THE STUDY ON ARTIFICIAL RECHARGE OF GROUNDWATER FOR LAND SUBSIDENCE USING EXISTING AGRICULTURAL PONDS

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ABSTRACT

Taiwan is an oceanic nation with a combined area of approximately 36,000 km². The Central Mountain Range were formed by Eurasian and Philippine Plates and stretches along the entire island from north to south, along the entire island, thus forming a natural line of demarcation for rivers on the eastern and western sides of the island. The uncontrolled development of groundwater resources has led to undesirable effects, especially in the coastal area where aquaculture is concentrated. These effects are land subsidence, saline water intrusion, lowering of water tables. The purpose of this preliminary study is to evaluate the reclaimed water reuse via aquifers. The sewage waste water discharged from the surrounding settlements closed to the pathway of the Taiwan High Speed Rail located at the land subsidence area. Purification technology using existing agricultural ponds as constructed wetland is to recharge aquifer by ponds or wells and then to mitigate the land subsidence for railway safe. From the data collection, the evaluation and analysis will be simulated by numerical model for the next stage. The constructed wetland system can be achieved the required quality for recharge from the reclaimed water reuse. Based on the well results from preliminary study of artificial recharge of groundwater using existing agricultural ponds to alleviate the land subsidence, the planned projects will be promoted by the Council of Agriculture along the pathway of the Taiwan High Speed Rail located at the land subsidence area in the future.

Keywords: Artificial recharge of groundwater, constructed wetland, land subsidence

1. INTRODUCTION

The villages along the Taiwan High Speed Rail in Yunlin County include Siluo, Erhun, Huwei, Tuku, Yuanchang, etc., which are located in the central part of the county. Since these villages have not yet built a sewage system, the discharge of sewage directly affects the environmental sanitation of villages. In addition, the construction of sewerage requires huge expenditures and takes a long time. In order to reduce the amount of pollution in villages along the Taiwan High Speed Rail, the natural purification method is used in the region and to treat domestic sewage for the reduction of the domestic sewage pollution. The agricultural ponds in the area can also be used to manage aquifer recharge along the Taiwan High Speed Rail which has positive benefits for the prevention and control of the land subsidence in this county. Therefore, the purpose of this study is to collect the sewage discharged from the residence along the Taiwan High Speed Rail, and evaluate the feasibility using the natural purification technology to recharge the existing agricultural ponds as a source of groundwater recharge (Figure1&2).

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Figure 1. (a) Topography, bathymetry and main geological units in Taiwan. Rectangle indicates the study area. The large red indicator arrow notes direction and convergence rate of Philippine Sea Plate relative to Eurasia Plate. Major thrust faults with triangles are on the up-thrust side. (b) Average land subsidence area in Taiwan during 2002 to 2006. Black lines are the administrative boundaries (Hsin Tung and Jyr-Ching Hu, 2012). (Data from Water Resource Agency, Department of Economics).

Figure 2. Cumulative land subsidence in Yunlin County by precise leveling from 1992 to 2007. Maximum cumulative land subsidence >110 cm occurred in Baojhon, Tuku and Yuanchang Townships. Red line indicates Taiwan High Speed Rail (TSHR) (Hsin Tung and Jyr-Ching Hu, 2012). Data from Water Resource Agency, Department of Economics.
2. STUDY AREA AND GEOLOGY

2.1 Temperature

The climate of Yunlin County belongs to the subtropical monsoon climate zone (refer to Figure 1). The annual temperature of the county is the lowest in January, and the temperature gradually rises to above 20 °C from March to April, and the highest temperature is 30 °C or higher from July to August. The annual average temperature is ca. 23 °C, and the climate is mild and pleasant.

2.2 Rainfall

The climate is sub-tropical; rainfall is alternately affected by typhoons in the rainy season, which lasts from May to September. The average rainfall is approximately 2,560 mm for the Zhuoshui River Basin. Consequently, almost all groundwater comes mainly from rainfall by infiltration in the mountain.

2.3 Water resources facility

Yunlin County has long been dominated by agricultural development. Because there is no large reservoir in the county for water source allocation and excess of groundwater development, the problem of land subsidence has been caused (refer to Figure 2). The Zhuoshui River is the main surface water source. The main water source facilities are Jiji River and the water collection. The Hushan Reservoir was built in 2003 and completed in 2015. The both two water source facilities can be integrated to improve the groundwater use. The utilization of water resources in the Yunlin area (from 1991 to 1999), the total water consumption is 1.968 MM3/year, of which is 56.2% from the Jiji Weir, 23% is distributed by groundwater, and 20.8% is allocated from other water sources.

