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A case study on the ecological evaluation of water conservation facilities on the basis of plant diversity

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Abstract. In this experiment, water conservation facilities in the Yinchuan Plains were studied to establish ecological evaluation criterion for water conservation facilities based on plant diversity indexes. Among the tested indexes, the Margalef and the Simpson indexes were found to effectively characterize the ecological degree of water conservation facilities. Natural lake plant diversity has been used to as a metric; the ecological criteria degree of water conservation facilities can be divided into 4 grades. The results showed that the ecological level of the field ditch, primary furrow, and second furrow qualified as class A, which is the highest grade. The branch canal was grade B, which is good. The lateral canal and flood furrow were grade C, which is a medium level. The trunk canal was grade D, which is the poorest. In addition, the results establish an ecologicalization evaluation system based on the plant diversity composite index of the original lake. Metrics such as biomass, carbon and nitrogen fluctuations, temperature, and humidity could be used to comprehensively evaluate the ecologicalization degree of water conservation projects, such as large reservoirs.

1. Introduction

The purpose of ecological hydraulic engineering and water conservation project ecologicalization is to protect the environment. Water resources conservation, space-time allocation, and rational utilization have been carried out for many years in the water industry. Currently, the ecological problems of water conservation facilities are national concerns [1, 2]. Societies must follow basic ecological and economical requirements, and use modern scientific, management, and technological achievements to develop efficient water conservation projects. Water conservation projects should offer a high degree of engineering and ecological benefits. In arid inland areas, water conservation is the lifeblood of both agriculture and ecology. Farmland windbreaks and garden green lands cannot operate without the assistance of water facilities [3]. It is therefore necessary to research and evaluate water conservation project ecologicalization for water conservation project construction. This research could significantly benefit the health and safety of ecological drylands [4].

The scientific community's current understanding of ecological hydraulic engineering lacks a cognitive quantization index; therefore, it is important to explore scientific environmental assessment indicators. Biodiversity is sensitive to the ecological status indicator because the loss of species decreases ecological resilience to disturbance or disruption [5]. Our research of the Yinchuan Plain revealed that the biodiversity index was a better metric for determining the ecology of ditch wetlands [6, 7]. It is commonly known that plant diversity leads to ecological stability, which leads to more

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complicated energy flows and material cycles [4]. These favorable qualities can increase retention and production, improve the ecology's ability to self-regulate, and ultimately create healthier and more stable ecosystems. Multiple supply and partitioned supply mainly demanded from a tactical point of view infrastructure supply. Multiple supply means that resources and energy are provided uniformly; partitioned supply means that the entire facility is divided into several partitions, and the resources and energy are provided according to each section's needs. The former promotes efficiency and the security of the Foundation Infrastructure Provider. Together, integrity and variety are a representation for foundation infrastructure ecologicalization [8].

Since plant landscapes are not affected by the water deposit status of water facilities, this study evaluates the ecosystems of streams, lakes, and reservoirs in the Yinchuan Plain using plant diversity indexes. The study establishes an evaluation system to judge whether or not water facilities are ecologically sound.

2. The Yinchuan plain and its establishing condition of water facilities

The Yinchuan Plain (105˚45′~107˚00′, 37˚50′~39˚20′) is located in the eastern part of northwestern China (figure 1); it belongs to the Ningxia Autonomous Region. It is composed of alluvium and alluvial material from the Yellow River and Helan Mountains; the total area is 7978 km^2. The mean annual precipitation in the Yinchuan Plain is around 200 mm, while the mean annual temperature is 8~10°C. It has a longer winter and a shorter summer, a later spring and an earlier autumn, and a strong wind that carries sand. In LandScope, the Yinchuan Plain is an oasis surrounded by several deserts, which means that water conservation facility ecologicalization is particularly important for this region.

