RELATIONSHIP OF DOMINANT HERBACEOUS PLANT SPECIES AND GROUNDWATER DEPTH IN TONGLIAO PLAIN, NORTHWESTERN CHINA

ZHU, Y. H.[1,2] – ZHANG, S.[2*] – SUN, B.[2] – YAN, L.[3] – WANG, Y.[3]

[1]*College of Architectural Engineering, Yan'an University, Yan'an 716000, China*

[2]*College of Water Conservancy and Earth Building Engineering, Inner Mongolia Agricultural University, Hohhot 001018, China*

[3]*China Institute of Water Resources and Hydropower Research, Beijing 100076, China*

**Corresponding author*
e-mail: szimau@163.com

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Abstract. Diversification of vegetation communities could be associated with the change of groundwater depth (GD). To get a better understanding of this relationship, a field survey assessing GD, and herbaceous plants etc. was carried in Tongliao plain (TP), northwestern China, where GD has declined significantly mainly due to pumping for agricultural irrigation. The photos data method was used to identify vegetation characteristics including coverage, biomass, height, ecological type, and name etc. Some diversity indexes were applied to identify the relationship between the groundwater table and the plant features. Growth and composition of vegetation were affected by the depth of groundwater and the degree of utilization of herbaceous vegetation on water resources. Different depth of groundwater had different influence on vegetation. The ecotype distribution of vegetation following depth based on survey data demonstrated that mesophytes, mesoxerophytes and xerophytes were found over groundwater depths between 1.38 and 3.43 m, 1.4 and 3.4 m and 2.4 and > 4.0 m respectively. This study proved that the depth of 3.4 m may be the transition range for the evolution of vegetation in TP.
Keywords: *vegetation characteristic, diversity, ecotype, transition range, water resources*

Introduction

Semi-arid regions cover ~22% of the land surface and supports 6% of the population in China. The ecosystems in such regions are fragile and sensitive (Fu and Burgher, 2015). Herbaceous vegetation is an important part of ecosystem, which could be very sensitive to a series of environmental factors (Boyd et al., 2017; Hedl et al., 2017; Singh et al., 2017). Especially in arid and semiarid regions, growth status and distributions of herbaceous plants could extremely associate with buried depths of groundwater table. The effects of groundwater utilization to the vegetations have become increasingly interested in eco-environment protection and restoration (McLendon et al., 2008; O'Grady et al., 2006). Plant communities (Liu et al., 2016), morphological characteristics and vegetation (Galassi, 2001) respond to soil and groundwater quality and vegetation productivity, vegetation and other factors between groundwater. For the Tongliao plain (TP), the researches concentrate on the ecological level, suitable water level, ecological warning level and the relationship between research and critical depth saline vegetation (Liu et al., 2013; Qian et al., 2017; Yang and Chui, 2017), etc. Many studies also focused on the relationship between trees, shrubs and groundwater (Monteleone et al., 2018; Nolan et al., 2017); the trees and shrubs include poplar, elm, and microphyll etc. However, our knowledge on the relationships between the dominant

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herbaceous vegetation of the large watershed and groundwater depth (GD) is still limited. Some models (Liu et al., 2006; Zhu et al., 2010) were often qualitatively considered with the lower boundary of the bottom of the root, and it should be further clarified.

To obtain a comprehensive understanding of grassland degradation requires a combination of change detection by remote sensing, field investigation and literature review. The purpose of this study is to enhance the understanding of grassland degradation and to find the role of GD in changes in vegetation diversity for the study area of TP using such a portfolio of methods. The novelty of this paper lies in linking grassland degradation and perceived change to GD and providing lower boundary of the bottom of the root for hydrological mathematical model. On the basis of the dominant herbaceous vegetation species in TP area, the observed data was used to analyze the relationship between ecotype plants, species diversity, importance value and GD. This research will not only provide data for the scientific research model, but also provide scientific support for the management of local environment.

Within this paper, the specific aims of this study are to (1) investigate the spatial patterns and trends of vegetation diversity and cover change; (2) link grassland degradation with the GD; and (3) explore the role of changes of GD in grassland.

