Marsland Press
Journal of American Science 2009:5(2) 83-90

# Estimation for Groundwater Balance Based on Recharge and Discharge: a Tool for Sustainable Groundwater Management, Zhongmu County Alluvial Plain Aquifer, Henan Province, China

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**Abstract:**
This study evaluates and estimates groundwater resources of the Zhongmu County China for the period between, 1980 and 2007, which is the main resource for agricultural and domestic water supply. Our approach is centered on quantitative estimation of two main parameters-input and output. Recharge and discharge components have been quantified based on inflows, outflows and changes in the aquifer groundwater storage. Inflow to the system includes groundwater recharge from precipitation lateral groundwater inflow, irrigation infiltration, influent seepage from rivers. Discharge from the system includes effluent seepage to rivers, evaporation losses, groundwater lateral outflow, and groundwater extraction. Our results show that the average total annual discharge of the area ($19928\times10^4 m^3/a$) exceeded total average annual recharge ($21984.70\times10^4 m^3/a$), implying that the system is in deficiency – an indication of unsustainable water withdrawal. Abstraction of groundwater could be minimized by providing sufficient canal irrigation water to the farmers. We further recommend the institution of a groundwater regulatory framework to optimize groundwater use on sustainable basis, provision of drinking water wells with a recharge structures and a ban on the construction of irrigation wells / tube wells within a distance of 200metres or less (depending on scientific criteria) of the drinking water supply well. [Journal of American Science 2009:5(2) 83-90] ( ISSN: 1545-1003)

**Key words:** Groundwater resource evaluation, recharge, discharge, water balance, sustainable use, Zhongmu County.

## 1. Introduction

Water is an essential natural resource for sustaining life and environment. The available water resources are under pressure due to increased demands with an ever increasing population and the time is not far when water, which we have always thought to be available in abundance and as a free gift of nature, will become a scarce commodity. From a volume perspective, most water use in Zhongmu is appropriated from groundwater. Rapid development of economy and increase of population bring more and more acute contradiction between the water supply and water demand, especially for agricultural purposes, has increase rapidly in recent times, and both surface water (including rivers, lakes, and springs) and groundwater have been exploited [Li-Tang ,et al,2007]. China's total water use was $579.5\times10^6 m^3$ in 2006, with 63.2% of agricultural use, 23.2% of industry use, 12.0% of domestic use, and 1.6% of ecological and environmental uses (supplied by the man-made measures) [MWRC, 2006]. Utilization ratio of agricultural water accounted for 75.7% (referred to as the proportion of water consumption to water use). About 90% of the agricultural water was consumed by farmland irrigation.

In order to properly evaluate the degree of significance and impact of groundwater development in Zhongmu, any scientific evaluation must focus strictly on Zhongmu's conditions. One means of objectively evaluating the relative significance of changes in water demands in Zhongmu is to employ water budget methodology. Water shortage has become a main factor in restricting sustainable socio-economic development. Agriculture is an important part of the local economy national well-known garlic production base and a major water consumer. Groundwater is the major water-supply source to agricultural in Zhongmu County, and in some towns it's even the only water supply source. About 90% of groundwater yield per year in Zhongmu County is used in Agricultural irrigation. The statistical data show that 83.57% of total surface water use ($22.9\times10^6 m^3/yr$) and 64.61% of total groundwater use ($6.10\times10^6 m^3/yr$) were consumed in agricultural irrigation during the period from 1998 to 2006 [BSZ, 1998-2006]. That means agriculture consumed 78.7% of the total water use in the provinces of Yellow River Basin every year.

In this paper, based on making full use of hydrology and hydrogeology data and predecessor's research results in the past 20 years, groundwater quantity assessment in Zhongmu County was carried out in order to offer scientific basis in the course of establishing the sustainable development use plan of groundwater resources. Then, according to the assessment results, the rationality of management and development of groundwater in Zhongmu County was analyzed.

Available water resources per capita are decreasing as a result of population growth. Groundwater basins constituting Zhongmu are very scarce and vary in quantity and quality. Recharge of renewable water aquifers is generally highest in the mountainous northern part of the country where precipitation is greatest. Most surface water belongs to poor grade water quality (grade V or below V in Chinese terminology, of which grade I is best and grade V is only applicable to agriculture irrigation). The surface waters have been polluted badly because of direct discharge of industrial and domestic wastewater. So, groundwater is the most important water supply source for urban and rural areas. Continuation of groundwater overexploitation at these high levels will lead to mining these sources as well as deteriorating the quality of abstracted water, which will lead at the end to an extensive damage of the aquifers.