Based on the data from Bureau of Water Resources, Department of Economic Affairs, 92% of the Jishui River catchment is allocated for agricultural water use in the Zhangyun area. The total living and industrial water consumption is only 8%. The groundwater pumping strategy should be obviously reduced in this area. In the meantime, the management of agricultural water use should be strengthened, and groundwater recharge should be increased. According to the statistics of public water use, the water consumption in Yunlin is 260,000 CMD(m3/day), including 120,000 CMD of surface water and 140,000 CMD of groundwater respectively. The Hushan Reservoir has been completed in 2015. It can be used in conjunction with Jiji Weir, and it is estimated that 432,000 CMD of surface water can be used for domestic water use. The Yunlin area can supply 332,000 CMD of domestic water, which is allocated by surface water. The use of groundwater in Changhua and Chiayi areas is benefited to the overall groundwater conservation and subsidence prevention efforts.

2.4 Topography and Geology

2.4.1 Regional plain situation

The study area is located in the proximity of the Choshui Alluvial Fan. It is mainly distributed from the north to the south direction of the Choshui River. This plain covers an area of 1,800 km². The alluvial fan of the Choshui River is located in the central part of the west coast of Taiwan. It is dominated by the Boshui River Basin, with Wuxi in the north, Beigang River in the south and the Eight Diagrams in the east (refer to Fig.1).
2.4.2 Regional geology

The exposed strata around the plain include the red clay, gravel layer, and the modern alluvium. Besides the modern alluvium, the other strata are mainly distributed in the Baguashan platform and the Doulisan hills. The alluvium is distributed in the turbid water alluvial fan (mainly composed of unconsolidated clay, silt, sand and gravel), which is the main stratum of the study area.

The Changhua fault on the right side of the study area is located along the western edge of the Eight Diagrams Hill. Due to the absence of fault outcrops, the topographical features are used only to predict the possible location of the fault, and the Central Geological Survey, Taiwan will list it as a suspected active fault at present.

2.4.3 Hydrogeology

Based to the "The National Groundwater Observatory Network Project, Taiwan" implemented by the Water Resources Bureau of the Ministry of Economic Affairs and the Central Geological Survey. The recent alluvium distributed mainly gravel and sand, Choshui Alluvial Plain, which consists mainly of coarse pebbles (refer to Fig. 2). (NOT CLEAR) Generally it can be assumed, that the hydrogeological profile changes from F1-aquifer system to F3-aquifer system when going from foothill and mountain areas in the north, east and west towards the coastal and lower areas in the inland and the south. The characteristics of aquifer system vary from gravel to fine sand, from the northeast to the southwest of the basin and the groundwater table gradually becomes shallower in this direction.

The alluvia fan separated three-part, proximal fan, middle fan and distal fan, the aquifer was divided into three aquifers and two aquitards within 220m depth. Basically, the aquifer system general set three layers. (NOT CLEAR) The natural recharge function is quite reasonable in the region. According to pumping test data, transmissivity (T) is ca. 1,800 m²/day, the specific yield (S) is ca. 0.15, and hydraulic conductivity (K) is ca. 340 m/day. During 1992–2007, over-pumping of groundwater caused large scale aquifer system compaction and land subsidence in the Choshui River Alluvial Fan, especially in the area of Yunlin county. The land subsidence impedes surface water runoff and endangers the operation of Taiwan High Speed Rail refers to Figure 3.

2.4.4 Agricultural Pond

In addition, from the report of Yunlin County Agricultural Pond Preservation Research Report - Agricultural Pond Survey, it is worthwhile to preserve the towns of Xiluo, Erlun, Huwei, Tuku and Yuanchang for agricultural pond. (NOT CLEAR) The suitable area for managed aquifer recharge should be larger than 1.5 ha the selected agricultural pond is based on the on-site investigation and purification technology using existing agricultural ponds (Figure 4.).
Figure 3. (a) Regional geological map of the Choshui River alluvial fan superimposed with 40 m digital elevation model. H: Recent; Q: Pleistocene to Pliocene; PM: Pliocene to Miocene; OE: Oligocene to Eocene; MI: Miocene. (b) Two hydrogeological profiles of the Choshui River alluvial fan. Profile lines are indicated in Fig. 4a. (c) Conceptual hydrogeological profile of the Choshui River alluvial fan at the profile b-b’ (Hsin Tung and Jyr-Ching Hu, 2012).

Figure 4. The selected agricultural pond is based on the on-site investigation and purification technology using existing agricultural ponds.
3. THE METHODS AND PRINCIPLES

3.1 Evaluation process

According to the preliminary investigation of the agricultural ponds from the Yunlin County, the 1:25,000 topographic map was used for the screening needs, and five sites were selected as the site for constructing wetland.

The main purpose of this study is to treat the sewage by the constructed wetland for water purification technology from the sewage of residence, and then introduce reclaimed water reuse into groundwater aquifer where the geological conditions were taken into consideration. Therefore, it is necessary to have sufficient sites in the vicinity of the farmland to be used as a possible site for the purification of constructed wetlands.

3.2 Analysis of hydrogeological suitability

The geological conditions of infiltration recharge are used as the preferred sites in terms of observation wells from the National Groundwater Monitoring Network in Choshui Alluvial Fan.

