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Study on vegetation ecological water requirement in Ejina Oasis

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The Ecological Water Requirement (EWR) of desert oasis is the amount of water required to maintain a normal growth of vegetation in the special ecosystems. In this study EWR of the Ejina desert oasis is estimated through the relational equation between normalized difference vegetation index (NDVI), productivity and transpiration coefficient, which was established by a combination of the RS, GIS, GPS techniques with the field measurements of productivity. The results show that about 1.53×10^8 m^3 water would be needed to maintain the present state of the Ejina Oasis, and the ecological water requirement would amount to 3.49×10^8 m^3 if the existing vegetation was restored to the highest productivity level at present. Considering the domestic water requirement, river delivery loss, oasis vegetation water consumption, farmland water demand, precipitation recharge, etc., the draw-off discharge of the Heihe River (at Longxin Mount) should be $1.93\times10^8-2.23\times10^8$ m^3 to maintain the present state of the Ejina Oasis, and $4.28\times10^8-5.17\times10^8$ m^3 to make the existing vegetation be restored to the highest productivity level at present.

Ejina Oasis, NDVI, productivity pattern, vegetation ecological water requirement.

Arid inland river basin is an ecosystem consisting of ice-snow zone, frozen soil, mountain forest, oasis, desert and desert riparian forest, and water resource is the life-giver of the complex ecosystem[1]. The measurable deterioration of its eco-environment in the mid to late 20th century can be linked to human activities that have fundamentally altered the water resources distribution pattern and water circulation processes in arid inland river basins, which has impacted the long-term sustainability of the ecosystems. Accordingly, the ecological water requirement and the issues of water distribution in arid inland river basins have become a research hot spot in recent years[2].

Covich[3] (1993) stressed the importance of guarranting the water supply for the restoration and healthy development of ecosystem to the water resource management. Gleick[4] (1996) defined the conception of basic ecological water requirement, i.e. providing the natural habitat with a certain amount of qualified water to minimize the variation of the natural ecosystem, and protect the species diversity and ecological integrity. Chinese scientists, as well as their foreign counterparts, have done much work on the ecological water significance and the calculation of ecological water requirement. Several conceptions of ecological water requirement have been put forward which mainly stressed the conception inclined to aspects of hydrology, environmental science and ecology, especially the plant ecology[5−10]. The conception of ecological water requirement adopted

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in this paper emphasizes the ecological aspect[9−12], mainly refers to the water amount consumed to maintain the steady growth of natural oasis and artificial oasis protective system. Because, unlike desert vegetation which can survive with sparse precipitation, natural oasis vegetations which consist of zonal xerophytes and artificial oasis protective plants mainly rely on the runoff formed in the mountain region and the runoff-converted water to exist, however, the limited water resource is very difficult to maintain the base flow of the river due to the increasing population and the intense water consumption.

Several methods available for estimating the water requirement of the ecosystem, the most commonly used are: (1) direct calculation method, it is worked out by the vegetation area of a given type times the water consumption norm; (2) indirect calculation method, it is obtained by the vegetation area of a given type at a given groundwater evaporation at that water table times the vegetation coefficient; (3) soil water balance method; (4) modified Penman formula; and (5) the combined method of remote, sensing, geographical information system and observed date, through the calculation of evapotranspiration the ecological water requirement is defined[13]. However, there is still few report on the calculation of ecological water requirement using a combined method of productivity pattern and transpiration coefficient.

In this study, such a new method was developed, which employed 3S techniques and observed productivity data, emphasized the relation between productivity distribution pattern and water demand for producing unit dry matter, and was used to estimate the ecological water requirement for maintaining the present state of vegetation in the Ejina desert oasis and the corresponding ecological water requirement to reach the highest productivity level. Based on this analysis, the minimum draw-off discharge of the Heihe River at the Longxin Mount hydrological section to maintain the stability of the Ejina Oasis was calculated. The result of this study provirded a useful reference for the management of water resources in the Heihe River Basin.

1 Study area and method

1.1 Description of study area

The study area is the Ejina Oasis which lies in the lower reaches of Heihe River (between 39°52′—42°47′N and 97°10′—103°7′E, elevation ranging from 898 to 1958 m), and is situated in south of Mongolia and western Inner Mongolia (Figure 1). The climate of the area, characterized by frequent and severe droughts and large differences in temperature, is typically continental. Mean annual temperature at Ejina is 6—8.5℃, mean annual frost-free period 130—160 d, Mean annual precipitation is only 40 mm, annual evaporation 4200 mm; prevailing wind direction is northwest, mean annual wind velocity 2.9—5 $m \cdot s^{-1}$, and annual number of gale (>17 $m \cdot s^{-1}$) days is 70 d or so. The zonal soil types in the area are grey desert soil and grey brown desert soil and there are also saline-alkaline soils and swamp soils in the lake basins and lowlands. The main plant species of the desert riparian forest are *Populus euphratica*, *Tamarix* spp., *Lyceum ruthenicum, Sophara alopecuriodes, Haloxylon ammodendron*, *Phragmites communis*, *Aneurolepidium dasystachys*, *Nitraria sphaerocarpa* Maxin, *Salsola passerina* and *Reaumuria soongorica*, etc.

