CONJUNCTIVE EXPLOITATION OF SURFACE AND GROUNDWATER IN THE EASTERN OF NILE DELTA

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ABSTRACT

Egypt is one of the African countries that could be vulnerable to water stresses under climate change in the future. An array of serious threats resulting from climate change in Egypt, one of the most important matters is the rise in sea level that could affect the Nile Delta area. Irrigation in the Nile Delta depends on surface water. However, conjunctive exploitation of surface and groundwater is taking place, and unless carefully managed, it can result in saltwater intrusion and deterioration of groundwater and soil quality. This paper provides a comprehensive analysis for sustaining the irrigation systems to set suitable strategies and practices for enhancing crop water productivity at the irrigation canal levels, taking into consideration the problems of water supply performance and efficiencies, inequity of water distribution, and poor irrigation and drainage management/practices. The study area is located on east edge in the Nile Delta, Egypt. The study concluded that water is available in sufficient quantity throughout the year and the farmers at head of the branch canal in this area use more water than their needs; but the farmers in tail of irrigation canal tend to use groundwater to cover the shortage in surface water. The study results show seepage water from the canal to the ground water exists, especially at the end of the studied reach which may occur due to the recharge from the canal to groundwater at the wells located at the sides of the canal. The groundwater declines in the areas around the tail of canal as a result of the intensive random extraction rates for groundwater for irrigation purposes by the farmers;

Keywords: Water management, Groundwater, Surface water, Nile Delta, Conjunctive Use

1. INTRODUCTION

Water resources in Egypt are becoming scarce because surface water resources originate from the Nile are currently fully exploited, while groundwater sources are being brought into full utilization (Arafat, et al., 2010). Groundwater is playing an important role in the economy of Egypt because of its importance for the domestic, agricultural, and industrial water supply. However, many cautions and worries are increasingly being voiced on the dangers that surround the groundwater resources. The main elements of these worries are related to depletion and quality deterioration brought by many modes of contamination. Besides the pollution from point and non-point sources such as agriculture, industries and domestic wastes, appreciable considerations are given nowadays to saline water intrusion in coastal and multi-layered aquifers of northern Egypt. It is becoming a very urgent responsibility to protect these resources and manage them in a sustainable manner as a must for survival. Therefore, Egypt has plans to use its limited water resources efficiently to overcome the gap between supply and demand. Moreover, most of water losses of irrigation systems and agricultural areas are irreparable partially through evapotranspiration and the disposal of land drainage to the Mediterranean Sea and/or coastal lakes (Abdel Gawad, et al., 2010). In addition, the need to produce more food with less water is urgent due to the exploration of population, while municipal and

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industry sector take an increment share with the need to keep enough water level for transportation. As a result, water allocation among different sectors is highly competitive with the agricultural sector.

The conjunctive use of surface and groundwater is one of the strategies of water supply management which has to be considered to optimize the water resources development, management and conservation within a basin, and artificial recharge of aquifers is certainly one of the tools to be used for that purpose (FAO, 1993). It can be defined as the management of surface and ground water resources in a coordinated operation to achieve a higher yield of such a system over a period of years that exceeds the sum of the yields of the separate components of the system resulting from an uncoordinated operation. Conjunctive use of groundwater and surface water is being adapted in many countries to enhance the intensity of irrigation and host at often benefits like cope with the water logging and salinity problems in canal irrigated areas, blending of water reduce the contamination load etc. (Y. Yang, et al., 2018). In Egypt, a number of scientific studies have been conducted which conclusively proved its importance and benefits in regards to: solving water logging problems, providing water source when surface water is not available, increasing efficiency of irrigation and mitigate for water scarcity in drought periods. Conjunctive use is being adopted in Egypt on two scales: planned, and random. The government of Egypt has operated the conjunctive use system in many locations such as Alfashn, Esna, and Menofia. But on the other hand, random conjunctive use has been used since the eighties by farmers at the canal tails or when the surface water is not sufficient. Water balance analysis used to help managing water supply and predicting water shortages in irrigation system (Burt, 1987). Therefore, matching between water supply and demand is considered a very important issue to overcome the huge amount of water lost in irrigation by delivering more water than crop requirements (Chambers, 1988; H. Moghimi, 2008).