Materials and methods

Study area

The study area is located in a typical ecotone in North of China, which is a climate transition zone from sub-humid to semi-arid with an annual rainfall of 350-450 mm and evaporation of 1817 mm (20 cm pan). The root layer soil is mainly meadow, Aeolian sandy, and sandy chestnut etc. The plain is mainly formed by dunes, sandlot, lowland, and pasture land etc. Spatial distribution of vegetation is strong heterogeneity with dominant plant species of *Salsolacollina, Setariaviridis, Artemisiafrigida, Cleistogenessquarrosa, Poapretensis, and Artemisia campbellii Hook etc*.

From July to August, 2015, based on grassland type distribution under remote sensing images in study areas, 32 investigation sites (100 m × 100 m) centered on herbaceous plant communities were investigated (*Table 1*). Typical points were selected within each investigation site. Three random sampling plots were surveyed with a diameter of 1 × 1 m, including plant height, ecological style, name, wet weight, and biomass etc. The vegetation coverage was analyzed by ENVI 5.3 software through the supervised classification method. Meanwhile, soil sampler (specification: L is 4 m, Φ is 10 cm) was used to measure the corresponding GD data in each sample plot. Kriging interpolation and draw contour lines of depth were worked out based on the groundwater table data (*Fig. 1*). To detect the soil type of each survey plot, spatial distribution data of soil types in China were used that were got from Chinese Academy of Science (http://www.resdc.cn) at a scale of 1:1,000,000.

Methods

Vegetation importance value (Ma et al., 2009), niche breadth (Feinsinger, 1981), richness index (Li et al., 2008), community species diversity index (Hejda and Pyšek, 2006), evenness index (Ma, 2005), and dominance index (Wood et al., 2005) were applied to identify the change of species diversity.

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Important value:

$$IV = (RD + RF + RC)/3 \tag{Eq.1}$$

Niche breadth:

$$Bi = (1/r)\sum_{j=1}^{r} P_{ij}^2 \tag{Eq.2}$$

Margalef richness index:

$$D = (S-1)/InN \tag{Eq.3}$$

Shannon community species diversity index:

$$D = -\sum_{i=1}^{S} (p_i Inp_i) \tag{Eq.4}$$

Alatalo evenness index:

$$D = \left[1/\sum_{i=1}^{S} (\frac{N_i}{N})^2 - 1\right] / \left[e^{(-\sum_{i=1}^{S} \frac{N_i}{N} In \frac{N_i}{N})} - 1\right] \tag{Eq.5}$$

Simpson dominance index:

$$D = 1 - In\sum_{i=1}^{S} \left(\frac{N_i}{N}\right)^2 \tag{Eq.6}$$

where: *IV* is the important value, *Bi* is the niche breadth, *RD*, *RF*, *RC* are the relative density, relative frequency, and relative coverage of vegetation, *D* is the diversity index, *S* is the total number of species, *N* is the number of trees of all species, *P* is the vegetation density, *i* is the i^{th} vegetation.

Results

Vegetation composition

41 species of herbaceous vegetation were identified, which belonged to 2 classes, 12 families and 24 genuses. Perennial and annual herbaceous vegetations presented 58%, and 48% respectively. They were classified as mesophytes, mesoxerophytes, xerophytes, psammophyte, ultra-xerophytes, and halophytes that presented for 38%, 8%, 38%, 15%, 3%, and 5% respectively. The most important is that 11 species of the dominant herbaceous species were recognized. They belonged to 2 classes, 3 families and 7 genuses, among which perennial and annual herbaceous vegetation accounted for 45% and 55% respectively.