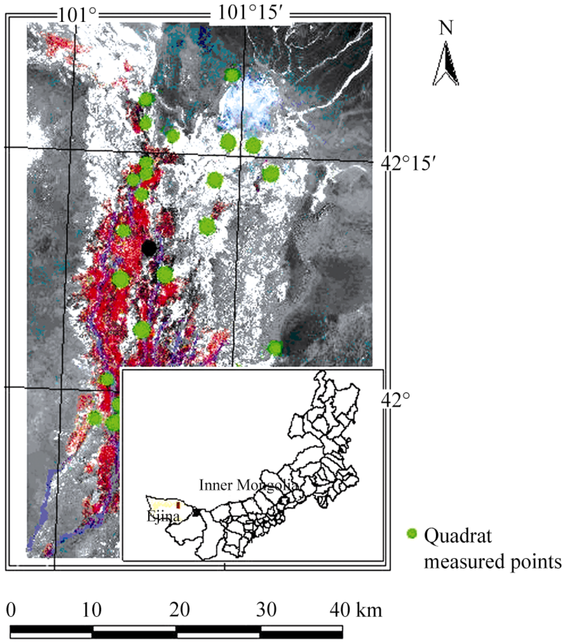

Figure 1 Location of the study area.

The Heihe River (called Ejina River after entering the Ejina) is the most important water resource in the area. It runs 250 km in the Ejina Oasis and emptied into the West Juyan Lake; during the 1950s its annual flow varied between 12×10^8—13×10^8 m^3; at least exceeded 1×10^9 m^3 during the 1960s—1970s, however decreased to 4×10^8 m^3 during the 1980s or even 2×10^8 m^3 in low-flow years.

According to the groundwater table data recorded at 13 observation points in the investigated 12 years, the groundwater depth varied between 2.18—3.11 m·a^{-1}, the shallowest water depth of 2.18 m occurred in April and the deepest depth of 3.11 m occurred in November, differing by 0.93 m. The groundwater depth exhibited a regional lowering trend, compared with the long-term mean water level of high-flow years, it lowered by 1 m on an average.

1.2 Study method

(i) Field investigation. Plant species composition, above-ground biomass, geographical coordinates of quadrate points, land use patterns and land cover regime around the area were investigated, the water content of the surveyed plant species and above-ground biomass were calculated on the basis of dry weight (determined by oven-dried method).

The productivity is represented by the above-ground biomass. A total of 34 points were selected for the biomass investigation (Figure 1), each observation point has five 5 m × 5 m quadrates (herb quadrate is 1 m ×1 m). In total, there are 170 quadrats. For the perennial shrub species only the current-year increments were determined; the productivity of *Populus euphratica, Tamarix* spp. was deduced from NDVI[14−19]. The investigation was conducted from August 7—29, 2001 and a supplement investigation was conducted at 5 points in the middle of August in 2002.

(ii) Remote sensing interpretation. According to the ETM images (Orbital No. 134-31) taken on 20 August, 2001, the study area was divided into 11 land-use types, the classification criteria and results are described in ref. [14]. Procedures include: (1) the geometric correction of ETM images was made in the ERDAS IMAGINE environment (using the Albers conical Equal Area Krasovsky projection method); (2) the latitude-longitude grids were projected on the corrected images to form the 1:50000 TM image map of Ejina Oasis; (3) GPS was used to draw the boundaries of land use and land cover types; and (4) the 1:100000 map of land use and cover type of Ejina Oasis was completed (Figure 2) in laboratory.

(iii) Data analysis. The ERDAS software was employed to complete related calculation, classification, clustering, merging, raster data conversion and vector data processing of ETM images of the Ejina Oasis. Since the visible light (RED) channel and near-infrared light (NIR) channel of ETM scanning radiometer are very sensitive to plant leaves and their growing state, the normalized difference vegetation index (NDVI), which is closely related to vegetation, is used to express the vegetation productivity. Its calculation formula is NDVI=$(\lambda_{NIR} - \lambda_{RED})/(\lambda_{NIR} + \lambda_{RED})$. Based on the formula, the NDVI values were calculated with the corrected composite images through ERDAS software. After that, the NDVI

