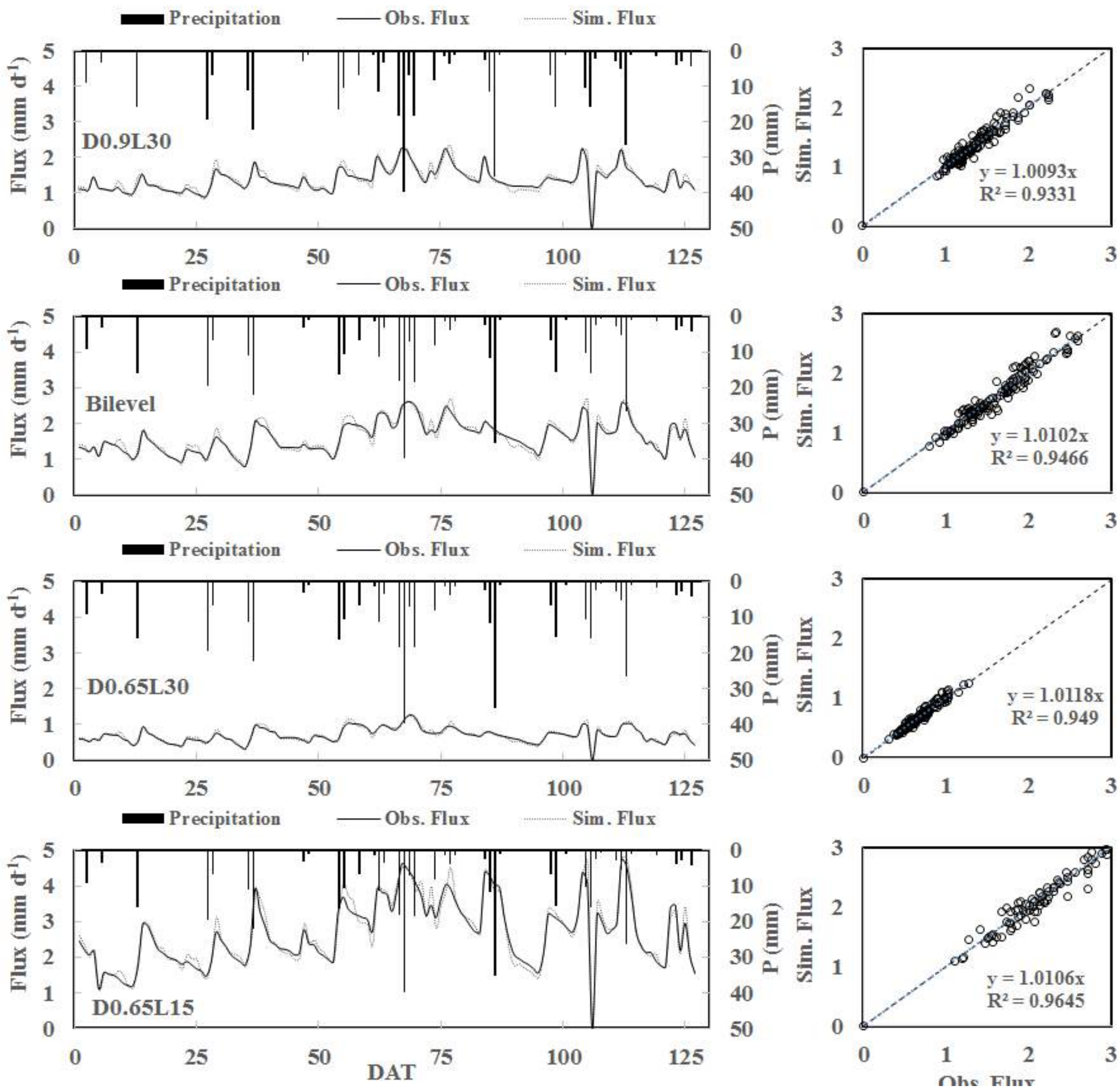


Figure 2. Temporal variations of drain discharges and precipitation (P) during the 2011-2012 growing season (the calibration period) for the four drainage systems.

Table 1. The criteria indices comparing the observed and simulated drain discharges (*DF*) and water table depths (*WD*) during the calibration and validation periods.

Year	Parameter	Criteria Index	Drainage systems			
			$D_{0.9}L_{30}$	*Bilevel*	$D_{0.65}L_{30}$	$D_{0.65}L_{15}$
2011-2012	*DF*	*MBE* (mm d^{-1})	-0.01	-0.01	-0.01	-0.02
		RMSE (mm d^{-1})	0.09	0.11	0.05	0.18
	EF	0.92	0.94	0.94	0.96	
		MBE (cm)	-0.01	0.10	0.13	0.25
	WD	*RMSE* (cm)	0.37	1.30	1.75	2.23
		EF	0.99	0.99	0.98	0.96
2015-2016		*MBE* (mm d^{-1})	-0.07	-0.13	-0.06	-0.17
	DF	*RMSE* (mm d^{-1})	0.46	0.85	0.40	1.02
		EF	0.84	0.84	0.86	0.85
		MBE (cm)	-0.16	-0.45	-0.53	-0.63
	WD	*RMSE* (cm)	1.67	3.96	3.89	4.54
		EF	0.91	0.92	0.96	0.89

The calibrated model was then applied to simulate *DFs* and *WD*s for different treatments during the 2015-16 growing season (the validation period). The agreement between observed and simulated *DF*s and *WD*s was quantitatively assessed using the *RMSE* and *MBE* statistics (Table 1). The model performance criteria for the validation period indicated the strong predictive capability of the model. *EF*, *RMSE*, and *MBE* for *DF*s ranged from 0.84-0.86, 0.4-1.02 mm d^{-1}, and –(0.06-0.17) mm d^{-1}, respectively, across different drainage systems, while for *WD*, the considered indices ranged from 0.89-0.96, 1.67-4.54 cm, and –(0.16-0.63) cm, respectively. Table 1 indicates that overestimation was about 6.4-7.9% for *DF*s and 2.8-3.8% for *WD*s.

The comparison between simulated and measured values of *DFs* with the 1:1 line in Figure 3 also indicated that HYDRUS-2D can be successfully used to predict daily fluctuations of *DF*s for different drainage systems in the 2015-16 growing season. The averages observed *DF* for the *Bilevel*, $D_{0.65}L_{15}$, $D_{0.65}L_{30}$, and $D_{0.9}L_{30}$ drainage systems during the validation period were 1.78, 2.18, 0.87 and 1.1 mm d^{-1}, respectively, while the corresponding simulated values were 1.91, 2.35, 0.94 and 1.1 mm d^{-1}, respectively. In addition, the correlation coefficients varied in the range of 0.91-0.93 across different drainage systems, indicating the strong predictive capability of the model.

Overall, both the visual inspection of the scatter plots and the calculated values of the criteria indices, which compare the observed and HYDRUS-2D-estimated *DF*s and *WD*s during both growing seasons (the calibration period of 2011-2012 and the validation period of 2015-2016), clearly indicate the high potential of the HYDRUS-2D modeling. There was a close match between the observed and simulated data, with acceptable errors in all treatments. This capability makes the model applicable to the assessment of different water table management strategies during the canola growing season. The high accuracy of HYDRUS-2D is mainly due to the use of a deterministic approach for simulating soil water dynamics based on the Richards equation (Doltra and Munoz, 2010). Earlier research has also demonstrated the high potential of HYDRUS-2D for simulating soil water dynamics in different drained fields (Janssen and Lennartz, 2009; Garg et al., 2009; Tan et al., 2014; Li et al., 2014 and 2015).

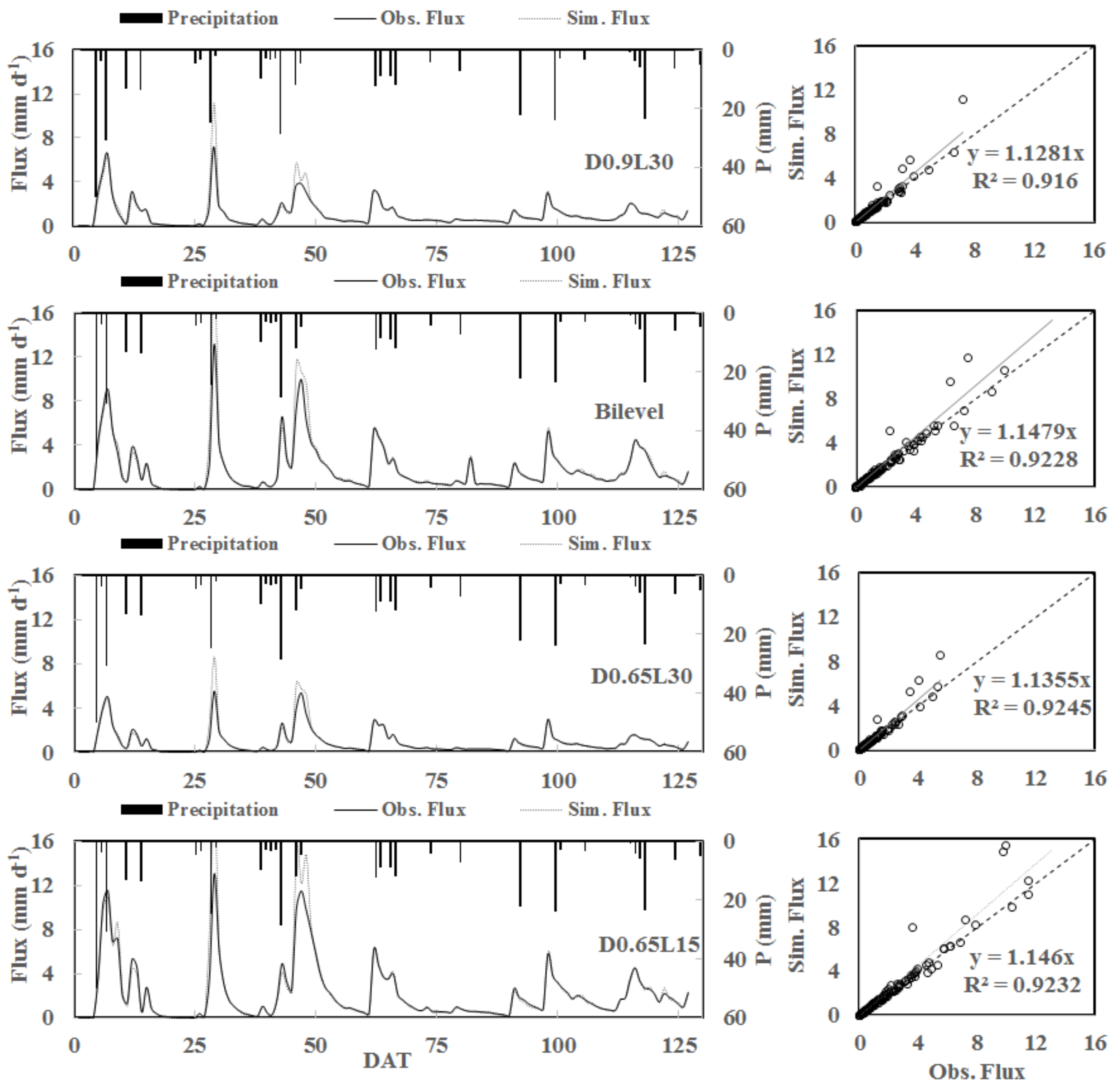


Figure 3. Temporal variations of drain discharges and precipitation (P) during the 2015-2016 growing season (the validation period) for the four drainage systems.

Conclusion

Improving the land and water productivity by modifying soil conditions is the main reason of the installation of subsurface drainage in the Northern paddy fields of Iran. Such technology also assists with winter cropping after rice cultivation, which can bring additional economic benefits to the local farmers. Nevertheless, subsurface drainage may lead to the negative consequences regarding soil water dynamics, especially under free drainage conditions. Therefore, this experimental and numerical study was carried out to evaluate the accuracy of the HYDRUS-2D model for simulating soil water dynamics under different drainage systems during the rainfed canola cropping in the paddy fields. The correspondence between both values and temporal trends of the observed and HYDRUS2D-simulated water fluxes and water table depths during the calibration and validation stages was good, indicating that the model is well suited for the experimental field conditions. Based on the results, it could be concluded that the HYDRUS-2D model, instead of labor- and time-consuming and expensive field investigations, could be reliably used for determining the optimal drainage system for the Northern paddy fields of Iran.

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EVALUATION AND COMPARISON OF LOCALLY MANUFACTURED PP450 SYNTHETIC ENVELOPES FOR COMPLEX CLAY SOILS OF NORTH AND SOUTH KHUZESTAN (IRAN)

Heydar Ali Kashkuli[1,*], Mina Afshari[2], Narges Zohrabi[3]

Abstract

The performance of subsurface drainage pipes installed utilizing granular envelopes for 100000 ha of sugarcane/irrigation-related projects in Khuzestan has been satisfactory. However due to rising transportation and installation costs for granular envelopes requiring a wider trench, a great tendency for the use of synthetic envelopes has developed in recent years. More than 300000 ha of new irrigation projects are planned to install only locally manufactured synthetic envelopes. The complexity of soil horizons in the vast Khuzestan plain, weakness of synthetic envelope manufacturing standard enforcement laws, lack of experience, insufficient field and laboratory research are the main reasons of concern about the successful long term performance of these envelopes. In this laboratory research three different PP450 synthetic envelopes (types 1, 2 and 3) were tested on two representative soil samples obtained from North and South Khuzestan in an upward directed flow permeameter. Outflow rates from drains with increasing total head at various time intervals, gradient ratio tests as well as hydraulic conductivity of soil-envelope tests were conducted. Analysis of the results revealed that while envelope type 1 was suitable for the soil from the north (Dehkhoda project) and envelope type 3 was suitable for the soil from the south (Ramshir project).

KEY WORDS: Gradient ratio, Hydraulic conductivity, Permeameter, Variations of discharge.

Introduction

Climatic and soil conditions in addition to the availability of water resources, makes the Khuzestan province a suitable place for agricultural development especially in the form of large irrigation

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projects, however; the providing of suitable drainage systems for successful production is necessary. Drainage is required to control the buildup of the water table due to irrigation water losses , deep percolation and salinity buildup in the root zone. Over the past four decades more than 100000 hectares of sugarcane projects in the Khuzestan province have had underground drainage pipes with sand gravel envelopes installed all showing a satisfactory performance.

Currently with due regards to the rising cost of sand gravel envelopes and transportation difficulties, there is a growing interest and urgency to use synthetic factory wrapped envelopes in new projects under development in the Khuzistan province which is estimated to be more than 300000 hectares. Synthetic envelopes have been used successfully in the United States, Pakistan, Egypt and the Netherlands since t synthetic envelopes have proven to be very effective in most cases, and have less cost compounded by easier installation. However their successful long term use has yet to be verifiedand requires extensive research taking into account Khuzestan soils; moreover, Geotextile filters can retain and prevent fine grains of soil from passing into and clogging the drain pipes (Hassanoghli and Rahimi, 1996).

Palmeira and Gardoni (2002) studied the biological clogging of geotextile and mineral envelopes under different pressures applied for filtering agricultural drain water over a five year period and showed that synthetic geotextile envelopes perform better and are more economical than other synthetic envelopes.

Agar (2011) used a permeameter to evaluate 3 geo-synthetic woven and unwoven envelopes and a gravel sand envelope used as drainage pipe covers in two different soils that is for clayand silt loam soils to preventsilt from entering into drainage pipes. The results show that all in all the geotextile envelope performance was superior in preventing silt from entering the drainage pipe as compared to a gravel sand filter.

Pedram et al., (2011) studied the clogging potential of synthetic PP450 envelopes under saline and non-saline conditions. This study was performed in laboratory conditions using two physical models permeameters. PP450 was used as the envelope as per the design criteria, and appropriate soil was selected to simulate the area. It was observed that water quality can affect the clogging of envelopes, which is an issue that must be considered when working in the Khuzestan province due to its saline soil and water conditions.

Mehdinezhadiani et al., (2008) used an upward flow permeameter to evaluate a certain type of PP450 and then compared its operation to gravel sand filters based on USBR standards, and concluded that both envelopes were acceptable for use in silt- clay soils found in the North of the Khuzestan province.

Nowshadi et al. (2015) evaluated the performance of 2 PP450 locally manufactured envelopes and a sand gravel envelope made according to USBR standards for silt loam soil, installing them in a soil tank model and concluded that discharge outflow from the gravel sand filter was considerably more as compared to that of synthetic envelopes. It was concluded that in areas where there is a need to lower the groundwater table rapidly synthetic envelopes are not suitable.