## 2. Objectives

The main objectives of the study are to:

(i) Identify and quantify all recharge and discharge components of groundwater;

(ii) Calculate the average annual groundwater balance; and

(iii) Prepare recommendation for sustainability of groundwater use for irrigated agriculture.

## 3. Physiography and Location of Study Area

Zhongmu County lies in the heart of Henan, on the southern alluvial flood plain of the Yellow River, between Zhengzhou and Kaifeng. It is located in the middle latitude belt and stretches from north latitude 113°46' to 114°12' and east latitude 34°26' to 34°56', total area of 1416.6 $km^2$ with a length of 55km in the north-south direction and a width of 35 km in the east-west extension and a population of 680,000. It has jurisdiction over 11 towns, 6 countries and 431 villages, with a population density of 476 persons per square kilometer in 2002. The study area is rather flat region; west-high and east-low, with the hill land and piedmont in the west and plain in the east, an altitude 85m, a gentle slope (1/2,000-1/10,000) to north slight undulation in the piedmont part.

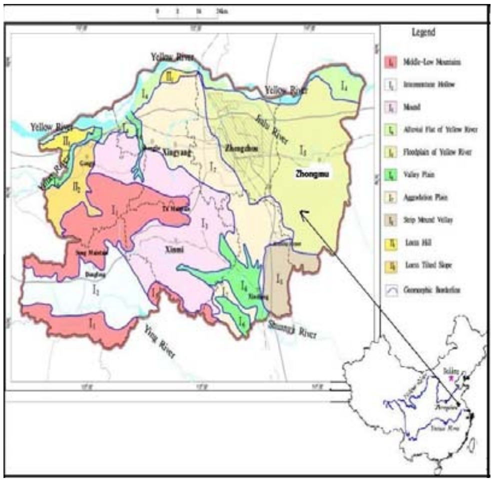


**Figure 1. Location of Zhongmu County**

Climatically, Zhongmu belongs to the typical mid-latitude temperate continental monsoon climate, four distinct seasons. It is cold in the winter and hot in the summer and the dry and moist season is obvious. It is warm in the spring and cool in the autumn. The sunshine duration in the whole year is about 2366 hours, with average annual temperature of 14.4°C. January, whose average temperature is 4.6°C, is the coldest month of the year, and July is the hottest with an average temperature of 32.1°C. The annual average rainfall is 640.9 mm and the frost-free period is 240 days. Zhongmu County, with rich water resources, 9 main Rivers Jialu, Qili, Zhangbagou, xiaoqin, Dilixiaoqing, Damenggou, Shigou, Yunliang, Shuikuigou rivers of various sizes that respectively belongs to the two great river systems of the Yellow River and the Huaihe River. Mean annual evaporation is 1492.6mm. The average relative humidity of the year is 67%. It is 113.5 meters above the sea level on average. Of the 1416.6 square kilometers, 930.600 mu of it is farmland, which covers 43% of the total area. Woods covers an area of 319000 mu which forms 1470 of the total area. 20000 mu is covered by water. It has a population of 659.000; 321000 laborers which constitute 49.37% of the total population. The number of social laborers stands at 220000 which form 58.5% of the laborers and 33.67% of the total population.

## 4. Geology and Hydrogeology

In most parts of Zhongmu County, the phreatic water is principally stored in the Holocene Yellow River alluvial plain aquifer, whose lithology consists of coarse grained main stream- facies or very fine grained flood plain facies or marginal facies. These have been distributed in an interlacing manner. Groundwater occur in various natural geological environments according to the depth of burial, the characteristics of the water- bearing medium, the tectonic structure, the dynamic conditions and the geophysico-chemical environment. On the basis of this we can subdivide the aquifer system as follows: shallow aquifer (unconfined aquifer less than 60 m deep), intermediate aquifer (confined aquifer 60~300 m deep), deep aquifer (confined aquifer 300~800 m deep) and super-deep aquifer (confined aquifer deeper than 800 m) [Li, G. R, Wang, X. G., Guo, Y. Q., 2005].