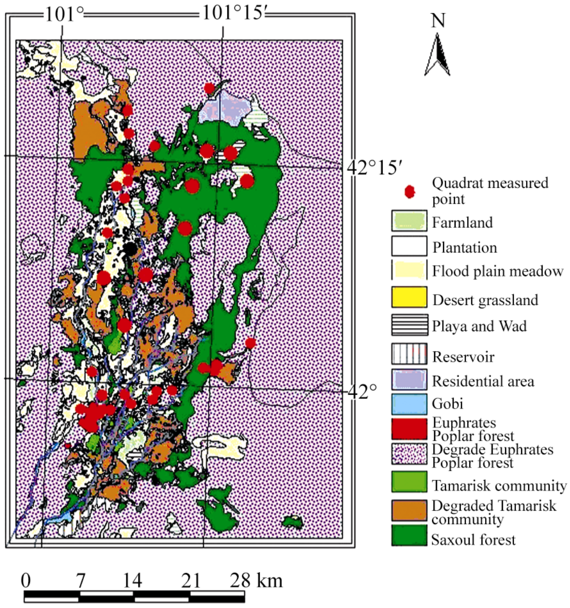

Figure 2 Land-use map of Ejina Oasis.

distribution map (Figure 3(a)) and the productivity distribution map (Figure 3(b)) were drawn respectively. Finally, the geographical coordinate of 34 sampling points were projected on the NDVI Distribution Map. The productivity level was represented by the mean productivity of various types of quadrats. The calculating procedure is shown in Figure 4. Of the 170 quadrats of 34 observation points, 116 were included to do NDVI analysis. Since the productivity data of normally growing *Populus euphratica* and *Tamarix* spp. are lacking their productivity values were deduced from NDVI in this study, and the above-ground biomasses of corn and cotton with the highest productivity in the study area were used to establish the regression relation between productivity and NDVI, then through the interpolation calculation the related values were obtained.

According to the obtained spatial distribution information of the productivity, the productivity levels of different land-use types were calculated and divided into six classes in terms of the patch composition of productivity, namely >4 hm^2, 3—4 hm^2, 2—3 hm^2, 1—2 hm^2, 0.09—1 hm^2 and <0.09 hm^2. Finally, the vegetation

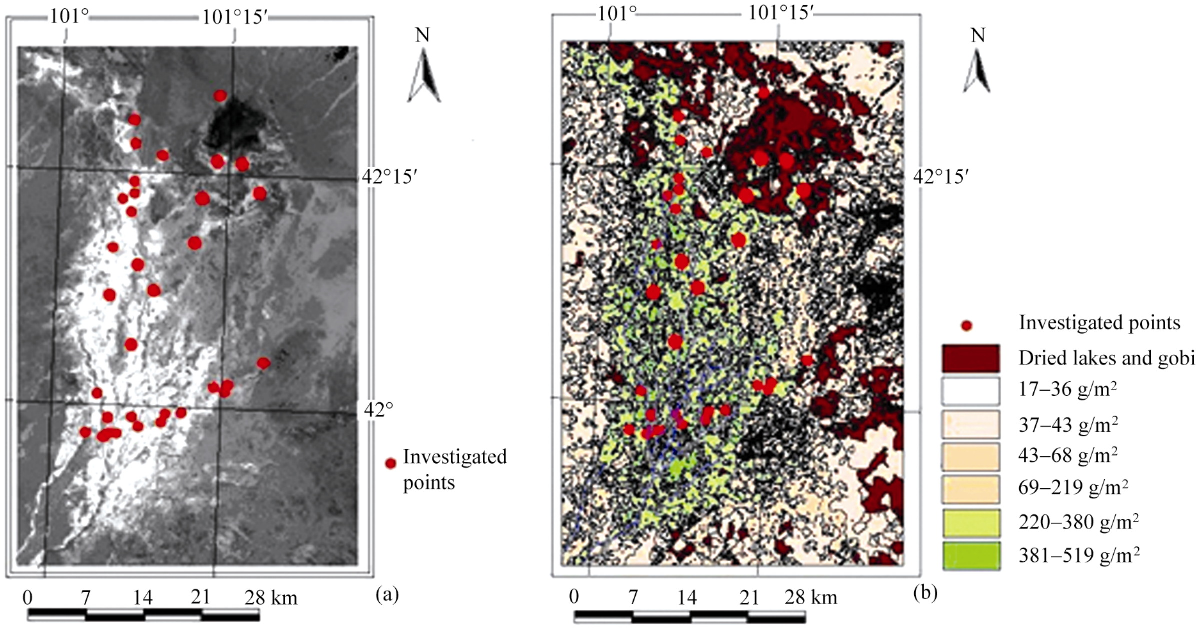

Figure 3 (a) The distribution of NDVI in Ejina Oasis; (b) the distribution of productivity in Ejina Oasis.