4. RESULTS AND DISCUSSION

4.1 Description of the preliminary investigation results

According to the agricultural pond listed in the “Yunlin County Farming Preservation Research Report”, find several suitable agricultural ponds were selected.

The location of the residence where the waste water from the farmhouses are close to the constructed wetland for purified water needs. The estimated amount of sewage water is based on the number of households that can be accommodated in the farms estimated with 250 litre per person per day (lpcd) by the residence.

According to the preliminary investigation results, the amount of sewage collected is average ca.500 CMD (m³/day).

4.2 The natural purification of technological evaluation

The natural purification of water quality is applied by soil, plants and other natural materials to gradually eliminate the polluting process of contaminated water under the physical, chemical and biological purification. In terms of the mechanism of natural purification, it can be divided into three categories: physical purification, chemical purification and biological purification. The main reactions of physical purification include: dilution, diffusion, sedimentation, volatilization, leaching, etc. For example, the adsorption, dilution and diffusion occurring in natural rivers or lakes can reduce the pollution hazard to a certain extent. The main reactions of chemical purification include: redox, compounding and decomposition, adsorption, coagulation, exchange, etc. For example, some organic pollutants will eventually form water and carbon dioxide by redox; copper, lead, zinc, cadmium and mercury in water.

According to the above mentioned natural water purification methods, the current domestic construction method is more suitable for the treatment of rural settlement domestic sewage by means of Free Water Surface System (call as FWS) and Vegetated Submerged Bed (call as VSB) of constructed wetland. After being discharged into the existing agricultural pond, the purified water is taken for recharge use. Taking the site of the study as an example, the estimated sewage volume is ca.
500 CMD. Referring to the constructed wetland as treatment area is estimated to be 0.5 hectares (ha), the wetland treatment method has been recommended to use the constructed wetland system of the study area. The water purification facilities are connected with the FWS type VSB constructed wetland system. The floating aquatic plant system serves as a pre-treatment facility for the existing constructed wetland system is to achieve the effect of water treatment (Figure 5.).

Figure 5. The water purification facilities are connected with the FWS type

4.3 Benefit assessment of managed aquifer recharge

The artificial recharge of groundwater is one of planned solutions for land subsidence prevention. It can be applied the excess surface water such as stormwater or a reclaimed water, which is infiltrated with a spreading recharge basin (or well) or artificially change the natural infiltration conditions through artificial systems to transport surface water to the aquifer called as Beneficial water reuse from storm or reclaimed water (Figure 6.). (NOT CLEAR)

Figure 6. Existing agricultural ponds through treatment and used for groundwater recharge by well

4.4 The methods and potential advantages of artificial recharge of groundwater

The groundwater technology supplemented by the farmland was clamped by hydrogeological conditions; in the case of the county, the best recharge location is the top area of the proximal alluvial fan. The middle to the distal fan area is caused by the
shallow layer of the impermeable layer being mud layer or clay layer, and the pond is easy to store water source. It is estimated that the middle to distal fan area can be infiltration rate ca. 1.0 m/day, which is much larger than the infiltration rate limited by the area of the agricultural pond, which is ca. 0.12 m/day (NOT CLEAR). It is estimated that the groundwater recharge amount of the 21 ponds is 6,300 CMD, that is, the annual average recharge amount is ca. 2.3 MM³.

5. CONCLUSIONS AND RECOMMENDATIONS

It is understood that the Taiwan High Speed Rail belongs to the alluvial mid-fan. The groundwater table can be arisen by aquifer piston recharge from the higher permeable materials of proximal alluvial fan. From the geological profile of the Taiwan High Speed Rail pathway, where are the main subsidence area of Yunlin County. However, because it belongs to the middle to distal fan, the mud and clay layer in the stratum of this area gradually becomes thickening, the subsurface was formed by pore pressure release of over-pumping from a mud or a clay layer. The groundwater recharge directly from the agricultural pond acted as the spreading basin, it is slightly difficulty to recharge the confined aquifer located at the pathway of the Taiwan High Speed Rail (NOT CLEAR).

A total of 28 agricultural ponds were surveyed and the amount of sewage collected, the distance from the Taiwan High Speed Rail, and the suitability for the constructed wetland are the best sites. The natural purification method is used to treat the sewage collected along the Taiwan High Speed Rail residence house. The FWS and VSB are more suitable for the constructed wetland to reclaimed water technology. The treatment method for domestic sewage in rural settlements is discharged into existing agricultural ponds through treatment and used for groundwater recharge. From the reclaimed water, the water source can be recharge average ca. 500 CMD. (NOT CLEAR)

Application of agricultural ponds or artificial basin as groundwater recharge purposes with considering the conservation of aquifers, it can be recommended to use these facilities as the flood detention space for flood mitigation functions. (NOT CLEAR) The hydrogeological conceptual model (i.e. MODFLOW) has been formulated for the managed aquifer recharge from the constructed wetland system in the next stage.

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