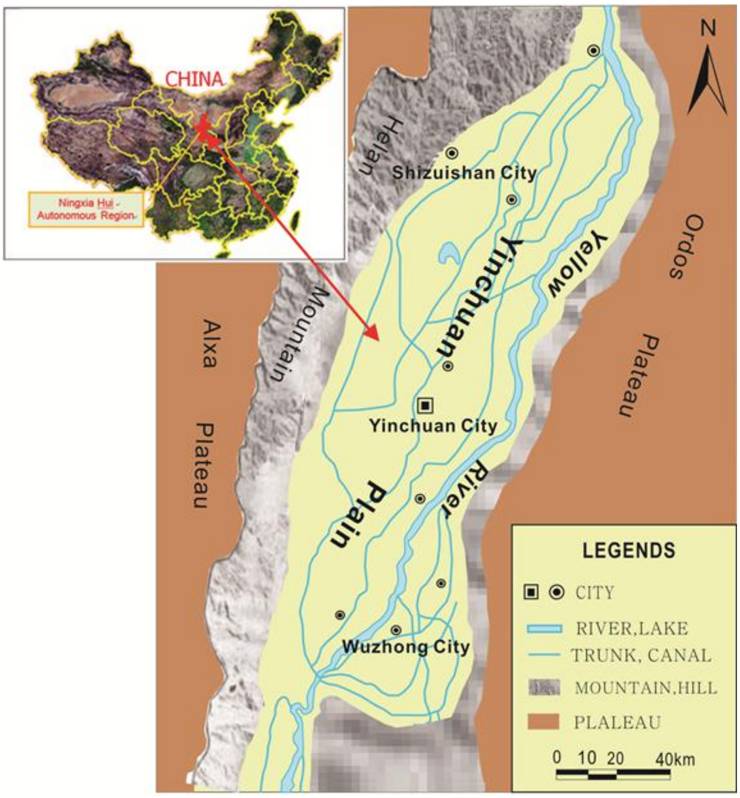

Figure 1. Map of Yinchuan Plain and its location. It is surrounded by the Tengger Desert of Alxa Plateau on the west, the Kubuqi Desert and Mu Us Desert of the Ordos Plateau on the east, and the Wulanbuhe Desert on the north. Thus, the Yinchuan Plain is an oasis formed by Yellow River irrigation.

The Yinchuan Plains were agriculturally developed during the Qin (777~206 BCE) and Han (206 BCE ~ 220 CE) Dynasties; a water system was formed that included a main channel, trunk canal, branch canal, lateral canal, field ditch, and wicking ditch. This system ensured the development of an oasis that irrigated farmlands. By the middle of the 20th century, about 15 canals in total were being used for irrigation, supplying a land area of about 9600 hm^2. In the 1960s, Qingtongxia Reservoir changed control-free irrigation history in the Yinchuan Plain because repairs to the Main channel completely changed the configuration, improved height differences, and expanded the irrigated area. Currently, there are about 18 canals in the Yinchuan plain; their total length is more than 1084 km, their total water flow is 603 m^3/s, and their total irrigated area is 330,000 hm^2. There are about 24 key drains with a total length that exceeds 660 km, a total water flow of 955 m^3/s, and a total irrigated area of 4.2×104 hm^2 [9, 10]. There are 151,800 hm^2 of river and lake wetlands, which amount to about 19.1% of the total area of Ningxia. Some of these wetlands were constructed last year.

3. Materials and methods

3.1. Field investigation and sampling

We carried out a field investigation for water environments in the Yinchuan Plains using a line transect and sample plot. We selected typical lakes, channels, and drainage ditches to set sample plots according to the habitat heterogeneity degree and land use pattern. We chose primordial lakes that had stable ecosystems and displayed without interference. For the main furrow, flood furrow, and trunk canal, we selected sections from each upside, intermediate, and bottom. For general ditches, we selected sections from upstream, midstream, and downstream that were refitted more than three years ago. It was located specifically from the top of one side of the ditch dam to the top of the other side of the dike under the section direction, then lie out samples on the section according to the ecological sequence. In the Yinchuan Plain, the ditches and canals were divided into 5 separate levels according to access relations; the middle stages are often difficult to distinguish in the field. Thus, we classified trunk and branch canals as first stage canals, and lateral and other low-level canals as second stage canals. The quadrat size of herbaceous plants was 1 m × 1 m, but the quadrat size of shrub communities was 4 m × 4 m. Each sample plot had three repetitions. We recorded the name, abundance, height, coverage, and life forms of terrestrial plants, as well as the name and coverage of aquatic plants [11]. We also measured the slope, gradient, slope length, root zone, water depth, flow rate, water flux, and construction status.