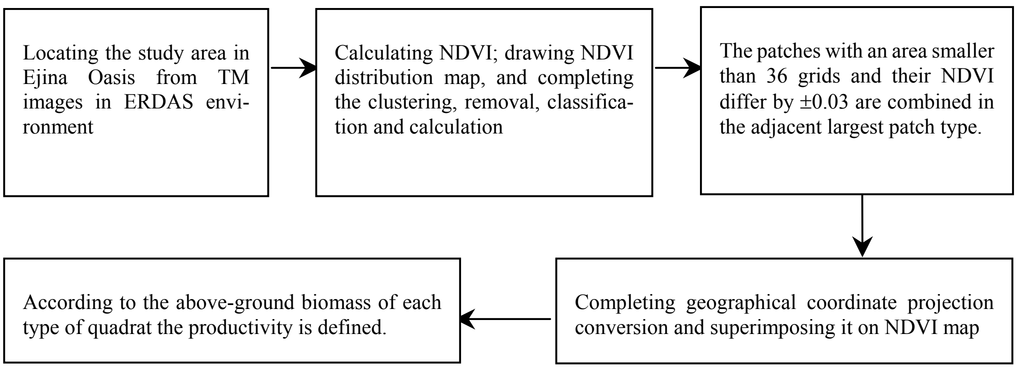

Figure 4 Calculating procedure of the productivity.

ecological water requirement in the Ejina Oasis was calculated according to the productivity difference and transpiration coefficient.

2 Results and discussion

2.1 Distribution pattern of productivity

There is a significant linear relation between the NDVI obtained by the 3S techniques and the above-ground biomass of corresponding survey quadrat (Figure 5, R=0.937>$R_{0.001,20}$ = 0.652). The simulated value and determined value curve of the productivity is quite approximate to the 1:1 line (Figure 6), that means that NDVI can be used to deduce the current-year productivity of the Ejina Oasis. In the Arcview environment the general distribution information of different productivities obtained by the graphic interrogation tool is as follows:

Type 1 (17—36 g·m^{-2}·a^{-1}) occurs in large parts of the Ejina Oasis and mainly consists of poorly growing *Ni-*

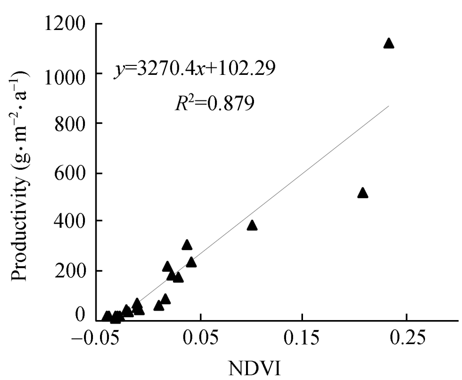

Figure 5 Relationship between NDVIs and productivities.

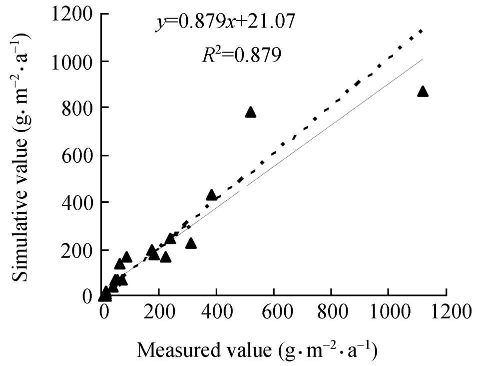

Figure 6 Precision contrast of the measured and the simulative values.

traria sphaerocarpa, severely degraded *Salsola passerina*, *Reaumuria soongorica* and *Haloxylon ammodendron*. The type is dominated by the two classes of 0.09−1 hm^2 and ≤0.09 hm^2, their numbers are 17191 and 44657, accounting for 27.3% and 71.0% of the total patch number, respectively. The total area is 13816 hm^2, of which the three classes of 0.09−1 hm^2, ≤0.09 hm^2 and ≥4 hm^2 are dominant. They are 4841 hm^2, 4019 hm^2 and 3483 hm^2, accounting for 35.0%, 29.1%, and 25.2% of their respective total patch area.

Type 2 (37−43 $g\cdot m^{-2}\cdot a^{-1}$) occurs in the surrounding area of the Ejina Oasis and exhibits a circular pattern around the centre of Ejina Oasis. It mainly consists of *Nitraria sphaerocarpa*, *Salsola passerine*, and *Reaumuria soongorica*, and the patch is dominated by the two classes of ≥4 hm^2 and ≤0.09 hm^2, their numbers are 497 and 164, accounting for 70.0% and 23.1 % of the total patch number respectively. The total area is 8.3×10^4 hm^2, of which the class of ≥4 hm^2 occupies 99%.