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***Table 1**. Sampling point information*

ID	X	Y	GD (m)	ST	Species	GE	LF	ET
1	120.37	43.64	> 4	Ca	*Poa annua*	*World*	*Th*	*M*
2	120.51	43.54	> 4	Ca	*Artemisia campbellii*	*North temperate zone*	*Pn*	*X*
3	120.28	43.47	> 4	Ca	*Poa annua*	*World*	*Th*	*M*
4	120.63	43.63	> 4	Ca	*Artemisia pubescens*	*North temperate zone*	*Pn*	*X*
5	121.83	44.10	2.25	Ca	*Chloris virgata*	*Pantropic*	*Th*	*M*
6	121.57	44.25	1.4	Ae	*Corispermum hyssopifolium*	-	*Pn*	*X*
7	121.28	44.42	3.1	Ca	*Artemisia pubescens*	*North temperate zone*	*Pn*	*X*
8	121.10	44.48	1.8	Ca	*Suaeda glauca*	*Central Asia - Mongolia*	*Th*	*Mx*
9	121.57	44.24	1.5	Fl	*Carex duriuscula*	*World*	*Pn*	*Mx*
10	121.59	43.54	3.3	Fl	*Artemisia pubescens*	*North temperate zone*	*Pn*	*X*
11	121.57	43.65	3.7	Ca	*Corispermum hyssopifolium*	-	*Pn*	*X*
12	121.25	43.65	3.4	Ca	*Suaeda glauca*	*Central Asia - Mongolia*	*Th*	*Mx*
13	121.87	43.35	2.8	Ae	*Suaeda glauca*	*Central Asia - Mongolia*	*Th*	*Mx*
14	120.43	42.79	> 4	Ae	*Setaria viridis*	*Pantropic*	*Th*	*M*
15	120.76	43.02	3.8	Ae	*Corispermum hyssopifolium*	-	*Pn*	*X*
16	120.97	43.26	> 4	Ae	*Echinochloa crusgalli*	*Pantropic*	*Th*	*M*
17	121.38	43.24	3.3	Ae	*Echinochloa crusgalli*	*Pantropic*	*Th*	*M*
18	121.66	43.34	3.1	Fl	*Setaria viridis*	*Pantropic*	*Th*	*M*
19	121.76	43.08	2.8	Ae	*Setaria viridis*	*Pantropic*	*Th*	*M*
20	121.35	43.07	3.3	Ae	*Echinochloa crusgalli*	*Pantropic*	*Th*	*M*
21	121.06	42.98	3.7	Ae	*Setaria viridis*	*Pantropic*	*Th*	*M*
22	121.84	43.32	2.8	Ae	*Echinochloa crusgalli*	*Pantropic*	*Th*	*M*
23	121.62	42.91	3	Ae	*Poa annua*	*World*	*Th*	*M*
24	121.73	42.92	2.9	Ae	*Leymus chinensis*	*World*	*Pn*	*M*
25	122.38	43.09	1.8	Ae	*Carex duriuscula*	*World*	*Pn*	*Mx*
26	122.66	43.37	2.4	Ae	*Carex duriuscula*	*World*	*Pn*	*Mx*
27	122.55	43.45	2.65	Ae	*Setaria viridis*	*Pantropic*	*Th*	*M*
28	122.72	43.59	2.2	Ae	*Corispermum hyssopifolium*	-	*Pn*	*X*
29	122.99	43.52	1.6	Ae	*Setaria viridis*	*Pantropic*	*Th*	*M*
30	123.18	43.80	1.38	Ae	*Setaria viridis*	*Pantropic*	*Th*	*M*
31	121.32	43.58	3.4	Fl	*Setaria viridis*	*Pantropic*	*Th*	*M*
32	120.77	43.64	> 4	Ca	*Artemisia frigida Willd*	*North temperate zone*	*Pn*	*X*

GD: groundwater (unit: m); ST: soil type; Ca: castanozems; Fl: fluvo-aquic soils; Ae: aeolian soil; -: not available; Th: Therophyte; Pn: Perennial; M: Mcsophyte; Mx: Mcso-xerophyte; X: Xerophyte

Geographical elements of herbaceous plant

Based on the previous studies and the vegetation survey results, the geographical elements of the dominant herbaceous plants were World, Eastern Asia and variations, Central Asia - Mongolia, Pantropic, Old World and North Temperate in the study area (*Table 1*).

Relationship between GD and herbaceous plant

Ecological niche is a concept in ecology that describes how a species responds to the distribution of resources and competitors. Niche breadth represents the sum of a variety of different resources utilized by a species. Through field investigation and laboratory data collation, important value proportion and niche breadth of each survey point dominant species were analyzed corresponding to the different groundwater tables.