The shallow aquifers have abundant groundwater because they can be easily recharged by precipitation, irrigation, rivers, and reservoirs. The confined aquifers, on the other hand, have abundant groundwater because of their huge extent and volume. In Zhongmu County based on the geomorphology, aquifer type, groundwater dynamics, hydrochemistry and influence of human activities, the groundwater can be classified as shallow groundwater subsystem in piedmont plain. The Quaternary sediments consists chiefly coarse grained sands, and gravel bearing medium to coarse sands. The aquifers gradually becomes finer grained with low permeability as we move away from the mountains and shallow groundwater in the central plain as we move further from the mountain.

In the north of Zhongmu County, the

phreatic water mainly stored in the Epi-Pleistocene and Neocene aquifers below the surface in 40m depth. Therefore, distribution regularities, genetic types, lithology, thickness and water abundance closely related to the local relief condition. The south and west mountain areas are characterized by karstic water in Carbonate systems, water in fractured systems in hard rock and clastic rock. Fractured rock systems generally have deep groundwater table depth and are relatively difficult to exploit. The lithology textures of the shallow aquifers in the study area have a great bearing on their transmissivity and yield. Aquifers systems with less than 60m in depths can be divided in the following four types:

(i) Monolayer type; the aquifers are thick, coarse grained and have good transmissivity.

(ii) Double type; aquifers of this type are located in the areas where the main stream facies is covered by flood plain facies deposits of the Yellow river accounting for 60-70%of the total area. The aquifers thus have a "double " structure with and upper finer grained part and a lower coarser grain part, with the upper part forming and aquitard composed of clayey sand and sandy clay, and the lower part a stable sand aquifer. Their specific well yields are commonly less than 5-10 $m^3$/hour/m, transmissivity approximately 500$m^2$/day in near- main- stream facies zones and 200 $m^2$/day in other areas.

(iii) Multilayer type; aquifers of this type are located in the peripheral facies zones of alluvial fans of the Yellow river. The main sand aquifer is absent, and this type is composed of alteration of silt, clayey sand and sandy clay, with poor transmissivity. Specific yield are commonly less than 5$m^3$/hour/m. Transmissivity coefficient is about 50$m^2$/day.

## 5. Methodology

Based on general hydrogeologic principles, a groundwater budget was prepared to estimate the amount of groundwater inflow, outflow and change in storage. Water balance techniques have been extensively used to make quantitative estimates of water resources and the impact of man's activities on the hydrologic cycle. On the basis of the water balance approach, it is possible to make a quantitative evaluation of water resources and its dynamic behavior under the influence of man's activities. The study of water balance is defined as the systematic presentation of data on the supply and use of water within a geographic region for a specified period. With water balance approach, it is possible to evaluate quantitatively individual contribution of sources of water in the system, over different time periods, and to establish the degree of variation in water regime due to changes in components of the system.

The basic concept of water balance is:
The amount of water entering a control volume during a defined time period (inflow, I), minus the amount leaving the volume during the time period (discharge, Q), equals the change in the amount of water stored (ΔS) in the volume during that time period.

$$I - O = \Delta S$$

$$\left(\underbrace{P_{pt} + I_r + G_{in} + R_i}_{\text{inflow}, I}\right) - \left(\underbrace{R_e + G_{out} + E_l + G_{ex}}_{\text{outflow}, O}\right) = \Delta S$$

**Where:**
Inflow (I) consists of; precipitation ($P_{pt}$) lateral groundwater inflow (Gin), irrigation infiltration ($I_r$), influent seepage from rivers ($R_i$).
Outflow (O) consists of; effluent seepage to rivers ... ($R_e$), evaporation losses ($E_l$ ), groundwater lateral outflow, and groundwater extraction ($G_{ex}$) and ΔS change in ground water storage.

### 5.1. Recharge Components

Natural recharge of the area is from direct precipitation, influent seepage from rivers, and irrigation waters which in a broad sense [Simmers, 1988] defined groundwater recharge as "an addition of water to a groundwater reservoir". Modes and mechanisms of recharge were classified by the same author into four broad categories:

- Downward flow of water through the unsaturated zone reaching the water table;
- Lateral and/or vertical inter-aquifer flow;
- Induced recharge from nearby surface water bodies resulting from groundwater abstraction; and
- Artificial recharge such as from borehole injection or man made infiltration ponds.

The different mechanisms are further described [Beekman et al., 1996; Selaolo, 1998; de Vries & Simmers, 2002; Lerner et al., 1990; Lloyd, 1986] by enhancing the classification based on the origin of the incoming water, movement of water in the unsaturated zone, aerial extent on which recharge acts upon, and time scale of the recharge occurrence.

