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# Sustainable groundwater development and management in the Quaternary Hang-Jia-Hu Plain, China

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**Abstract:** Based on the results of study on regional water supply system, water quality assessments, Quaternary aquifers investigation, and correlation analysis of groundwater depression resulting from land subsidence in the Hang-Jia-Hu Quaternary Plain, this paper presents the groundwater resources policy and sustainable management methods suitable for this area. Suggestions for controlling land subsidence by implementation of wise groundwater policy and management measures are also given.

**Key words:** Groundwater resources, Sustainable development and management, Land subsidence, Hang-Jia-Hu plain, Hydraulic engineering

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## INTRODUCTION

Hang-Jia-Hu Quaternary Plain is in the southern part of the Changjiang Delta, is 6490 $km^2$; is historically a major agriculture region named "Fish and Rice Field", densely populated, and in the economic economically developed zone now rapidly reaching urbanization. The total requirements for water resources are increased due to the large population, industrialization and urbanization. Resort overexploitation of groundwater from aquifers to replace unuseable water from polluted rivers led to ground subsidence and consequent inundation by flood. This research is aimed at studying the regional water supply system and to analysis the causes of irrational groundwater overexploitation resulting in land subsidence in the plain. Land at trying to improvising the best groundwater resources policy and sustainable management methods suitable for this area.

## REGIONAL HYDROGEOLOGICAL CONDITIONS

Regional hydrogeological conditions considered in this study included:

**Climatic factors** The studied area has subtropical monsoon climate, average precipitation of 1200 mm/a, warm and humid atmosphere with average annual temperature of 15.5 ℃ – 16.7 ℃ (Zhu et al, 1996).

**Geological setting and groundwater** Quaternary sediment environment. Aquifer characters, especially the recharge and discharge conditions of confined aquifers and the history and present situation of groundwater development in the plain had been investigated (Zhu et al, 1996). The groundwater resources are unequally distributed in three combined layers of confined aquifers made up of alluvial sand and gravel (Fig.1). Groundwater samples were taken from 52 wells for water quality assessment (based on Groundwater Quality Standard GB/T14848 - 93, China). In order to study the properties of aquifers and regional water supply system, and to create the monitoring net for groundwater water resources management, census data on: regional initial and recent piezometric surface mapping, $^{14}C$ dating of 4 samples of deeper confined groundwater were collected. The total discharge and the average discharge rates in the different regions with typical water levels for the two deeper layers of confined aquifers were calculated (Zhu et al, 1996).

The earliest pumping of groundwater in

the plain was in 1914. Due to the easy availability of groundwater, the low capital costs of its development for water supply, and its normally excellent natural quality, there has been increasing interest and rapid development of groundwater resources. Thus there is now an increasing number of counties in which an important proportion of potable urban water is obtained from aquifers. Groundwater is also widely developed for rural water supply.

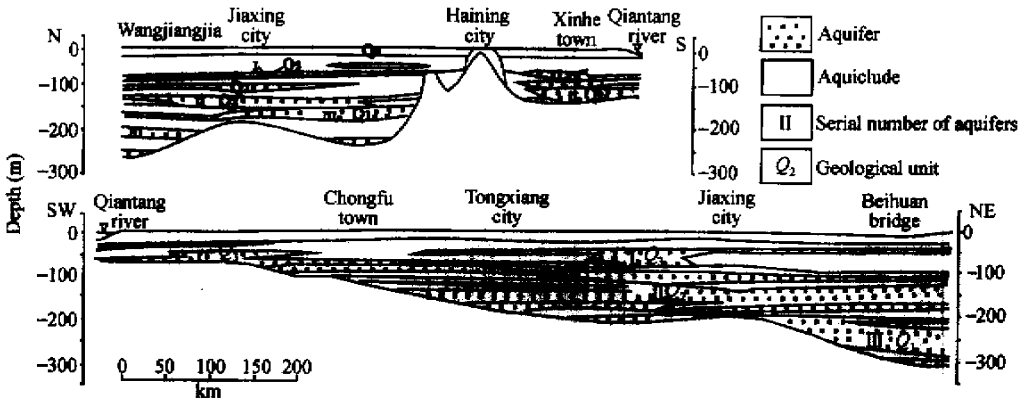


**Fig.1 Hydrogeologic sections of Hang-Jia-Hu Plain**

Correlation analysis of groundwater depression with the land subsidence in Jiaxing City was done to decide the limit discharge rates and the warning groundwater level (Fig.2). The harm of land subsidence and its economic losses had been estimated.

