地理学报(英文版) 2003年第13卷第4期

Ecological water demand: the case of the slope systems in the East Liaohe River Basin

作者: YAN Denghua HE Yan

The ecological water demand (EWD) is the least water amount required to maintain the structure and the function of the special eco-system and the temporal scale of a study on the EWD must be a season´s time. Based on GIS and RS with the source information of hydrological data of 46 hydrological gauges covering 52 years and the digital images of Landsat TM in 1986, 1996 and 2000, the landscape patterns, precipitation and runoff in the East Liaohe River Basin were analyzed. With the result of the above analysis, the spatial and temporal changes of the ecological water demand in the slope systems (EWDSS) of the East Liaohe River Basin (ELRB) were derived. Landscapes in the ELRB are dispersed and strongly disturbed by human actions. The hydrological regime in ELRB has distinct spatial variations. The average annual EWDSS in the ELRB is 504.72 mm (324.08-618.89 mm), and the average EWDSS in the growth season (from May to September) is 88.29% of the year´s total EWDSS .The ultimate guaranteeing ratio of the EWDSS in ELRB is 90%. The scarce EWDSS area in the whole year and in the growth season are 60.47% and 74.01% of the entire basin respectively. The trend of scarce EWDSS area is most serious according to the quantity and area of scarce EWDSS regions.

Ecological water demand: the case of the slope systems in the East Liaohe River Basin YAN Denghua1,2, HE Yan1, DENG Wei1, HOU Youshun3 (1. Northeast Inst. of Geography and Agricultural Ecology, CAS, Changchun 130021, China; 2. China Inst. of Water Resource and Hydropower, Beijing 100044, China; 3. Xiaochi Middle School, Taihu County, Anhui Province, Taihu 246410, China) 1 Introduction The role of the precipitation re-distribution in a watershed controls anthropogenic production and domestic functions and holds the ecological and environmental security too. Academician Liu Changming has pointed out that the water in a watershed can be divided into three groups, namely ecological water, resource water and hazard water. He also recognized that the water cycling is related to eco-hydrological processes and the regulation mechanism of the water cycling on the vegetation is the primary and important topic to the biological aspect of the water cycling. The study on the ecological water demand (EWD) is the key to the water regulation in a watershed (Liu and Sun, 1999). The Academician strongly promotes studies on the EWD. Unfortunately, the initiation of the study on EWD is a little late and EWD lacks a general definition or theoretical frame and methodological system. The studies on EWD in the arid area have taken the lead. This paper points out that the EWD is the water meeting certain quality standard to comply with the special ecological function of a water body and the EWD has spatial and temporal variations. The principal part of the EWD is a given ecosystem. So the features of the ecosystem are critical to the EWD in a watershed. The construction of the ecosystem structure, the function achievement and the healthy status of the ecosystem control the amount of water demanded in a basin. Specially, since the destination of the EWD is to rationally allocate the water in a watershed and the ecosystem has distinctive seasonal rhythm, the temporal scale of the study on the EWD is mainly season based. As the temporal scale is getting shorter, the study result would be more feasible. If the temporal scale of the study becomes too long, the study result would be insignificant to water regulation in a watershed. Though the general concept of the EWD has not been presented internationally, some scholars have always conducted some researches on it (Liu, 2001; Li and Zheng, 2000; 2001; Jia and Xu, 1998; Yan et al., 2001; Bergstrom and Graham, 1998; He et al., 2000; Hutjes et al., 1998; Munro et al., 1998; Thoms and Sheldon, 2000). The eco-hydrology, a newly formed interdisciplinary subject, is improved in the study on the projects in the UNESCO/IHP-V&VI, and the study on EWD in a watershed is the main topic of those projects (Zalewski et al., 1997; Zalewski, 2000). We hold that the EWD is the primary and important project. It is similar to the studies on the formation and evolutio n of the eco-hydrological pattern and the response of the eco-hydrological processes to the water quality management. Till now, the EWD has not had the uniform scaling method. The calculation of EWD of the river system is just based on pollutants and sediment transportation. The EWD of the slope system (EWDSS) is based on water transformation from cycling and evaporation from land and plant ET (Liu, 2001; Li and Zheng, 2000; 2001; Jia and Xu, 1998; Yan et al., 2001). Based on the geomorphologic patterns, the watershed can be divided into two systems, namely river system and slope system. The study on the EWD of the river system in the ELRB has been published by another paper (Yan et al., 2001). This study would like to analyze the spatial and temporal evolution of the EWDSS and its relationship to the water balance in the East Liaohe River Basin (ELRB). 