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The Mitigation Strategy for Taiwan HSR Passing through the Land Subsidence Area of Yunlin County

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Yunlin County is located in the southwestern area of Taiwan, of which partial or whole areas of 13 out of 20 townships have serious land subsidence. This research uses the data of rainfall stations, groundwater monitor wells, and land subsidence monitor wells in Yunlin County to investigate whether climate change has affected Yunlin County's hydrological environment and its corresponding land subsidence. According to the land subsidence monitoring data of 2002, the greatest subsidence rates in the area which the HSR passes through was over 10 cm/yr. In order to reduce the extent of land subsidence along the HSR route, in 2005 the government chose specific areas to carry out a well sealing plan, which was to seal dozens of official wells at a distance of 1.5 kms on each side of the high speed rail (HSR) route. The plan was completed in 2008. From the actual land subsidence monitoring data of 2009, the greatest subsidence rates in the area which the HSR passes through was decreased from 10.6 cm/yr to 7.0 cm/yr. Thus limiting over pumping of groundwater has improved the land subsidence problem.

Keywords: Climate change; Land subsidence.

1. Introduction

Land subsidence has been occurring in the southwestern part of Taiwan from 1970 to the present. Yunlin and Changhua townships are the most serious areas which face land subsidence. According to survey results, the land subsidence rates (6.4 cm/year) were the same for Changhua and Yunlin townships individually. The measurements (more than 3 cm/year) of the continuous land subsidence areas

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in Changhua and Yunlin townships cover the area of 138.85 km^2 and 267.06 km^2, respectively. There are no surface water storage facilities in these two townships. For this reason, the surface water supplements in these two townships have shortages during the dry season. Groundwater then becomes the primary water resource for irrigation, industry and urban demands. As a result, land subsidence is caused by groundwater over pumping. Serious land subsidence problems from 1970 until the present still exist in these two townships. Land subsidence eventually creates floods, structure damages, and seawater intrusion.

Climate change is an important factor of water resource management in the southwestern part of Taiwan including Yunlin County. The change of precipitation has confused the management operation of the water supply systems in Yunlin County in recent years. The gap of water resources during shortages has always been satisfied with groundwater pumping. The demand of groundwater will be expectantly larger in the future, making the prevention of land subsidence even more difficult.

The Taiwan High Speed Rail (HSR) is the most important transportation construction in recent years. The HSR passes through the majority of western Taiwan, including Taipei, Taoyuan, Hsinchu, Miaoli, Taichung, Changhua, Yunlin, Chiayi, Tainan, and Kaohsiung counties. The total length of the HSR is 330 km and its highest speed is 300 km/hr. Figure 1 shows the HSR train entering the station in Taichung.

Figure 1 HSR train and station.

Because the speed of the HSR is higher than the general passenger train and the highway, the smoothness and stability of the HSR tracks are extremely important for safety. Any deformation of the HSR tracks must be controlled within an allowance range. The HSR passes through the Chou-Shui Alluvial Fan, including Changhua County and Yunlin County. The soil layers of the Chou-Shui Alluvial Fan have a high compression or consolidation potential. Unfortunately, the HSR passes through the most serious land subsidence area, including Huwei, Tuku, and Yuanchang in Yunlin County as shown in Figure 2. The differential settlement of the HSR tracks caused by land subsidence may impact the driving safety of the HSR. This is a serious issue of utmost concern by the Taiwan government.

A mitigation strategy is needed for the water resource management of Yunlin County to protect the driving safety of the HSR. Therefore, the Water Resources Agency (WRA) carried out a groundwater pumping reduction project from 2005 to 2007. The purpose of this project was to reduce yields of groundwater pumping within a banned region of a 3-km width along the HSR tracks in Yunlin County. As a result, several deep wells belonging to government agencies were decommissioned and sealed. The remaining wells are still being monitored to avoid groundwater over pumping. According to the land subsidence monitoring results from 2006, the improvement of preventing land subsidence was significant and