Type 3 (43−68 $g\cdot m^{-2}\cdot a^{-1}$) occurs to the east of the center of the Ejina Oasis and borders the western edge of the Badain Jaran Desert. It mainly consists of degraded *Tamarix* spp., *Haloxylon ammodendron*, *Lycium ruthenicum*, *Nitraria sphaerocarpa*, *Zygophyllum mueronatum*. The type is dominated by the three classes of ≤0.09 hm^2, 0.09−1 hm^2, and ≥4 hm^2, their numbers are 747, 275 and 209, accounting for 58.6%, 21.6 % and 16.4% of the total patch number. The total area is 4.8×10^4 hm^2, of which the area of the patch ≥4 hm^2 is 4.79×10^4 hm^2, accounting for 99.5% of its total area.

Type 4 (69−219 $g\cdot m^{-2}\cdot a^{-1}$) has a small range and its main plant species include *Phragmites* communis, *Karelinia caspica*, etc. The type is dominated by the three classes of ≤0.09 hm^2, 0.09−1 hm^2, and ≥4 hm^2, their patch numbers are 277, 156 and 34, accounting for 56.3%, 31.7% and 6.9% of the total patch number. The total area is 3531 hm^2, of which the patch ≥4 hm^2 occupies 96.4%, with an area of 3402 hm^2.

Type 5 (220−380 $g\cdot m^{-2}\cdot a^{-1}$) mainly occurs on the river banks and consists of typical riparian vegetation including normally growing *Populus euphratica*, *Tamarix* spp., *Sophora alopecuroides*, *Phragmites communis*, etc. The type is dominated by the three classes of ≥4 hm^2, ≤0.09 hm^2 and 0.09−1 hm^2; their numbers are 304, 233 and 78 respectively, accounting for 45.5%, 34.9% and 11.7% of the total patch number. The total area is 5.93×10^4 hm^2, of which the patch of ≥4 hm^2 occupies 99.7%.

Type 6 (220−380 $g\cdot m^{-2}\cdot a^{-1}$) occurs in the center of the Ejina Oasis, and is immediately close to the braided river system in the lower reach of the Heihe River and exhibits a stripe distribution. The vegetation consists of typical riparian plant species, including normally growing *Populus euphratica*, *Tamarix* spp., *Sophora alopecuroides*, *Phragmites communis*, *Ameruolepidium dasytachys*, etc. The type is dominated by the two classes of ≥4 hm^2 and ≤0.09 hm^2 .Their patch numbers are 147 and 35, accounting for 67.7% and 16.1% of the total patch number. The total area is 1.54×10^4 hm^2, of which the patch of ≥4 hm^2 occupies 99.4%.

The oasis productivity (current-year above-ground biomass) can be divided into two groups; the first group includes Types 1, 2, 3 and 4. Its productivity varies between 16.6−68.8 $g\cdot m^{-2}\cdot a^{-1}$ and the land use and land cover mainly comprise desert grassland and degraded *Haloxylon ammodendron* as well as *Tamarix* spp. (Figures 2 and 3).The second group includes Types 5 and 6, with a productivity of 220−318.4 $g\cdot m^{-2}\cdot a^{-1}$. The land use and land cover comprise typical riparian vegetation species such as *Populus euphratica* forest, *Haloxylon ammodendron* forest, *Phragmites communis*, *Sophora alopecuroides*, etc.

As viewed from the characteristics of different classes of patch numbers and area, the patch of desert vegetation type (namely Types 1, 2, 3 and 4) is dominated by the class of <1 hm^2, the patch number exceeds 45000 and it extensively occurs in the oasis and tends to be scatteringly distributed. In other words, there are numerous desert vegetation patches of <1 hm^2 in the center of the oasis. On the contrary, the riparian vegetation type (Types 5 and 6) is dominated by the patches of >4 hm^2, it tends to be concentration distribution. Therefore, as viewed from the patch number, the desert vegetation type not only holds a leading place in the Ejina Oasis but also leads to the fragmentation of the riparian vegetation landscape. As viewed from the patch area of different productivities, both the desert vegetation and riparian vegetation are dominated by the patches of >4 hm^2. It shows that the desert riparian forest landscape still is a dominant landscape and at its very initial stage of fragmentation.