PP450 envelopes manufactured in the Khuzestan province are currently endorsed and used extensively for all the drainage projects under construction in the province. Gharamohammadlu (2013) examined 3 types of PP450 synthetic envelopes manufactured locally and identified the variations in their characteristics as shown in table 1 which affect their performance in different soils..

Table 1. Characteristics of the three locally manufactured envelopes reported by Gharemohammadlu (2013)

Synthetic envelope	O_{90} (μm)	Envelope thickness under a load of 2 (mm) kPa	Sample weight (gr. m^{-2})
Type 1	400	4. 05	510
Type 2	430	3. 47	462
Type 3	465	4. 075	478. 8

With due regards to the differences in characteristics, it was deemed necessary to study the suitability of all the 3 locally manufactured PP450 envelopes for the soils in the North and South of the Khuzestan province using an upward flow permeameter in the laboratory.

An important often neglected factor in the design and selection of drainage envelopes for the Khuzestan province's predominantly clay soils, is their complexity due to the presence of intermixed silt- sand lenses at shallow depths. This factor was considered in developing a specific method of soil sampling for this study.

Materials and methods

This research was performed in the laboratory using a standard upward flow permeameter. The pemeameters used in this research were designed, based on ASTM D5101 standards. They were made of transparent plexiglass material of 5 mm thickness and 90 mm inside diameter. Each was 250 mm in length and had 10 manometers installed on the sides to show the hydraulic head at the soil-envelope contact interface.

The Hydraulic head was applied via a constant head tank with an adjustable water surface to create the desired head and hydraulic gradient for each experiment. Figure 1 shows the permeameter used in this study.

Figure1. Photograph of the permeameter used in this research

The standard Soil sample height in the permeameter was 100 mm. Initially a hydraulic head of 30 cm was applied at the on start of the experiment. With due regards to soil sample height this would create an average hydraulic gradient of 0. 5. By applying hydraulic gradients of 0. 5, 1, 2 and 3 a steady constant discharge at each gradient ratio was recorded for the gradient ratio; and the hydraulic conductivity of the soil-envelope was obtained from it. Results for a gradient of 0. 5 were not logical and thus were discarded. The standard test for envelope performance is the Gradient Ratio test. According to Vlotman() recommendations this experiment should be carried out with an upward flow permeameter. GR is a factor of the soil and envelope that shows a potential clogging of envelopes. This parameter should be calculated at each hydraulic gradient using equation (1). Any increasing trend of GR with the gradient is an indication of envelope clogging. By increasing the hydraulic head over time, the discharge, hydraulic conductivity, GR and hydraulic conductivity of soil-envelope is measured. Discharge was measured using equation (2) and hydraulic conductivity corrected at standard temperature was calculated using equation (3).

Soil samples were collected from drain depth in trenches dug for pipe laying in the projects under construction. Due to the occurrence of sand silt lens deposits at shallow depths in the plain, collecting samples from these weak layers, occurring at drain depths that are more likely to cause envelope clogging was attempted .

$$GR = \frac{i_{es}}{i_s} \quad (1)$$

$$Q = \frac{V}{t} \quad (2)$$

$$K_{est} = \frac{Q}{i_{es} \times A} \quad (3)$$

Results and discussion

Steady Outflow Discharge

The constantoutflow discharge for each envelope with an increasing hydraulic gradient (at gradients 1, 2 and 3) is shown in Figure 2 for soils in the Dehkhoda area ..

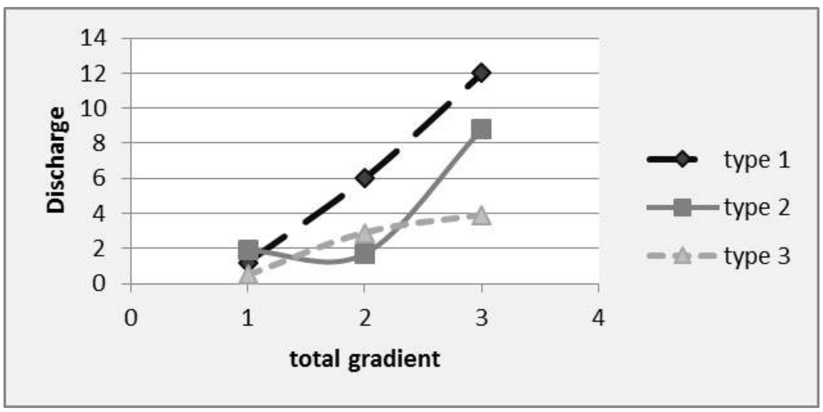

Figure 2. Discharge versus total gradient (Dehkhoda soil)

It takes about 24 hours for the discharge to reach a steady constant rate at a new gradient. Gradient was increased and set at 1,2 and 3 and the steady constant discharge rate corresponding to these gradients was recorded after 48, 72 and 96 hours, , respectively. As shown in Figure 2 the gradient of the discharge rate is more for envelope 1 showing a higher discharge rates in all the gradients. Thus envelope type 1 is considered more desirable as compared to the other 2 types. Steady constant discharge for envelopes 1, 2 and 3 was recorded as 3.9, 8.8 and 12 mm/min respectively.

In Figure 3 the variation of the steady discharge with its gradient is shown for soils in the Ramshirarea . In this test the system was adjusted to reach a gradient of 1 after approximately 48 hours from the beginning 72 hours after the onstart the gradient was adjusted at 2 and 96 hours later it was adjusted to a gradient of 3. Figure 3 shows the steady constant discharge at each gradient after reaching the steady state values of discharge. As observed, the discharge values corresponding to envelope 1 are the highest and for envelope 2 is the lowest. After 3 days at gradient 2, the trend of increasing discharge is faster for type 1 envelope as compared to types 2 and 3 which continue rising at equal rates. Therefore for soils in the Ramshir region type 1 is the most suitable because it can deliver the highest discharge. Envelopes 3 and 2 are the next suitable choices, respectively.

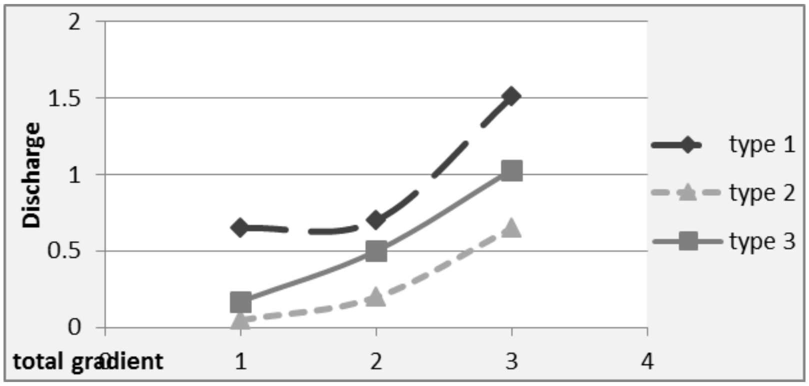

Figure 3. Discharge changes versus total gradient (Ramshir soil) total gradient

Gradient Ratio

Gradient ratio is measured for the determination of the threshold of soil particle movement and clogging potential. When GR is greater than one it means that envelope clogging has occurred due to soil particle movement. Furthermore the trend of increasing GR in relation to the total gradient is an indication of envelope clogging.

Figure 4 shows the results of the GR tests for soils in the Dehkhoda region. The graph shows that for all the gradients, GR is less than one. Envelope type 3 clogging starts at gradient 3 and GR of one. Since clogging has not occurred for envelope type 1 at gradient 3 despite soil failure, is is considered a better envelope at higher gradients.

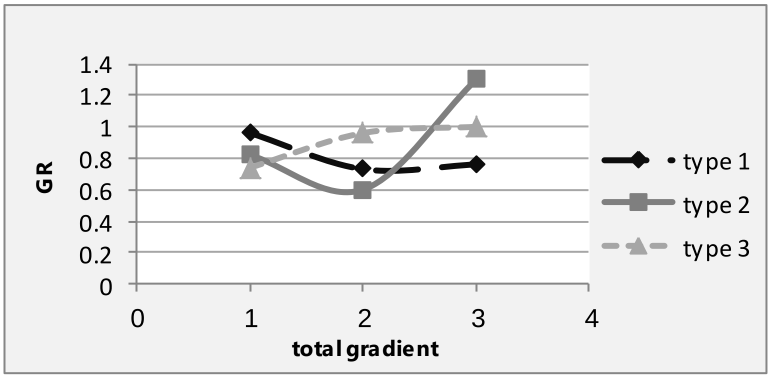

Figure 4. Gradient ratio versus total gradient (Dehkhoda soil)

Figure 5 shows the GR at different gradients for soils in the Ramshir area. As seen in the graph the lowest values of GR belong to envelope 3. The value of GR at all points , even at gradient 3, where soil failure occurs, is less than 0.5. Therefore clogging did not occur in envelope 3 and therefore is considered asthe best envelope type for soils in the Ramshir area. For envelope 2, GR at gradient 1 is slightly larger than one and increases after soil failure at gradient 3 whereas for envelope 1 at gradient 3 where soil failure occurs the GR does not show a rising trend indicative of envelope clogging.

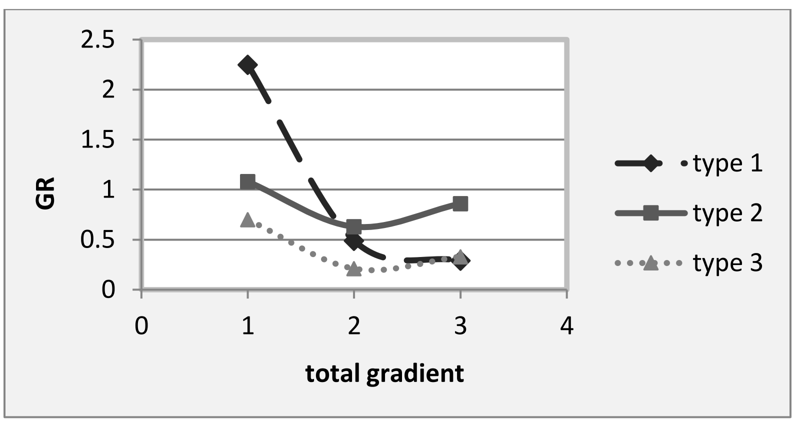

Figure 5. Gradient ratio versus total gradient (Ramshir soil)

Hydraulic conductivity of the soil-envelope and total gradient

Figure 6 shows the change in hydraulic conductivity of the soil-envelope with a total gradient for soils in the Dehkhoda region. As the gradient increases for all three envelope types, the hydraulic conductivity of the soil-envelope increases providing a higher value for envelope type 1. The

Hydraulic conductivity of the soil-envelope for type 2 envelope at gradient 2 shows a slight decrease and increases slightly at gradient 3. The increase in hydraulic conductivity after the decreasing trend is an indication of soil failure. Therefore in terms of hydraulic conductivity, envelope 1 is suitable for soils in the Dehkhoda region followed by envelope type 2.

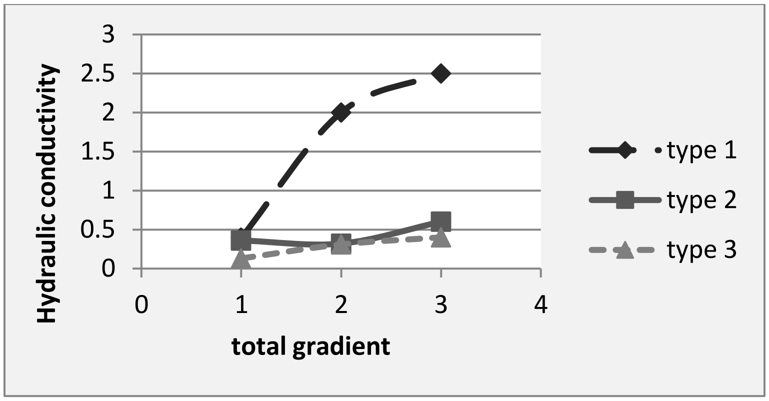

Figure 6. Hydraulic conductivity of soil-envelope at different gradients (Dehkhoda soil)

The corrected hydraulic conductivity of soil-envelopes in soils in the Ramshir area are shown in Figure 7. For all 3 envelopes that have an increasing total gradient, the hydraulic conductivity of the soil-envelope increases. The increasing trend of the hydraulic conductivity of the soil-envelope for envelope type 3 is greater as compared to types 1 and 2.

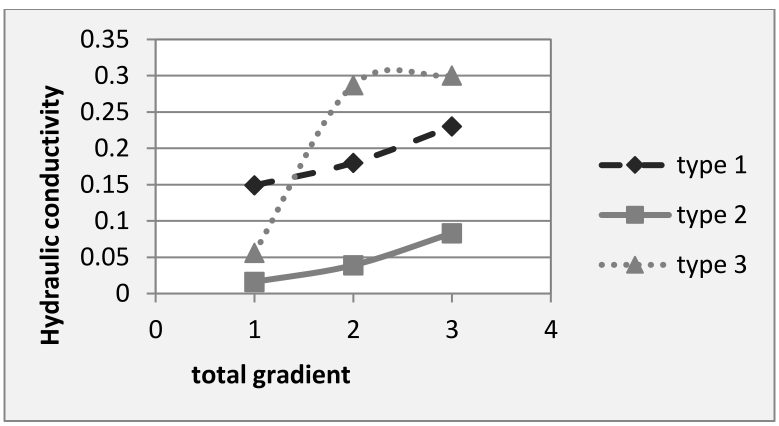

Figure 7. Hydraulic conductivity of soil-envelope at different gradients (Ramshir soil)

Conclusion

The analysis of the experimental results for soils in the Ramshir area show that the largest discharge rates correspond to type 1 envelopes followed next by type 3 envelopes. The highest hydraulic conductivity of soil-envelope is related to type 3 and type 1 envelopesrespectively. from the results from the GR test results show that the type 3 envelope was more suitable followed by type 1 envelope. Therefore taking into account all 3 of the obtained test results, envelope 3 is the most suitable choice for soils in the Ramshir area followed by envelope 1. Test results for soils in the Dehkhoda area show that type 1 envelope is more suitable followed by type 2. Furthermore the performance of type 3 envelope for soils in the Ramshir area was weak and is not recommended

In conclusion , the researchers found that the three locally manufactured envelopes under PP450 specification showed considerable differences in performance which have to be taken into account during their application for soils in the Khuzestan province.

Recommendations

1- The impact of chemical factors on the envelopes should also be examined since this parameter was not incorporated in the study.

2- For a more thorough and comprehensive analysis of the performance of envelopes, it is recommended that a field test be conducted with due regards to the various limitations that laboratory experiments have (time limitations, disturbances in soil structure etc…)

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INVESTIGATION THE METHODS TO ASSESS OF IMPERMEABLE LAYER DEPTH IN THE TIDAL LANDS OF MINUSHAHR

Abd Ali Naseri[1], Amir Ebrahim Yussefpour[2], Rahim Mohammadzadeh[3,*], Hamidreza Gharemohammadlou[4], Behzad Hojjati[5], Ramin Niknam[6], Amin Rafienia[7]

Abstract

The depth of the impermeable layer or the barrier in soil is one of the most important parameters in the designing of subsurface drainage systems; however the assessment of the layer is not always easy. In practice, a soil layer is considered as being impermeable or slowly permeable if its hydraulic conductivity is very small (one fifth to one tenth) as compared to the hydraulic conductivity of the upper layers. The impermeable layer is found where the soil is poorly aggregated or exhibits a massive structure. If it is permanently saturated as part of the soil profile in the lowlands and coastlands where saturation conditions prevent organism activities, soil aggregating resulting into a layer with slow permeability in the soil. The identification of the impermeable layer depth is complicated especially in regions having a variable groundwater table such as tidal regions; thus, different methods are recommended to be used for the accurate determination of the impermeable layer depth. The aim of the present study is the investigation and comparison of the results obtained from the main and practical methods of identification of the impermeable layer depth in the tidal lands of Minushahr in the Khuzestan province, Iran. Three sites were chosen randomly in Minushahr to test and compare the three methods of estimating the depth to the impermeable layers, i.e. soil properties in different strata, one fifth to one tenth of the weighted mean hydraulic conductivity of the upper layer and infiltration rate differences of successive layers. The results showed that the soil had a massive structure, without any roots or plant activity and organic matter in the layer of 120 to 150 cm; also, there is a change in color and mottles were observed e which in itself can be attributed to redox conditions due to the tide and fluctuation of the groundwater table; in addition there an increase in soil consistency and digging resistance in the layer of 140 to 160 cm was seen as compared to the upper layers. The results from the experiments of the saturated hydraulic conductivity indicated that the hydraulic conductivity in depths of about 150 cm is approximately one seventh of the upper layers., a ring infiltrometer test in different depths of soil also revealed a significant decrease at a depth of 150 cm as related to surface soil. The results of the present study were almost the same for soil layering, saturated

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hydraulic conductivity and soil infiltration rate tests in successive layers so that the impermeable layer was determined in a depth of 150 to 200 cm.