2 The study area The East Liaohe River originates from southeast of the peak of the Xiaohancongdingzi of the Hadaling Mountain in the town of Yanping, Dongliao County, Jilin province of Northeast China. The River flows through Dongliao, Liaoyuan, Lishu, Gongzuling, Shuangliao in Jilin province, Xifeng, Changtu, Kangping in Liaoning province and Horqin Left Wing Rear Banner in Inner Mongolia. The ELR joins the West Liaohe River at Fudedian. The total length of the trunk stream is 360 km which drains an area of 11,450 km2. The area has a temperate monsoon climate with distinctive seasonal characteristics. Spring is dry and windy, summer is hot and rainy, fall is cool and sunny, and winter is long and cold. The southwesterlies prevail with an average wind velocity of 3-5 m s-1 in the watershed. The annual mean temperature is 4-8oC with a frost-free season of 125-140 days. The annual average precipitation is 470-700 mm. The precipitation is uneven and more than 70% of precipitation occurs in the period between June and August in the basin. Much of the rain enters surface runoff resulting in the loss of water and soil saturation. The annual average depth of run-off in the watershed is 102.54 mm (equals to the average runoff of 2.10×109 m3), and the average annual evaporation is 1.60×103 mm. The ELRB is strongly disturbed by the anthropogenic exploitation. The area of the cultivated land is 73.72% of the whole watershed. Unfortunately, the ability of ecosystem service of the ELRB is very vulnerable as the forest area is just 0.29% of the whole basin. 3 Data and methods 3.1 The basic data 3.1.1 Hydrological data The hydrological data used in this study are selected from the hydrological observation data of each hydrological gauge and the processed data. The hydrological data before 1978 are obtained from the Water Resource in Liaohe River Basin (edited by the Irrigation Works Bureau of Liaoning Province in 1983). The hydrological data of 1978-1985 are obtained from the hydrological supervised almanac in Liaohe River Watershed, and the data between 1986 and 1999 are taken from the hydrological database of Jilin Province. The total cumulative hydrological data are those of 46 hydrological gauges covering 52 years. The hydrological indexes include precipitation, runoff, evaporation and siltation. 3.1.2 The landscape data The sources of the landscapes in the East Liaohe River are Landsat TM digital imagines of 1986, 1996 and 2000. The wave bands of the images are 4, 3 and 2 RGB. The ground resolution is 30 m and the time spectrum is the period between June and October. 3.2 The application of the data 3.2.1 The classification of landscapes and the remote explanation Firstly, we establish the interpretation mark and interpretation accuracy after image geoprocessing, coordinate transforming and image enhancing. Then we interpret the image using the method of direct interpretation, image processing, information combination and logic interpretation on the platform of GIS. The two-level classification system is adopted in the study. The 1st level classification concludes 6 classes, which are cultivated land, woodland, grassland, water area, built-up land and unused land. The 2nd level includes 21 types. Field check indicates the remote sensing image interpretation accuracy is 96.7%. 3.2.2 The spatial analysis on the data The spatial analysis is done on the platform of Arc/info8.0.2 and Arcview3.2. (1) The model of EWDSS The EWDSS in ELRB is mainly consumed by crop growth and the ground ET. So the EWDSS is the water consumed by the ET of the slope systems. In the info table dlhland.pat of the landscape types, we add 12 fields with each field being the monthly ET. We put month by month ET of the landscapes to the new 12 fields in terms of the landscape types. With Arcview3.2, we add another 2 fields with each field being the yearly ET and growth season (from May to September) respectively. We get the value with the Field Calculator operation. With the Arc/info platform, the above calculated ET was changed into the 14 Grid files. The resolution of the Grid is 30 m. The following formula is used to calculate the EWD of the slope system: where EWt is the average EWD in the tth period; E (t, x, y) is the function of the temporal and spatial distribution of the ecological water demand; t, x, y, and s are the time, longtitude, latitude and watershed area respectively. As pixel is taken as the spatial unit in the calculation, the expression can be changed into: (2) where n is the number of the pixels; EWti is the ecological water demand of the i pixels in the t periods. (2) The balance of the EWD and the water in the watershed Based on administration and water system maps of the watershed, the hydrological gauge point shapefile is established. We change this shapefile into Arc and take the Addxy operation. The projected coordinate of the hydrological gauge can be derived. We also put the coordinates into the statistical table of hydrology data and convert it into Coverage. The contour map can be obtained and changed into a shapefile with the platform of the Arcview3.2. Taking the Createtin command with the watershed border as the boundar y, we change the contour map into the TIN maps. Then by taking the TINLATTICE command, the TIN maps can be converted into the GRID maps. The spatial analysis on the water balance is operated on the platform of MAP Calculator model in the Arcview3.2, and statistics of the water is also derived with the platform of Arcview3.2. 3.2.3 The statistical analysis on the data The statistical analysis on the data is operated with SPSS10.0. 