2.2 Vegetation ecological water requirement

(i) Determination of transpiration coefficient. Transpiration coefficient (also known as amount of water requirement) refers to the quantity of water needed to produce one gram of dry matter. About 300—600 g of water is required for plants to produce one gram of dry matter. However, different plants species have different water requirement amounts; for example, the transpiration coefficient of *Searia viridis* is 285, *Sorghum sudanemse* 304, corn 349, wheat 557, *Brassica campestris* 714 and *Medicago sativa* 844. Huang gave out the transpiration coefficients of 138—344 for some arid desert plants, such as *Haloxylon ammodendron*, *Caragana Korshinskii*, *Artemisia salsoloides, Caligonum mongolicum, Hedysarum scoparium* and *Tamarix* spp.; the corresponding figure for *Elaeagnus angustifolia* is 383 and *Populus gansuensis* 513[15]. Of course, the amount of water requirement is also related to other ecological factors, such as solar radiation intensity, temperature, atmospheric, soil regimes, plant development stage, etc. The transpiration coefficient is inversely proportional to the water use efficiency of plants (the higher the water use efficiency, the lower the transpiration coefficient); and the transpiration coefficient of woody plants is generally smaller than that of herbs[16]. Up to now, no transpiration coefficient relating to studies of *Populus euphratica* is reported. But Su et al. pointed out that *Populus euphratica* has higher water use efficiency than *Populus gansuensis* and *Elaeagnus angustifolia*[17]. It is estimated that the transpiration coefficient of *Populus euphratica* is lower than that of the *Elaeagnus euphratica* (383). Taking the above facts into consideration, the quantity of water required to produce one gram of dry matter for the vegetation in Ejina Oasis (its dominant species include *Populus euphratica, Tamarix* spp., *Haloxylon ammodendron* and *Sophora alopecuroides*) were defined as 300 g and then the water consumption amount of the Oasis was calculated.

(ii) Vegetation water consumption. (1) Water consumption of *Populus euphratica* forest. The corresponding productivity of the normally growing *Populus euphratica* forest land in Types 5 and 6 is dominant in both patch area and patch number. As viewed from the distribution of patch area, Type 5 occupies 56.1% and Type 6 43.9% of the whole normally growing *Populus euphratica* forest land; from the patch number Type 5 occupies 57.7% and Type 6 41.8%.

From the weighted mean calculation of different productivities of different types the mean productivity is 0.29 $kg·m^{-2}$ and water requirement is 82.94 $kg·m^{-2}$. According to the relation between NDVI and productivity (Figure 5), the largest productivity is estimated to be 0.52 $kg·m^{-2}$, and the corresponding water requirement is 156 $kg·m^{-2}$ (Table 1).

The type of productivity corresponding to the degraded *Populus euphratica* includes Types 1, 2, 4 and 5, as viewed from the distribution of patch area Type 5 occupies 81.5% and holds the leading place; Types 1, 2 and 4 occupy 9.5%, 6.7% and 2.3% respectively. From the weighted mean calculation of different types of productivity of the degraded *Populus euphratica* the mean productivity is 0.06 $kg·m^{-2}$ and the mean water consumption is 17.7 $kg·m^{-2}$.

Table 1 Productivity and water consumption of different types of vegetation in representative investigation areas

Item	Area (10^6 m^2)	Current-year biomass (10^6kg)	Mean productivity ($kg·m^{-2}$)	Max productivity ($kg·m^{-2}$)	Mean water consumption ($kg·m^{-2}$)	Max water consumption ($kg·m^{-2}$)
Normal *P. euphratica*	48.43	14.04	0.29	0.52	82.94	156
Degraded *P. euphratica*	17.71	1.05	0.06	0.52	17.7	156
Normal *Tamarix* spp.	181.42	48.45	0.27	0.46	80.1	137.4
Degraded *Tamarix* spp.	201.95	8.63	0.04	0.46	12.9	137.4
Normal *H. ammodendron*	1.01	0.06	0.06	0.07	19.67	19.67
Degraded *H. ammodendron*	0.55	0.02	0.04	0.07	10.64	19.67
Riverside grassland	39.42	5.37	0.14	0.32	40.8	95.4

(2) Water consumption of *Tamarix* spp. Forest. There are 13.0×10^4 hm^2 of *Tamarix* spp. forest in the Ejina Oasis, of which normally growing forest is 8.9×10^4 hm^2, accounting for 68.4%; seriously degraded forest is 4.1×10^4 hm^2, accounting for 31.6%.

The patch types of different productivities in the normally growing *Tamarix* spp. forest land include Types 5 and 6. Type 5 has the largest patch area and number, occupying 70% of the total patch area and 51.2% of the total patch number. The weighted mean calculation of different types of productivity in normally growing *Tamarix* spp. shows that the mean productivity and the water consumption are 0.27 $kg \cdot m^{-2}$ and 80.1 $kg \cdot m^{-2}$, respectively. The NDVI deduced calculation shows that the maximum productivity and water consumption are 0.46 $kg \cdot m^{-2}$ and 137.4 $kg \cdot m^{-2}$, respectively.

The patch types of different productivities corresponding to degraded *Tamarix* spp. forest land include the six types. As viewed from the distribution of patch area, Type 1 hits up to 84.7%; but as viewed the distribution of patch number, Type 6 hits up to 84.9%. The weighted mean calculation of different types of productivity in the degraded *Tamarix* spp. forest land shows that the mean productivity and the mean water consumption are 0.04 $kg \cdot m^{-2}$ and 12.9 $kg \cdot m^{-2}$, respectively.