KEY WORDS: Impermeable Layer, Saturated Hydraulic Conductivity, Infiltration Rate.

Introduction

Plants require air as well as moisture and nutrients in the root zone. Excess water from rainfall, irrigation, and the water table restricts the available air and inhibits plant growth. In arid and semi-arid irrigated regions, poor natural drainage causes water logging in the field and soil salinity develops due to the rise of the water table. In arid and semi-arid areas, low rainfall with an uncertainty in its occurrence results into moisture deficiency during most of the crop season subsequently irrigation is necessary for improving crop production, but in these areas, if irrigation canals are available, farmers have a general tendency to over irrigate. If lands are flat with no or little natural drainage, the ground water table will rise and this will often leadto salinity development and water logging (Pali, 1986; Pali, 2015). Salt-prone land and water resources are major impediments to the optimal utilization of crop production systems in many arid and semi-arid regions of the world, including Iran (Alizadeh et al. 2004; Moghaddam and Koocheki 2004). In order to improve saline and water logged soils which occur due to the rise in the groundwater table, the installation of subsurface drainage system is considered as one of the best remedies. Determining the depth of the impermeable layer or barrier in soils is one of the most important parameters in the designing of subsurface drainage systems. Most of the drainage formulae for determining the depth and spacing of the drains require information about the distance to the impermeable layer (Luthin, 1973). However, the assessment of the distance to the impermeable layer is not always easy. An impermeable layer is a soil layer through which no flow occurs or, in a practical sense, the flow is so small that it can be overlooked. In other words, an impermeable layer or barrier is a stratum or layer that prevents or restricts the saturated movement of water in the soil. Since soil layers in irrigated areas are found in a generally horizontal orientation parallel to the ground surface, an impermeable layer is usually considered as a barrier to the vertical movement of water which may also restrict the horizontal movement of water because of geologic nonconformity (USBR, 1978; Ahmadi, 1999).

Despite all this, the term "impermeable" is relative and all soils are permeable to some extent, but there are some methods to determine and identify the depth of the impermeable layer in the soil. In practice, a soil layer is considered impermeable or slowly permeable if its hydraulic conductivity is very small (one fifth to one tenth) as compared to the hydraulic conductivity of the upper layers (USBR, 1978; Ahmadi, 1999). Other applicable methods for the identification of a barrier are the evaluation of the infiltration rate differences in successive layers of soil, in addition to the investigation of soil properties variation (texture, structure, moisture, soil consistency, digging resistance, soil color, and mottling and gley condition) in the soil profile.

An impermeable layer is found where the soil is poorly aggregated or exhibits a massive structure. In permanently saturated layers of the soil profile in the lowlands and coastlands, biologic activities and soil aggregation are preventive and thus form a layer that has a slow permeability in the soil. The identification of the impermeable layer depth is complicated, especially in regions having a fluctuating groundwater table such as tidal regions; thus, it is recommended that different methods be applied to more accurately determine the depth of the impermeable layer. Therefore, the aim of the present study is the investigation and comparison of the results obtained from the major and practical methods applied for the identification of the impermeable layer depth in the tidal lands of Minushahr in Khuzestan, Iran.

Materials and methods

Experimental site layout

Three sites (S_1: cultured by palm: S_2: barren lands with canebrake and S_3: cultivated with vegetables) were chosen in the tidal lands of Minushahr, in the Khuzestan Province, Iran (Figure1) to test and compare the three methods of estimating the depth to the impermeable layers, i.e. the conducting of a soil survey by logging the soil properties in different strata, the determination of saturated hydraulic conductivity coefficients in different layers (one fifth to one tenth of the weighted mean of the hydraulic conductivity of the upper layer) and the determination of the infiltration rate differences in successive layers.

Soil survey

A soil survey in the selected sites was performed using an auger boring method. The auger boring method is a means of obtaining soil samples from different depths by drilling, without having to dig a pit. This way, a continuous series of soil samples is taken which makes it possible to assemble a core showing the soil horizons. Soil samples were obtained from a borehole created by an auger and were analyzed qualitatively by an experienced technician, in terms of soil color, observation of mottling and gley condition, soil texture (using the feel method) and structure, state of the root in the soil, the soil consistency and soil resistance against digging.

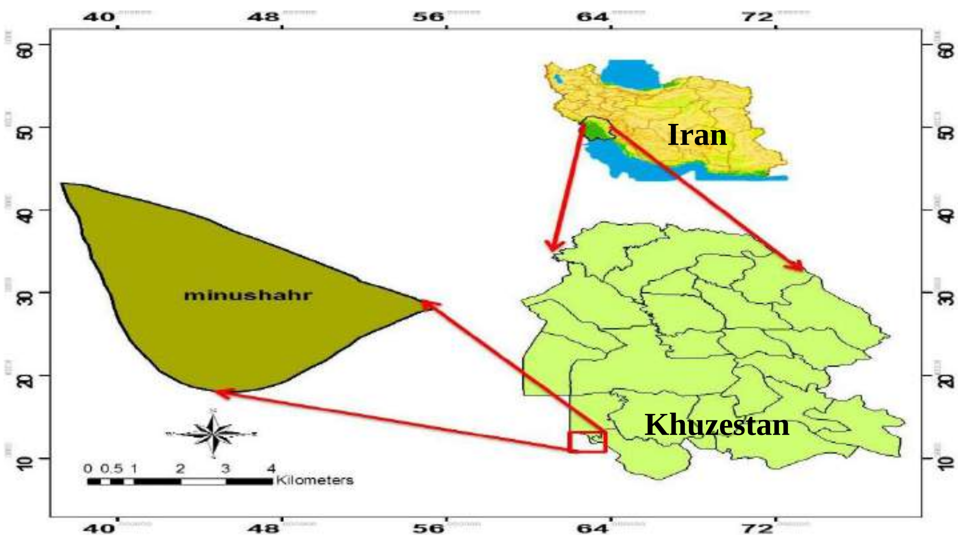

Figure 1. The study area map

The Determination of the Hydraulic conductivity of Saturated Soil

The Determination of the hydraulic conductivity of saturated soil in different layers of soil was done in layers of 0-50, 50-100, 100-150 and 150-200 cm using three replicates created by the auger hole and the inverse hole methods. The methods consist of pumping the water out or in an auger-hole extending below and up the water table and then measuring the rate of the rise and fall of the water in the hole, respectively (Figure 2). All of the tests were carried out when the ground water table was stable

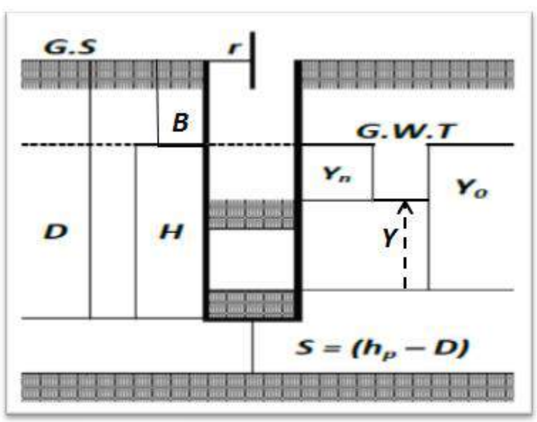

Figure 2. Borehole characteristics

(D is depth of borehole (m), B is depth to stable ground water level from the surface* (m), H is the stable ground water level (m), Y_0 is the ground water level difference from the stable ground water after its removal at the beginning of the rise rate measurement (m), Y_n is the ground water level difference from the stable ground water at the end of the rise rate measurement (m), Y is the ground water level during the rise rate measurement and r is the borehole radius (m).

*Depths of stable ground water level from the soil surface in the selected sites were regarded as an average of ground water depth from surface during one month

Determination of soil infiltration rate

Determination of soil infiltration rate in different layers was done in layers of 0 (surface), 50 cm, 80 cm and 120 cm depths based on the stair method (Figure 3) in three replicates. All of the infiltration tests were conducted to the upper section of the water table depth (about 120 cm) for the qualitative evaluation of the soil permeability value trend.

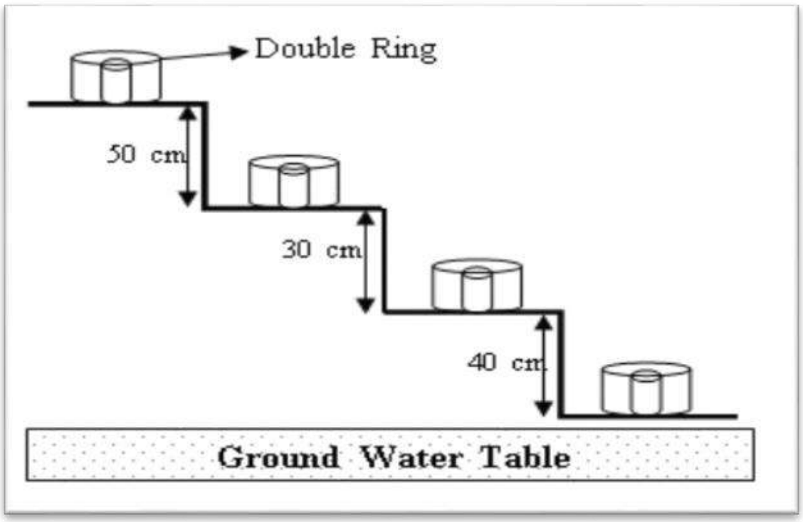

Figure 3. Method of determining the infiltration rate in different layer as a stair state

The double-ring infiltrometer method consists of driving two open cylinders, one inside the other, into the ground, partially filling the rings with water or other liquid, and then maintaining the water at a constant level. The volume of water added to the inner ring, to maintain the water level constant was the measure of the volume of water that infiltrates the soil. The volume infiltrated during timed intervals was converted to an incremental infiltration velocity, expressed in millimeter per hour and plotted versus elapsed time. The maximum-steady state or average incremental infiltration velocity, depending on the purpose/application of the test was regarded equivalent to the infiltration rate. Finally, the obtained results from the three studied methods were compared qualitatively at three sites with each other.

Results and discussion

Soil logging data obtained from soil hole surveys are shown in Table 1. The results of the saturated hydraulic conductivity and infiltration rate of water tests in different layers of soil at three sites are indicated in Table 2 and 3, respectively.

Table 1. Soil logging results of three sites (a): Site 1; (b) Site 2; (c): Site 3 and (d): The list of symbols and abbreviations in the table

(a)

Depth (cm)	*Texture*	*Moisture*	*Color*	*Gley*	*Mottling*	*Resistance*	*Structure*	*Root*
0-30	SiC	1	LG	-	-	+	SG.	+++
30-60	SiC	2	GB	-	-	+	Co.	+
60-100	SiC	3	DB	-	-	+	Gr.	+
100-150	SiC	4	GB	-	++	+++	Ma.	-
150-200	SiC	4	OG	++	+	++	Ma.	-
200-250	SiCL	4	G	++	+	++	Ma.	-
250-300	L	4	G	++	-	+	Ma.	-
300-400	SiCL	4	LG	++	-	+	Ma.	-

(b)

Depth (cm)	*Texture*	*Moisture*	*Color*	*Gley*	*Mottling*	*Resistance*	*Structure*	*Root*
0-30	SiC	1	LG	-	-	+	Co.	++
30-60	SiC	2	GB	-	-	+	Cr.	++
60-100	SiC	3	GB	-	-	+	Cr.	+
100-150	SiC	4	DB	+	+	++	Pl.	-
150-200	SiC	4	OG	++	++	++	Ma.	-
200-250	L	4	G	++	++	++	Ma.	-
250-300	L	4	G	++	-	+	Ma.	-
300-400	SiCL	4	LG	++	-	+	Ma.	-

(c)

Depth (cm)	*Texture*	*Moisture*	*Color*	*Gley*	*Mottling*	*Resistance*	*Structure*	*Root*
0-30	SiC	1	LG	-	-	+	SG.	++
30-60	SiC	1	LG	-	-	+	SG.	+
60-100	SiC	2	GB	-	+	+	Ma.	+
100-150	SiC	3	GB	-	++	++	Ma.	-
150-200	SiCL	4	GB	++	++	++	Ma.	-
200-250	SiCL	4	OG	++	+	++	Ma.	-
250-300	L	4	OG	-	-	+	Ma.	-
300-400	L	4	OG	-	-	+	Ma.	-

(d)

Texture	*Moisture*	*Color*	*Mottling & Gley*	*Resistance*	*Structure*	*Root*
SiC: Silty Clay SiCL: Silty Clay Loam C: Clay L: Loam	*1: Dry 2: Moist 3: Wet 4: Saturate*	*B: Brown RB: Raddish Brown DB: Dark Brown LB: Light Brown OB: Olive Brown GB: Grayish Brown G: Gray LG: Light Gray DG: Dark Gray OG: Olive Gray*	*(-): Less than 2% of exposed surface (+): 2-20% of exposed surface (++): More than 20% of exposed surface*	*(-): Non (+): Soft (++): Average (+++): Hard (++++): Extremely Hard*	*Pl: Platy Pr: Prismatic Co: Columnar Gr: Granular Ma: Massive SG: ingle Grain Cr.: Crumb*	*(-):Non (+):Few (++):Average (+++):Many*

The results of soil logging indicate that the region soil has a relatively heavy texture (silty clay) in surface and soil texture has a growing trend towards heavy texture (clay and silty clay loam) and it can be observed as a layer consisting of green, olive green and light green loam and silty clay loam soil generally at depths of 150-400 cm. Generally, the layer properties of soils in Minushahr can be divided into 3 classes including:

A) The Upper layer (0-150cm): The Presence of roots, organism activities and organic matter in these layers lead to the creating and developing the soil aggregates and increasing the soil hydrodynamic coefficients such as saturated hydraulic conductivity (K_s) and infiltration rate (I_b) coefficients.
B) The Middle layer (100-250 cm): These layers are exposed to fluctuations of ground water table that it leads to the appearance of mottling and red-brown spots due to sequential periods of oxidation-reduction. The soil of these layers is usually saturated; subsequently, the plant roots could not develop largely in these layers and soil has an undeveloped soil with a massive structure, dark green color and a hard resistance against digging. Therefore, the soil does not have a desirable hydrodynamic condition in this region.
C) The lower layer (250-400 cm): The layer has an undeveloped soil because a perennial saturation condition that prevents soil aeration and leads to the appearance of the gley condition. Water flow characteristics in the present layer are very limited.

Slow percolating permeable and impermeable layers are found where the soil is poorly aggregated or exhibits a massive type of structure. The soil of such layers typically belongs to one of the following textural classes: sandy clay loam, silty clay loam, clay loam, sandy clay, silty clay, and clay (Farr & Henderson, 1986). Therefore it can be claimed on the basis of available evidences that the barrier is near depths of 150-200 cm.

The results from the experiments of the saturated hydraulic conductivity indicated that the hydraulic conductivity in the layers 130 to 150 cm is about one seventh of the upper layers. By definition, as used by the US Bureau of Reclamation (USBR, 1978), a barrier zone is a layer that has a saturated hydraulic conductivity less than or equal to one fifth of the weighted average hydraulic conductivity of the strata above it. Therefore, on the basis of the coefficients of saturated hydraulic conductivity in the selected sites, there is a barrier layer in depths of 130-150 cm.

Table 2- Coefficients of saturated hydraulic conductivity (K_s) in different layers of three sites

Depth	K_s (m/day)		
	Site 1	Site 2	Site 3
0-50 cm	4.24	2.12	2.93
50-100 cm	3.62	1.68	1.34
100-150 cm	1.21	0.87	0.64
150-200 cm	0.58	0.32	0.41

On the other hand, the results of ring infiltrometer test in the different depths of soil revealed a large decrease in the intake rate of soil at a layer of 120 cm as compared to the surface and upper layers of the selected sites .This is shown as the decreasing trend of soil permeability with an increase in the depth.