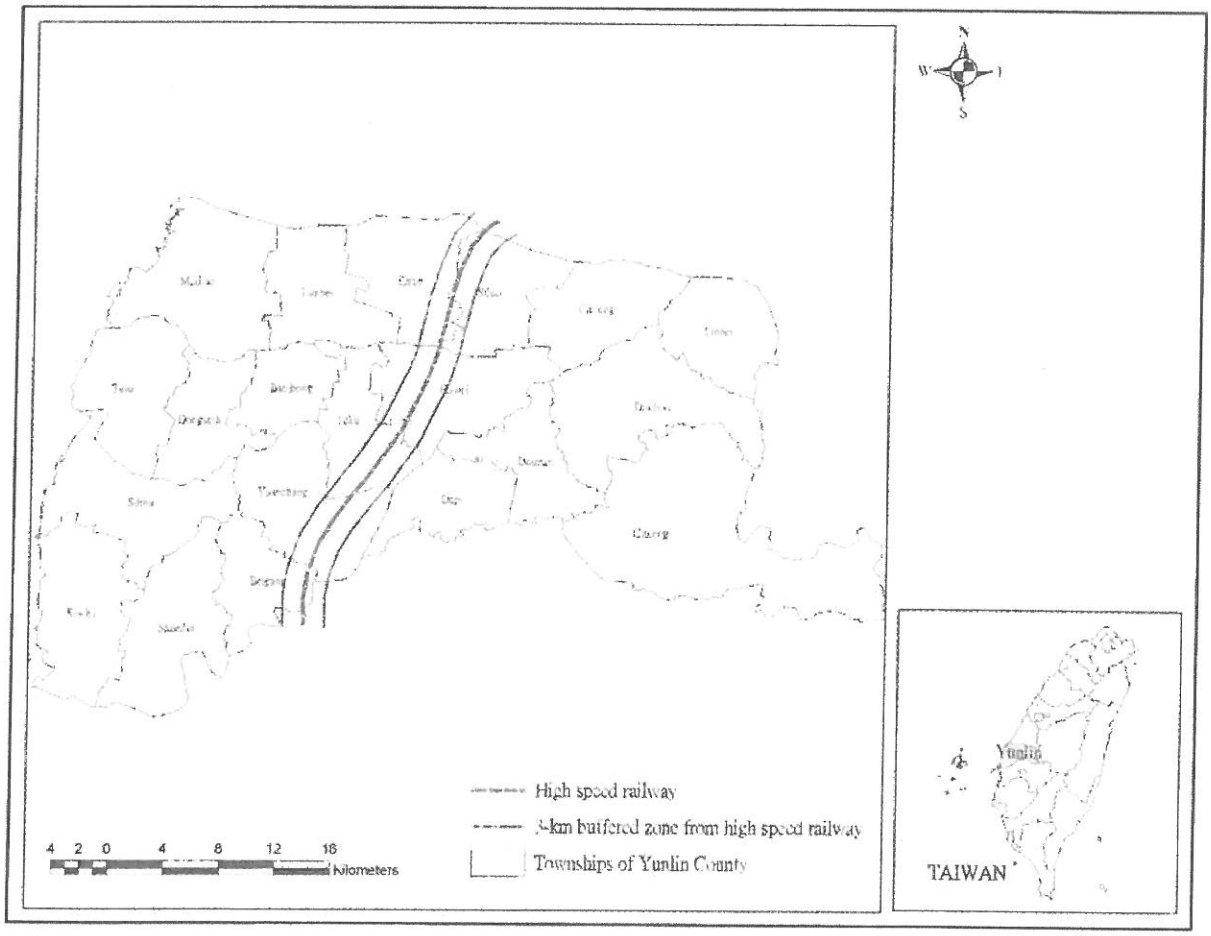

Figure 2 HSR route in Yunlin County.

showed that reduction of groundwater pumping was an effective strategy for conserving the safety of the HSR.

2. Climate Change in Yunlin County

The climate change phenomenon is discussed in this research using rainfall monitoring data from the Yunlin Irrigation Association. The period of rainfall records consists of 48 years, from 1961 to 2007. Those data can help us know the hydrology differences in Yunlin County of recent years. Figure 3 shows the accumulated rainfall per year at the Huwei and Huili rainfall monitoring stations. The linear regression shows accumulated rainfall per year has increased from 1961. The increased rates are 4.9 mm/year and 3.0 mm/year at the Huwei station and Huili station, respectively. In addition to the accumulated rainfall increase, Figure 3 also shows that the period between the wet years and dry years became shorter. For