The selection of performance assessment concept is essential to successful management of an irrigation system. The ultimate purpose of performance assessment is to achieve efficient and effective irrigation performance by providing related feedback to management at all levels (Hvidt, 1996). The objectives of this study were to make a comprehensive analysis for developing the irrigation system to set some strategies and practices for enhancing crop water productivity through the branch canal level, taking into consideration the problems of water supply performance and efficiencies, inequity of water distribution, water quality deterioration, and poor irrigation and drainage management/practices. The assessment of water balance of this study was employed at two hubs: First, is the analysis of the entire water balance parameters between water supply and demand in the study area; second, is the measurement of the water availability, adequacy, equity and distribution of irrigation within a 24-hour cycle that are proposed by Molden and Gate (1990).

2. MATERIALS AND METHODS

2.1 Study Area

The study area was selected as a good representative of the Nile Delta region, having two main features. The dominant irrigation system is surface irrigation, the soil is clay, and the cropping patterns includes the main crops of the Nile Delta. Second, the farm sizes are very small and ranged from about 1-3 acres. In addition, the water balance parameters were measured accurately to control the water inflow and outflow from the study area. The study area is located on east edge of Menia El-Qamh city and the southern edge of Sharqia governorate in the Nile Delta, as shown in Figure
(1). The study area is the command area of El Alfya canal (9240 feddans), which is a branch canal from Bahr Abouel-Khdar Canal. The coordinates of the study area are as follows: Latitude: 30°29'43.05", Longitude: 31°20'45.06". The direct canal that is supplying the command area, is Al-Alfya canal from Mustafa Afandy at KM 2.00. The total area served by Al-Alfya canal is 9,160 fed. through 8.95 km long and number of sub-branches, as shown in Figure (1). The major area of this study that face many problems, is Karaqra canal. It is extending for Al-Alfya canal which its length is 6.06 km and serves 2,600 fedd.

Like most of the old lands in Egypt, Menia El-Qamh areas is characterized by surface (flood) irrigation method. Basin or Furrow irrigation is practiced in this area based on the crop types i.e. farrow method is suitable for maize and cotton while basin method is fine for rice and berseem. Water flows from main canals to branch canals (primary, secondary and distributary canals) by gravity, while farmers used to lift irrigation water to their fields using their own (or rented) small mobile pumps. Water is then made available to farmer fields, through openings along the Mesqas, which flows by gravity to fields. Private shallow groundwater wells cover significant part of the area especially at the downstream part. The drainage water goes out from the area through Abo Akhdar, Kafr Rabie, Shehata and El Goda Drains. The main cultivated crops in winter season are Berseem, Wheat, Brood bean, Sugar beet, Flax, as field crops, in addition to Mango, Citrus, Grapes and date palm as permanent crops. Where Cotton, maize and Rice are summer crops and represent about 60% of the total cultivated area in addition to some ornamental and medical plants. The annual cropped area is about 817.7 hectares.

The main problems and challenges facing the improvement of on-farm management for irrigation at this location are; (i) lacking of some good implementation for technologies that provided by Irrigation Improvement Project, (ii) seasonal water shortage, and (iii) use of low quality of water (drainage water) in irrigation.

2.2 Determination of Performance Indicators

The assessment of the water balance of this study was conducted in two steps. The first step looks at the water delivery performance determined according to indicators of adequacy, equity, efficiency and dependability that are proposed by Molden and Gate (1990). Because the performance assessment concept is essential to a successful management of an irrigation system, it is also the key factor to improve daily operation, to diagnose problems, and monitor the effect of the interventions to solve these problems. The second step is concerned with the full water balance
analysis between water supply and demand in the study area, through the monitoring and evaluation of irrigation operations.