Table 3- Infiltration rate (I_b) of water in different layers of three sites

Depth	I_b (mm/hr)		
	Site 1	Site 2	Site 3
Surface soil	9.63	5.25	11.3
50 cm	6.86	4.33	5.61
80 cm	5.08	2.86	5.02
120 cm	4.04	2.58	2.83

Conclusion

Three methods including soil properties changes, saturated hydraulic conductivity coefficients and soil infiltration rates in successive layers were tested for estimating the soil impermeable layer depth in tidal lands where the ground water table fluctuates. The results of the present study are almost the same for soil layering, saturated hydraulic conductivity and soil infiltration rate tests in successive layers so that the impermeable layer was determined in depths of 130 to 160 cm. However the determination of the hydraulic conductivity of the soil layers is difficult, thus it is proposed that various methods be used to identify theimpermeable layers using a higher confidence degree more precisely

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DETERMINING AN APPROPRIATE SYNTHETIC ENVELOPE FOR A SALINE SOIL AND EVALUATING DRAINAGE WATER QUALITY BY MEANS OF ONE DIRECTION PERMEABILITY TEST AND CYCLIC FLOW (CASE STUDY: SHADEGAN, KHUZESTAN)

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Abstract

The selection of an appropriate envelope (filter) and management of drainage water from subsurface drainage systems play a significant role in the design and implementation of these systems. By applying synthetic envelopes instead of mineral envelopes (sand and silt), subsurface drainage systems benefit from environmental, economic and technical issues. In this research, an effort has been made to select the most proper synthetic envelope among the three prevalent PLM synthetic envelopes (Iranian PP450 and PP700 and foreign PP450) using a permeability test in accordance with ASTM D-5101 standard and the saline soil of the Shadegan drainage project (Khuzestan). In addition, salinity variations of drainage water were analyzed on the most suitable envelope through four cyclic flows (applying a flow for five days and pausing it for three days) and two hydraulic gradients (1 and 2.5). In conclusion, the average hydraulic conductivity of Iranian PP450 and PP700 and foreign PP450 respectively were measured as 0.11, 0.13, and 0.21 m/day and the average gradient ratio were equal to 0.78, 0.84, and 1.86 m/day. According to the permeability test, Iranian PP700 was considered as the best synthetic envelope due to lesser changes of hydraulic conductivity and gradient ratio. In the study of drainage water salinity variations which have been obtained from soil- Iranian PP700 envelope combination, the main changes of drainage water salinity, due to the soil volume limitations in the permeameter apparatus, occurred in the first 24 hours. Furthermore, drainage water salinity decreased during other days of the test. By providing more dissolution opportunity as a result of the cyclic flow, the electric conductivity of drainage water increased immediately after applying the flow.

KEY WORDS: Subsurface drainage, Synthetic envelope, Physical clogging, Permeameter, Drainage water, Shadegan.

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Introduction

From the beginning of the 19th century subsurface drains have been installed to improve crop growing conditions in agricultural soils. Silts and fine particles are considered to be the problem in subsurface land drainage system with due regard to the risk of mineral clogging (Vlotman, 1998 and Skaggs et al., 2012). In order to achieve a better drain performance in reclamation projects, envelope materials are required. In the 1990's, gravel, prewrapped organic and synthetic fabrics (geotextiles) have become the most common drain envelope materials used to protect drain pipes from the entry of sediments. Geotextiles are preferred to granular envelopes, mainly for economic and environmental reasons and due to the fact that appropriate granular materials are often not available continuously or locally (Knops et al., 1979; Dierickx, 1980; Irwin and Hore, 1979; Eggelsmann, 1980; Stuyt et al; 2000). The need for a drain envelope depends primarily on the soil properties and the soil characteristics in the region where subsurface drainage is planned (Dieleman and Trafford, 1986). In general, for all projects in Iran the cost of material and transportation of synthetic materials is lower than the cost of gravel which nowadays is the most common material used as drainage envelop in Iran. The PLM envelopes are of a permeable structure composed of loose randomly oriented yarns, fibers, filament, grains granular or beads, around a corrugated drainpipe made by specialized companies. Most PLMs are manufactured from recycled material like polypropylene waste fibers from the carpet industry. Whatsmore, the increasing growth of petrochemical industries in Iran, provide the possibility of manufacturing these products in Iran. In order to select the most suitable drain-pipe envelope material, regardless of time consuming field tests, laboratory tests are the most optimal means due to the short duration and relatively low cost. Several experimental techniques can be applied to determine physical and hydraulic properties of synthetic envelopes (Hassanoghli, 2009). One of these laboratory experimental methods is the permeability test which is based on determining the soil -synthetic envelope system permeability and clogging behavior (ASTM, 1993).

Large-scale development of irrigation has taken place in many arid and semi-arid areas since the late nineteenth century. In many irrigated areas around the world, rising water tables have subsequently led to waterlogging and associated salinity problems. This has occured where drainage development has not been able to keep pace with irrigation development or where the maintenance of drainage facilities has largely been neglected (FAO, 2004). Salinization affects about 20–30 million ha of the world's 260 million ha of irrigated land. Water and soil salinity are two important limitations for agricultural production in arid and semi-arid regions (FAO, 2003). Soil degradation resulting from salinity is a worldwide environmental issue since it contributes to severe adverse impacts on agricultural productivity, especially in arid, semiarid and coastal areas (Qadir et al. 2007; Rengasamy, 2006). Saline soils can be considered to be highly degraded and least productive due to their simultaneous effect of salinity on soil physical, chemical and biological properties (Rengasamy and Olsson, 1991). Dispersed saline soils are compacted and have reduced water infiltration and hydraulic conductivity, which play a major role in water, air, and solute movement through the soil profile (Shainberg and Lety, 1984; Suarez et al., 2006). Gan et al. (2010), using the horizontal soil column infiltration method, proved that water diffusivity significantly increased when soil salinity increased. However, soil texture plays a major role in determining whether soil salt contents would significantly affect hydraulic properties (Dongli et al., 2014).

Drainage water management (DWM) is gaining popularity and being increasingly implemented in the Midwestern U.S. and has received considerable attention in the scientific literature (e.g., Adeuya et al., 2012; Breve et al., 1997; Fausey 2005; Gaynor et al., 2002; Jaynes 2012). Current estimates of land under DWM are not available; however, the implementation of DWM is increasing as a result of water quality concerns (Skaggs et al., 2012). Environmental and agronomical benefits are associated with controlled subsurface drainage such as yield boosts and reduced drainage pollution to the environment (Drury et al., 2006; Mejia et al., 2000; Ghane et al., 2012; Skaggs et al., 2012; Sunohara et al., 2014; Nash et al., 2015). Leaching of salts from root zone in saline soils is one of the most important DWM techniques to prevent excessive accumulation of salts that would limit the yield potential of crops (Letey et al., 2011). Concerning the evaluation of leaching soluble salts from soils profiles, Dileman and Trafford (1986), Hoffman (1980), Konuku et al. (2005) and Corwin et al. (2007) reported that the leaching of soluble salts is basically done by mass flow. Furthermore, Raj and Nath (1980) concluded that one unit volume of water is adequate for leaching a great deal (%90) of soluble salts from soil profile. Also in Iran Pazira and Homaee (2010) in Khuzestan plain, Rajabzadeh (2009) in central part of Khuzestan province, Mostafazadeh-Fard (2008) in Roudasht of Isfahan province, Rahimi (2005) in Kaveer Namak of Bajestan have had experiments on saline soils. Results for investigation of trend of saline soil improvement using leaching methods showed that using leaching process, soluble salts were washed away from soils profile of the agronomy programs and the salinity of the soil surface layer were reduced to a level suitable for cultivation of salt tolerant and semi tolerant plants). Comparing between two leaching methods in saline and sodium soils of Roudasht in Isfahan (Iran) and in his experimental condition, Mohammadi (1992) concluded that cyclic leaching is more effective in leaching salt (Mohammadi, 1991). Results of field experiments in Ramshir, Khuzestan to reduce the salinity and sodium level of soil, indicated that adding average 100cm water to soil, electrical conductivity was reduced from an average 27.03 to 16.93dS/m (Shabani et al., 2014). In addition, research shows that salinity level of the drainage water is high in the beginning of growing season. This is due to an imbalance between soil and irrigation water. So applying leaching before planting decreases clogging drainage envelope risk and reduce yield (Rajabzadeh et al 2009).

Further studies operate steady flow for leaching process to decrease soil salinity and comparison of cyclic and steady flow operation has been neglected in leaching studies. In this study, the soil and drainage water were collected from one of the drainage projects in south of Iran (Shadegan) which show significant salinity, to simulate real condition in permeability tests. In one hand, performance of three synthetic envelopes through common permeability test in accordance with ASTM D-5101 standard and saline soil of Shadegan drainage project (Khuzestan) was examined.

On the other hand, cyclic leaching operation according to irrigation regime was applied in order to analyze salinity variations of drainage water on the most suitable envelope.

Materials and methods

In the present study (from October to December 2012), permeability test was done for determining the soil-synthetic envelope system permeability and clogging behavior for cohesion less soils under unidirectional flow conditions (ASTM, 1993). The test requires setting up a cylindrical, clear plastic permeameter (figure 1) with a PLM and soil, and passing water through this system at varying heads. Measurements of heads and flow rates were taken at different time intervals. The changes in gradient ratio values with time versus the different system hydraulic gradients, and the changes in the rate of flow through the system were noted carefully. Soil-envelope permeameter equipped with support stand, soil-envelope support, Two Constant Water Head Devices, one mounted on jack stand (adjustable) and one stationary (figure 1).

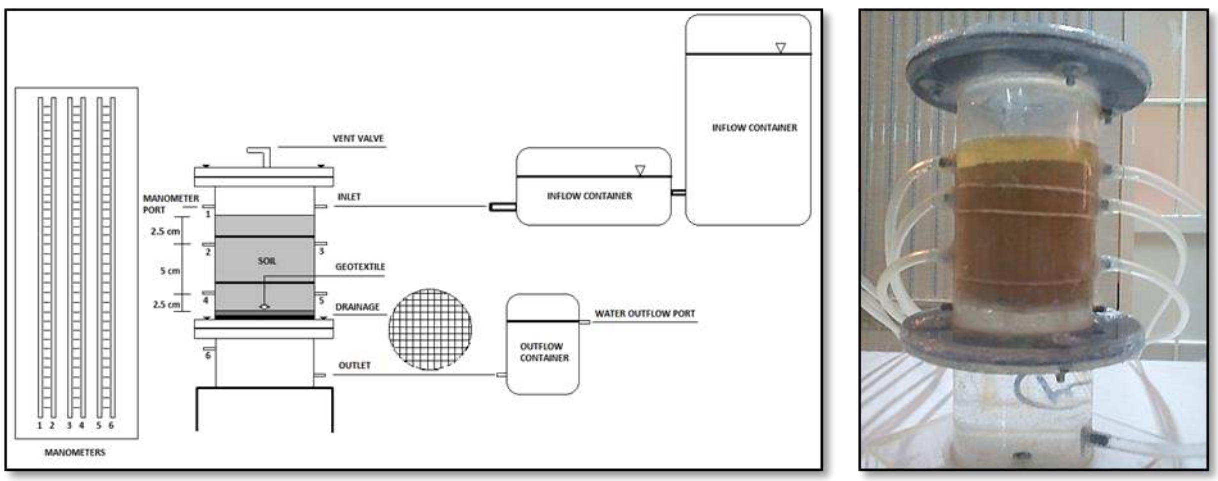


Figure 1. permeameter "set up" diagram (ASTM, 1993)

The values of hydraulic gradients used in these tests were established by moving up and down the inlet reservoir. Permeameter test was implemented in two main parts that are described below:

1. First of all, to select the most appropriate geotextile, the value of hydraulic gradients were equal to (1, 2.5, 5, 7.5 and 10) respectively. Tests were repeated three times for each envelopes, each time for a constant hydraulic head. Therefore, nine tests performed to choose the most suitable geotextile for Shadegan soil.
2. In the second part of examination, permeameter test was done during 32 days with the suitable envelope chosen in previous section in three repetitions. The simulation of cyclic leaching was adapted to irrigation regime for five days applying the flow and three days for pausing it. Electric conductivity of drainage water extracted from permeameter apparatus was measured during the test.

Envelope material

Three synthetic PLMs (pre wrapped loose material) which are permeable structure consisting of loose, randomly oriented yarns, and usually wrapped around the corrugated plastic drainpipes by specialized companies were used in present study. One circular specimen from each swatch was cut in the laboratory sample with the specimen having a diameter of 110 mm (4.33 in). Table 1 shows the properties of these three geosynthetics materials. In this research, Foreign PP450, Iranian PP450 and Iranian PP700 are called respectively as PP450 A, PP450 B, and PP700.

Table 1. Properties of geosynthetics materials

Mass variations (%)	Thickness (mm)	Mass per unit area (g/cm2)	Hydraulic conductivity (m/d)	O90 (μ)	Synthetic envelope
38.6	7.0	0.067	52.21	450	PP450 A
51.2	6.2	0.056	149.21	450	PP450 B
54.0	8.9	0.065	169.36	700	PP700

Test water and soil preparation

Test water should be maintained at room temperature about 16 to 27°C (60 to 80°F). Permeameter test should be done by non-saline water to obtain best suited envelope (Anon, 2006). Therefore, in this study all of the permeability tests were carried out by with normal water of EC: 0.7dS/m. Test water chemical properties are shown in table 2.

Table 2. Chemical properties of test water

SAR $(meq/lit)^{0.5}$	Nitrate (parts per million)	Anions $(meq/lit)^{0.5}$			Cations $(meq/lit)^{0.5}$				pH	EC (ds/m)
		SO_4^{2-}	Cl^-	HCO^{3-}	Ca^{2+}	Mg^{2+}	Na^+	K^+		
0.83	28	2.4	2.9	1.5	4.4	1.3	1.4	Negligible	7.52	0.7

Table 3. Physical and chemical properties of Shadegan soil

Soil texture	Sand (%)	Silt (%)	Clay (%)	Anions $(meq/lit)^{0.5}$			Cations $(meq/lit)^{0.5}$				SAR $(meq/lit)^{0.5}$	OC (%)	pH	ECe (ds/m)
				SO_4^{2-}	Cl^-	HCO_3^-	Ca^{2+}	Mg^{2+}	Na^+	K^+				
Silty clay	12	47	41	43	700	17	91	211	462	Negligible	37.6	0.71	7.25	76.2

According to soil properties shown in table 3, the EC of soil collected from south of Iran, was 76.2 dS/m. Shadegan soil is categorized as saline- sodic soil because of having EC more than 4 dS/m and SAR more than 13 $(meq/lit)^{0.5}$. For processing the soil the air dried (for 3 days) material passed through 10 mm (3.8 in.) and retained on the No.10 sieve was subjected to a second round of grinding to ensure that the sample has been broken down into individual grains. A representative sample weighing about 1300 g (or 3000 g for the 150-mm diameter drain pipe) was subdivided into four parts using a soil splitter, with one part to be used for the tests. Air-dried processed soil was placed above the support cloth to a depth of 103 mm (4.12 in.). The final depth of soil after settlement will be approximately 100 mm (4 in). The soil was placed carefully into the permeameter with appropriate tool in layers not exceeding 25 mm (1 in.) at a time until the total soil height of 103 mm (4.12 in.) was reached. Table 2 and 3 show the properties of water and soil used in experiments (ASTM, 1993).

Procedure

After fitting the constant head devise, the manometer tubes, the outlet tubes, overflow tubes to their corresponding permeameters, the geotextile-soil-water system was saturated. For the first step, the inflow level was adjusted to achieve a hydraulic gradient (i) of 1. Then flow was let in and the initial starting time was recorded and the following data at 0, 0.5,1, 2, 4, 6, and 24 h from the initial starting time were recorded : the time in hours (cumulative), the flow rate from the system; time in seconds (t) for a measured quantity of flow (Q) in cm3 (for a minimum duration of 30 s and a minimum quantity of flow of 10 cm3), the temperature (T) of the water in the system in 0C, the water level readings from the individual manometers. After the final reading when the system has stabilized, the inflow was raised to obtain next hydraulic gradient and measurements were repeated, and so on till i = 10. The test was run continuously (Anon, 2006). For the second step, the inflow level was adjusted to achieve two hydraulic gradient of 1 and 2.5 and all of measurements were carried out as previous step. In addition, drainage water salinity was obtained from measuring electric conductivity of water that was egressed from geotextile -soil system. It is necessary to mention that each test of two steps repeated three times. According to soil texture and infiltration rate of irrigation water that was suggested in previous researches in Shadegan drainage project, it was considered to flow water for five days (simulation of irrigation) and pause it for three days (Esmaeili et al., 2011). After every manometer reading, drainage water sample was taken from the lowest inlet port which was located exactly under the soil column. Thus, water sample gathered from this port passed whole soil volume and is an appropriate drainage water sample (figure 2).