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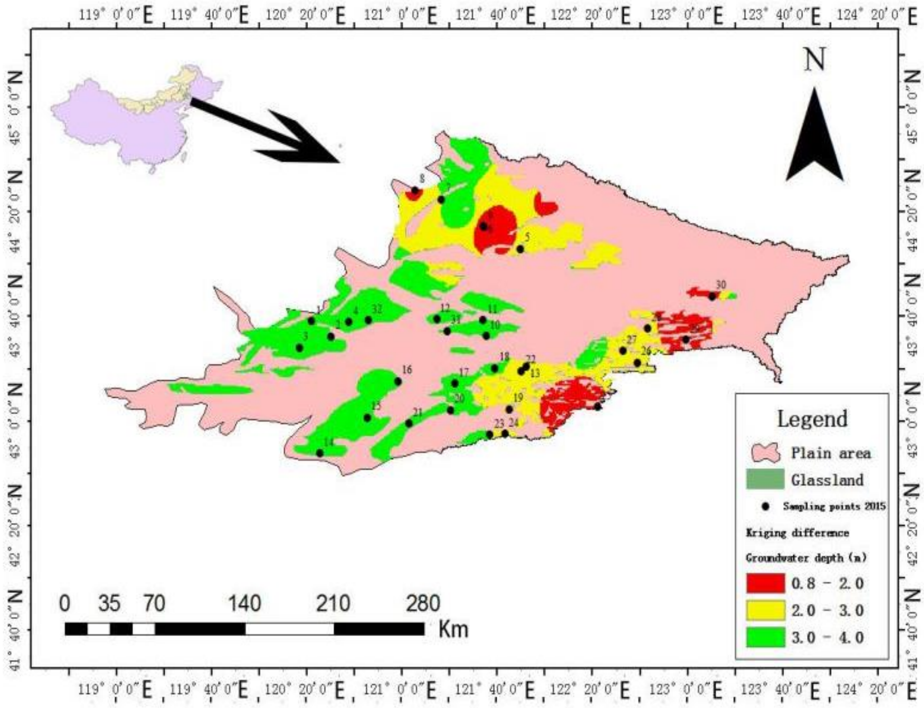

Figure 1. *Field survey sites and groundwater depth contour*

The data in *Table 2* shows that, in the direction of increasing depth gradient, corresponding vegetation types changed with slight difference. There are five dominant vegetation species at the depth of 1~2 m. Their importance value ratio and niche breadth were lower, indicating that the depth range is not suitable for the growth of these species; eight types of vegetation were found at about 2~3 m and > 4 m respectively. *Chloris virgata. Leymus chinensis and Artemisia frigida Willd* appear concentrated with the higher value of the proportion and niche breadth. At the depth of 2~3 m, vegetation species decreased, but the proportion of importance value and niche breadth increased.

Table 2*. Proportion and niche breadth of each species corresponded to TP*

Species	**Groundwater depth (m)**			
	1~2	**2~3**	**3~4**	**> 4**
Poa annua	0 (0)	0 (0)	0.47 (0.04)	0.53 (0.06)
Artemisia campbellii	0 (0)	0.18 (0.006)	0.26 (0.01)	0.56 (0.06)
Artemisia pubescens	0.09 (0.002)	0.06 (0.0007)	0.6 (0.07)	0.25 (0.01)
Chloris virgata	0 (0)	1 (0.2)	0 (0)	0 (0)
Corispermum hyssopifolium	0.25 (0.01)	0.15 (0.005)	0.45 (0.04)	0.15 (0.005)
Suaeda glauca	0.23 (0.01)	0.27 (0.01)	0.23 (0.01)	0.27 (0.01)
Carex duriuscula	0.5 (0.05)	0.5 (0.05)	0 (0)	0 (0)
Setaira Viridis	0.22 (0.01)	0.21 (0.009)	0.36 (0.03)	0.21 (0.009)
Echinochloa crusgalli	0 (0)	0.23 (0.01)	0.4 (0.03)	0.37 (0.03)
Leymus chinensis	0 (0)	1 (0.2)	0 (0)	0 (0)
Artemisia frigida Willd.	0 (0)	0 (0)	0 (0)	1 (0.2)

(): niche breadth

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The value of the *Artemisia campbellii*, *Artemisia pubescens*, *Corispermum hyssopifolium*, *Setaira Viridis* and *Echinochloa crusgalli* significantly increased, indicating that they were the main vegetation community composition in this depth. *Softwood Artemisia*, *Corispermum hyssopifolium* and *Suaeda glauca* were widely distributed ranging from 1~4 m, the proportion of importance value and niche breadth were relatively balance.