- Water Balance Parameters

Water use index indicator was used to measure the water delivery performance in the branch canals and selected mesqas. The indicator of water used index rate (WUI) was calculated by the following equation:

$$WUI = \frac{Q_{DTotal}}{Q_{RTotal}}$$  \hspace{1cm} (1)

Where $Q_{DTotal}$ is the amount of water diverted (m$^3$) into the irrigation network, and $Q_{RTotal}$ is the total irrigation water requirements for the area served (m$^3$). A value of WUI equal to 1.0 indicates that enough water is being supplied to meet the water demand. Nevertheless, a value of WUI is higher than 1.0 indicates that there is a wastage of water through irrigation network and the value of WUI lower than 1.0 indicates the shortage of water.

- Evaluation of the performance indicators

Performance indicators were used in this study to evaluate irrigation in the sample branch canals, mesqas and farmers’ practices at the pump level. The method proposed by Molden and Gates (1990) based on the four indicators, i.e. adequacy, efficiency, equity, and dependability is concluded to be effective for assessing distribution system performance.

**Adequacy Indicator**: Distribution of required amount ($P_A$); the objective of adequacy is to deliver the required amount of water over the command area served by the system:

$$P_A = \left(\frac{1}{T}\right) \sum_{t} \left(\frac{1}{R}\right) \sum_{i} a_i p_{A_{i,t}}$$  \hspace{1cm} (1)

where $p_{u_{i,t}} = \frac{Q_{Di,t}}{Q_{R_{i,t}}}$, if $p_{A_{i,t}} > 1$, then $p_{A_{i,t}} = 1$

**Efficiency Indicator**: Conservation of water resources ($P_F$); the objective of water distribution efficiency is to conserve water, matching water deliveries with water requirements:

$$P_F = \left(\frac{1}{T}\right) \sum_{t} \left(\frac{1}{R}\right) \sum_{i} a_i p_{F_{i,t}}$$  \hspace{1cm} (2)

where $p_{F_{i,t}} = \frac{Q_{R_{i,t}}}{Q_{Di,t}}$, if $p_{F_{i,t}} > 1$, then $p_{F_{i,t}} = 1$

**Equity Indicator**: Distribution of fair amount ($P_E$); if equity is interpreted as spatial uniformity of water distribution, then the indicator would be the average relative spatial variability of the ratio of the amount distributed to the amount required over the time period of interest:

$$P_E = \left(\frac{1}{T}\right) \sum_{t} CV_R \left(\frac{Q_{Di,t}}{Q_{R_{i,t}}}\right)$$  \hspace{1cm} (3)

where $CV_R$ is the spatial coefficient of variation of $Q_{Di,t}/Q_{R_{i,t}}$ over the region $R$.

**Dependability Indicator**: Uniform distribution over time ($P_D$) indicates the dependability of water distribution as the temporal variability over a region in the ratio of amount distributed to amount required:

$$P_D = \left(\frac{1}{R}\right) \sum_{t} CV_T \left(\frac{Q_{Di,t}}{Q_{R_{i,t}}}\right)$$  \hspace{1cm} (4)

where $CV_T$ is the temporal coefficient of variation of $Q_{Di,t}/Q_{R_{i,t}}$ over time $T$. 
In evaluating these indicators, spatial averages were weighted against the surface area of the irrigation network through branch canals to take into account their relative importance. For this study, the region (R) consisted of the total area covered by the selected command areas and the period (T) covered five months of summer season (May–September) and seven months of winter season (October–April). From the computed values, performance was classified as “good,” “fair” or “poor” according to the criteria of Molden and Gates (1990), listed in Table 1.

Table 1. Evaluation criteria for each indicator (Molden et al. 1990)

<table>
<thead>
<tr>
<th>Measure</th>
<th>Performance Class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Good</td>
</tr>
<tr>
<td>$P_a$</td>
<td>0.90 - 1.00</td>
</tr>
<tr>
<td>$P_e$</td>
<td>0.85 - 1.00</td>
</tr>
<tr>
<td>$P_f$</td>
<td>0.00 - 0.10</td>
</tr>
<tr>
<td>$P_d$</td>
<td>0.00 - 0.10</td>
</tr>
</tbody>
</table>

- Determination of crop water requirements and water delivery

The calculation of crop water requirement by CROPWAT model were used in this study, which employs Penman-Monteith methods to calculate reference crop evapotranspiration, (FAO, 1992). Crop coefficients were developed for the main crops using FAO’s irrigation manual handbook (FAO, 2002). Water application efficiency was assumed equal to 65% (for surface irrigation).