Figure 2. Sampling the drainage water extracted from the apparatus

Calculation

Hydraulic gradient (i): The hydraulic gradient was Calculated as follow (ASTM; 1993)

$$i = D\,h/L \quad (1)$$

Where, D h = difference in manometer readings for soil zone analyzed, manometer 1 minus manometer 6, cm, and L = length or thickness of soil between manometers being analyzed, cm

System permeability (k): the system permeability was obtained at the temperature of the test and corrected to 20°C using Eq (3).

$$K_T = \frac{v}{i \times t \times A \times 100} \quad (2)$$

$$K_{20} = \frac{K_T \times \mu_T}{\mu_{20}} \quad (3)$$

Where:

K_T=system permeability at test temperature, m/s,

K20 = system permeability at 20°C, m/s,

Q = quantity of flow measured, cm3,

i = hydraulic gradient of the system,

A = cross-sectional area of the specimen, cm2,

t = time for measured quantity of flow, s,

μT = water viscosity at temperature of the test, and

μ20 = water viscosity at 20°C.

Gradient ratio: For each hydraulic gradient the gradient ratio, GR, was reported for the system using Eq. (4) and data for the final time interval used, Shows the meaning of the values in the equation schematically.

$$\Delta h_s = \frac{(M_2 - M_4) + (M_3 + M_5)}{2} \tag{4}$$

$$\Delta h_{SF} = \frac{(M_4 - M_6) + (M_5 - M_6)}{2} \tag{5}$$

Mn = the manometer reading, cm, for the manometer numbered n.

L_s= 5.10 cm (2 in.), and

L_{sf} = 2.55 cm (1 in. + the specimen thickness)

Experimental site layout

Shadegan plain is a flat drainage network of 2500 ha field which is located in south of Iran in Khuzestan province. The highest and lowest level of this land are seven and two meters above sea level. Its average slope is too low and equal to 0.0005. The drainage network is positioned in semi-arid region with wheat as the dominant cultivation. According to consulting engineers studies, drainage pipes installed in depth of 1.7, distance of 50 meters with lateral length of 220 to 230 meters (figure 3). Also, drainage pipes diameter is equal to 125 mm which are made of PVC materials (Hassanoghli et al., 2013).

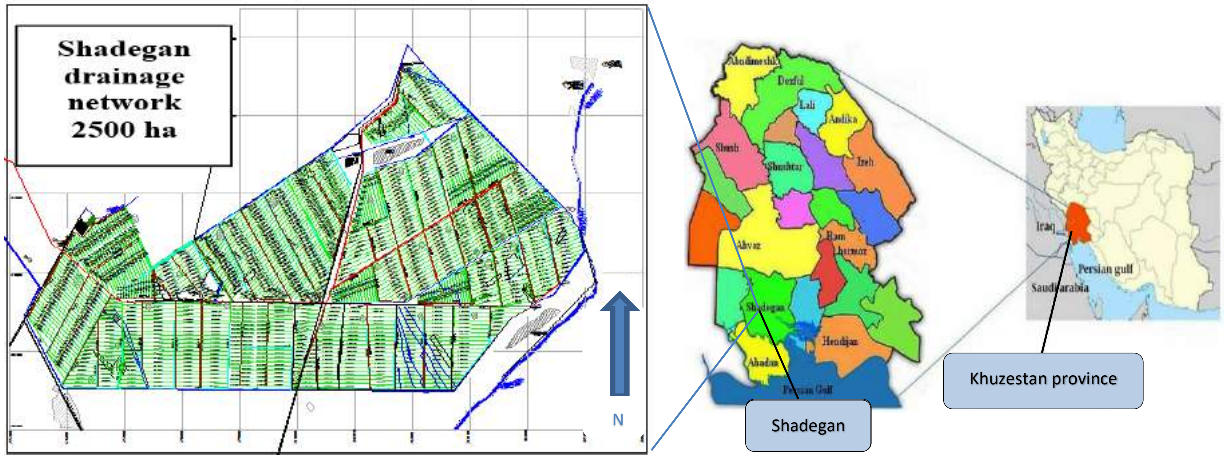
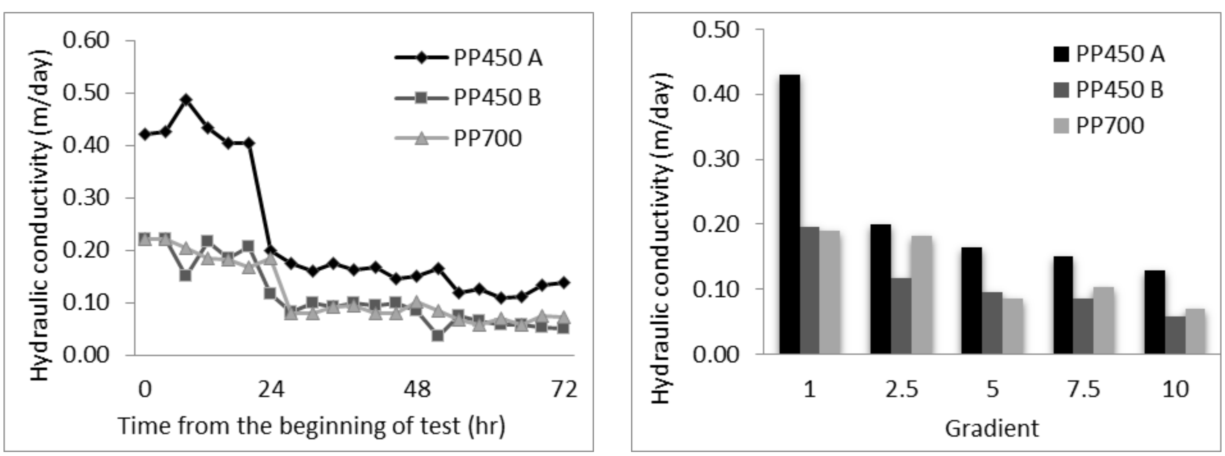


Figure 3. Geographical location of Shadegan drainage network in Khuzestan province

Results and discussion

Selecting the most appropriate geotextile

Considering hydraulic conductivity variations in figure 4, it is obvious that this parameter is high at the beginning of test and gradually decreases by passing time and increasing hydraulic gradient. The average of hydraulic conductivity for PP450 A, PP450 B, and PP700 in gradient 1 respectively is equal to 0.43, 0.2, and 0.19 meter per day, in gradient 5 is 0.16, 0.09, and 0.09 meter per day, and in gradient 10 is 0.13, 0.06, and 0.07 meter per day.

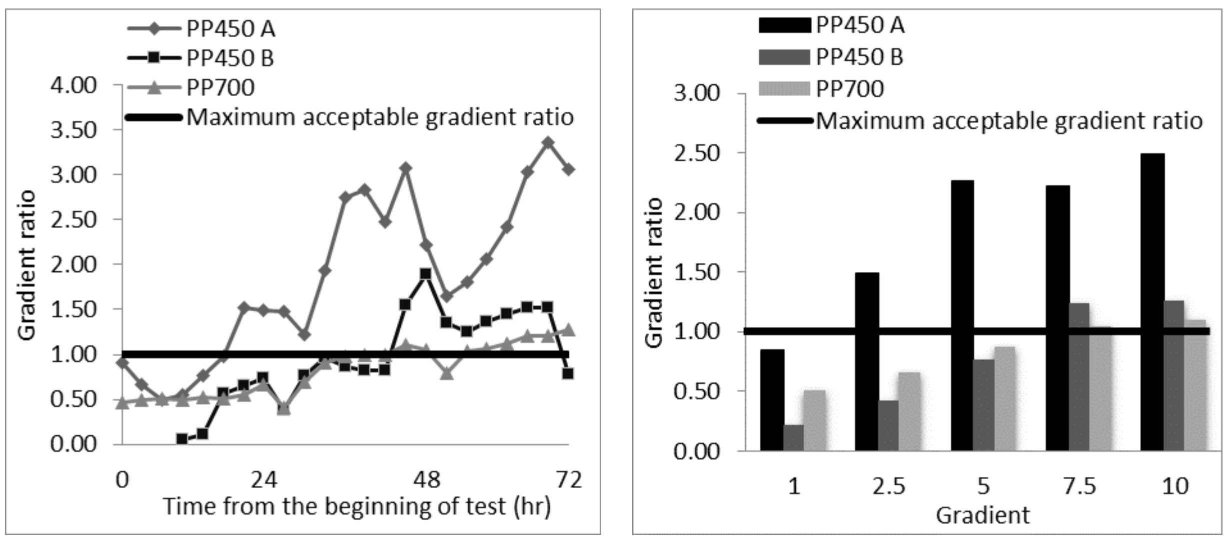


A B

Figure 4. variations of hydraulic conductivity versus time (A) and versus gradient (B)

Increasing gradient and passing time leads to a decrease in hydraulic conductivity. This phenomenon is as a result of displacement of fine particles of soil into pores and even geotextiles. In addition, pressure caused by high gradients leads to geotextile clogging and subsequently hydraulic conductivity decrease.

Results of comparing three envelopes operation show that the hydraulic conductivity of PP450 A in all gradients is higher than both. Furthermore, the average of the hydraulic conductivity from high to low for PP450 A (0.214 m/d), PP700 (0.126 m/d), and PP450 B (0.112 m/d) have been obtained respectively. The Results of the hydraulic conductivity of the geotextile- Shadegan soils are similar to another research in the Khoramshahr region (Pedram et al., 2011). Moreover, according to the above mentioned results in figure 4, the hydraulic conductivity of PP700 has greater uniformity than PP450 A and PP450 B. ; thus its function during the beginning period of agricultural lands operation has less risk.



A B

Figure 5. variations of gradient ratio versus time (A) and versus gradient (B)

Results shown in figure 5 demonstrate the fact for all geotextiles the hydraulic gradient increases lead to the increment in the gradient ratio. Based on the soil characteristics particles transfer into geotextile and pores as a result of water head increase, and thus envelope clogging potential increases.

The average of the gradient ratio for PP450 A, PP450 B, and PP700 in gradient 1 is equal to 0.84, 0.22, and 0.51, in gradient 5 is 2.25, 0.77, and 0.87, and in gradient 10 is 2.48, 1.26, and 1.1 respectively. Therefore, the minimum gradient ratio and maximum gradient ratio are obtained respectively from PP700 and PP450 A. The gradient ratio amounts of PP450 A are not in the acceptable range and this is a sign of geotextile clogging. The comparison of the function of the two other geotextiles, PP450 B and PP700 are nearly equal for gradients 1 and 5. While, PP700 has a lesser amount of gradient ratio in hydraulic gradient 10 than PP450 B. So, gradient ratio of PP700 has further uniformity than PP450 B.

Evaluation of drainage water salinity by means of the cyclic flow

In most repetitions from both gradients of 1 and 2.5, the electric conductivity variations versus time are the same as shown in figure 6. Drainage water salinity is represented in the graph is low at the beginning of test and is 2.2 ds/m. Following that, the passing of more volume of water from the and the soil column, electric conductivity of water extracted from apparatus increased considerably. Afterwards, the EC of the obtained samples'were reduced as a result of continuing the test. Eventually, because of the limited volume of soil in the permeameter and continuous inlet flow, the main salinity changes to drainage water occurred during the initial 24 hours of the test. Therefore, water quality had no significant variations from the second day of the test.

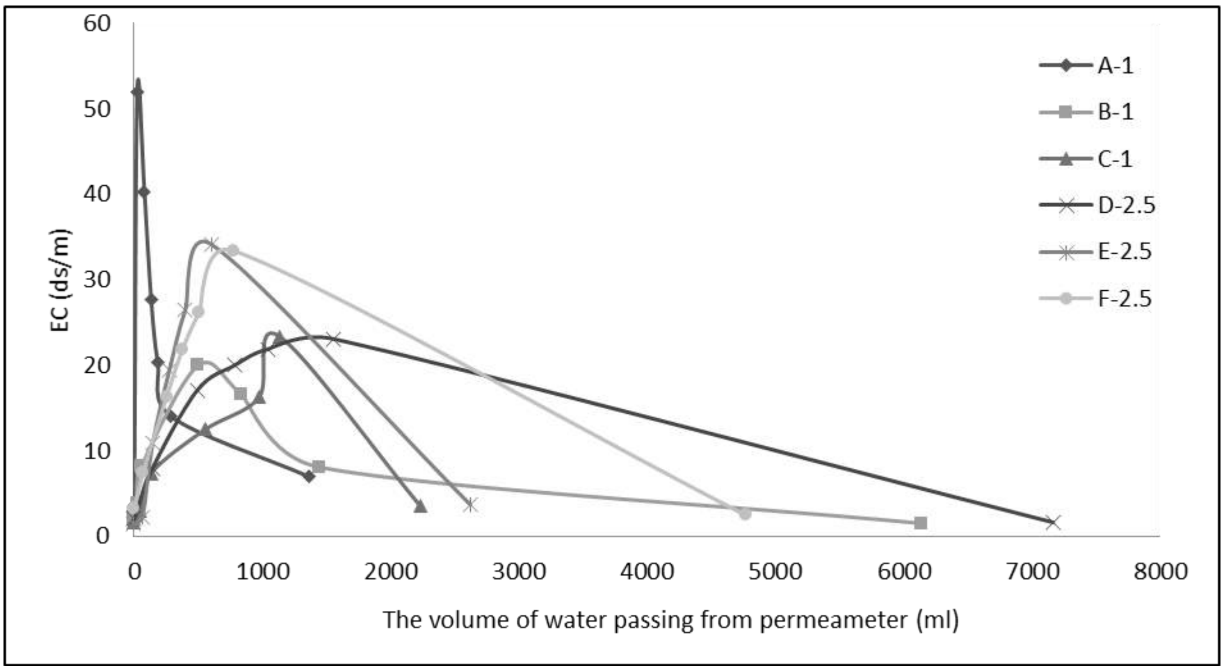


Figure 6. Electric conductivity changes versus the volume of water passing from permeameter (every gradients of 1 and 2.5 with three repetitions) during primary 24 hours

According to the results portrayed in figure 7, it is agreed that applying a cyclic flow might change the leaching process and water drainage quality. The Maximum changes of drainage water salinity occured in the initial 24 hours of test. This amount then reduced until the pausing of the flow and the the desisting of irrigation for three days, where it was observed that soil salts solubility increased. Therefore, after re-applying the flow, drainage water salinity increased after being applied for five days. Finally, test results illustrate that the salinity of drainage water decreased during the test as a result of the leaching process in general and increased slightly in the alternating flow. Thus, by applying cyclic flow , the leaching process will be done more quickly. Eventually, the upward growth of Drainage water EC is directly connected to the water drainage volume outflow from apparatus and the time required for the dissolution of soil minerals. In this test, due to the limited soil volume in the permeameter, leaching operations occurred over a short time.