3.2. Selecting the diversity index

Biological diversity is a function of biological richness and evenness [12]. There are many relevant calculation models for community biodiversity. However, the various methods weigh richness and evenness differently. This study mainly used the Margalef species richness index, the Simpson species dominance index, the Shannon-Weiner species diversity index, and the Pielou species evenness index [13].

In the below formulas, 'S' indicates the number of species within the samples; 'Pi' indicates the relative important value of a species within the samples (Relative important values = [Relative abundance + Relative frequency + Relative significant]/3).

- Species richness index: Margalef index

$$R = (S-1)/InN \tag{1}$$

This reflects the number of species in the community or habitat. A higher number indicates higher species diversity.

- Simpson species dominance index: Simpson index

$$D = 1 - \sum_{i=1}^{s} p_i^2 \tag{2}$$

This reflects species dominance in the community. A higher number indicates a lower dominant species.

- Species diversity index: Shannon-Weiner index

$$H = -\sum_{i=1}^{s} PiInPi \tag{3}$$

This reflects the species diversity in the community. A higher number indicates more community complexity.

- Pielou species evenness index: Pielou index

$$E = H / InS \tag{4}$$

This reflects the uniformity of spatial distribution for species. A higher number indicates a more homogeneous plant distribution and a greater contribution degree to the ecological environment [12].

Using Microsoft Excel 2007, we calculated the diversity indexes of each lake or canal sample, then concluded that according to its architecture. Finally, we added them separately and averaged them to find the diversity indexes of the lake, canal, ditch, and so on. We often combined the trunk furrows, branch furrow, lateral furrows, field furrow, and little furrows in our calculations because they were too similar to properly distinguish.

4. Results and analysis

4.1. Plant diversity in lakes and ditches

We compared the Margalef index of lakes and ditches in the Yinchuan Plains. The results showed that the flood furrow had the highest number of individual plants, and the trunk canal had the lowest number of individual plants. The difference between the two nearly 1 times; Next to the flood furrow is the second furrow and then the primary furrow, then the lakes, the next are field ditch and trunk canal, species richness of lateral canal are low, close to trunk canal (see figure 2).

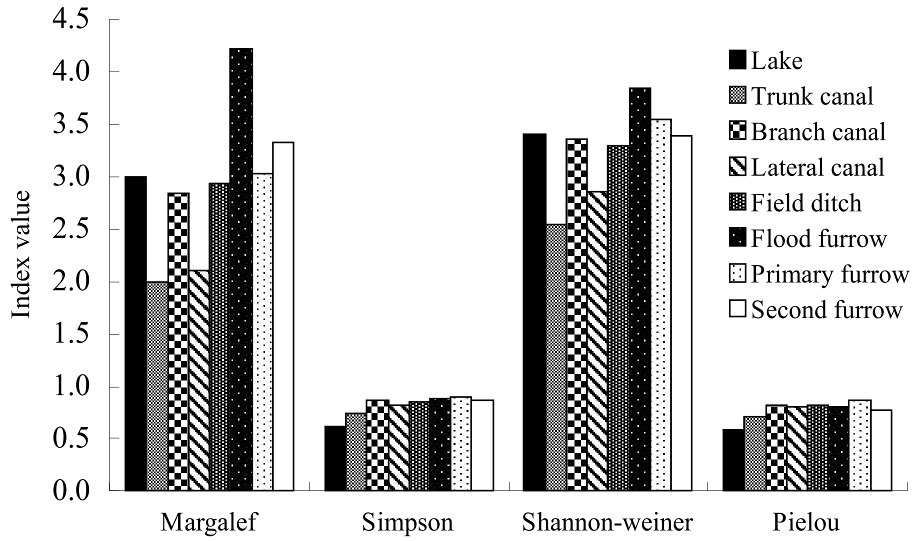

Figure 2. The plant diversity indexes values in the Yinchuan Plain across 4 biological diversity indexes (Margalef, Simpson, Shonn-winner, and Pielou index), across lakes and 6 types of water facilities (trunk canal, branch canal, lateral canal, field ditch, flood furrow, primary furrow and second furrow).