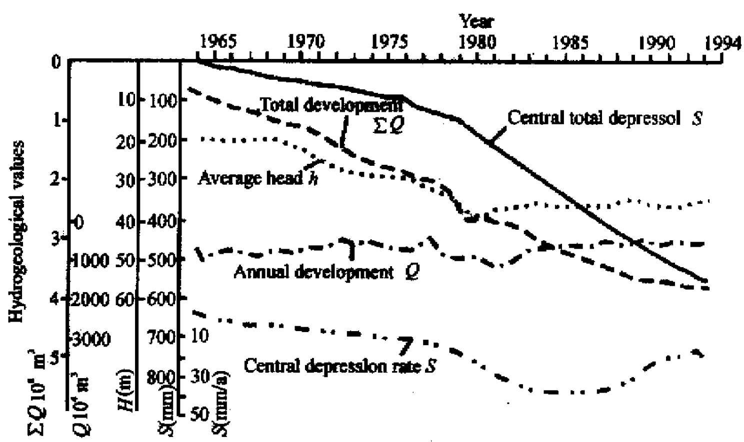


**Fig.2 Diagram of groundwater development and land depression curves**

**Surface water** almost 10.5% (679 $km^2$) of the plain is covered by rivers and canals belonging to the Tai Lake drainage basin with very slow flow. In order to assess surface water quality, a series of samples were taken from 10 river quality monitoring stations in the plain and 3 water supply works in Jiaxing City (Zhu et al., 2000). The analyses items included pH value, hardness, $Cl^-$, DO, COD, $BOD_5$, $NH_3^+$, $NO_2^-$, $NO_3^-$, As, Hg, $CN^-$, $Cr^{6+}$, $Pb^{2+}$, and $Cd^{2+}$ (Table 1). Water quality assessment was based on Standard of Surface Water Quality (GB3838-88, China).

**Table 1 Surface water quality in the study area** (mg/L)

| No | Hardness | pH | $Cl^-$ | DO | COD | $BOD_5$ | $NH_3$ | $NO_2^-$ | $NO_3^-$ | As | Hg | $CN^-$ | $Cr^{6+}$ | $Pb^{2+}$ | $Cd^2$ | Class |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 64.2 | 7.4 | 17.4 | 5.4 | 5.7 | 4.6 | 0.85 | 0.058 | 0.34 | 0 | 0.0001 | 0 | 0 | 0 | 0.001 | Ⅳ |
| 2 | 63.8 | 7.4 | 32.2 | 4.4 | 6.5 | 5.4 | 1.63 | 0.046 | 0.24 | 0 | 0.0001 | 0 | 0 | 0 | 0 | Ⅳ |
| 3 | 60.3 | 7.2 | 29.5 | 2.5 | 6.2 | 5.2 | 1.04 | 0.045 | 0.18 | 0 | 0 | 0 | 0 | 0 | 0 | Ⅴ |
| 4 | 77.9 | 7.6 | 56.5 | 2.1 | 16.0 | 12.1 | 11.4 | 0.076 | 0.11 | 0 | 0.0001 | 0 | 0 | 0 | 0.0001 | Ⅴ |
| 5 | 60.7 | 7.7 | 33.1 | 8.0 | 5.9 | 2.5 | 0.70 | 0.033 | 0.12 | 0 | 0.0001 | 0 | 0 | 0 | 0 | Ⅲ |
| 6 | 58.9 | 7.5 | 58.4 | 7.4 | 2.1 | 6.0 | 2.29 | 0.025 | 0.18 | 0 | 0.0001 | 0 | 0 | 0 | 0 | Ⅳ |
| 7 | 84.5 | 7.4 | 54.8 | 3.3 | 7.6 | 3.6 | 5.20 | 0.084 | 0.21 | 0 | 0.0001 | 0 | 0 | 0 | 0.0002 | Ⅳ |
| 8 | 95.3 | 7.4 | 51.0 | 2.0 | 8.0 | 4.6 | 6.52 | 0.074 | 0.09 | 0 | 0.0001 | 0 | 0 | 0 | 0 | Ⅴ |
| 9 | 63.6 | 7.3 | 39.5 | 4.5 | 4.8 | 3.5 | 1.39 | 0.031 | 0.21 | 0 | 0.0001 | 0 | 0 | 0 | 0 | Ⅳ |
| 10 | 62.8 | 7.7 | 86.4 | 4.2 | 7.9 | 6.1 | 0.60 | 0.150 | 3.40 | 0 | 0 | 0 | 0 | 0 | 0 | Ⅴ |

## PROBLEMS AND DISCUSSIONS

After 1979, the number of wells, their depth, and the pumping rate of groundwater increased; while 60 – 80% (Zhu et al, 1996) were only used for industry washing and cooling. Due to the great number of users and wells, and the lack of governmental supervision, the uncontrolled exploitation of groundwater resources, is very common in this area. This uncontrolled activity has already led to the depletion and deterioration of deeper aquifers. The big problem is that the recharge of confined groundwater happened 2000 – 3000 years ago according to the results of $^{14}C$ dating (Zhu et al, 1996), the groundwater developed in the plain is fossil without recently recharged. This can result in a permanent reduction of groundwater storage capacity.