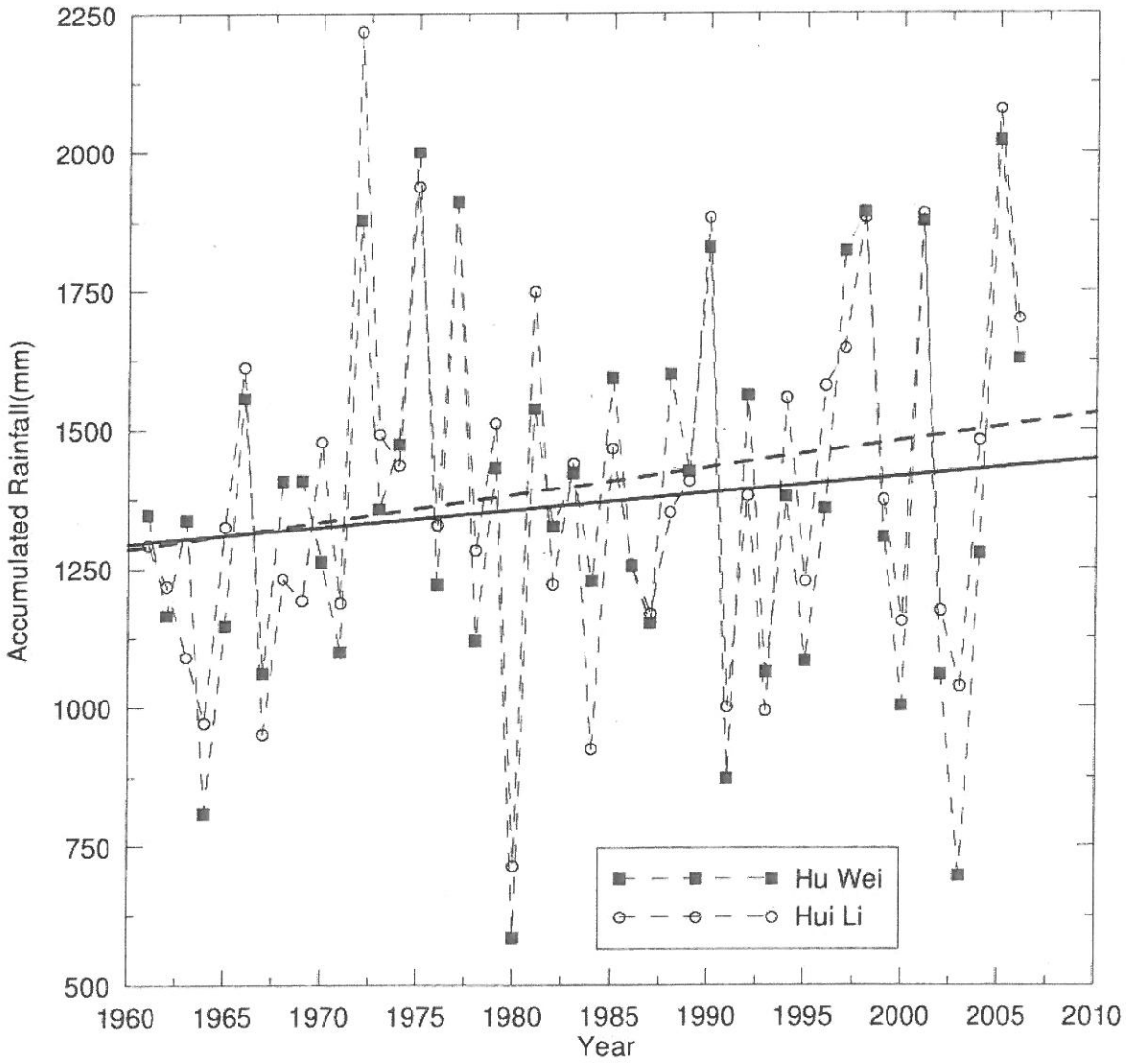

Figure 3 Rainfall per year in Yunlin County (1961–2007).

example, the time interval between the significant wet years of 1981 and 1990 was, in the past, nine years. But recently, the time interval has shorten to only four years between that of 2001 and 2005. The rainfall during the dry years was less than before, an evidence of climate change in Yunlin County. During the 29 years from 1961 to 1990, there were only two years, 1964 and 1980, where the accumulated rainfall per year was less than 1000 mm. But during the 17 years from 1990 to 2007, there were three significant dry years. Those phenomena show from the accumulated rainfall that rainfall will expectantly and dramatically change in Yunlin County in the future.

Figure 4 shows raining days per year from 1961 to 2007. According to the linear regression result of the data, the raining days per year did not increase significantly. The raining days per year did not reflect the increase of accumulated rainfall per year, which means that the rainfall intensity has increased. Therefore, there was higher rainfall intensity. The maximum average rainfall intensities were

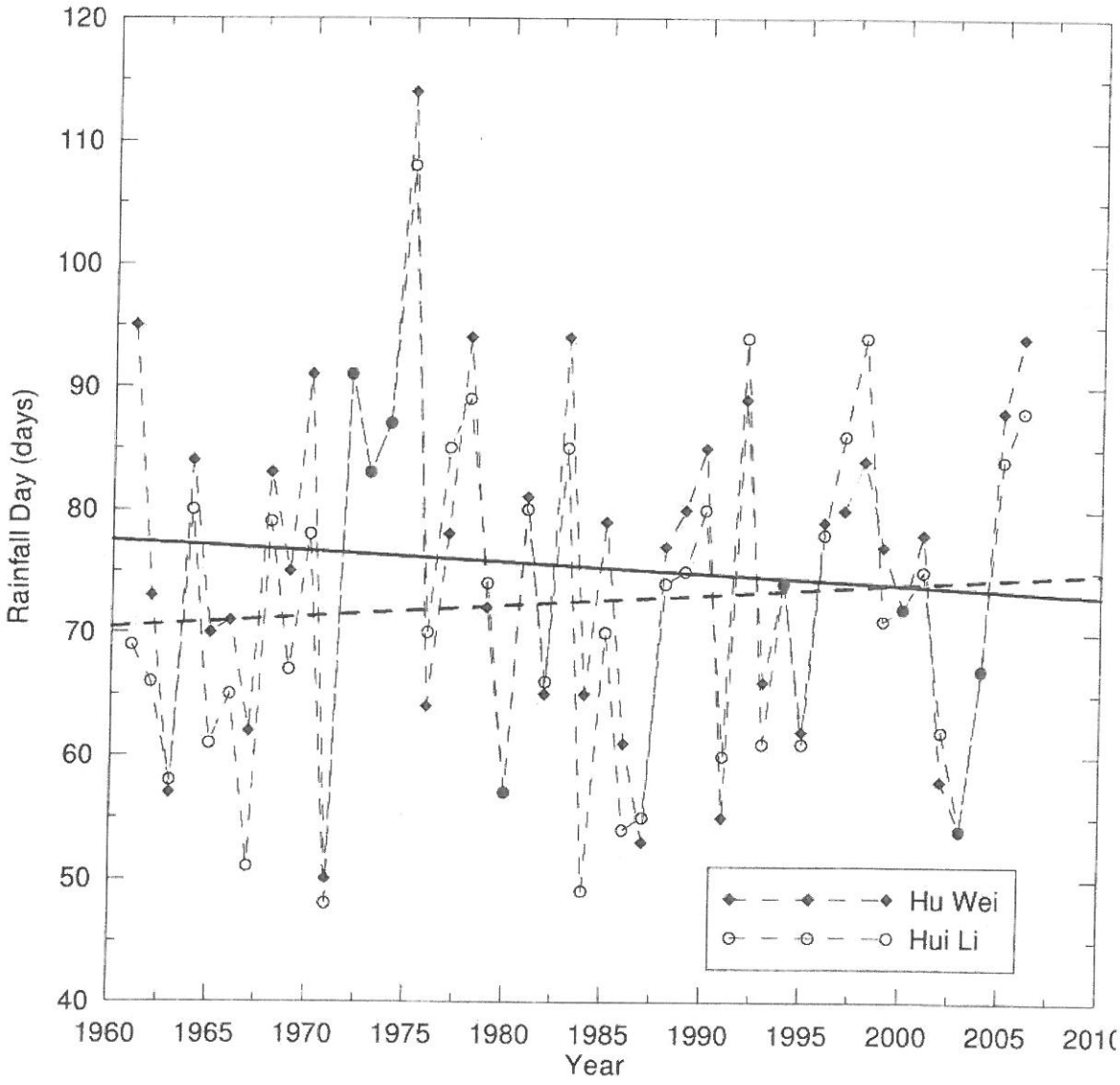

Figure 4 Raining days per year in Yunlin County (1961–2007).

