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Ecological water resources requirement of the Ningxia natural oasis using the groundwater level variation amplitude method

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Abstract This paper presents the groundwater level variation amplitude method, which is used to calculate the Ningxia ecological water resource requirement. The information of annual groundwater level variation from observation wells is used to search for the yearly variation value of the closed groundwater flow field. The ecological water resources requirement of Ningxia natural oasis is estimated on the basis of superposition of the yearly variation value of the closed groundwater flow field, remote sensing vegetation data, and hydrogeological data. This method overcomes the insufficient quantum for ecological water demand to a certain degree, and provides a new concept for the calculation of ecological water resources requirement and for ecological protection and recovery in the northwest arid and semi-arid areas in China.

Key words hydrology; ecological water resources requirement; natural oasis; groundwater

INTRODUCTION

Ningxia is an area with a serious lack of water. The groundwater resources balance is kept mainly by the Yellow River water constantly flowing across the area, and this will go on in the future. The excess agricultural water consumption takes up much of the water for ecological environment construction. The historical "72 connected lakes" have gradually withered or even disappeared. The desertification and salinization of soil, retreat of vegetation, reduction of area and quality of farmland lead to Ningxia's small environmental capacity and poor stability of the ecosystem, and the ecological environment is in a severe worsening trend. Water is one of the most sensitive limiting factors for the combination body of nature – society – economy. In arid areas water is one of the "bottleneck" factors which limits socio-economic development and is also the key driving factor for ecological evaluation. Study of the Ningxia ecological water resources requirement based on ecological environment protection can determine the minimum value for the water supply. This is of great importance for protecting the Ningxia ecological environment, maintaining the ecological stability of oasis, even further, coordinating the reasonable distribution of economic water demand and ecological water demand, and promoting the construction of ecological water-saving society in Ningxia Province.

DISCUSSION ON CALCULATION METHODS FOR ECOLOGICAL WATER RESOURCES REQUIREMENT OF OASIS

Ecological water resources requirement has become the hot point of study. Some of the domestic scientists have carried out further and more extensive discussion on the ecological water resources requirement concept in the northwest arid area of China. For the weak ecological environment area, ecological water resources requirement shall refer to the surface and groundwater resources required for preventing the ecological environment from getting worse and for improving the ecological environment. For desert oasis, ecological water resources requirement shall refer to the water volume consumed by the system which supports the stability and development of oasis scenery, and supports sustaining and improving environment quality of oasis (Jia, 1998). For arid and semi-arid areas, ecological water resources requirement refers to the water volume consumed by the system, which satisfies the aim of ecological environment protection and supports sustaining the scenery and improving environment conditions for the purpose of maintaining its

balance (Wang, 1999). In "Study of Water Resources and Ecological Environment Assessment in Northwest Arid Area in China", which is one of the important scientific brainstorm projects of the country in the 9th Five-year Plan, the operative calculation method for "ecological environment water resources requirement" is put forward for the first time definitively. With the help of GIS and remote sensing technology, Wang Fang and others calculated the vegetation water resources requirement on the base of establishing the theory of zonality and non-zonality of vegetation water requirement.

At present, there are many methods to calculate ecological water resources requirement, and they can be divided into two groups: one is called the "area-quantum method" and the other is called the "groundwater level variation amplitude method". The basic concept of the "area-quantum method" is: when the ecologic water resources requirement of a certain area is studied, the types of vegetation and the sorts of area shall be determined first, then the water demand quantum for each sort of vegetation shall be determined, and finally the ecologic water sources requirement of the area can be calculated. Though the "area-quantum method" has been widely used now, it has some problems. The first is the problem in determination of "quantum". The biological water demand of vegetation is a complicated and difficult problem in botany itself, making the accurate determination of water requirement quantum for all sorts of vegetation difficult. The quantum is usually determined with the Penman equation, which is recommended by the Food and Agriculture Organization of the United Nations (FAO) at present and the parameters can be obtained through tests. The second is the problem of scale. Even if the quantum for vegetation water resources requirement can be obtained accurately, the ecological water resources requirement laws at different scales are not the same, the water resources requirement of the same vegetation in different geographic environments is not the same, either, because of the spatial variability of underlying surface factor, hydrologic parameters, etc. This leads to the difficulty in quantum selection and it is not possible to determine various quanta for various types of vegetation or for various environments in the same area. What is more is that this kind of law is not a simple linear extension or superposition. The way to apply the study findings of small scale to large scale, the mechanism of ecological water resources requirement and the conversion of study findings of different scales have not been effectively further studied, and most of them are qualitative conclusions. The third is the problem of "practical value". Ecological water resources requirement is a variate which varies with the differences of time and location. From the view of ecological water resources requirement study at home, it can be seen that there are more qualitative descriptions while mechanism studies are fewer. It is of practical value to study the maximum duration when the ecosystem is threatened by water and the water requirement features of the ecosystem at the duration, and to calculate the water volume required for reasonably maintaining the ecosystem, particularly for arid and semi-arid areas,. Otherwise, the instructive function to the study of reasonable distribution of economic water consumption and ecological water consumption in arid and semi-arid areas and the significance levels are not great.