When the species in the level ditches did not display a significant difference in dominance, there were no significant differences between their Simpson indexes. The branch canal and primary furrow had the highest Simpson indexes (0.893, 0.875), while the trunk canal had the lowest (0.743). This illustrates that the dominant species of the trunk canal was relatively more populous, and the dominant species of the branch canal and primary furrow were relatively less populous. The dominant species in other ditches were between these two extremes.

We compared the Shannon-wiener index and Pielou index of each ditch in the Yinchuan Plain (figure 2). The results show that the flood furrow had the highest Shannon-Wiener value at 3.837, but its Pielou value was in the middle at 0.798; this means that there were a high number of plants, and the distribution had some aggregation. The trunk canal, lakes, second furrow, branch canal, and field ditch showed middle Shannon-Wiener indexes between 3.298-3.540, but their Pielou index had a large gap between 0.609-0.821; this indicates that the plant distribution was not uniform. The trunk canal and lateral canal had the lowest Shannon-wiener values at 2.541 and 2.861, respectively, and their Pielou indexes were relatively low at 0.709 and 0.798, respectively; this indicates that the plant species distribution was minimal and uneven.

The Simpson and Pielou indexes of different plant communities in the Yinchuan Plain wetlands were very similar. This illustrated that the less dominant species in ditches had large evenness; in contrast, more dominant species in ditches had small uniformity.

4.2. The spatial distribution of plant diversity

The Yinchuan Plains have higher altitudes in the south and west. The 2000 years of oasis development basically lasted the flow direction that from south to north, from the first terrace and shore of the Yellow River Plain to the second terraces of the alluvial plains. In this study, we roughly divided the irrigation area into two stages in chronological order. The oasis was considered an old irrigation area; the oasis subsequently developed into the new irrigation area. According to the survey results, the plant species and community types of the new irrigation areas were richer than that of the old irrigation area; for instance, aquatic plants were extremely rich in the flood furrow of the new irrigation area, except for common species in the old irrigation areas, such as Potamogeton natans L., Nymphoides peltatum (Gmel.) O. Kuntze, Ceratophyllum demersum L., Potamogeton pectinatus L., Utricularia vulgaris L., Salvina natans L., etc. Phragmites australis (Cav.) Trin. ex Steud, Typha angustata Bory & Chaub., Polygonum lapatifolium L., and Polygonum hydropiper L .etc. Typical wetland plant communities grew in the flood furrow and drainage ditch of the new irrigation area, including Comm. Scirpus triqueter, Comm. Scirpus tabernaemontani, Comm. Triglochin palustre, Comm. Acorus calamus, rare species Butomus umbellatus L., Crypsis aculeate (L.) Ait. Wetland vegetation in lakes included Phragmites australis (Cav.) Trin. ex Steud, Scirpus Tabernaemontani, Typha angustifolia L., Scirpus validus Vahl, Sagittaria trifolia L. var. sinensis (Sims.) Makino, Potamogeton distinctus A. Benn., Nymphoides peltatum(Gmel.) O. Kuntze, etc [14].