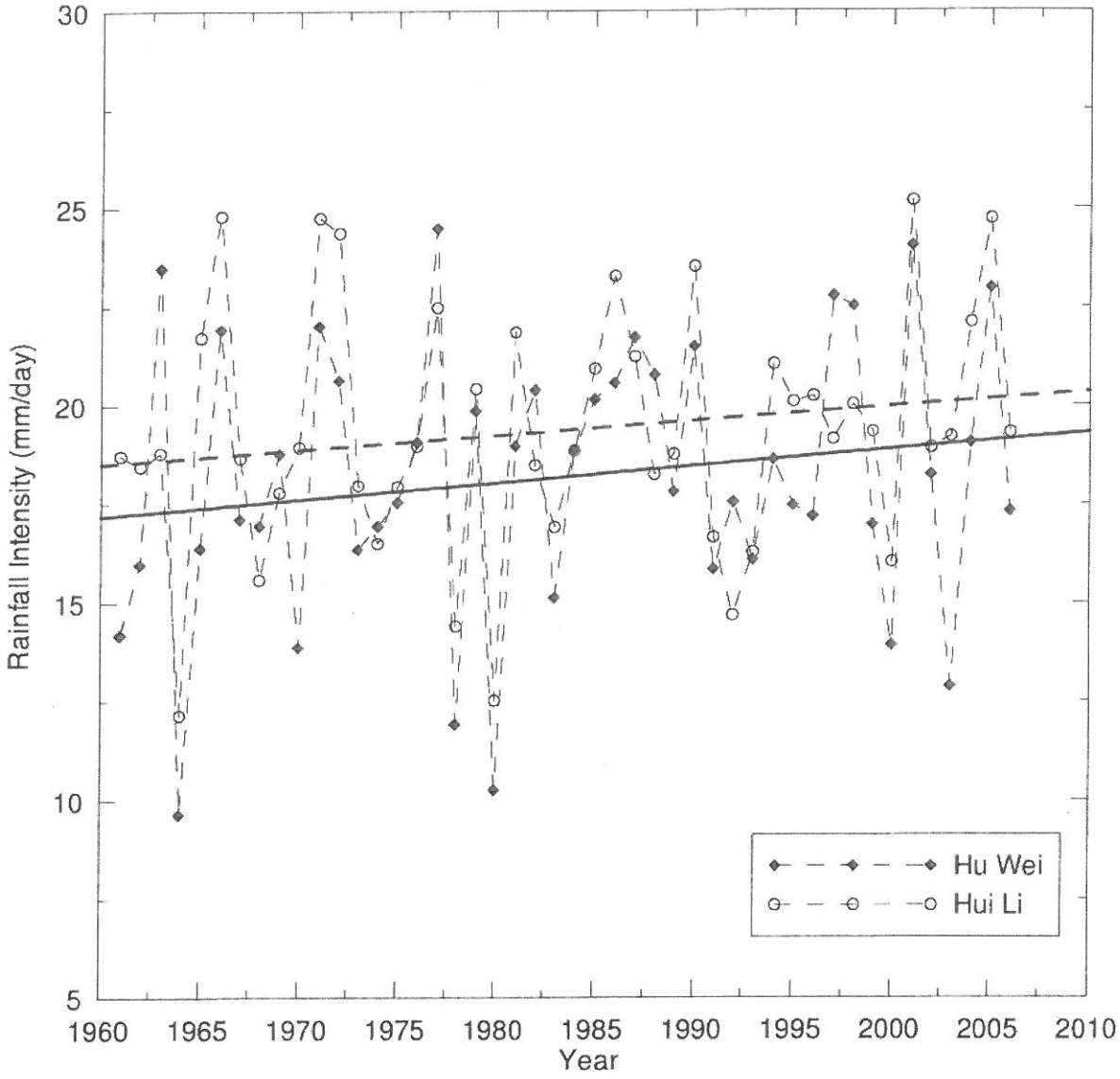

Figure 5 Rainfall intensity each year in Yunlin County (1961–2007).

24.8 mm/day and 25.18 mm/day at the Huwei station and Huili station, respectively. In recent years, the average rainfall intensities were higher than before, which means rainfall has become more concentrated in fewer days. This situation has impacted the water supply systems which essentially need a stable water resource.

3. Water Supply and Demands in Yunlin County

The major water supply systems in Yunlin County are the Taiwan Water Corporation and Yunlin Irrigation Association. The Taiwan Water Corporation usually supplies urban and industrial waters. The Yunlin Irrigation Association supplies irrigation water for farming. In addition to the Taiwan Water Corporation and Yunlin Irrigation Association, there are a large number of private wells in Yunlin