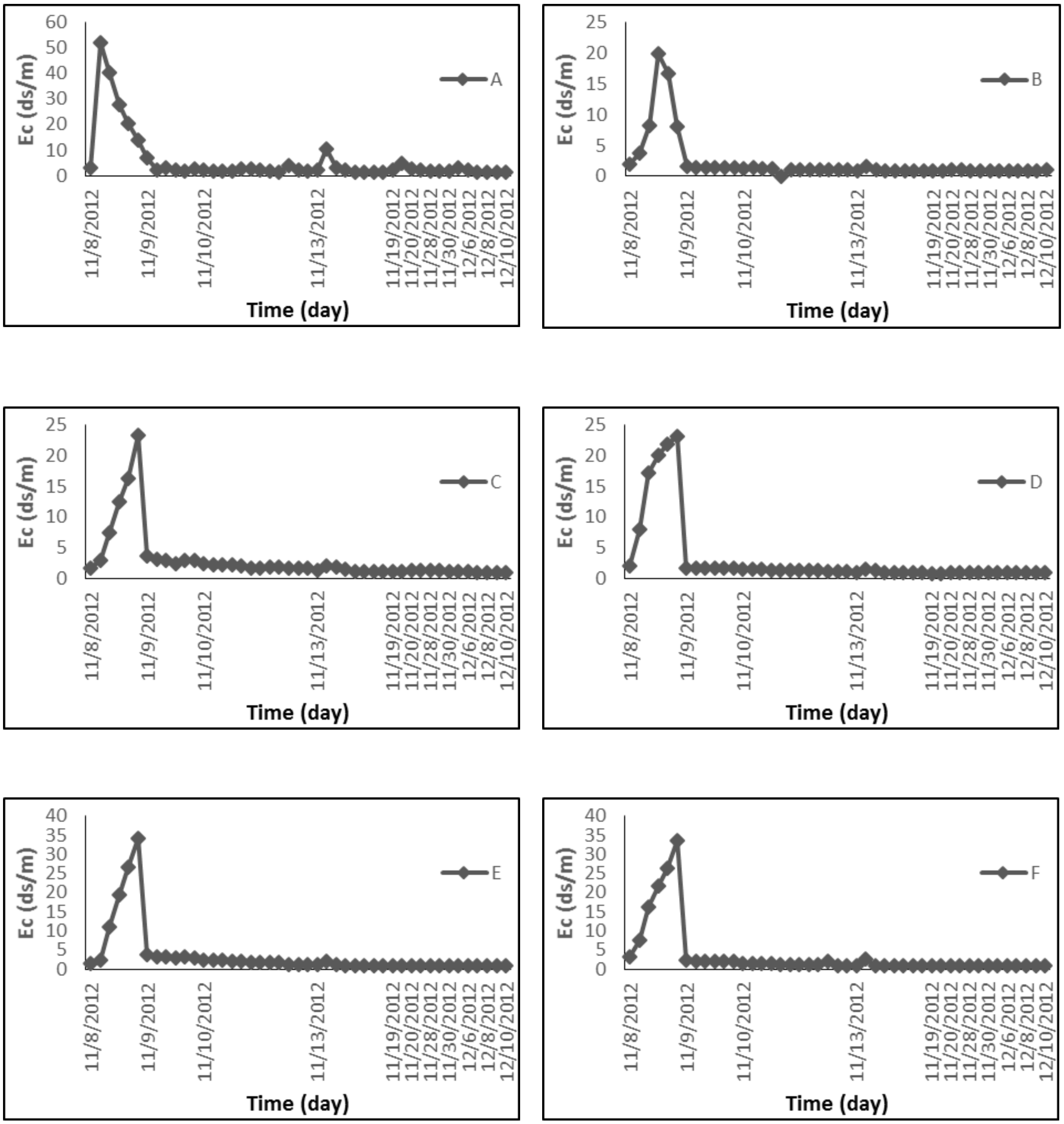


Figure7. Variations of water drainage electric conductivity versus time (A, B, and C for gradient 1 and D, E, and F for gradient 2.5)

Conclusion

The main conclusions of this research are described below:

- ✓ According to ASTM D5101, two geotextiles of PP450 B and PP700 are appropriate for Shadegan soil and even PP700 is more suitable as a result of having higher hydraulic conductivity and lower variation range in both hydraulic conductivity and gradient ratio.
- ✓ By applying the cyclic flow (similar to the irrigation process), leaching will be done more quickly than constant flow due to the increase in the time required for the dissolution of soil minerals

Acknowledgement

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APPLICATION AND EFFICIENCY OF DIFFERENT DRAINAGE TYPES ON IRRIGATED LAND IN UKRAINE

D. Savchuk[1], O. Babitska[2,*], O. Kharlamov[3]

Abstract

The processes of farming lands and settlement flooding are very wide spread in the south of Ukraine. These processes are accompanied with an increase in the ground water levels and thus create a lot of harmful effects.

Different types of drainage systems are widely used to protect rural areas from flooding. More than 400 thousands of hectares of horizontal type drainage systems have been constructed in irrigated areas and more than 200 thousands of hectares of vertical type drainage systems have been constructed. In addition, drainage systems of different types were built.in more than 550 settlements,

During field investigations authors have estimated a high efficiency and operational reliability of gravity type horizontal drainage systems and unstable working modes of vertical type drainage systems due to its discreet working regime.

As an example, the project for a drainage system for the village of Nova Mayachka was developed taking into account experience in the design, construction and operation of drainage systems to solve the issues of flooding. In recent years this village suffered the most from flooding. The existing engineering system in the village consists of 20 wells of vertical drainage, which were made for the intake and removal of ground water, but they do not insure the removal of surface water.

This system has recently provided a number of measures aimed at removing surface and ground water by means of the constructing of new open horizontal drainage systems, artificial ponds and closed discharges of drainage water to water lowering wells in the existing vertical drainage system. The project was developed taking into account the maximum use of the existing system of vertical drainage and the existing system of surface water removal in vicinity of the settlement.

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Such drainage system construction will insure an essential increase of village security level from the harmful effects of flooding; reduce the drainage discharge and expenses for electricity to pump water out.

KEY WORDS: Flooding, groundwater levels, Drainage systems, Efficiency, Correlation.

Introduction

Underflooding of agricultural lands and rural settlements is substantially widespread in Ukraine. It is accompanied by the raise of groundwater levels and stipulates different negative processes. Drainless territories on which large volumes of surface water are accumulated in wet periods especially suffer from underflooding that transforms here into stable and long lasting phenomena.

Drainage systems in the country are located in different regions and have an area of about 4 mln.ha, from which 3,3 mln.ha are located in humid zone, 0,6 mln.ha – in the zone of irrigation and 0,2 mln.ha – in the zone influenced by Dnieper reservoirs (fig. 1). The largest number of drainage systems is located in western, northern and southern regions [Savchuk D.P., Babitska O.A., Maliuha V.V., 2015].

Long term of operation (30-50 years) and insufficient financing of maintenance activities in the period of economic crisis starting from 1991 lead to worsening of drainage systems technical conditions and lowering of their efficiency. In the same time, large part of drainage units has normal operation conditions and still have an ability for long time functioning.

Modern conditions of existing drainage systems functioning necessitate assessment of their state, determination of reconstruction volumes, modernization and application of more efficient protective measures.

To solve the problems, comprehensive research has been conducted in the massifs of horizontal and vertical drainage in Kherson region (Inguletsky and Northern-Crimean irrigated massifs) in which efficiency of different types of long term operation of drainage systems has been assessed and means and measures that improve their efficiency has been determined [Demchenko O., 2007].

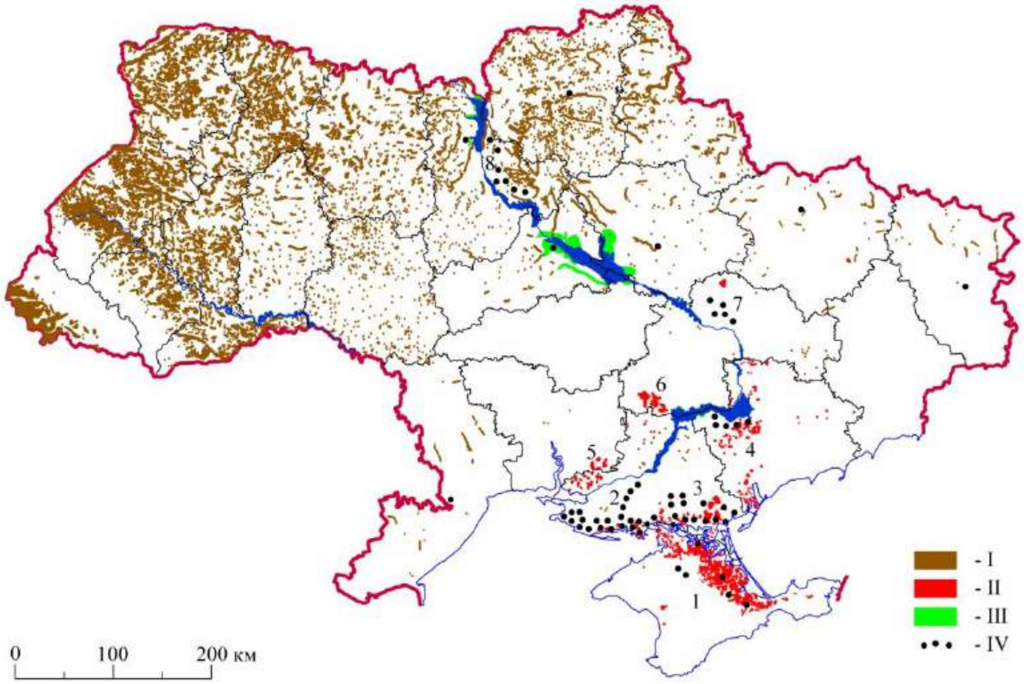


Figure1. Drainage systems location scheme:

I – overmoistured lands; II – irrigated lands; III – Dnieper reservoirs; IV – vertical drainage; irrigation massifs: 1 – Crimean, 2 – Krasnoznamiansky, 3 – Kakhovky, 4 – Pivnichno-Rohachytsky, 5 – Inguletsky, 6 – Kryvoriz'ky, 7 – Frunzensky, 8 – Bortnytsky

Mathematical relationship between groundwater levels and atmospheric precipitation has been determined as a result of the researches.

It was established that, in the regional scale, maximal groundwater level increase is observed in the spring almost every year. It indicates substantial influence of atmospheric precipitations in winter and spring on groundwater levels.

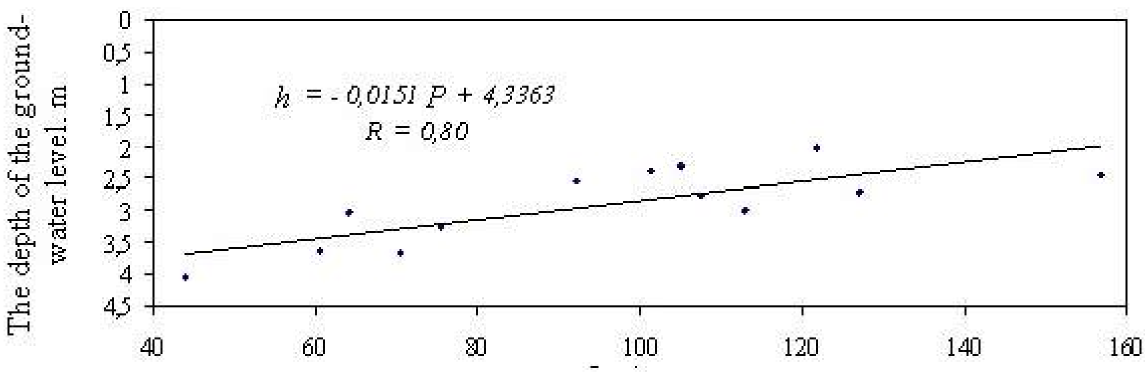
Statistical methods were used to establish correlations between water regime and factors it is determined with. Such methods can be used for steady state ground water regimes typical for irrigated massifs with relatively stable irrigational and economic conditions [Bishoff E. A. and others, 1977; Kats D.M., 1967].

Correlation was determined between independent variable – regime factor P (precipitations, mm) in the considered case, and dependent variable h (groundwater level, m).

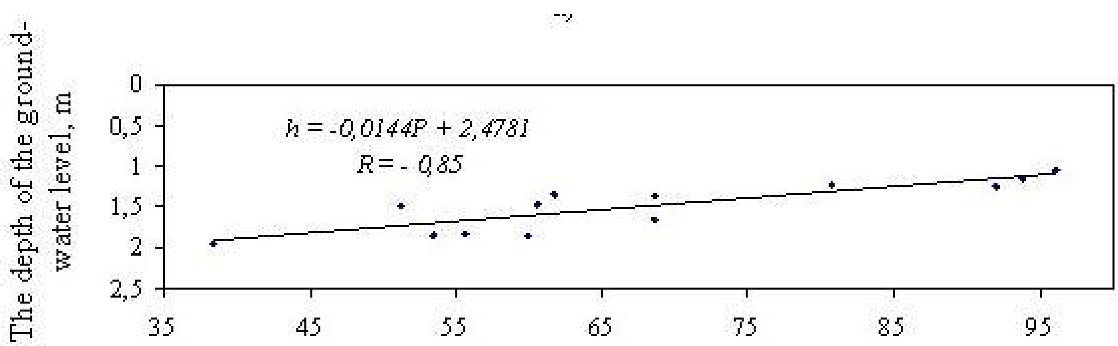
Observation data about ground water levels in observation wells in the period between 1995 and 2008 was used in the calculations.

As the largest values of groundwater levels are observed in the spring, monthly averaged values for March was used to determine correlation. Precipitations sum was calculated for three winter months – December, January and February.

As the result of processing long term observation, correlation between precipitations and groundwater levels (fig.2) was established. Established relationship type is linear negative correlation which implies that increase of precipitations leads to increase of groundwater level (on 0,5–2,0 m).



a)



b)

Figure2. Regression relationships between groundwater levels in the spring and winter and spring precipitations: a – on the areas with horizontal drainage; b– on the areas with vertical drainage

Coefficient of correlation varies from 0,62 to 0,80. Comparison of correlation coefficient values with theoretically predicted ones shows significant relationship between groundwater levels in the spring and winter precipitations.

It was determined that on vertical drainage systems, groundwater levels in the spring vary from 0,5 to 2,0 m (that is higher than critical depths and drainage rates). This can be explained as a consequence of discreet vertical drainage working regime that do not give an ability to use entire available potential and do not insure persistent drainage of territories [Romashchenko M.I. and others, 2007; Demchenko O., 2007].

In general, it can be stated that winter atmospheric precipitations are a powerful factor of underflooding processes development in the spring even if drainage is present.

On the base of generalized materials of performed researches, the complex of measures has been developed to protect the settlements of the south of Ukraine and nearby territories that suffers from flooding [Savchuk D.P. and others, 2012; Babitska O.A., 2009, Kuzmin V.V. and others, 2011]. Protection complex includes creating local systems of surface water removal, modernization of present vertical drainage system, horizontal drainage construction, and consecutive transition to modern water saving irrigation methods (drip irrigation, micro-sprinkling). This complex of measures is proposed for the following settlements in Kherson region: Nova Mayachka, Skadovsk, Henichesk (fig. 3, 4, 5).

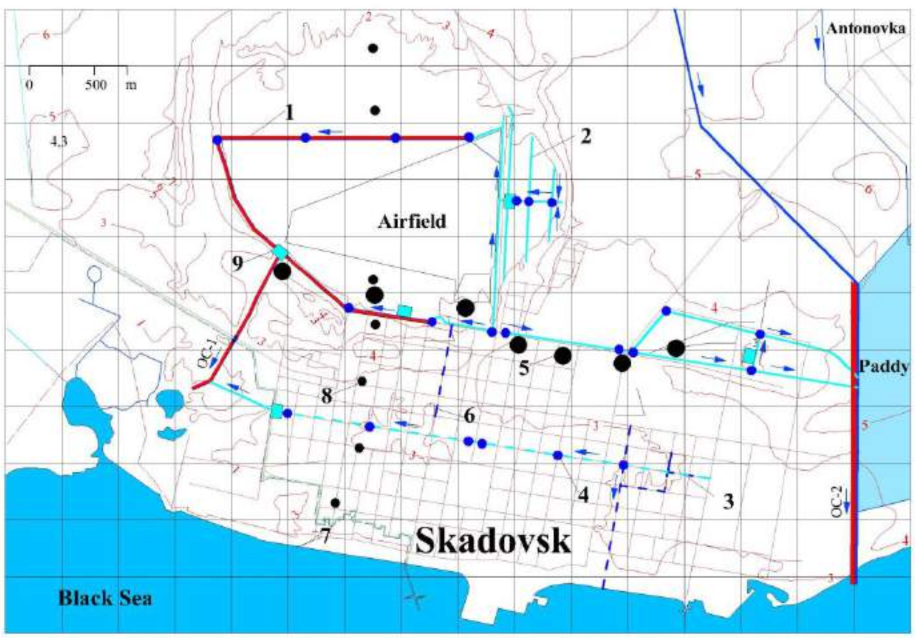


Figure3. Drainage system in Skadovsk town:

1 – open spillway canals, 2 – network of drainage collectors, 3 – closed horizontal drains, 4 – water absorbing wells, 5 – vertical drainage wells, 6 – storm water collectors , 7 – catch-water (sea), 8 – wells for monitoring ground water level, 9 – artificial water bodies.

Protective system of Skadovsk town provides creating open spillway canals that insure surface and drainage water removal. Network of drainage collectors insures interception of ground and surface water. Collector with a drain combines functions of surface and drainage water removal to narrow areas of alienated lands. Closed horizontal drains insure interception of ground water flow. Combined drainage of self-flowing type reinforces draining effect of collector network. Arrangement of drainage intake wells allows converting surface water flow into underground. In the case of high flow intensity, excess water is pumped in the drainage network, the network of collectors and storm water drains. Water intake wells can be arranged in households located in the zones affected by flooding. Vertical drainage network operation in persistent mode is performed to lower ground water level and pressure. Development of towns' storm water collection system insures arrangement of surface water flow while reconstruction of drinking water supply system and development of sewer network lowers water losses. Monitoring of flooding processes is done using monitoring wells while artificial water bodies insure additional accumulation and partial detoxification of surface water.