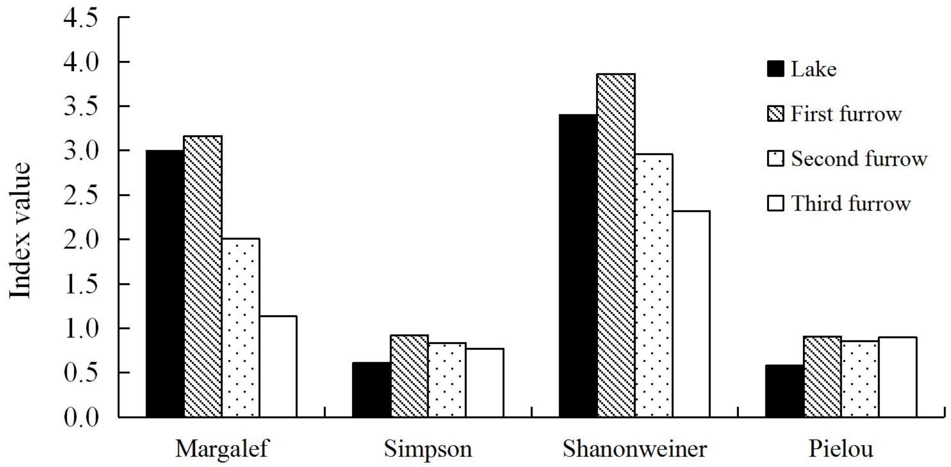

Figure 3. The plant diversity indexes of macro-ditches. There are 5 macro-furrows with lengths greater than 100 km length in the Yinchuan Plain; we selected 3 of them and calculated their biodiversity indexes, which represents the ecological status of water conservation facilities upstream, midstream, and downstream. Additionally, we compared the value differences between them and lakes.

Research has shown that ditch wetland plant diversity in the Yinchuan Plains was high, and it had a strong edge effect [15]. Using lakes and drainage ditches as examples, their species diversity was relatively high, which contrasted with the plant diversity index of the three large drainage ditches of the Yinchuan Plains from south to north in this order: drainage ditch, trunk drainage ditch, primary lake, and drainage ditch. The Margalef and Shannon-Wiener indexes were both the highest in the first drainage ditch (figure 3), and the lowest in the third drainage ditch. Plant species diversity was highest in the first drainage ditch, followed by the lake, and lowest in the trunk drainage ditch. Plant species abundance and complexity decreased from upstream to downstream. The Simpson and Pielou indexes showed few differences in the three drainage ditches, meaning that plant dominance and uniformity did not display many differences between the upstream and downstream areas. The results indicated a significant difference between the drainage ditch and lake [16]. We studied the interspecific relationships between wetland plants in the Yinchuan Plains and concluded that wetland dominant plant populations varied due to annual dynamic changes in wetland large-scale renovation, water contents, and water levels.

5. Evaluating the ecologicalization of lakes and ditches in the Yinchuan Plain

5.1. Ecological index and its effects

To facilitate calculations, the plant diversity indexes of lakes and ditches were carried out in the principal component analysis (table 1). The results showed that the cumulative contribution rate of the Margalef and Simpson indexes were 97.455%, and the Eigenvalue was >1, which indicates that the first two diversity indexes contained more than 85% of the information. Therefore, these two diversity indexes can indicate the ecological degree of lakes and canals in the Yinchuan Plains. The principal component factor loading of each diversity index divided by the Eigenvalue of the arithmetic square root determines the coefficient of each diversity index; the final function expression is:

$$y_1=0.488x_1+0.535x_2+0.507x_3+0.468x_4 \quad (5)$$

$$y_2=0.518x_1-0.438x_2+0.480x_3-0.557x \quad (6)$$

Table 1. Principal component analysis of plant diversity indexes in lakes and ditches.

Ratio/Index	First principal component	Second principal component
Eigenvalue	2.475	1.423
% of Variance	61.884	35.571
Cumulative %	61.884	97.455
Margalef	0.767	0.618
Simpson	0.842	-0.522
Shannon-Weiner	0.797	0.572
Pielou	0.737	-0.665

Table 2. Scores of lakes and ditches on the first and second main component.

Type	First principal component score	Rank	Second principal component score	Rank
Lake	3.786	5	2.596	2
Trunk canal	2.992	8	1.536	8
Branch canal	3.460	6	2.241	6
Lateral canal	3.304	7	1.656	7
Field ditch	3.946	4	2.278	5
Flood furrow	4.847	1	4.422	1
Primary furrow	4.157	3	2.394	4
Second furrow	4.170	2	2.542	3

From table 2, we can find that the scores of the flood furrow on the first main component and second main component were the highest; however, the trunk canal was the lowest on the first and second main component scores. The rank of the branch canal and lateral canal were the same on different main component, but the ranks of other water conservation facilities changed.

5.2. Classification of ecologicalization evaluation

First, plant diversity was generally low in the Ningxia wetland, which was caused by the obvious differentiation and the species single of plant community; for example, reed is the dominant species and constructive species. At the same time, the water environment was relatively homogeneous, which leads to wider ecological reed amplitude with *Typha angustifolia* and other broad nature aquatic plants. It also repulsed other plants, resulting in low biodiversity in a relatively stable lake. In recent years, due to the increase of human disturbance, reed communities in wetlands have been in severe degradation in the Yinchuan Plain [17]. Wetland plant diversity therefore displayed a high discrepancy.