The same dominant vegetation at the different GD, the proportion and niche breadth are different, which indicates that the growth and distribution of vegetation are affected by groundwater. The proportion and niche breadth of different dominant vegetation at the different GD were different too, which suggests there are differences in the utilization degree of water resources by different species. However, under the same groundwater level, some dominant species vegetation with the same characteristics had similar proportion and niche, which indicated that the same species had similar adaptation strategies to groundwater or have a similar competition on demand for groundwater.

Variation of herbaceous vegetation cover and biomass

Through correlation analysis, the correlation coefficients between GD and vegetation characteristics below 0.5 only very weak. However, the correlation coefficients between GD and biomass and vegetation coverage were significant at the 0.05 level (2-tailed), which meant that the GD has the most significant effects on the plant communities.

To further understand the relationship between them, we analyzed vegetation characteristics of survey sites to different depth gradient. Wet weight, biomass and vegetation coverage of survey sites increased first, and then decreased with the rising of GD; It shows that the groundwater has a certain influence on them (*Fig. 2*). Ranging from 1.4~2.4 m, these indexes that highlight rising trends with the coefficient of variation were 0.24, 0.45 and 0.32. There was a rapid decrease in these indexes at the depth of 2.65~3.4 m. In addition, the maximum value of the coefficient of variation of the three were 0.62, 0.75 and 0.44. At the same time, the dominant species vegetation, *Leymuschinensi* and *Artemisiapubescens*, which have lower value of each index was mostly the perennial at the depth of 2.9 m and 3.3 m. However, the dominant species vegetation, *Chloris virgata* and *Echinochloa crusgalli*, which have higher value of each index is mostly the annual at the depth of 2.8 m and 3.0 m. Every index continues the downward trend at the depth of 3.4~ > 4 m with the value of 0.62, 0.59 and 0.31. The trend line shows that the depth of about 3.4 m was the evolution of vegetation transition zone, which became elevated by the reduced. With the increase of depth gradient, the dominant species of survey sites evolved from the mesophytes to the xerophytes. Although each index declines overall, the individual differences in levels of groundwater, it suggests that different depth of groundwater has different influence on vegetation.

Herbaceous vegetation ecological variation

Based on the average GD data of field survey of 32 points and dominant species vegetation ecological values of survey sites, the correlation coefficient calculated. The results showed that the plant ecotypes and GD were significantly correlated. To a certain extent, GD determines the type of plant ecological distribution (*Fig. 3*). By superimposing dominant species vegetation and the corresponding GD of each survey

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point, the quantitative relationship was revealed. The ecotype of dominant vegetation, such as mesophytes, meso-xerophytes and xerophytes correspond to a depth range, namely 1.38~3.43 m, 1.4~3.45 m and 2.40~ > 4.00 m. Only the planting of mesophytes and meso-xerophytes dominant species exist in the GD of 1~2 m; they have significant depth transition phase. Only the dominant species planting of xerophytes coexist in the GD of more than 3.5 m. In the 2.65~3.43 m, mesophytes appeared more concentrated. Meso-xerophytes rooted in uniform distribution ranging from 1.4~3.45 m. Because the distribution of dominant species vegetation was increasing, the depth at about 3.4 m would be the evolution of vegetation transition zone.