The basic concept of "groundwater level variation amplitude method" is to determine the groundwater level required for the growth of each sort of vegetation in the area at first, then to determine the minimum water volume for maintaining this groundwater level, and this water volume is the ecological water resources requirement in this area. "Groundwater level variation amplitude method" is more used in arid and semi-arid areas. Because of the small precipitation in this area, surface water is lacking, but if the groundwater level can be kept at the proper level, vegetation can grow normally. From this view, the "groundwater level variation amplitude method" is a scientific one. According to the actual conditions in Ningxia, it is better to adopt this method for the calculation of ecological water resources requirement.

ANALYSIS OF NINGXIA GROUNDWATER RESOURCES BALANCE

Except for in the southern mountain area and the Helan Mountain area, no runoff yield or confluence is formed, basically because of the rare precipitation in Ningxia. The groundwater

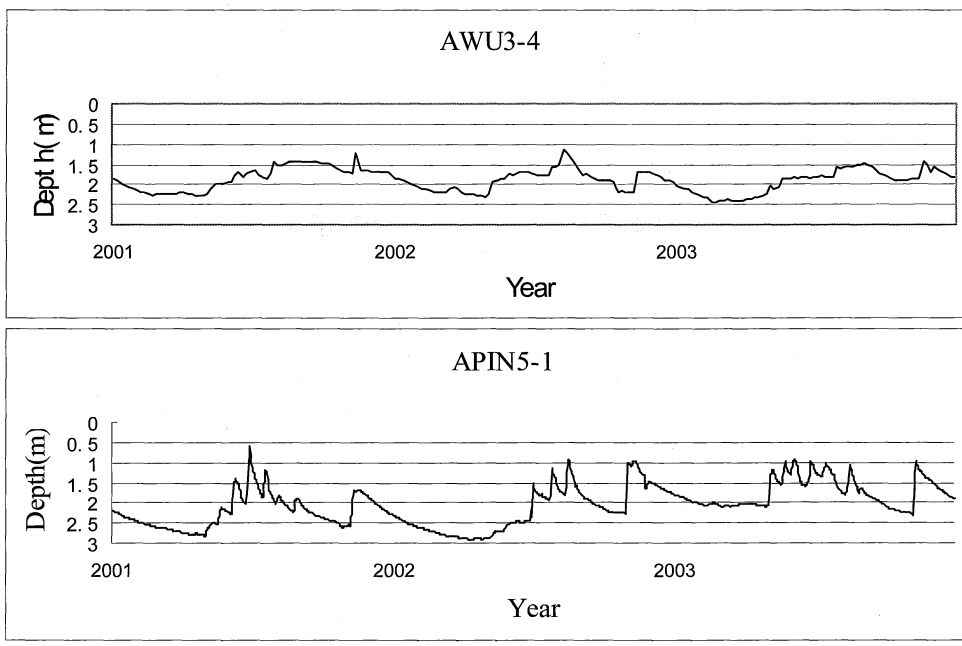

Fig. 1 Ningxia well depth hydrograph (data supplied by Ningxia Hydrological Management Bureau).

compensation mainly comes from the irrigation water from the Yellow River between April and June. The lowering and insufficiency of groundwater results from two aspects. One is phreatic water evaporation and vegetation transpiration. The other is inter-exchange and inter-movement of groundwater flow fields between the regions. Therefore, the annual mean variation of groundwater depth is analysed. The general trend is that the highest water level appears around the period between July and August and the lowest level appears between February and March, see Fig. 1.