3. RESULTS AND DISCUSSION

3.1 Inflow Parameters

The performance indicators used in this study-required calculation of the water volumes delivered to specific reaches of the branch canal as shown in Figure (2). Therefore, water levels were continuously monitored using automatic recorders, so it was necessary to establish a relationship between water levels and discharges to enable conversion of these records. We converted flow heights to discharge using individual rating curve for each measurement point. While, routine discharge measurements at selected locations on the sample canals were carried out by an Acoustic Doppler Current Profiler (ADCP). It is a hydroacoustic current meter similar to a sonar, used to measure water current velocities over a depth range using the Doppler effect of sound waves scattered back from particles within the water column. Establishment of the flow calibration through this study depends on data point of discharge measurements on branch canal’s length as presented in equation.

\[ Y = 72.59X - 119.69 \]

The accuracy of calibration is high, with the coefficient of determination is up to 0.97.

Figure 2. Selected locations for measuring flow and Observed wells in study area.
Figure (2) represents the water flow that calculated from the calibration relation of flow. This figure indicates the summer season starts at the beginning of May month until the end of September month with an average of 5.5 m³/sec and maximum flow around 6.8 m³/sec at downstream of head of Bar Abo El-Akhdar canal. Winter season, starting at the beginning of October month until the end of April month with an average of 1.8 m³/sec and maximum flow around 3 m³/sec. The water management on Bar Abo El-Akhdar canal is clear and fixed through irrigation seasons. The water flow to Mostafa Afandy canal has 5% from the quota of Bar Abo El-Akhdar canal due to its location at the head reach the main canal. 20% volume of water flow was used for cultivating the area served by Alfya canal.

3.2 Outflow Parameters

The outflow was estimated at the end of the command area through groundwater level. Groundwater level was measured in six observation wells, to monitor farmers’ practices through irrigation seasons. On the surface of the study area Quaternary deposits consisting of clay, sand, silt, and sandy clay with some rock fragments are found, overlying older formations. Observation wells were used to determine the aquifer interaction with surface water as well as, the relation between the groundwater heads and groundwater extraction. Moreover, understand how surface development has impacted the aquifer. The monitoring wells were being recorded for groundwater heads and groundwater samples were collected and chemically analyzed, as presented in Table (2).

<table>
<thead>
<tr>
<th>Sample Code</th>
<th>OW1</th>
<th>OW2</th>
<th>OW3</th>
<th>OW4</th>
<th>OW5</th>
<th>OW6</th>
</tr>
</thead>
<tbody>
<tr>
<td>PH mg/l</td>
<td>7.71</td>
<td>7.75</td>
<td>8.56</td>
<td>8.42</td>
<td>7.50</td>
<td>7.46</td>
</tr>
<tr>
<td>Carbonate CO₃ mg/l</td>
<td>0</td>
<td>0</td>
<td>38.4</td>
<td>43.9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Bicarbonate HCO₃ mg/l</td>
<td>585.6</td>
<td>388</td>
<td>519.7</td>
<td>442</td>
<td>292.8</td>
<td>244</td>
</tr>
<tr>
<td>Total Alkalinity mg/l</td>
<td>585.6</td>
<td>388</td>
<td>558.1</td>
<td>485.5</td>
<td>292.8</td>
<td>244</td>
</tr>
<tr>
<td>Electrical Conductivity (EC) ms/cm</td>
<td>2.13</td>
<td>1.88</td>
<td>1.37</td>
<td>1.39</td>
<td>0.959</td>
<td>0.751</td>
</tr>
<tr>
<td>Total Dissolved Solids (TDS) mg/l</td>
<td>1361</td>
<td>1207</td>
<td>878</td>
<td>895</td>
<td>614</td>
<td>480</td>
</tr>
<tr>
<td>Calcium Ca mg/l</td>
<td>146.92</td>
<td>143.39</td>
<td>81.11</td>
<td>93.41</td>
<td>56.46</td>
<td>50.37</td>
</tr>
<tr>
<td>Potassium K mg/l</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Magnesium Mg mg/l</td>
<td>35.1</td>
<td>29.25</td>
<td>24.11</td>
<td>30.83</td>
<td>10.2</td>
<td>10.2</td>
</tr>
<tr>
<td>Sodium Na mg/l</td>
<td>280</td>
<td>230</td>
<td>178</td>
<td>132</td>
<td>140</td>
<td>103</td>
</tr>
</tbody>
</table>