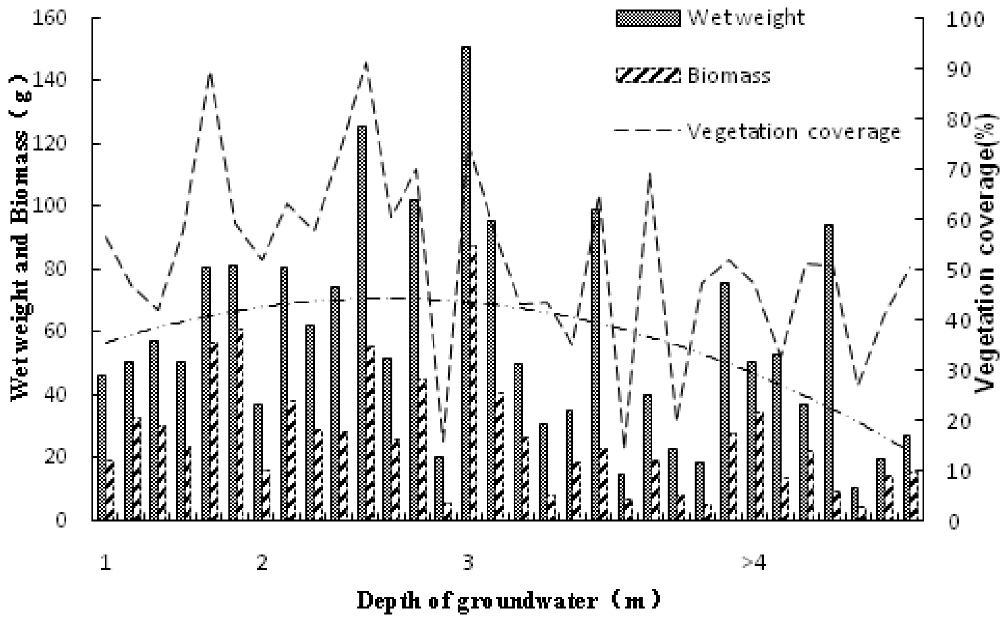

Figure 2. *Vegetation characteristics of survey sites to different depth gradient*

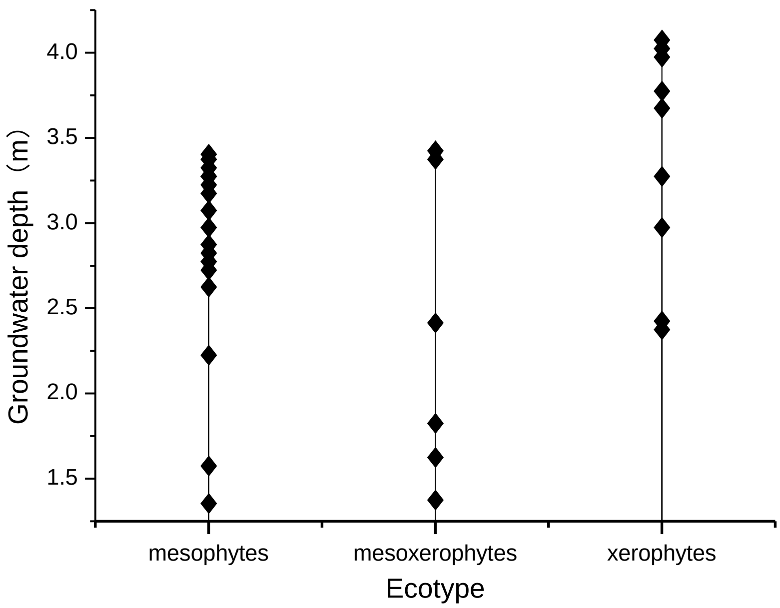

Figure 3*. Dominant species pattern distribution with groundwater level*

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Variation of species diversity index

Through field investigation and laboratory data collation, the distributions of each diversity index were analyzed following the direction of depth gradient, in order to study the internal correlation between GD and herbaceous vegetation species diversity (*Fig. 4*).