4 Results and discussion 4.1 The landscape pattern and hydrological regime in the ELRB 4.1.1 The general state of the landscapes in the ELRB With respect to the landscapes composition, the distribution ratios of the cultivated land (including paddy field and dryland), woodland, grassland, water area, built-up land, and unused land are 73.72% (12.42%＋61.29%), 14.69%, 1.3%, 2.82%, 7.18% and 0.29% respectively. Cultivated land is the main landscape type. The woodland area in the ELRB is too small and is just 40.87% of the average forest cover ratio of Jilin province (Figure 1). This shows that ELRB is strongly disturbed by the anthropogenic activities. According to the general landscape pattern, the cultivated land is too large. The diversity index and the evenness index of landscape are low, namely 0.969 and 0.301 respectively. The predominant index of the landscape is slightly higher, reaching 2.249. Unfortunately, the fragmentation index of the landscape in ELRB is 66.70. This shows that the landscape in the ELRB is too fragmental. With the sorted landscape indexes, the fractal dimension index and the form index is large. The average distance index is higher. The contagion index and the interaction index is smaller. This shows that the landscape units are disperse (Table 1). 4.1.2 The monthly average ET process of each landscape The ET of each landscape has distinctive monthly variation, and the change of ETs of the water area and paddy field is the strongest. The evaporation of the water area reaches the peak in May, and ET of grassland and dryland reaches the peak in June, and that of woodland and paddy field reaches the peak in October. The required water of built-up land includes much water consumed by industrial and domestic activities. This water does not belong to the EWD. This paper would like to analyze the water consumed by ET of the landscape. Till now, no studies have been conducted on the ET of naked land and built-up land. So this study would like to calculate the EWD by adopting the average land ET. The period between October and April next year is not the growth season, and the ET observation of cultivated land, grassland and woodland are not performed either. So in this period, the ET of each landscape is adopted from the land ET (Figure 2) (Luo et al., 1996; Wang, 1998; Wang et al., 1998). 4.1.3 Hydrological regime The precipitation in the ELRB has the diverse regional variation. The precipitation range is from 395 mm to 650 mm. The precipitation decreases from southeast to northeast of the basin. Erlongshan Lake, Yanmu Lake and so on are the precipitation peaks. Influenced by the geomorphology and the prevailing wind, the hinterland to the east of Erlongshan Lake is the precipitation sink. The distribution of the precipitation in the period between May and September is similar to that in a year. However, the hinterland of Erlongshan Lake is no longer the precipitation sink (Figure 3A). Caused by the spatial variations of landscape pattern and precipitation, the runoff coefficient of ELRB from May to September also has the spatial difference. As the water storage and maintaining ability of the woodland are very strong, the mountainous area in the southeastern part of the basin is the runoff coefficient sink. Due to the scarcy precipitation in the western part, the area centered around the Xiaoliaohe is a low runoff zone (Figure 3B). 4.2 The spatial and temporal variations of the EWDSS 4.2.1 The seasonal variation of the EWDSS With the platform of Arcview3.2, we take the EWDSS of each month as the statistical field and establish contour, tin and grid maps in turn. At the same time, we give the value of the border with zero and establish border.grd. With the model analysis, by taking the operator of Map Calculator and subtracting border.grd from the grid of EWDSS of each month, the spatial distribution of the EWDSS in each month can be derived. At the same time, still with the analysis model, taking the operation of the Map Calculator and adding the EWDSS from May to September together, the EWDSS in the growth season can be derived. With the same method, the yearly distribution of EWDSS can also be derived. In the Legend Editor model, taking the operator of Statistics, the EWDSS in the whole watershed in different statistical periods can be derived. The yearly average EWDSS of the ELRB is 504.72 mm (from 324.08 to 618.889 mm) and has the distinct seasonal evolution. The EWDSS is focused on the period between May and September. It is 88.29% of EWDSS of a year. Under the condition of a = 1, taking the normal test on the monthly EWDs, we get D = 0.266397 and P > 2. This shows that the EWD is the normal distribution (Figure 4). 4.2.2 The spatial variation of the EWDSS With respect to spatial distribution of the EWDSS in a year in the ELRB, EWDSS is concentrated on dryland and paddy field located to the lower reaches of Erlongshan Lake. It is a zone with high EWDSS. Outside of the high value zone, the scattered patches with less EWDSS were distributed. There is a scattering zone of the high EWDSS with the axis of the watershed border located to the upper reaches of Erlongshan Basin (Figure 5). According to the spatial distribution of the EWDSS in the growth season, the region with the high EWDSS in ELRB is dispersing. After the beginning of June, the region with high EWDSS became zonal. And in July, the zonal distribution of the high EWDSS is formed. Coming into October, the zones of the high EWD become diverse and in September the distribution of the high EWDSS is the plot form. 4.3 The relation between EWDSS an