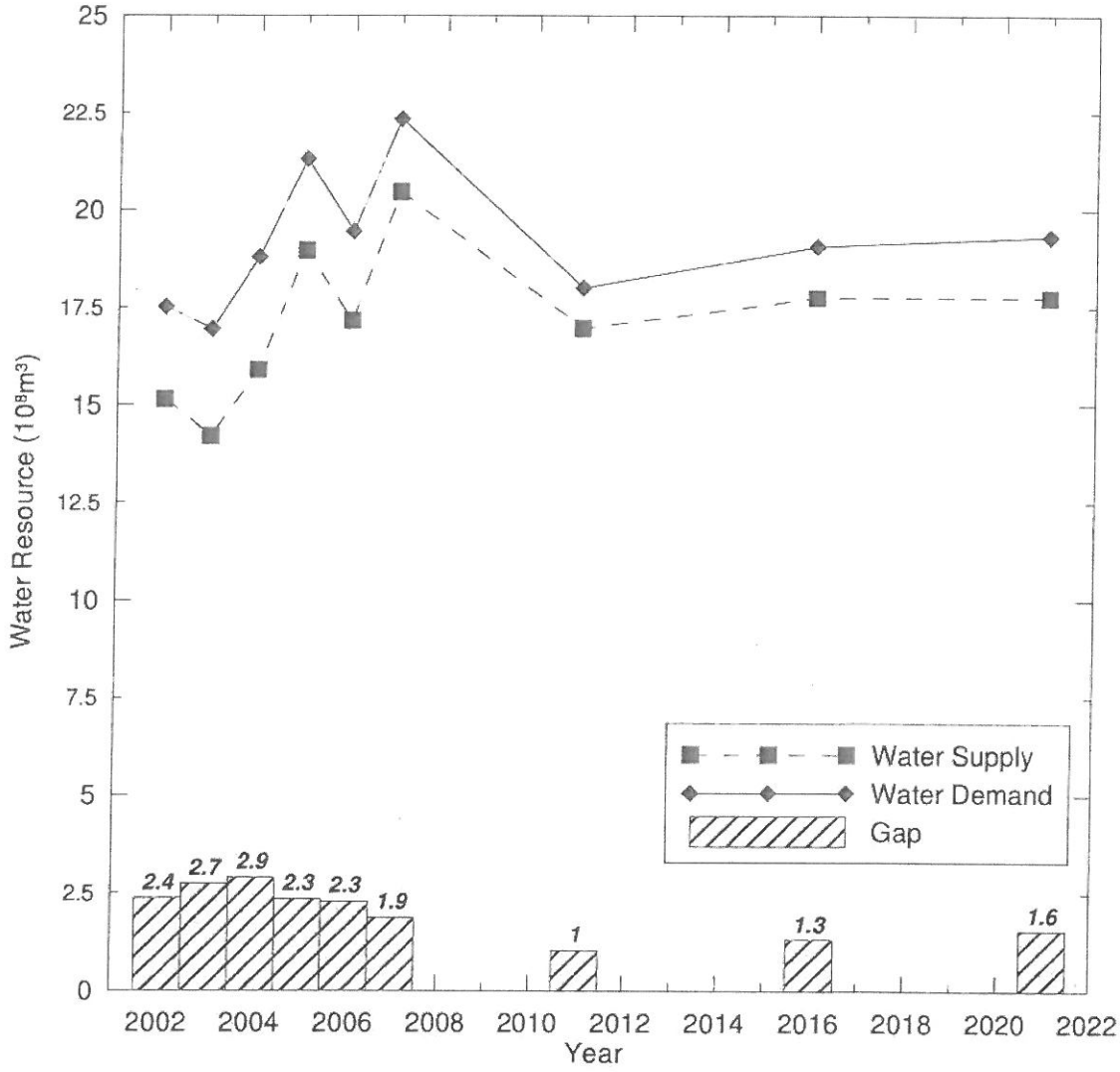

Figure 6 Water supply and demands in Yunlin County.

County. According to the result of the general survey on wells, Yunlin County has over 110,000 wells. Figure 6 shows the water supply and demands from 2002 to 2021. The water supply and demands from 2002 to 2007 were actual records collected by the Taiwan Water Corporation, Yunlin Irrigation Association, and Water Resources Agency. According to these actual records from 2002 to 2007 and with the possible water resource exploitation in the future, the water supply and demands were estimated for 2011, 2016, and 2021. The actual records show that the water supply was less than the water demands from 2002 to 2007. The average gap of water resources in Yunlin County is 0.24 billion cubic meters. Even with expectations that the Hushan Reservoir will operate from 2014, the gap of water resources still will exceed 0.1 billion cubic meters in 2016 and 2021. It should be emphasized that the records of the water demands did not contain the yield of groundwater by all the private wells. The gap is larger than what the records show if groundwater pumping ceases in order to prevent land subsidence (WRA, 2009).

4. Groundwater Level Variation

Groundwater level variation can reflect the groundwater over pumping effect. The decline of groundwater level of a region means the groundwater is continuously being over pumped. Figure 7 shows the groundwater level variation of four aquifer layers at the Husi groundwater level monitoring station near the HSR. Before 2005, the groundwater declined significantly. During this period, groundwater was over pumped in this region. Not only was the groundwater level in decline for one aquifer layer, but also for all four aquifer layers, indicating that each aquifer layer was over pumped. The situation was really serious and land subsidence most likely occurred during this period. It also means that disequilibrium existed between the water supply and demands. But from 2005, the groundwater level near the HSR increased and became stable. This means actions taken to prevent land subsidence were effective. Land subsidence has remarkably slowed down (Water Resources Agency, Consumptive Water Statistics Database).