The unrestricted exploitation may cause significant aquifer deterioration from a combination of different effects: (1) Continuously falling groundwater levels and depletion of storage reserves. (2) Cross boundary flows and intrusion of saline water into aquifers, resulting in the abandonment of deep wells. (3) Consolidation of aquitards leading to land subsidence and problems with building stability and sewer flows, especially obvious damage in flood events in this area. An over 600 $km^2$ area around the center of groundwater overexploitation has caused serious land subsidence, at annual average rate is 25 – 40 mm/a. The economic losses caused by land subsidence are more than $31 \times 10^9$ RMB (Zhu et al, 1996). (4) The situation of the surface water resources makes artificial recharge expensive. The regional surface water is organic polluted and limited in COD, $BOD_5$, DO and NH3. It is difficult for local people to find new sources of water supply, and even for injection. Surface water sources require extensive treatment, because of coloration and other problems associated with high natural organic content and intermittently heavy suspended sediment load. (5) Recharge basis and recharge recovery wells are also necessary. All these have adverse effects on groundwater development and utilization. So the development cannot be sustainable.

The definition of overexploitation in this area is not difficult, and depends on many factors and circumstances. In any case, overexploitation of groundwater is undesirable and has a lot of negative environmental, social and economic consequences. In economic terms, groundwater is a resource for which property rights are not capable of clear legal definition, and thus is considered common-property resource. The exploiter receives all the benefits of groundwater development but pays only part of the costs (investment in well construction and recurrent cost of pumping).

Irrational overexploitation of groundwater has administrative, social and technical roots. The principle causes are the inadequate information faulty evaluation, and uncontrolled exploitation of groundwater resources; while other causes are: (1) poor hydrogeological understanding; (2) defective licensing policies, disregard for, and lax implementation of legislation on the use and conservation of groundwater resources; (3) lack of awareness of the need of groundwater resource management, lack hydrogeological database; (4) indiscriminate drilling of excessive number of water-supply wells in relation to their total yield. Water is a limiting development factor in the area. Actually, all counties have few or no existing policies for groundwater exploitation and management. The lack of appropriate policies comes from the basic ignorance of the hydraulic behavior and the total hydrogeological system concept.

## RECOMMENDATIONS

To avoid, or to compensate for aquifer depletion, it is necessary to introduce alternative, protective and corrective methods (Foster, 1991). The following recommendations are should be followed to prevent the overexploitation: (1) prohibiting or limiting the construction of new wells to protect the rights of present users against subsequent developers of groundwater supply; (2) restricting exstraction rates and pumping periods of existing wells; (3) improvement in aquifer recharge; (4) groundwater desalinization, for aquifer affected by saline water intrusion. Generally, these projects or alternatives are expensive, but necessary. In any case, an adequate policy must be developed, adoption of adequate legislation is a prerequisite for the control of groundwater extraction.

Some measures recommended for controlling land subsidence include: ordering reduction in pumping rates by at least 65%, raising water price, spreading further scientific knowledge of sustainable groundwater resources management, water saving etc. Local laws and regulations related to protection of water resources have to be implemented immediately in this area.

## CONCLUSIONS

In this case, physically unsustainable development of confined aquifers resulting in inefficient utilization of groundwater resources. From the late 80's the alternatives/corrections often seemed to progressively fail because of lack of comprehensive maintenance. The exploitation of groundwater resources without government scientific control in this area has already caused the serious depletion and irreversible deterioration of important regional aquifers. There are many reasons for the overexploitation, which is historically mainly due to poor management and poor hydrogeological assessment. It is necessary to implement management criteria based on good hydraulical and hydrochemical monitoring programs. Also it is necessary to implement control strategies based on economic criteria but not dependent directly on market forces as such. Groundwater should be regarded as a valuable, but potentially fragile resource which in some cases is highly vulnerable to mismanagement. In this area, development of groundwater resources may have major ecological implications and thus always needs careful evaluation because of the close association of groundwater with the water supply environment. Exstraction and protection policies must be well defined and flexible. As with many other things it must be concluded that prevention is better than cure.

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