Comparison is made between the above two figures. In Fig. 1 APIN 5-1, the large fluctuation of groundwater depth in some months in a year indicates a frequent compensation of groundwater. Besides the infiltration from periodical surface irrigation runoff, the inter-compensation between groundwater flow fields appears very frequently, which shows the groundwater flow field in the area is not closed. In Fig. 1, AWU 3-4, the fluctuation of groundwater level in a year is basically flat with only one fluctuation. This shows that the agricultural irrigation in this area is concentrated from April to June, and irrigation water is transferred to groundwater after a period of time, leading to the rising of groundwater level. The groundwater depth around July is the shallowest and the depth from the next February to March is the deepest. The regular variation of groundwater level just tallies with the regular water demand for plant growth, showing that groundwater is mainly consumed by phreatic water evaporation and vegetation transpiration, and that the groundwater flow field in this area is relatively closed. This part of groundwater consumption is considered as the ecological water resources requirement of vegetation in this area.

CALCULATION CONCEPT OF ECOLOGICAL WATER RESOURCES REQUIREMENT OF NINGXIA NATURAL OASIS

According to the general concept of ecological water resources requirement, the land utilization map on a scale of 1:100 000 was obtained from TM remote sensing information in 2000, with resolution ratio of 30 m at first, then the different types of Ningxia ecosystems (e.g. forest, brush, grass, lake, wetland, etc.) are distinguished and separated. Because the digital map may have errors

from initializing itself, proper correction is conducted to each type of area in remote sensing information with the reference of area statistic results in Ningxia. According to the determined scale of ecological protection and construction, the water resources requirement of Ningxia oasis is estimated indirectly through using and analysing the observation data in years about the variation of groundwater depth on the base of yearly level variation value of the closed groundwater flow field. The processes are shown in Fig. 2.