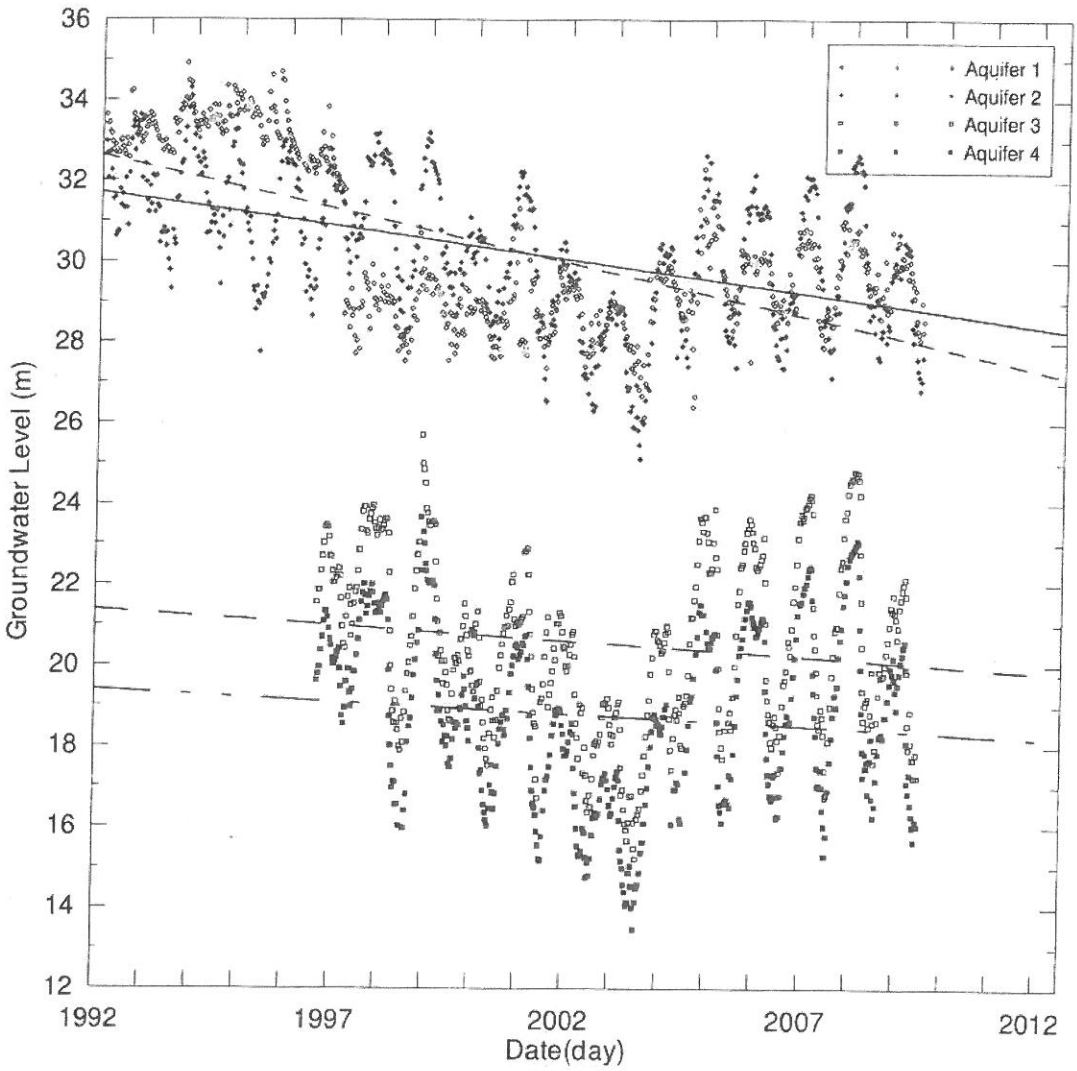

Figure 7 Groundwater level variation (Husi station).

5. Land Subsidence along HSR

The most serious areas of land subsidence are Tuku, Yuanchang, and Huwei. The route of the HSR crosses these three villages. According to historical records, the maximum land subsidence rate was 12.2 cm/year in this region in 2002. However, the land subsidence rate has retarded in recent years. Figures 8–10 show

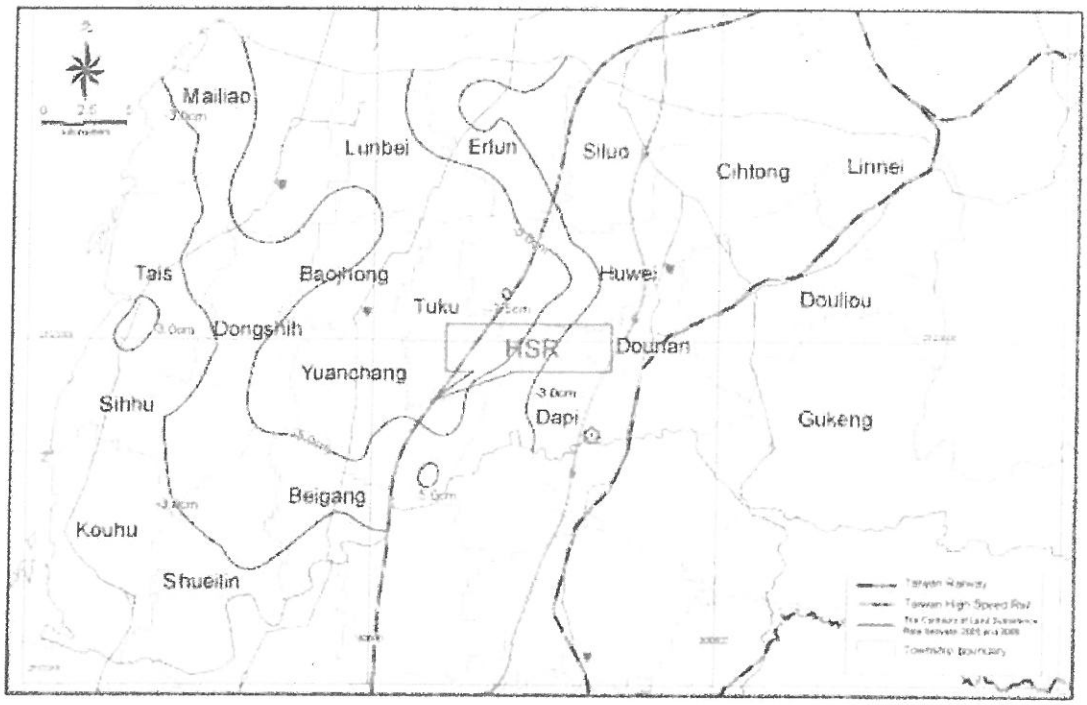

Figure 8 Land subsidence rate (2006–2007).