(3) Water consumption of riverside grassland. Riverside grassland is the main natural pastureland of the Ejina Oasis and relies on the Heihe River flooding to exist, these main plant species distributed in which include *Phragmites*, *Sophora alopecuroides*, *Ameruolepidium dasystachys*, *Achnatherum splendens*, etc. It covers an area of 71987 hm^2, including 5 types of productivity, of which Type 5 occupies 45.85% of the total area, while Types 1, 2, 6 and 3 occupy 15.26%, 8.52%, 7.73% and 0.52%, respectively.

From the weighted mean calculation of different productivities the mean productivity of riverside grassland is 0.14 $kg \cdot m^{-2}$, mean water consumption 40.8 $kg \cdot m^{-2}$, maximum productivity 0.32 $kg \cdot m^{-2}$, and corresponding water consumption 95.4 $kg \cdot m^{-2}$.

(iii) Vegetation ecological water requirement. Mean water consumption for the vegetation in the Ejina Oasis is 128.44×10^6 m^3 (Table 2), and the water consumption to gain the maximum productivity is 319.01×10^6 m^3 (Table 3). Water consumption here is the water quantity directly consumed by vegetation without considering soil evaporation. Generally, soil evaporation values in arid zones can be estimated through the vegetation water consumption adding 20% of it. For example, soil evaporation in the Ejina Oasis is $128.44 \times (100\%+20\%) \times10^6 =152.86\times10^6$ m^3, similarly, the optimal ecological water requirement is $294.56\times(100\%+20\%)\times10^6 = 384.56 \times 10^6$ m^3.

Table 2 Ecological water requirement of existing vegetation in Ejina Oasis

	Area (10^4 hm^2)	Productivity ($kg \cdot hm^{-2}$)	Water requirement (10^6 m^3)
Normal growing *P. euphratica* forest	2.01	2764.67	16.67
Degraded *P. euphratica* forest	0.48	590.00	0.85
Normal growing *Tamarix* spp. forest	8.91	2670.00	71.37
Degraded *Tamarix* spp. forest	4.11	430.00	5.30
Normal growing *H.ammodendron* forest	0.49	655.67	0.96
Degraded *H. ammodendron* forest	3.47	354.66	3.69
Riverside grassland	7.20	1360.00	29.38
Artificial forest	0.02	3636.33	0.22
Total			128.44

Table 3 Ecological water requirement for vegetation to reach maximum productivity in Ejina Oasis

	Area (10^4 hm^2)	Productivity ($kg \cdot hm^{-2}$)	Water requirement (10^6 m^3)
Normal growing *P. euphratica* forest	2.01	5200.00	31.36
Degraded *P. euphratica* forest	0.48	5200.00	7.49
Normal growing *Tamarix* spp. forest	8.91	4580.00	122.42
Degraded *Tamarix* spp. forest	4.11	4580.00	56.47
Normal growing *H.ammodendron* forest	0.49	655.67	0.96
Degraded *H. ammodendron* forest	3.47	655.67	6.83
Riverside grassland	7.20	3180.00	68.69
Artificial forest	0.02	7482.33	0.45
Total			294.67

2.3 Water requirement to maintain the Ejina Oasis

It has been testified that the withering of Populus euphratica forest in the Ejina Oasis is unrelated to the deforestation but insufficient draw-off discharge of the Heihe River. In the case of water shortage of the basin, how much water should be allocated to the Ejina Oasis is still a difficult problem to the management of the Heihe River. We try to discuss it under the following preconditions.

(1) The boundary or the Ejina Oasis is defined by the spatial scope of existing vegetation (its boundary is defined using 1:10000 land use map).

(2) The current ecological water requirement is represented by the water consumption to produce the weighted mean above-ground biomass at the productivity level in the land use limit.

(3) The optimal ecological water requirement is defined based on the water consumption of the plot.

(4) The water source of vegetation growth in the Ejina Oasis comes from surface water or surface water-converted ground water.

The regional ecological water requirement is the sum of vegetation ecological water requirement, domestic water consumption in cities and farmland water consumption minus the precipitation recharge. Vegetation water requirement refers to the quantity of water required to produce the current-year total biomass, as shown in Tables 1－3. Domestic water requirement refers to the quantity of water consumed by 20000 non-agricultural population in Hubu Town in the Oasis (0.4 $m^3 \cdot person^{-1} \cdot d^{-1}$)[20]; agricultural water requirement refers to the quantity of water consumed by the existing 1600 hm^2 of farmland, following an irrigation norm of 9000 $m^3 \cdot hm^2$; and the precipitation recharge refers to the effective atmospheric precipitation, it is calculated based on the monthly precipitation >5 mm and 0.3×monthly effective precipitation.