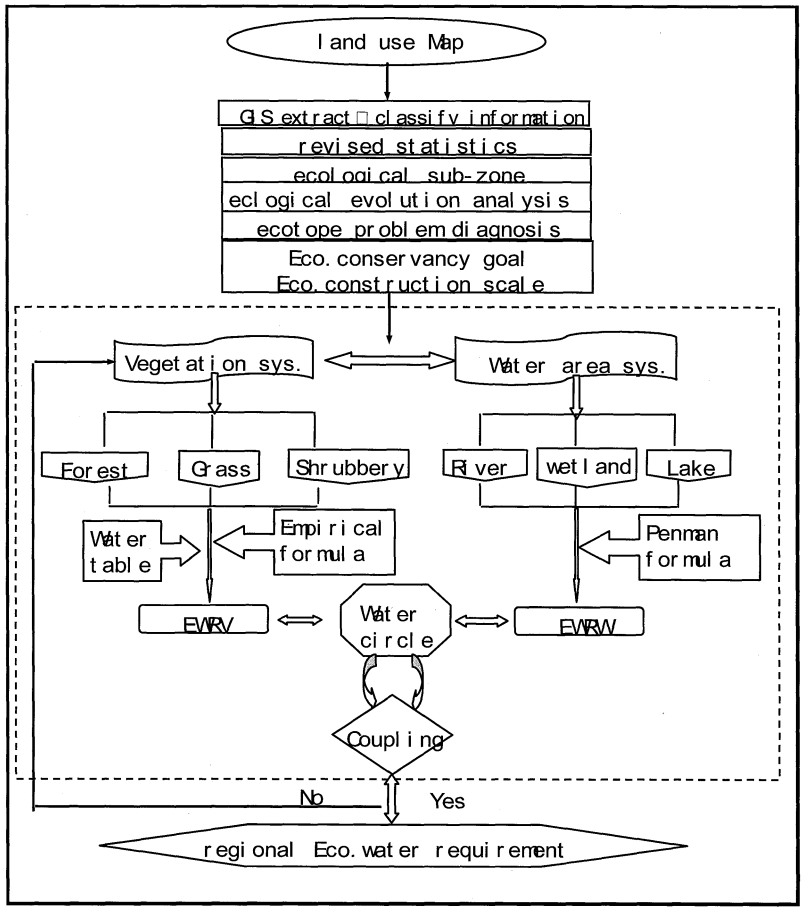

Fig. 2 Flow chart of calculation of Ningxia ecological water resources requirement. Notes: EWRV, ecological water requirement of vegetation; EWRW, ecological water requirement of water body.

CALCULATION PROCESS OF ECOLOGICAL WATER RESOURCES REQUIREMENT OF NINGXIA NATURAL OASIS

Water volume required by natural oasis

The conversion of "the four kinds of water" in Ningxia is very complicated, and it is not easy to obtain the desirable variation data for groundwater depth in the ecological sub-zone. The working procedures are: (1) locate on observation well in each ecological sub-zone; (2) collect the statistical information of annual groundwater depth from each observation well in each ecological sub-zone; (3) take the information from observation well with the flat depth variation only one time of rising and lowering trend as the effective analysis information; (4) ply the Ningxia Groundwater

Depth Curve (omitted), Distribution Map of Ningxia Groundwater Observation Wells (omitted), Distribution Map of Ningxia Aerated–zone Lithological Character (omitted) and Map of Classified Coverage of Ningxia Ecological Vegetation (omitted). The groundwater depth variation corresponding to each ecological sub-zone of Ningxia natural oasis is shown in Table 1, and the specific yield corresponding to the observation well in each ecological sub-zone is shown in Table 1. The specified yield in an observation well is determined by geological structure of the aerated zone. The artificial oasis area is deducted from the ecological sub-zone area. The ecological water resources requirement of Ningxia natural oasis vegetation can be calculated through superposition of the spatial vegetation data from remote sensing, the corresponding groundwater variation amplitude, and the specific yield, etc. The equation can be written as follows:

$$W_{EWRV} = \mu \times H_V \times F \tag{1}$$

where W_{EWRV} is ecological water resources requirement; μ is specific yield; H_v is yearly maximum variation amplitude; and F is area of ecological sub-zone.

The detailed calculation is shown in Table 2.

Table 1 Characteristics of Ningxia Annual Mean Groundwater Depth Value.

Well no.	Corresponding ecological sub-zone	Minimum value (m)	Month	Maximum value (m)	Month	Yearly maximum variation amplitude (m)
Z_{LIN-1}	Land with woods	1.89	Aug.	4.01	Apr.	2.12
S_{Y-13}	Bush	0.72	Jun.	2.7	Mar.	1.98
Z_{LING-8}	Land with scattered woods	1.51	Sept.	3.23	Mar.	1.72
S_{YIN-4}	Grassland with high coverage	1.32	Oct.	2.73	Apr.	1.41
A_{WU3-4}	Grassland with medium coverage	1.15	Sept.	2.41	Mar.	1.26
Z_{LIN-8}	Grassland with low coverage	0.82	Jun.	1.1	May	0.28

Table 2 Calculation of ecological water resources requirement of Ningxia natural oasis.

Ecological Sub-zone	Area (hm^2)	Yearly maximum variation amplitude (m)	Specific yield	Water requirement (10^8 m^3)
Land with woods	6 652	2.12	0.120	0.17
Bush	23 693	1.980	0.09	0.40
Land with scattered woods	9 080	1.72	0.106	0.17
Grassland with high coverage	57 980	1.41	0.100	0.82
Grassland with medium coverage	95 623	1.26	0.095	1.14
Grassland with low coverage	179 006	0.28	0.100	0.50
Total	372 035			3.20

Calculation of ecological water resources requirement of river and lake water bodies

The rivers in Ningxia are all seasonal except for the Yellow River and the Jinghe River in the southern mountain area. The ecological water resources requirement in channel only considers the water surface evaporation. When the water surface evaporation is more than precipitation, the difference value between channel water surface evaporation and precipitation is the water resources requirement of water surface evaporation of the water body if the channel has a water surface. When precipitation is more than evaporation, the ecological water resources requirement

of evaporation is considered as zero. Therefore, the ecological water resources requirement of evaporation of each corresponding month can be calculated according to the water surface area, precipitation and water surface evaporation. The calculation equation is:

$$\begin{cases} W_E = A(E_0 - P) & \text{if} \quad E > P \\ W_E = 0 & \text{if} \quad E < P \end{cases} \tag{2}$$

in which W_E is the ecological water resources requirement of water surface evaporation; A is mean water surface area of each month (km^2); E_0 is mean evaporation capacity of each month (mm).