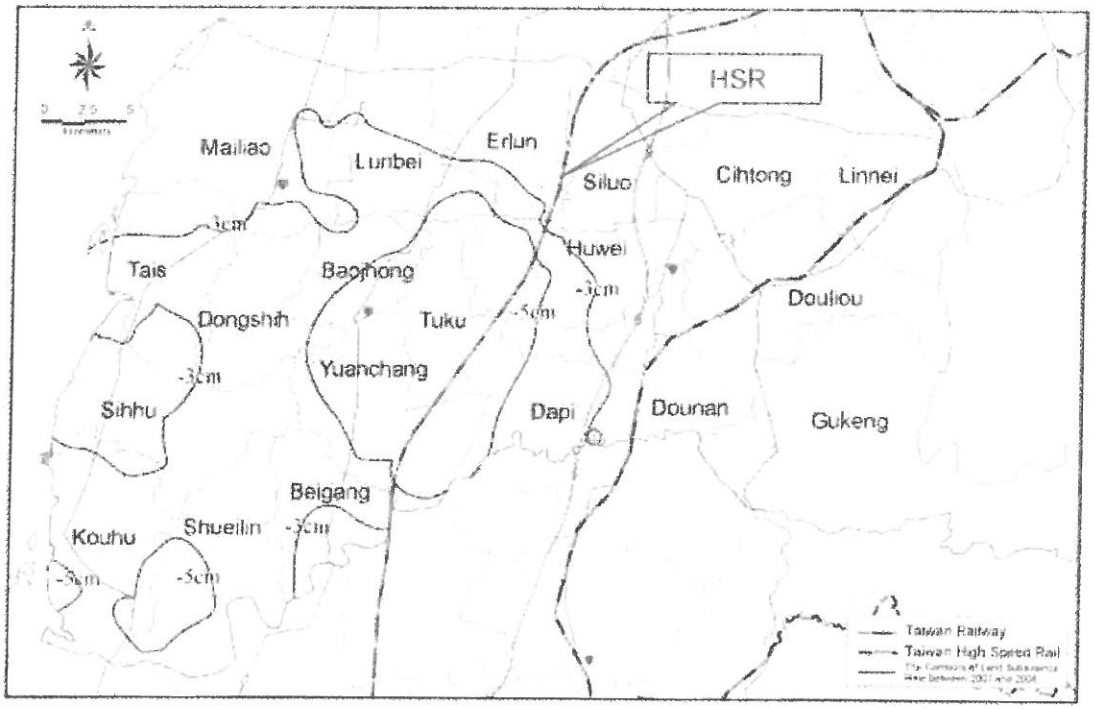

Figure 9 Land subsidence rate (2007–2008).

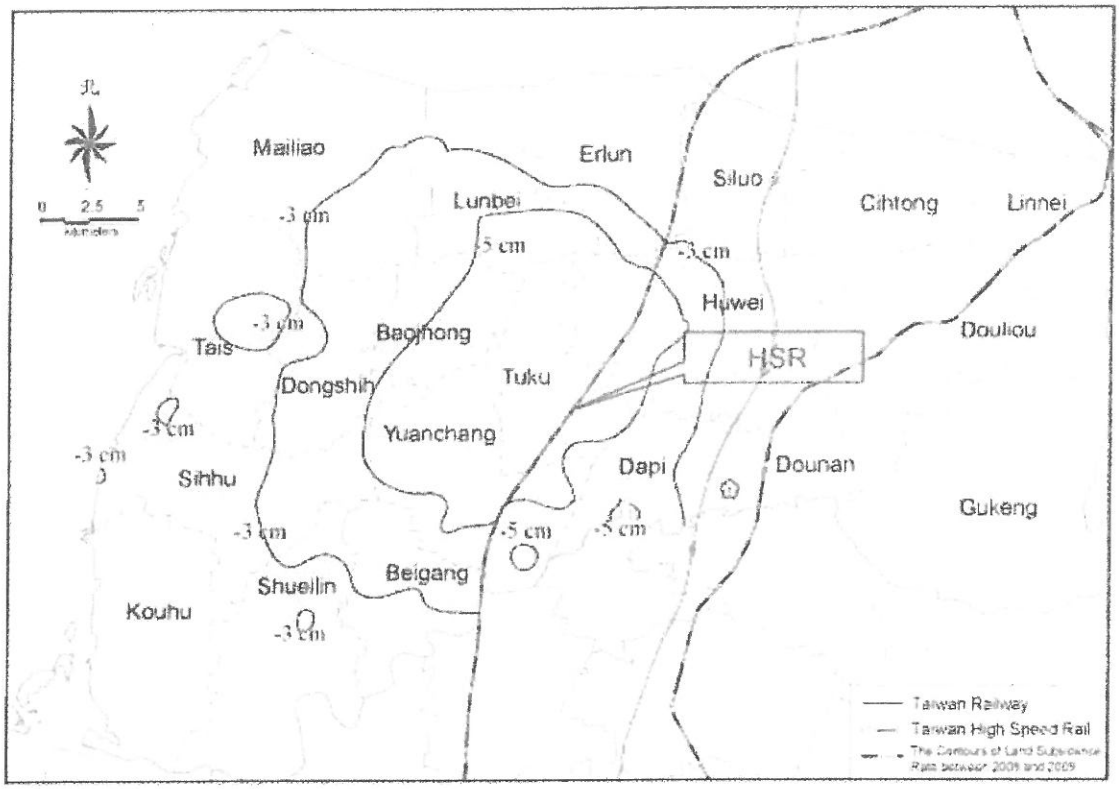

Figure 10 Land subsidence rate (2008–2009).

the subsidence rate of Yunlin County from 2006 to 2007, from 2007 to 2008, and from 2008 to 2009, respectively. The maximum subsidence rates were 8.2 cm/year, 7.1 cm/year, and 7.4 cm/year during these three periods. It shows that the land subsidence of the regions along the HSR has improved and the effort of reducing groundwater pumping may be the major reason for the improvement (Water Resources Agency, Land Subsidence Database).