Analytical results (Table 4) show that about 149.12 × $10^6 m^3$ of recharge water is needed to maintain the present state of the Ejina Oasis and 344.82×$10^6 m^3$ of recharge water is required for the vegetation of the oasis to reach the highest productivity at present (Table 5). The results refer to the ecological water requirement for the vegetation growth in oasis. Considering the intense evaporation resulting from the extreme arid climate, frequent leakage, and almost no surface runoff contributed to the river, the transfer losses of water can never be neglected. If the discharge at the Longxin Mount hydrological station is viewed as the basis to allocate the water of the Heihe River, a transfer losses rate k should be given to reflect the relationship between the discharge water volume and the water volume arrived to the Oasis, namely there is a K coefficient between the Oasis's water requirement and the discharge at the Longxin Mount hydrological station. The K value (K=1+k) is related to the water delivery distance, river channel regime, river bed form, dry and wet regime of river bed and weather condition, etc. Owing to limited observation data, the minimum of K is defined as 1 in this paper, in other words, the water transfer loss rate of the river channel is 0 (k=0). According to the observed data in recent years, when the draw-off discharge at the Longxin Mount hydrological station is 300×10^4－400×10^4 m^3, the water head cannot arrive to the center of Oasis; when the draw-off discharge is 2000×10^4 m^3 , about 1400×10^4 m^3 of water can reach the center of the Oasis. When the draw-off discharge at the Longxin Mount hydrological station exceeds 2000×10^4 m^3, the loss rate of leakage and evaporation is about 30%. It is obvious that the loss of leakage and evaporation along the Longxin Mount hydrological station to the center of the Oasis is directly proportional to the draw-off discharge and has a decreasing trend. Based on the above analysis and other related facts, it may be presumed that the K coefficient along the Longxin Mount station to the Ejina Oasis is unlikely to exceed 1.5 (k=0.5). This estimation is approximately consistent with the results observed by local hydrological workers1).

Under the defined the conditions, a K-value curve

Table 4 Water requirement to maintain the present state of vegetation

Type	Water requirement ($10^6 m^3$)
Vegetation water requirement	152.86
Farmland water requirement	14.40
Domestic water consumption	2.88
Precipitation recharge	21.02
Needed recharge water amount	149.12

Table 5 Water requirement to reach the highest productivity

Type	Water requirement ($10^6 m^3$)
Vegetation water requirement	348.56
Farmland water requirement	14.40
Domestic water consumption	2.88
Precipitation recharge	21.02
Needed recharge water amount	344.82

1) Yang B L. Ejina River, Heihe engineering construction Bureau of Alxa Meng, Ejina Water Affair Office, 2002, 50－51

(Figure 7) can be derived analytically. According to the curve, if the K coefficient of transfer leakage and evaporation was 1.3－1.5, the draw-off discharge of the Heihe River (at Longxin Mount hydrological station) to maintain the present state of the Ejina Oasis would be 1.94×10^8－2.24×10^8 m^3; and the value would amount to 4.28×10^8—$5.17\times10^8 m^3$ to make the dominant riparian vegetation (*Populus euphratica*, *Tamarix* spp.) and riverside grassland get a higher productivity.

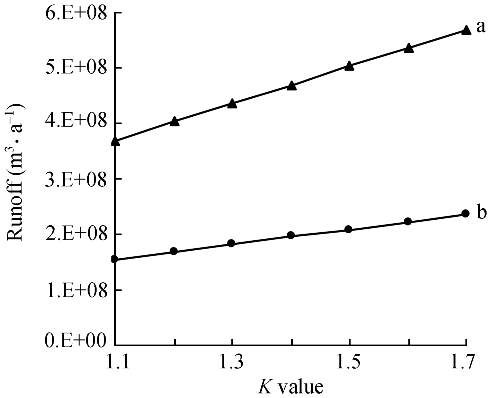

Figure 7 Assessment of ecological water requirement of the Ejina Oasis. a, Current ecological water requirement; b, potential ecological water requirement.

3 Conclusion

The productivity of the Ejina Oasis can be divided into two groups: the first group includes degraded *Haloxylon ammodendron* forest and *Tamarix* spp. forest, with a productivity level of 16.6－68.8 $g\cdot m^{-2}\cdot a^{-1}$; the second group consists of *Populus euphratica* forest, *Haloxylon ammodendron* forest, *Phragmites communis*, *Sophora alopecuroides*, etc., with a productivity level of 220－318.4 $g\cdot m^{-2}\cdot a^{-1}$.

The water requirement to maintain the present state of the Ejina Oasis is 1.53×10^8 m^3, and 3.49×10^8 m^3 for the existing vegetation to reach the highest productivity level at present. In consideration of domestic water consumption in cities, channel water transfer loss, oasis vegetation water consumption, farmland irrigation water and precipitation recharge, etc., the draw-off discharge of the Heihe River (at Longxin Mount hydrological station) for maintaining the present state of the Ejina Oasis should be 1.94×10^8－2.24×10^8 m^3, and that for the existing vegetation to reach the highest productivity should be 4.28×10^8－5.17×10^8 m^3.

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