Second, the two main functions of water conservation facilities are transporting and storing water. A facility's ecological stability is just one aspect of this comprehensive function. Ignoring the main functions of water conservation facilities and only paying attention to its ecological construction can lead to wasted resources. In this study, the flood furrow had the highest plant diversity, but the construction of the detention basin and flood frequency has decreased in recent years. The spare problem is conspicuous, which equals to ecological land, but it is not the ideal ecological construction location for water conservation facilities. The Yinchuan Plains are located in a semi-arid area with little rainfall and a strong evaporation ratio. Therefore, we should use water-saving irrigation for wetlands, and consider water resource problems when constructing water conservation facilities [18].

Third, we focused on the ecological evaluation standard of water conservation facilities based on plant diversity. According to the results of the principal component analysis, the Margalef and Simpson indexes contained more than 85% of the information, so their weighted average can be used as the comprehensive evaluation index of ecological water conservation facilities (see table 2). We found that the number of native lakes was lower than the median number. Using the number of native lake as the datum, value 0.25 on both sides and then get an interval. Then, we used a good area when the value was 0.5 on both sides, and so on; table 3 shows the results.

Table 3. Ecological evaluation grading standards of water conservation facilities.

Rank	Interval
CK	3.191
A	2.941～3.441
B	2.691～2.941, 3.441～3.691
C	2.441～2.691, 3.691～3.941
D	<2.441, >3.941

Note: A is best, B is good, C is medium, D is poor, CK is standard.

5.3. Classification of water conservation facilities' ecologicalization in the Yinchuan Plain

According to table 3, water conservation facilities in the Yinchuan Plain can be divided into four levels. Table 4 shows that the ecological level of the field ditch, primary furrow, and second furrow are class A, which is the highest grade. The branch canal is grade B, which is good. The lateral canal and flood furrow are grade C, which is a medium level. The trunk canal is grade D, which is the poorest. Therefore, the field ditch, primary furrow, and second furrow showed high ecological water conservation in the Yinchuan Plains. Even though the ecological evaluation level of the flood furrow was not high at grade C, it displayed the highest plant species diversity (see figure 4) due to high changes in water volume, no seepage prevention, and a slope that produced a variety of moisture gradients. However, these plants are succession pioneer; the species configuration was not stable in water conservation facilities. There was low plant diversity in wetlands such as the trunk canal, which is the main component of the Ningxia canals and important transport canals, and which plays an important role in ecological corridor [19]. Canal beds are typically made of clay or some other type of impenetrable material to minimize loss caused by leakage in the water transport process. Slopes are typically made of cement with a hardening treatment, which severely destroys the water necessary for plants to grow and the soil environment. Some studies have put forward that the main factors influencing vegetation distribution in the Yinchuan Plains are moisture, organic matter, salt, and pH [20], which results in lower plant diversity over a long period of time. These also contribute to wetland vegetation degeneration.

Table 4. Ecological classification of water conservation facilities in the Yinchuan Plain.

Type	Rank	Type	Rank
Lake	A	Field ditch	A
Trunk canal	D	Flood furrow	C
Branch canal	B	Primary furrow	A
Lateral canal	C	Second furrow	A