**(a) Precipitation inputs**

Rainfall occurs in the area mainly during the monsoon months. The average annual rainfall was calculated as 580.30 mm. The surface area covered by the aquifer is approximately 1393.00 km$^2$ The annual groundwater recharge due to monsoon rainfall has been estimated with the help of the following equation:

$$Q_P = P \times \alpha \times n \times F \times 0.1$$

**Where**:

$Q_P$ = annual precipitation infiltration recharge ($10^4 m^3/a$),
P= annual precipitation (mm), α is precipitation infiltration coefficient,
n= precipitation valid infiltration coefficient (0.8 value was adopted for the study);
F = aquifer area, calculation area (km$^2$).

(b) **Lateral groundwater inflow**

The Groundwater in Zhongmu County is recharged by lateral inflow from the north, southwest and west. Computation formula is the following:

$$Q_{OR} = T \times I \times L \times t \times 0.001$$

Where:

$Q_{OR}$= annual groundwater lateral flow recharge quantity ($10^4 m^3/a$),
T= hydraulic conductivity (m$^2$/d);
I= average hydraulic gradient (‰),
L= the length of calculated section (km),
t= recharge days per annual (d/a). (365days was adopted for the study)

(c) **Influent seepage from rivers**

The area under study has an extensive river network which recharges the groundwater. There is Jialu River which is the main River flowing across Zhongmu County was used. The computing formula of recharge from Jialu River：

$$Q_{sr} = q \times l \times t \times 0.1$$

Where:

$Q_{sr}$ = annual river infiltration recharge quantity ($10^4 m^3/a$);
$q$ = infiltration volume per unit river length (m$^2$/d);
$l$ = river length in Zhongmu County (km);
$t$ = wet days per year (d/a).

(d) **Irrigation infiltration**

Recharge from surface-water irrigation is the largest component of aquifer. Computing formula of irrigation leakage recharge capacity is:

$$Q_{IR} = \beta \times Q_I$$

Where:

$Q_{IR}$ = agricultural irrigation leakage recharge ($10^4 m^3/a$),
$\beta$ = irrigation leakage coefficient,
$Q_I$ = annual irrigation water volume ($10^4 m^3/a$).

**5.2. Discharge Components**

The total amount of groundwater withdrawn artificially or naturally from aquifers is termed groundwater discharge.

**1. Artificial groundwater discharge**

(i)**Groundwater extraction** ($Q_{ex}$)

The artificial withdrawal of groundwater from shallow aquifer is by means of dug wells. These withdrawals are mainly for domestic industrial and agricultural purposes.

According to statistical data from water conservation office and water conservancy between 1980 and 2007, industrial exploitation quantity ($Q_{IE}$= 829.60x$10^4 m^3$/a), agriculture exploitation quantity ($Q_{AE}$11096.00 x$10^4 m^3$/a) and domestic consumed water quantity ($Q_{DE}$ 936.51 x$10^4 m^3$/a) were calculated in each computing unit. Given a sum total of $Q_t$ =12862.11 x$10^4 m^3$/a.

**2. Natural groundwater discharge**

The major sources of natural groundwater discharges are:

(i) Effluent seepage to rivers, (ii) evaporation losses, (iii) lateral out flow.

Evaporation intensity method was adopted to calculate evaporation quantity:

$$Q_E = \varepsilon \times F$$

Where:

$Q_E$ = annual phreatic evaporation quantity ($10^4 m^3$/a),

$\varepsilon$ = phreatic water evaporation intensity (m/a),

$F$ = evaporation area ($10^4 m^2$). Evaporation area was determined according to evaporation limit depth (3m).

**6. Change in Groundwater in Storage**

Aquifers in the Zhongmu alluvial Plains are generally unconfined, the change in water in storage in the aquifers can be estimated using the water-level change maps and the average specific yield of the aquifer indifferent sub areas which ranges between -0.05 m/a and -0.19 m/a .

The expressions of groundwater reserves variable in shallow aquifer is as following:

$$\Delta W = 100 \times (h_2 - h_1) \times \mu \times \frac{F}{t}$$

Where:

$\Delta W$ =Groundwater reserves variable in shallow aquifer ($10^4 m^3$/a);

$h_1$ =the groundwater table at the beginning of the calculating time (m);

$h_2$ =the groundwater table at the end of the calculating time (m);

$\mu$ =Specific yield in range of stage of shallow groundwater;

$F$ =Calculated area (1393.00$km^2$);

$t$ =Length of calculating time (a).