According to the chemical analysis results, it can be concluded that the pH of the different studied locations ranged between 7.46 to 7.71 for the locations 1, 2, 5 and 6 while the pH values were 8.56 and 8.42 for the locations 3 and 4. The occurrence of
CO3 was absent for the locations 1, 2, 5 and 6 while the CO3 occurred at the locations 3 and 4. The occurrence of CO3 at locations 3 and 4 was the reason for pH values higher than 8.2. The total alkalinity values of the groundwater ranged between 244 and 585.6 mg/L. The values decreased with the direction of the water flow in the canal. The EC values of the groundwater decreased with the direction of the water flow at canal and ranged at the beginning of the selected reach between 2.13 and 1.887 ds/m to 0.959 and 0.751 ds/m at the end of the studied reach of the canal. The TDS values of the groundwater coincided with the values of EC due to the strong relation between the EC and TDS.

The results of the major cations show that the dominant cation is Na (sodium) followed by Ca (Calcium), Mg (Magnesium) and K for all the studied locations. The results also show that concentrations of those cations were corresponding with the values of TDS and EC. Monitoring plays a pivotal role in determining sustainable abstraction volumes, the feasibility of developments, and strategy for efficient overall management of the resource. Scientifically sound monitoring assesses groundwater, surface water (flow and quality) and atmospheric variables at carefully determined intervals. Though periodic monitoring provides some information, only long-term monitoring can provide data sufficient to determine trends and develop predictive models. Four regular groundwater levels monitoring rounds were conducted through the period of this study.

Figure (4) shows the recorded measurements for groundwater levels, for different days. According to the field measurements, the depth of the groundwater levels ranges from 5.3 to 3.0 m throughout the monitoring period. It is clearly shown that every two observation points, which constitute a cross section on the canal, are similar in groundwater levels. After analyzing the groundwater levels for the four rounds and comparing it with the status of surface water availability at Alfya canal; it was noticed that the shallow groundwater levels are highly affected by the extraction rates. As the depths of groundwater is directly proportional with the extraction rates. It is noticed that the local depth of shallow groundwater declines dramatically at the area around the tail of Alfya canal. The reason of this decline is the intensive random extraction rates for groundwater to be used for irrigation purposes by the farmers. The farmers tend to use the groundwater as a sustainable source of irrigation water as the surface water is not available all the time at the ends of the canal.

Figure 4. Groundwater levels for observation
From the previous observations, the following can be concluded:

- There is seepage action for surface water from the El Alfy canal to the local surrounding groundwater especially at the end of the studied reach.
- The seepage water from the canal causes decrease in the EC values at the local surrounding groundwater especially at the last two wells.

3.3 Equity of Water Distribution

The WUIs evaluated at the heads of the monitored branch canals (Mostafa Afandy canal (MC), El- Alfy canal (BC), and El- Karakra canal (SBC)) in study area. The following notes could be made related from Figure (5). The values of WUI for all branch canals in irrigation season are similar performance that indicate the water management in study area. Some WUIs are larger than 1.0 that does not necessarily indicate over supply; water delivered at the head of a branch canal is typically larger than actual crop water and soil leaching requirements in order to account for conveyance and field application losses. On the other hand, a WUI that is well below 1.0 indicates severe water shortage. The WUI values for Mostafa Afandy canal were more than 1.0 through irrigation seasons which indicates over irrigation. For Summer season, the values were closed to 2.0, while in winter season, the values were closed to 3.0 except the period of winter closure. The performance of Alfy canal through irrigation seasons as summer and winter was almost stable and fixed which it is closed to value 1.0. while the El-Karakra canal’s values were lower than 1.0 through irrigation season. So, the famers in these areas were using shallow well for irrigation.