6. Mitigation Strategy

In order to protect the driving safety of the HSR, WRA carried out the "Project for Filling or Moving Wells of Government Agencies in Banned Regions within a 3-km Width along HSR in Yunlin County". The project dealt with 69 wells of Yunlin Irrigation Association, 16 wells of Taiwan Water Corporation, and 2 wells of Taiwan Sugar Corporation. There were 29 wells filled, 39 wells that ceased pumping, and 19 wells monitored. Figure 11 shows the distribution of the wells that have been dealt with in this project. The reduction of the yield of groundwater was 400 million cubic meters per year in this project. The gap of water resource of this project was satisfied by allocating surface water from other vicinities. The land subsidence rate along the HSR declined from 10.6 cm/year to 7.0 cm/year after this project. Also after this project, the threat from land subsidence for the safety of the HSR was reduced. In order to respond to the climate change in Yunlin County, the Taiwan government must consider carrying out similar projects of reducing groundwater pumping (WRA, 2009).

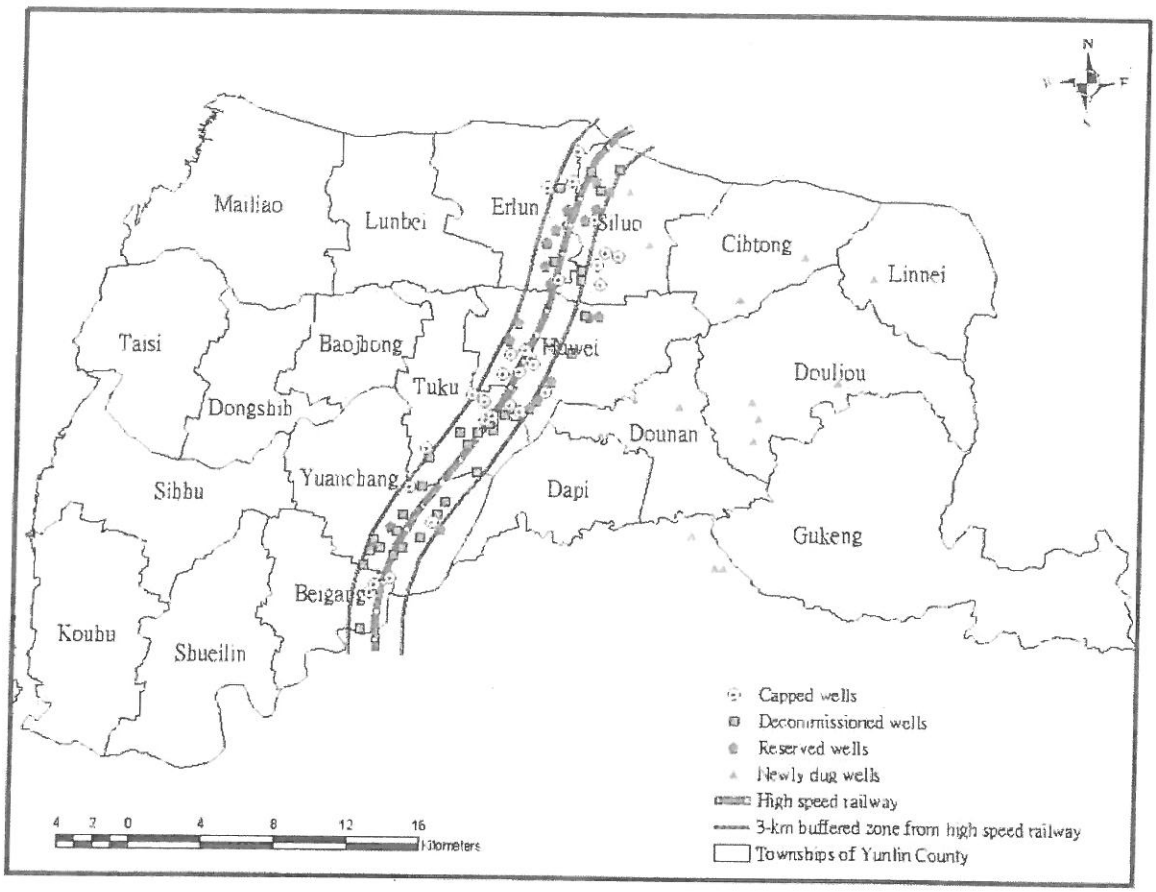

Figure 11 Well distribution of the project.

According to the effectiveness of this project, groundwater pumping reduction became an effective strategy for the protection of the HSR. So this project marked a milestone toward land subsidence prevention and the HSR protection in this area. The wells owned by the public sectors were dealt with and the groundwater pumping was reduced significantly. But there still are many private wells in the banned regions of the HSR. The future work is to increase rations of surface water supplement using engineering means (building water storage facilities) and non-engineering means (rational water resource management). As a result, the dependence of groundwater resources will be reduced. Finally, all wells in this banned region will be sealed. That is, groundwater pumping will be restricted in the banned regions of the HSR. When this target is achieved, land subsidence will be eliminated in a very short period of time.

7. Conclusion

Insufficient rain caused by climate change is happening in Yunlin County and will continue to impact the quantity of surface water resources. Thus, the situation of water resources management will become very grave. The achievement of groundwater pumping reduction depends on whether substitution water resources can be

made available. In other words, climate change may hinder the goal of land subsidence prevention by the need to use pumped groundwater for water shortages until other water resources are made available.

In order to protect the driving safety of the HSR, prevention of land subsidence in Yunlin County is urgent. How to reduce groundwater pumping is the most important issue for the government agencies. A rational strategy of surface water allocation should be generated and operated. The only way to decrease the rate of subsidence in Yunlin County is through reduction of groundwater pumping. The experiment, involving the well plugging projects of 2005, also confirms this opinion.

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