**7. Results and Discussions**

The annual groundwater budget is summarized in table1, showing the range of annual calculations between 1980 and 2007.

**Table 1. Summary of water balance calculations for the Zhongmu County(1980-2007).**

| | | | |
|---|---|---|---|
| **1. Recharge Components** | | | |
| Recharge from Rainfall | | | 11201.86 x$10^4 m^3$/a |
| River Recharge | | | 271.98 x$10^4 m^3$/a |
| Irrigation recharge | | | 3058.85 x$10^4 m^3$/a |
| Groundwater lateral inflow | | | 5395.20 x$10^4 m^3$/a |
| Total Aquifer Recharge | | | 19927.89x$10^4 m^3$/a |
| **2. Discharge Components** | | | |
| Evaporation losses | | | 6580.34x$10^4 m^3$/a |
| Groundwater lateral outflow | | | 1112.72 x$10^4 m^3$/a |
| Groundwater Pumping | Industrial pumping | 829.60x$10^4 m^3$/a | 12862.11x$10^4 m^3$/a |
| | Agriculture pumping | 11096.00x$10^4 m^3$/a | |
| | Domestic consumption | 936.51x$10^4 m^3$/a | |
| Effluent seepage to rivers | | | 1429.53 x$10^4 m^3$/a |
| Total Discharge | | | 21984.70 x$10^4 m^3$/a |
| Change in Storage | | | -2056.11 ×$10^4 m^3$/a |

According to table 1, we know the multi-annual average recharge quantity of groundwater is 19927.89×104m3/a from 1980 to 2007 in Zhongmu County, the multi-annual average discharge quantity is 21984.70×104 m3/a, and the multi-annual average loss quantity is 1527.52×104 m3/a.The groundwater table is of downtrend in Zhongmu County, which expresses that the groundwater balance is at minus situation in this area at present.

In the studied area, the dug wells are fully penetrating. Monitoring data from 17 groundwater observation wells in were used to calculate the average groundwater reserves variable in shallow aquifer from 1980 to 2007 at every computing unit.

Thus, using the expressions of groundwater reserves variable, the deficit groundwater of the area is then calculated to be -1527.52X104m3/a

**8. Conclusion**

Sustainable groundwater resources development implies use of groundwater as a source of water supply, on a long term basis, in an efficient and equitable manner sustaining its quality and environmental diversity. Zhongmu County area has been prepared to estimate the inflows and outflows to the groundwater system. Zhongmu is blessed with abundant and clean water resources that are sufficient to sustain the level of growth projected into the future. Based on a variety of calculations and available data, the gross annual average recharge of groundwater is 19927.89×104m3/a from 1980 to 2007 and a gross annual average discharge of groundwater is 21984.70 x104m3/a resulting to a dramatic deficiency of -2056.11×104m3/a in the water balance. The main reasons of the minus balance of the phreatic water are overexploitation and inadequate recharge. The safe yield of ground water aquifers is a quantity of water that may be harvested on a sustainable basis and is equivalent to annual replenishment/recharge. Continuing overdraft exceeding the safe yield will require conservation practice implementation to reduce demand, and increase water use efficiency. In some areas, conservation will not reduce ground-water use to the safe yield of the aquifer and land-use changes will be inevitable. This raises question about the sustainability of groundwater use in the area. There should be a balance in recharge and discharge components to maintain an equilibrium in the area. Groundwater is an important natural resource with high economic value and sociological significance. It is important that this resource be utilized in such a manner that a permanent depletion of the resource in both quantity and quality aspects is avoided and that any other environmental impacts. Given the sensitivity of the water balance to processes like artificial recharge, further work towards improving the reliability of calculated values is important.

**Recommendations**

- ✧ Abstraction of groundwater could be minimized by providing sufficient canal irrigation water to the farmers.
- ✧ A groundwater regulatory framework needs to be developed to optimize groundwater use on sustainable basis.
- ✧ By providing all drinking water wells with a recharge structure.
- ✧ By banning construction of irrigation wells / tube wells within a distance of 200metres or less (depending on scientific criteria) of the drinking water supply well.

**Acknowledgements**

We thank the Chinese government scholarship, without which this work will not have been realizable. We are also indebted to the ministry of higher education, Cameroon for initiating this wonderful cooperation with the government of the Peoples Republic of China.

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