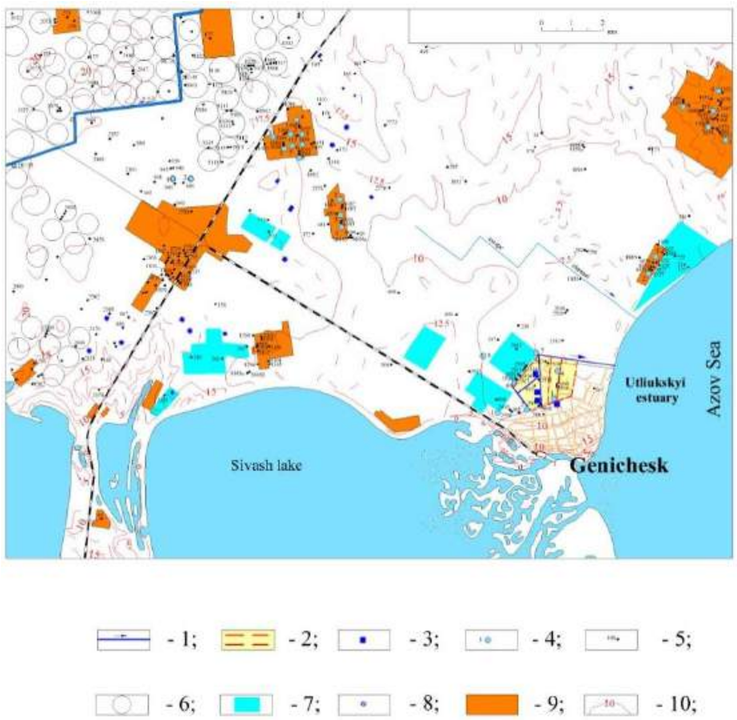


Figure4. Situational scheme of flood protection system located in Henichesk town and nearby territory:

1 – system of self-flow water removal collectors with drains (projected), 2 – system of closed horizontal drainage, 3 – nature conservational water body; 4 – vertical drainage wells, 5 – monitoring wells, 6 – irrigation systems («Fregat» sprinklers), 7 – local (small scaled) irrigation; 8 – artificial water bodies, 9 – settlements, 10 – relief contours.

Complex of measures for Henichesk town and nearby territories provides building of Jaroshyns'ky main and side self-flow collectors, construction of closed horizontal drainage system, restoration and development of vertical drainage and storm water collection systems, replacement of old water supply systems, creating means for hydroecological monitoring of territory state. In the lowest places along the collector, arrangement of artificial evaporation pounds that in the same time function as nature conservation complexes for steppe landscapes is planned.

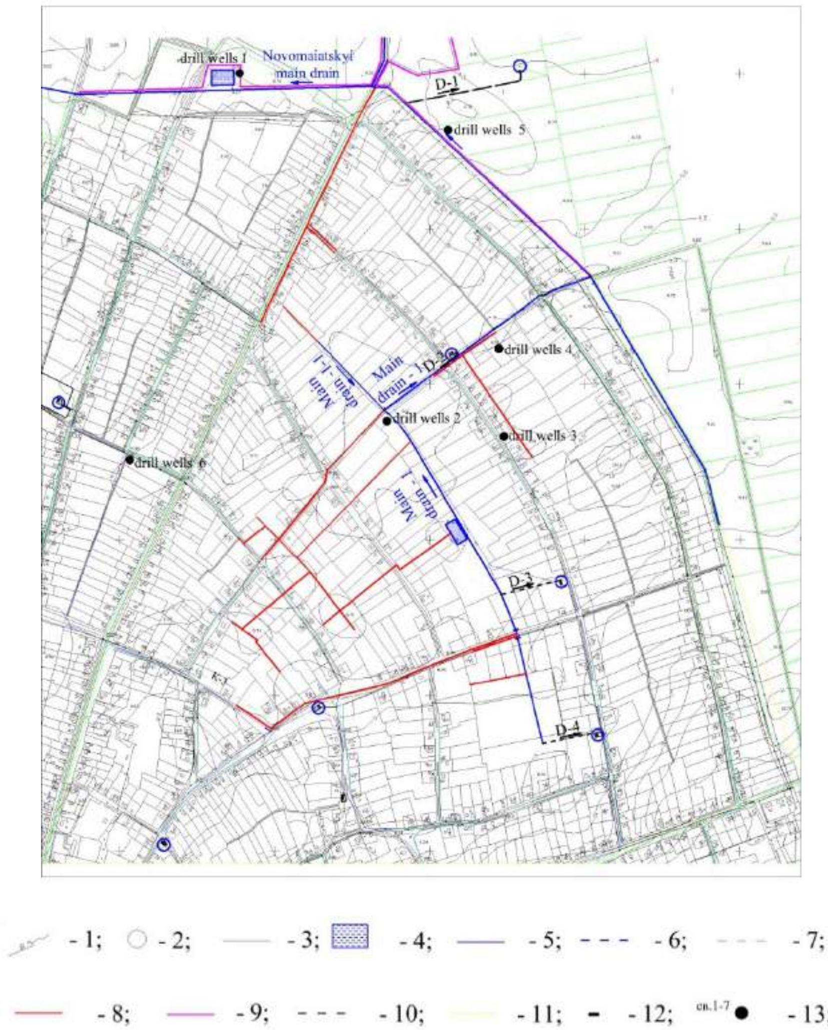


Figure5. Horizontal drainage system in Nova Mayachka 1 – relief contours and levels; 2 – vertical drainage wells; 3 – pressure pipelines; 4 – artificial water bodies; 5 – main open collector (Novomayatsky main collector, MC – 1, MC - 1-1); 6 – main closed collector (MC - 1), 7 – closed drainage collector (D-1 – D-4); 8 – water removal trenches and ditches; 9 – embankment; 10 – drain to inset into water lowering well; 11 – boundary of area of protection from harmful water effects; 12 – pipe crossing; 13 –drilled wells.

Horizontal drainage system on the territory of Nova Mayachka is arranged in the northern part of the settlement which hypsometrically is the lowest and suffers the most from flooding. Horizontal drainage systems include catch-water, Novomayatsky main collector - MC, main collector - MC-1, collector - MC-1-1, water removal trenches. A peculiarity of the drainage system consists in the fact that water lowering wells of existing vertical drainage systems work as catch-waters. Novomayatsky main collector is an open canal built in the central part of Novomayatsky drainless depression (valley). Embankment with the height equal to 1,5 m have to be constructed on the right side of the canal. Embankment catches surface flow from the other part of Novomayatsky depression and does not admit flooding of settlement territory. Water volume that floods the settlement drops by a half in this case.

Construction of such protection complexes insures substantial increase of the level of settlements and nearby territories protection from flooding along with lowering of drainage flow and expenses spent on electricity needed for forced water removal.

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GROUNDWATER MAPPING WITH GEOSTATISTICAL METHODS: THE CASE OF MANISA SALIHLI

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Abstract

Groundwater mapping using classical methods may take months and even years based on the size of the area to be mapped. However, recently developed methods decreased the time consumed for such mapping practices to minutes. Geostatistical methods are the most commonly used methods for groundwater mapping over large areas in a short time. In the present study, groundwater levels were measured using groundwater wells opened in 9101 in a 2 ha net irrigation area under the jurisdiction of Salihli Right Bank Irrigation Association located within the boundaries of the Manisa province of Turkey (between 38° 30' – 38° 37' East Longitudes and 28° 00' – 28° 16' North latitudes of Gediz basin of Aegean region). Measurements were made in September, which is the most critical month for groundwater levels. Groundwater levels were assessed through geographical information systems (GIS) and geostatistical methods. Then, spatial distribution maps were created for groundwater levels and geostatistical methods were compared. Current findings revealed that groundwater levels in the North Western section of the irrigation district was closer to plant root regions and created a threat for sensitive plants in 2003. By the year 2015, groundwater levels were 150 cm or deeper. Such levels indicated efficient operations of drainage systems and high irrigation efficiency levels. Leaching and salinity monitoring were recommended for the study area.

KEY WORDS: Ground water, Geostatistics, Manisa Salihli.

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Introduction

Water scarcity is among the most significant problems experienced by world countries. All human activities more or less depend on quantity and quality of water. Increasing demands for fresh water resources brought together comprehensive assessment of potential water resources and efficient used of current resources. Groundwaters can provide a significant alternative resource for fight against present droughts and optimum use of limited water resources. In irrigated fields, beside groundwater tables, salinity should also be monitored, assessed and salinity levels should be kept below threshold values for sustainable agriculture. Monitoring groundwater quality and quantity with classical methods is a quite time-consuming and costly process. Together with developing technologies, various new methods have recently been developed for groundwaters monitoring and assessment. However, it is quite significant to get accurate data in short time. Groundwater mapping with conventional methods may take days, even months, just based on the size of the land to be mapped. However, newly developed methods may reduce the time to map such lands to minutes. The methods to be sued in groundwaters maps, especially the geostatistical methods, are directly related to accuracy of the maps to be used. Geostatistical approaches present spatial distribution of relevant parameters and they are quite convenient to map spatial distribution of groundwaters levels and quality parameters. Geostatistical methods can present the relationships among the investigated parameters and the relationships in their spatial distributions with less cost and time. Such methods are employed in various disciplines. They may estimate the parameter value of unsampled locations and may create estimation maps accurately and reliably.

Soil physical, chemical and biological characteristics can vary spatially even within couple meters. Identification of such spatial changes and distributions is a quite significant issue in agricultural productions. Changes or variations in soil characteristics may result in differentiations in resultant yields even with the same cultural practices (Mulla and McBratney, 2000; Jiang et.al., 2006).

Classical statistical methods may not be sufficient in assessment of spatial variations in data obtained from different sections of the field since sampling locations are not taken into consideration in variance and standard deviation calculations of classical methods. To overcome this problem, Matheron developed the concept of “local variations” in 1960s. The model was first applied in mining to identify the reserve sites and the method was later on called as “Geostatistics” (Köksal, 1988; Gündoğdu, 2004). Geostatistical methods were initially employed in geological sciences, then widespread in other science disciplines. Carlson and Osiensky (1998) used geostatistical methods to determine spatial nitrate distribution in groundwaters of Northern Idaho (Gündoğdu, 2004).

In geostatistics, the similarity between the data of two points decreases as the distance between them increases and the ultimately disappear after a certain distance (Erşahin, 1999). The knowledge on such a distance with similarities between data points may provide significant advantages in agricultural and scientific practices (Akbaş, 2004).

Kriging is a geostatistical approach and provide the least variation and unbiased results as compared to other interpolation methods. It allows also the calculation of standard deviations for estimations (Deutsch and Journel 1992, Abtew et.al., 1993, Başkan 2004). As compared to again other interpolation methods, the most significant characteristics of kriging is to calculate variation for each estimation points or area. With kriging variance, the error in estimation is also assessed (Tercan and Saraç, 1998). If the kriging variance is lower than the actual variance, then the data estimated for unsampled location can be assumed to be reliable (Başkan, 2004).

In present study, water table levels of Salihli Right Bank irrigation scheme were assessed through geographical information systems and geostatistical methods. Spatial distribution maps were created with relevant methods, geostatistical methods, interpolation methods and Semivariogram/covariance methods were compared and the best geostatistical method was decided for groundwaters or water table mapping.

Materials and Methods

Study Area

The irrigation district of Manisa Salihli Right Bank Irrigation Association located in Gediz Basin of Aegean Region between 38° 30' - 38° 37' East Longitudes and 28° 00' – 28° 16' North latitudes were selected as the study area (Figure 1).

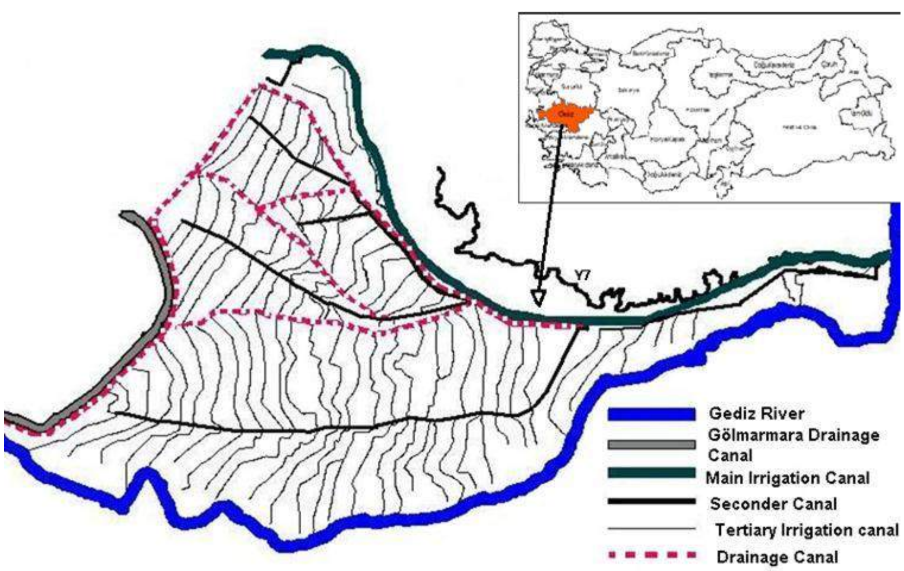

Figure 1. Map of study area

The irrigation scheme was opened for operation in 1963. Earth tertiary canals were concrete paved in 1968. Drainage canals were completed in 1984. Demirköprü Dam over Gediz River is the primary water resource of the scheme. Total canal network is 718 km, net irrigation area is 9101.2 ha. Irrigation canal length per unit area is 32.3 m/ha, drainage canal length is 12 m/ha (Tekiner, 2008). There are 18 different soil series within the study area. With regard to soil characteristics, 9.2% of soils were 2nd class, 22.9% were 3rd class, 57.9% were 4th class and 10% were 5th class (Usul and Bayramin, 2004).

Climatic Characteristics of the Basin

Study area has a humid or semi-humid climate with hot and dry summers and warm winters. Long-term meteorological data (1960-2015) for the study area are provided in Table 1. Annual average temperature is 16.6°C, average maximum temperature is 23.1°C, average minimum temperature is 10.2 °C. Average relative humidity is 62.5% and wind speed is 1.5 m/s. Annual precipitation is 457.9 mm. December has the greatest precipitation with 75.6 mm and August has the least precipitation with 4.8 mm. Annual average open water surface evaporation is 1262.2 mm (Anonymous, 2016).

Table 1. Meteorological data for study area (1960-2015)

Months	Average Temperature (°C)	Average Maximum Temperature (°C)	Average Minimum Temperature (°C)	Average Relative Humidity (%)	Average Total Precipitation (mm)	Average Wind Speed (m/s)	Average Open Water Surface Evaporation (mm)
January	6.4	11.2	2.4	74.6	66.1	1.4	1.1
February	7.5	12.7	3.1	70.6	61.3	1.5	
March	10.5	16.5	5.0	66.8	54.3	1.6	2.5
April	15.3	21.7	8.9	61.5	40.7	1.6	96.8
May	20.6	27.6	13.1	56.0	28.4	1.7	162.7
June	25.2	32.4	16.8	50.0	18.0	1.8	215.7
July	27.5	35.0	19.0	49.9	5.6	1.9	254.1
August	26.9	34.7	18.5	52.1	4.8	1.8	235.2
September	22.6	30.5	14.6	56.2	15.0	1.5	159.9
October	16.9	24.3	10.6	65.3	30.7	1.2	94.8
November	11.5	17.9	6.4	71.5	54.5	1.1	32.3
December	7.9	12.8	3.9	75.6	78.5	1.3	7.1

Irrigation and drainage water quality

Analyses results for water samples taken from main irrigation and drainage canal are provided in Table 2. Based on US Salinity Lab classification system, main irrigation canal water was classified as C_2S_1 and drainage canal water was classified as C_3S_1. According to Ayers and Westcot (1994), irrigation water does not have any problems, but drainage water may exert salinity and toxicity problems, there were not any problems with regard to infiltration and pH.