![Figure 5. Monthly WUI at head branch canal level](image)

3.4 Performance Of The Delivery System

This section analyzes monthly water delivery performance in 2017 among irrigation canals as a spatial function and the difference between irrigation canals (Mostafa Afandy canal (MC), El- Alfy canal (BC), and El- Karakra canal (SBC)) of irrigation system through the irrigation systems as a temporal function.

- Spatial Values of Performance Indicators

The adequacy values for the spatial function in months are given in Figure (6). The PA values were closed to 0.8 in all months during summer season, while the values...
varied through winter season. While, the spatial values of efficiency PF were similar to PA in summer season and variable in winter season that indicated a reflection of the extreme water delivery for the irrigation systems than available water consuming main crops as rice paddy in summer and wheat crop in winter seasons. According to performance standard, adequacy performance during summer seasons was evaluated as “fair” and during winter seasons was “poor” in middle season, while it was “fair” in the first months of this season. According to performance standard, efficiency performance during summer season was evaluated as “fair” during irrigation seasons. These results mean that water use is not efficient. Values of the equity indicator PE for irrigation months, presented in Figure (6), were almost uniformly poor, higher than 0.2 through irrigation seasons summer and winter. According to performance standard, equity performance throughout the irrigation seasons was evaluated as “poor”.

![Figure 6. Spatial Performance indicator values at branch canal level](image)

- Temporal Values of Performance Indicators

The temporal value of PA for Afandy canal was closed to 1.0 Figure (7). While, the value of El-Karakra canal was closed to 0.6. This indicates the irrigation canals that feed from Afandy canal faced water shortage. According to performance standard, adequacy performance for both irrigation canals was evaluated as “fair”. The temporal value of PF for Karakra canal was better than Afandy canal which PF of first was 0.95 and 0.5 for second. This indicates the losses of water through Karakra canal was 50% through irrigation months in summer and winter. According to performance standard, efficiency performance for both irrigation systems was evaluated as “poor”. The dependability indicator PD was generally poor (over 0.2).

![Figure 7. Temporal Performance indicator values at branch canal level](image)
4. CONCLUSION AND RECOMMENDATION

Water balance analysis is used to help managing water supply and identifying water shortages in irrigation. Therefore, matching between water supply and demand is considered as a very important issue to overcome the substantial amount of water losses in irrigation due to delivering more amount than crop requirements. Delivering the amount of water at the schedule saves water and increases crop water productivity, and as a result may increase water to other farmers and raise overall income. The goal of producing more crops per drop is the key issue of achieving both food and environmental security. The findings of study were concluded as follows:

- Water is available in sufficient quantity throughout the year (adequacy was fulfilled);
- The farmers in this area use more water than their needs because they located at the head of the branch canal;
- The irrigation rotation is irregular due to the manipulation of the people in-charge in open and closing the gates or farmers at the head of the canals;
- There is seepage action for surface water from the El Alfyia canal to the local groundwater;
- The seepage water from the canal causes decrease in the EC values at the local groundwater especially at the last two wells.

It is strongly recommended that the study should be repeated on a larger scale to include the entire command area to measure the assessment of water balance over this area by monitoring and evaluating water availability, adequacy, equity distribution among various mesqas, night irrigation and reuse of drainage water in irrigation. In addition, the impact of the water delivery system on farmers’ behavior should be measured at the head of the branch canals on other locations inside the main canal.

5. ACKNOWLEDGMENTS;

We thank International Center for Agricultural in the Dry Area (ICARDA) funded this study by Water Management Research Institute (WMRI) and Ground Water Research Institute (GWRI) of the National Water Research Centre (NWRC) in Egypt.

6. REFERENCE