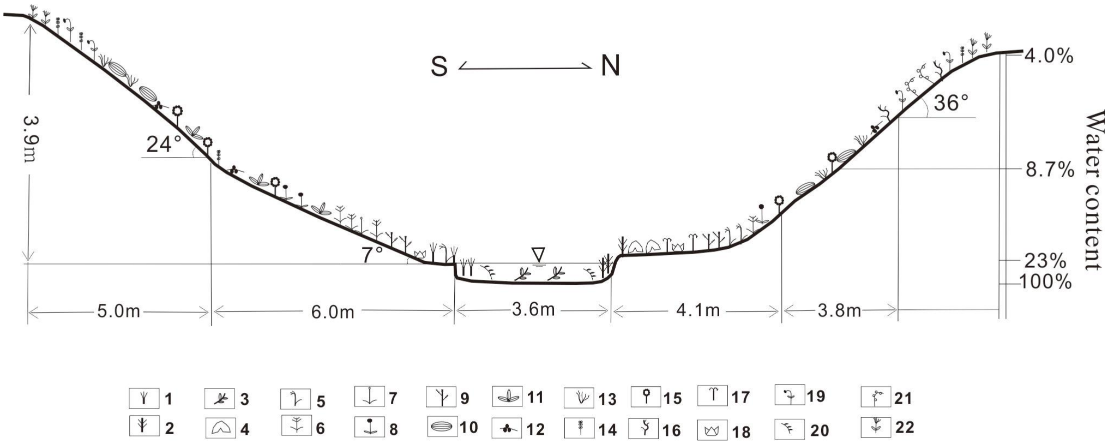

Figure 4. Map of ecological arrays on the slope of the Gaojiazha Ditch. This ditch is a flood furrow stretching from west to east, about 17 km length and 20-30 m width. It provided drainage for flash floods and irrigation water; the slope possessed a significant moisture gradient.

Note: 1 Phragmites australis (Cav.) Trin. ex Steud, 2 Typha orientalis Presl C. Presl, 3 Potamogeton distinctus A. Benn, 4 Sagittaria trifolia L. var. sinensis (Sims.) Makino, 5 Juncellus serotinus (Rottb.) C. B. Clarke, 6 Calamagrostis epigeios (L.) Roth, 7 Setaris viridis (L.) Beauv. Ess. Agrost, 8 Inula japonica Thunb., 9 Equisetum hiemale Desf., 10 Plantago asiatica L., 11 Sonchus brachyotus L. , 12 Xanthium sibiricum Patrin ex Widder, 13 Leymus secalinus (Georgi) Tzvelev, 14 Inula salsoloides (Turcz.) Ostenf, 15 Taraxacum officnala Hand.-Mzt.Monogr.Gothob., 16 Suaeda glauca (Bunge) Bunge, 17 Scirpus triqueter L.Mant., 18 Halerpestes ruthenica(Jacq.) Ovcz., 19 Salsola collina Pall., 20 Ceratophyllum demersum L., 21 Halogeton arachnoideu Moq., 22 Peganum harmala (Maxim.) Bobrov.

6. Conclusion and discussion

This study constructed a practical and reliable grading evaluation criterion for ecological water conservation facilities based on the plant diversity index. The engineering effect of water conservation is usually obvious, and can be constantly adjusted as required. However, the effects of a water conservation project are usually hysteretic and covert. We investigated plant diversity under the influence of water conservation projects, and chose Margalef and Simpson indexes as diversity and evaluation indexes of comprehensive ecological water conservation facilities. This approach considers engineering, ecological, and economic factors.

According to the ecological water resources evaluation standard established in this paper, the eight classes related to water conservation facilities in the Yinchuan Plains can be divided into four grades.

It is possible to use the diversity of native lake composite indexes as a benchmark to evaluate other water conservation facilities in the Yinchuan Plains. The results show that the field ditch, primary furrow, and second furrow had the highest grade (A). The trunk canal had the lowest grade (D).

The plant diversity index for evaluating ecological water conservation is not better when its value is bigger; rather, its purpose is to consider the basic characteristics of the local water ecosystem. Our study revealed that using the average state of native lake wetlands as the standard value to establish an evaluation system is effective. Other studies had proved that factors such as the ecological sequence, hydrological conditions, water conservation project construction, soil, and the water environment can influence plant diversity in the ditches of the Yinchuan Plains [7]. Due to significant differences in the plant diversity index value under different climate and terrain conditions, we think that this is appropriate for evaluating the ecological effect of small and medium-sized water conservation facilities; however, it is not indicative to the material production function of the ecosystem, climate regulation, entertainment, and so on (Jing et al. 2005). If a comprehensive evaluation of an ecological water conservation project is necessary, especially in large lake reservoirs, it is also necessary to introduce other indicators such as biomass, carbon and nitrogen fluctuations, temperature, and humidity.

Acknowledgments
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