Total water resources requirement of Ningxia natural oasis

Based on the summary of each individual water resources requirement, the water resources requirement of natural vegetation all through the year is distributed according to its growing rules (approximately according to crop growing rules). The distribution of total ecological water resources requirement of each month is shown in Table 4.

Table 3 Study results of ecological water resources requirement for water body of Ningxia River and lake.

Month	1	2	3	4	5	6	7	8	9	10	11	12	Total
Precipitation (mm)	3.75	5.49	3.37	4.37	4.25	66.1	23	98.4	20	7.49	4.37	0	241
Evaporation (mm/d)	0.7	1.48	2.82	5.06	6.25	6.71	6.66	5.59	3.80	2.24	1.01	0.27	1300
River and lake (hm^2)	13000	14200	14300	14500	15030	15400	15500	15400	14300	14400	14100	13300	
Water requirement (10^8m)	0.02	0.04	0.12	0.16	0.29	0.13	0.28	0.12	0.09	0.09	0.03	0.01	1.37

Table 4 Ecological water resources requirement in Ningxia.

Month	1	2	3	4	5	6	7	8	9	10	11	12	Total
Water requirement 10^8m	0.07	0.15	0.36	0.56	0.86	0.52	0.79	0.46	0.33	0.29	0.12	0.05	4.57

CONCLUSION

With the consideration of high groundwater and rare precipitation in the Yinchuan Area of Ningxia, the "groundwater level variation amplitude method", which is proper to calculate Ningxia ecological water resources requirement, is put forward. The information of annual mean groundwater level variation from observation wells is used to search for the yearly variation value of the closed groundwater flow field. The ecological water resources requirement of Ningxia natural oasis is estimated on the base of superposition of the yearly variation value of closed groundwater flow field, remote sensing vegetation data, and hydrogeological data. This overcomes the insufficient quantum for ecological water demand to a certain degree and provides a new concept for calculation of ecological water resources requirement and for ecological protection and recovery in the northwest arid and semi-arid areas of China.

REFERENCES

Arnold, J. G., Srinivasan, R., Muttiah, R. S. & Williams, J. R. (1998) Large area hydrologic modeling and assessment Part I: model development. *J. Am. Water Resour. Assoc.* **34**, 73–89.

Liu, Changming, Wang, Lixian & Xia, Jun (2004) *Study of Water Resources Distribution, Ecological Environment Construction and Sustainable Development Strategy (Ecological Environment Volume)*, 140–141. Science Publishing House, China.

Wang, Fang (2002) Study of ecological water resources requirement in northwest China (2) – calculation and analysis of regional ecological water resources requirement based on technology of remote sensing and Geographical Information System. *Acad. J. Nat. Resour.* **17**(2), 129–137.

Wang, Xiqin, Liu, Changming & Yang, Zhifeng (2002) Progress and prospect of study of ecological and environmental water resources requirement. *Progr. Water Sci.* **13**(4), 507–512.

Wang, Fang, Liang, Ruiju, Yang, Xiaoliu, *et al.* (2002) A study of ecological water requirements in northwest China I: theoretical analysis. *Acad. J. Nat. Resour.* **17**(1), 1–8.

Xia, Jun & Sun, Xuetao (2002) Challenge ahead of study of ecological water resources requirement in western area, China. *Water Conservancy* **5**, 57–60.

Zhang, Li, Dong, Zengchuan & Zhao, Bin (2003) Calculation method for ecological water resources requirement of natural vegetation in arid area. *Progr. Water Sci.* **11**, 745–748.