Table 2. Irrigation and drainage water quality analyses

Analyses	Main Irrigation Cana	Main Drainage Canal
pH	7.33	7.84
EC (dS/m)	0.56	1.34
Sodium Absorption Ratio (SAR)	0.75	3.85
Sodium (me/l)	1.16	7.25
Chlorine (me/l)	0.80	1.90
Calcium (me/l)	2.22	3.43
Magnesium (me/l)	2.57	3.67

Groundwater measurements

For reliable measurements, 40 groundwater observation wells should opened in 1000 hectare and 100 wells should be opened in 10 000 hectares (Güngör and Erözel 1994). By the year 2003, there were 81 wells opened the study area, but reliable measurements were able to be performed only 35 of them. The number further decreased to 19 in 2015. Locations of groundwater monitoring wells are presented in Figure 2.

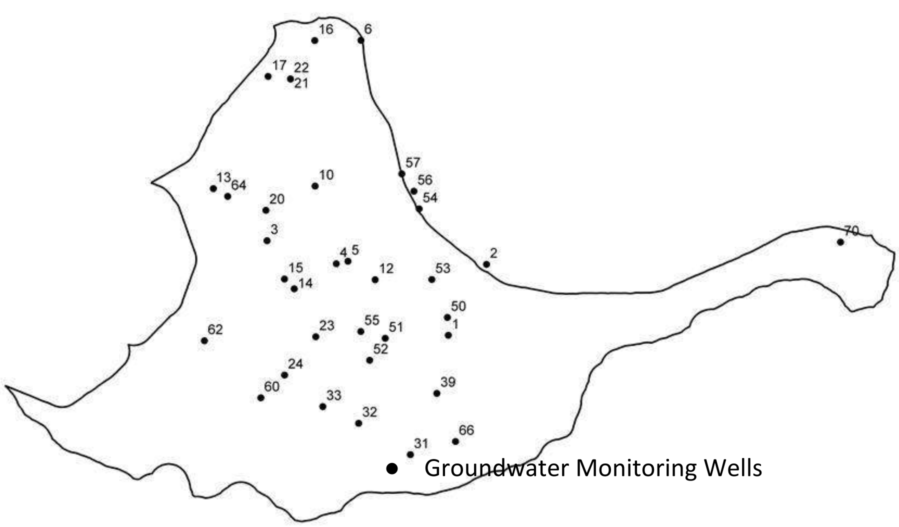

Figure 2. Groundwater monitoring wells in study area

Results and discussion
Geostatistical methods

Geostatistical interpolation methods were employed in this study to map groundwater levels. Kriging method yielded better outcomes than Inverse Distance Weighting (IDW), Global Polynomial Interpolation (GPI), Local Polynomial Interpolation (LPI) and Cokriging methods. AMong the kriging methods (Ordinary, Simple, Universal, Indicator, Probability and Disjunctive), Ordinary kriging yielded the best results. Ordinary kriging and Cokriging are two geostatistical techniques used to create continuous maps of spatially auto correlated attributes. Both procedures use the same primary variable, but CoKriging, like multivariate statistics, incorporates additional independent variables (King et. al., 2016). Kriging interpolation method uses the data of sampled locations and estimates the optimum values of unsampled locations (İnal et.al., 2002). Kriging interpolation allows unbiased optimum identification of spatial distribution of the relevant traits of unsampled locations by using semivariogram structural characteristics (Trangmar et.al., 1985, Başkan, 2004). The greatest attribute of kriging method separating it from the other interpolation methods is to calculate variance values for each point or area, such a variance is the measure of accuracy fort he estimated value (Başkan, 2004; Yaprak and Arslan, 2008).

Descriptive statistics for pre and post-irrigation season are provided in Table 3. Exponential function with the least nugget value was used to create the groundwater maps in kriging and semivariogram/covariance methods (Table 4). Semivariogram values increases with increasing distances between sampling locations. The maximum value of semivariogram yields “sill” value and observation points vary around this value. The distance in which semivariogram reaches to sill value is called as “range”. It indicates that distance in which observation values are independent from each other. From this distance and further, there aren’t any spatial relationships between any two sampling locations. In range values lower than the distance between the closest points, variation of differences between the values are not able to be identified. Such a case results in a positive semivariogram value different from zero. Sampling and analyses errors also result in similar effects. These positive values, which theoretically should be zero, is known as “nugget” effect (Bailey end Gatrell, 1995; Hengl, 2009; Fotheringham et.al., 2010; Kalkhan, 2011; Chun and Griffith, 2013; Oliver and Webster, 2014; Aydin et.al., 2015). Therefore, exponential model was selected as the best semivariogram model and used in groundwater mapping.

Table 3. Descriptive statistics

Parameters	Pre-Irrigation		Post-Irrigation	
	2003	2015	2003	2015
Count	35	19	35	19
Min	102	107	50	143
Max	351	310	309	321
Mean	247.2	198.68	193.74	203.32
Std. Dev.	55.851	62.826	56.626	57.475
Skewness	0.3208	0.425	0.17692	0.89721
Kurtosis	2.8073	2.3574	2.7521	2.6937
1-st Quartile	213	147.75	156.75	153.5
Median	247	197	187	191
3-rd Quartile	293.25	234.25	243.25	229

Table 4. Semivariogram values

Model Type	**Lag size**	**Nugget**	**Range**	**Partial sill**
Circular	1363.5	1470.3	10755.1	3182.5
Spherical	1363.5	1467.8	12686.9	3252.1
Tetraspherical	1363.5	1474.4	14871.4	3365.3
Pentaspherical	1363.5	1461.7	16046.5	3354.4
Exponential	1363.5	1228.1	16046.5	3477.6
Gaussian	1363.5	1865.9	12366.1	3554.0
Rational Quadratic	1363.5	1663.2	16046.5	2682.3
Hole Effect	1363.5	1857.8	15057.2	2427.7
K-Bessel	1363.5	1876.3	15089.2	4269.4
J-Bessel	1363.5	1829.9	15367.7	2208.3

Groundwater levels

Groundwater levels were measured from observation wells pre and post-irrigation seasons between the years 2003-2015. The maps created by using these values are presented in Figures 3, 4, 5 and 6. While groundwater levels were around 200 cm at northern and northwestern sections of the study area in pre-irrigation season of 2003, the level was more than 300 cm at South and southeastern sections of the study area. In 2015, groundwater levels slightly increased in pre-irrigation season and reached to 150 cm. Such a rise was mainly because of sufficient precipitations in relevant period.

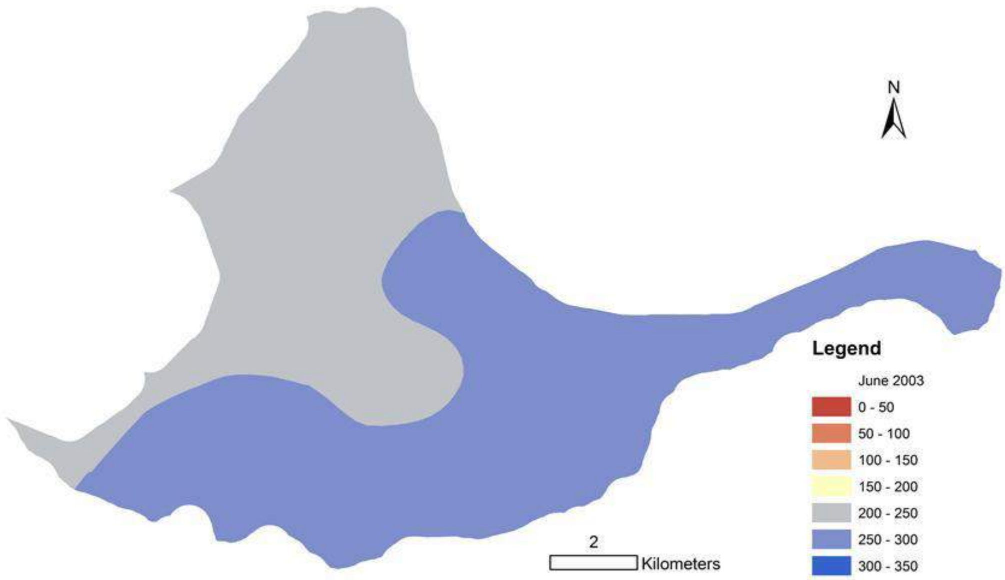

Figure 3. Groundwater levels in pre-irrigation season of 2003 (cm)

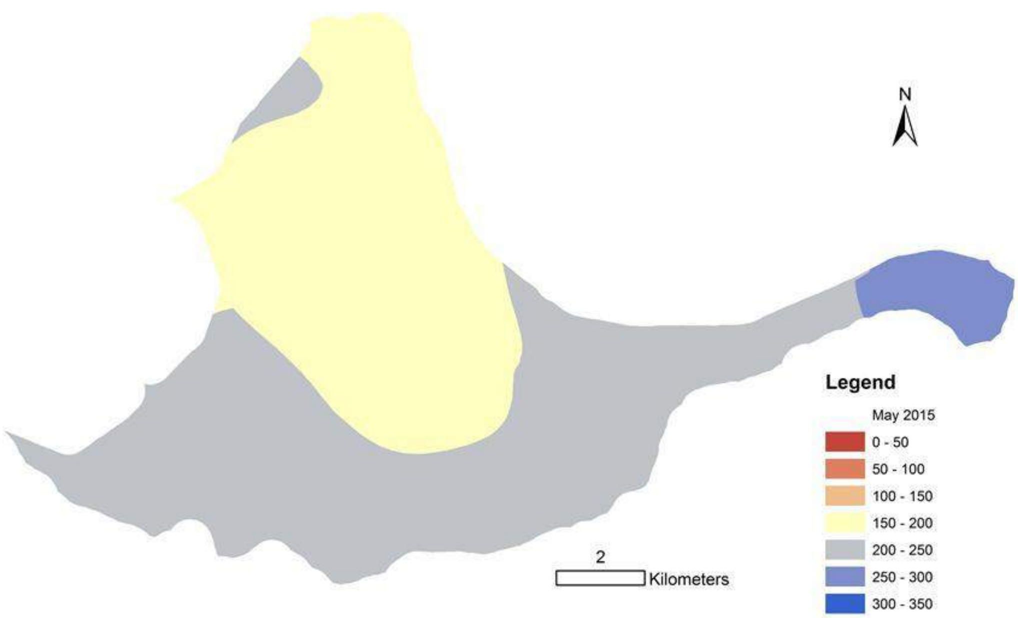

Figure 4. Groundwater levels in pre-irrigation season of 2015

During the post-irrigation periods, groundwater levels raised. Despite the sub-surface drainage systems of the study area, 50-100 cm rises were observed in groundwater levels in post-irrigation seasons and groundwater levels reached to plant root regions at Northwestern section of the study area. Groundwater levels reached to 100 cm at northern and Northwestern sections of irrigation district. Such a case created a threat on plants sensitive to high water tables. In 2003, 911 mm irrigation water was applied throughout the irrigation season (it was estimated that about 58.7% of it charged groundwater) (Tekiner, 2008). In post-irrigation period of 2015, such rises were observed as 50-100 cm decreases. The closest groundwater level was around 150 cm and deeper within the study area.

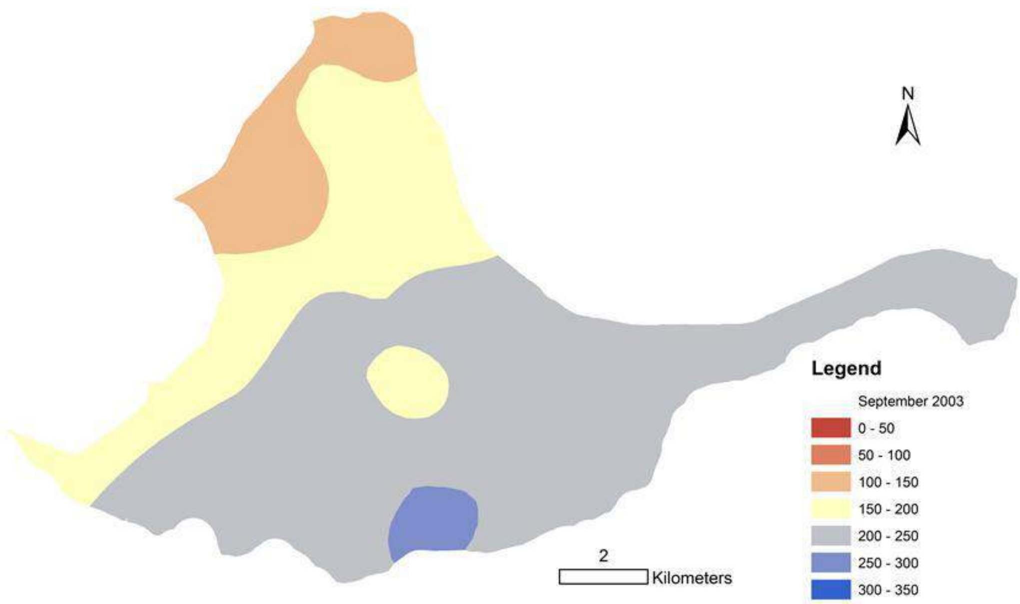

Figure 5. Variation in groundwater levels in post-irrigation season of 2003

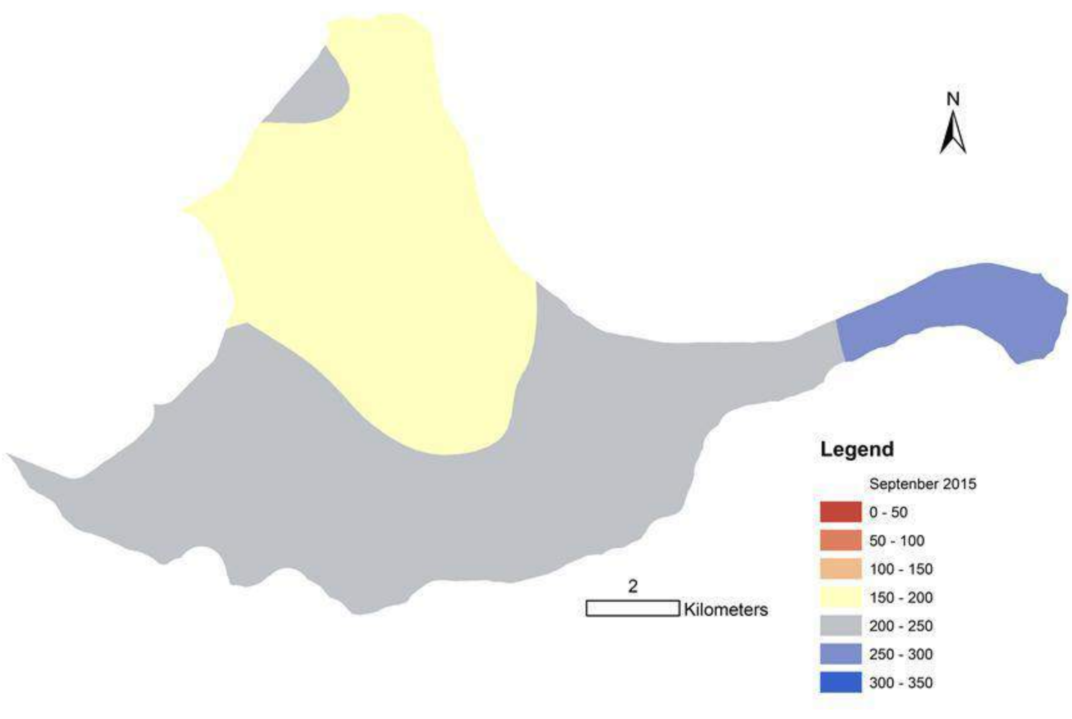

Figure 6. Variation in groundwater levels in post-irrigation season of 2015

In 2003 between the beginning and end of irrigation season, groundwaters exhibited a rising trend. In 2015, a reverse case was observed, in other words, groundwater levels decreased at the end of irrigation season. The reason of such a case was the use of high-efficiency irrigation systems, recent droughts and efficient operation of drainage systems during 13-year observation period.

Conclusion and recommendations

Kriging was identified as the best interpolation method to map groundwater levels through geostatistical methods. Among the kriging methods, ordinary kriging yielded the best outcomes. As semivariogram/covariance method, exponential model with the least nugget value was found to be the most reliable model for the production of groundwater level maps.
Increasing irrigation efficiencies, excessive input use (water, fertilizer, pesticides and etc.) may result in soil salinity in long-run especially in regions with insufficient precipitations for leaching. Such increasing salinity levels then create various burdens in agricultural activities. Therefore, further studies are recommended for the efficiency of leaching practices.

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