d the water balance in the watershed 4.3.1 The balance between the EWDSS, the precipitation and runoff depth in the watershed The annual average precipitation depth in the East Liaohe River is 522.372 mm, and the annual average runoff depth is 118.028 mm. The EWD of the river system is 44.3% of the yearly runoff (Yan et al., 2001). The EWDSS is 96.62% of the precipitation and 4.28 times of the annual runoff. Even if the water blocked by the slope is transformed into the EWD, the surplus runoff transformed to the EWDSS after the runoff is consumed by the EWD of the river system. The guarantee ratio of the EWDSS is just 90.4%. The EWDSS is more than the precipitation in May, June, July, September and October. The EWDSS in September is 19.76 mm more than the precipitation. However, the precipitation in October is 31.80 mm more than the EWDSS. Thus it can be seen that the above result is the seasonal regulation on the water. Except June, the EWDSS can be guaranteed. Except January and February, the EWDSS is more than the runoff depth. The largest ratio between the EWDSS and the runoff depth is 4.767 times (Table 2). 4.3.2 The EWDSS balance subarea In the slope system, some of the precipitation blocked by vegetation will seep into the soil. The surplus will convert into the soil water and surface runoff. Unless the irrigation needs the surface runoff, the water blocked by vegetation (including the absorbing water by the breath of the leaves) and the soil water are the only source of the surface ecological process, and those kinds of water come from the precipitation. So comparing the precipitation with EWDSS, the EWDSS balance subarea can be derived. With the model of analysis of the Arcview, by taking the Map Calculator operation and substituting the precipitation grid with the EWDSS in a year or in the growth season respectively, the spatial pattern of the EWDSS balance can be derived. Dividing the result grid into 6 levels and giving each level a name, the results are as follows: (A) the scarcest water region (<-50 mm); (B) the scarcer water region(-50--30 mm); (C) the slightly scarce water region (-30-0 mm); (D) the slightly rich water region (0-100 mm); (E) the a little richer water region (100-200 mm); (F) the richer water region (200-300) and (G) the richest water region (>300 mm). According to the spatial distribution, the ecologically scarce water region is centralized to the lower reaches of the Erlongshan Lake. The ecological scarce water region in the upper reaches of the watershed is just distributed in the hills and valleys (Figure 6). With respect to different kinds of the EWDSS subarea, the yearly scarce water area accounts for 60.471% of the whole watershed. The A type is the dominant type with the area of 31.183% of the whole watershed. The D type area is prime rich water area with 21.185% of the whole basin. The H type area is very small and is just 0.072% of the whole basin. The scarce water area in the growth season is 74.01% of the whole basin and is 1.22 times of scared water area in a year. The scarcest water area is 45.265% of the scarce water area. In the growth season, the richest water area is vanished. The area of each kind of rich water region decreases. The slightly rich water region decreases 3 times. The richest water area decreases slightly and the richer water area decreases nearly 1/4 (Table 3). In total, according to the scarce water quantity and area of EWDSS, the regime of the scarce water area is more serious. So the integrated water regulation must be developed. 5 Conclusions (1) EWD is the ecological water with certain quality complying with the special ecological function of a water body. It has the spatial and temporal variations. EWD is restricted by the healthy condition of the ecosystem. The maximum temporal study scale is a season. (2) GIS and RS can be a powerful spatial analysis technique in studying the ecological water demand. (3) The landscape pattern in the East Liaohe River Basin highlights the dominant features and is heavily disturbed by the anthropogenic activities. The hydrological regime has the distinct spatial distribution. (4) The yearly EWDSS is 504.27 mm. It has the distinct temporal variation and belongs to the normal above distribution. (5) The EWDSS in the East Liaohe River Basin has the spatial variation. The lower reaches of the watershed is the high ecological water demanded area, while the upper reaches has the low ecological water demand. (6) The extreme guaranteeing ratio of EWDSS in the East Liaohe River Basin is just 90%. If the water regulation between seasons can be disposed well, the ecological water demand can be ensured in other months except July. (7) The scarce water area is 60.471% of the whole basin. Furthermore, the scarcest ecological water demand is the prime. The scarce water area in the growth season is 74.01% of the whole basin and the scarcest water area is 1.5 times that of the year mean. (8) According to the quantity and area, the scarce water area is more serious. So the integrated water regulation must be developed. Acknowledgments We thank Professor ZHANG Xuelin (Northeast Institute of Geography and Agricultural Ecology, Chinese Academy of Sciences) and Dr WANG Changming (China Institute of Water Resource and Hydropower) for their help with English perfection.

关键词： East Liaohe River Basin; slope system; ecological demand water; GIS & RS