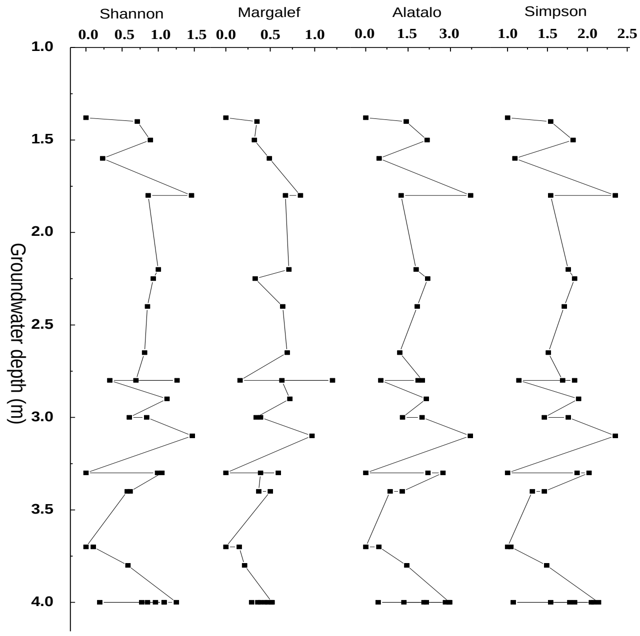

Figure 4. *The result of diversity ordination to different depth gradient*

At depth ranging 1.8~2.4 m, species diversity was relatively stable, means were 0.91, 0.59, 1.76 and 1.71, expressed as per survey quadrate vegetation types ranged from 2-6 species. As the depth gradient increases, at depth ranging about 2.65~3.4 m, the diversity index fluctuated frequently, the various diversity index means were 0.82, 0.54, 1.74 and 1.67; at depth ranging 3.4~ > 4 m, diversity index showed slight fluctuations, means were 0.67, 0.35, 1.59 and 1.58, expressed as per survey quadrats vegetation types ranging from 1-5 species. With the increase of depth, the diversity index value of vegetation species fluctuated, about 1.8~2.4 m > 2.65~3.4 m > 3.4~4 m > 1.4~1.8 m. With the increase of depth, all index increased firstly, then decreased, generally in the 1.8~2.4 m up to the maximum. The values of Margalef, Shannon-Wiener and Simpson index at the 1.8~2.4 m were slightly higher than the values at other depths, while the Alatalo index value is 2.56 ~3.4 m below the value of 1.8~2.4 m. The smallest variation is the Magalef index, and the maximum variation range is Alatolo index. The result suggests that the most suitable depth of groundwater for plant growth in the region is 1.8~3.4 m, after as the underground water level decline gradually, the diversity of the species evenness and abundance emerged decline trend. The relationships between species diversity index and groundwater revealed that with the increase of depth gradient, the diversity index value of vegetation species fluctuated, closely related with each other.

Based on the four indexes, most scholars have studied the relationship between them and vegetation, climate, groundwater, soil water and so on. Most predecessors considered that, as the depth increases, the diversity of vegetation shows an obvious

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decreasing trend. However, because of the complexity of the natural ecosystem and the actual situation of the local pastoral transitional zone, the diversity of vegetation at the depth of the transition zone was deeply influenced.

Discussion

In arid and semiarid regions, herbaceous vegetation is among the most important ecosystem components. Each vegetation is also very sensitive to environmental factors, so it is necessary to reveal the basis (Chauhan and Johnson, 2008) for the evolution of groundwater on vegetation. In arid and semiarid regions, the evolution of herbaceous vegetation will be affected in addition to precipitation and temperature, may also be affected by other environmental factors (Tao et al., 2017). TP is a typical semi-arid region where the ecological environment is fragile. Between groundwater and the characteristics of herbaceous vegetation, there obviously will be some intrinsic link.

Groundwater-Dependent Ecological systems (GDEs) refers to the survival and development of vegetation ecosystem which depends on groundwater systems. GDEs belongs to interdisciplinary. For now, it is not very clear on the relationship between the groundwater system and vegetation ecosystem; there are full of challenges and opportunities in this area. Deeper GDEs (Kløve et al., 2011; Zhu et al., 2012) have been divided into three categories according to the exposed conditions. On the basis of previous studies, domestic scholars also have made a lot of research and field investigation on the relationship between vegetation ecosystems in large areas and groundwater systems.

This paper will determine GD at about 3.4 m to divide completely dependent and semi-dependent GDEs basis: Completely dependent GDEs is at 2.65~3.4 m of the GD, mainly refers to the vegetation ecosystem which relies on capillary action to recharge in semi-arid zones; semi-dependent GDEs is at 1.4~2.4 m of the GD, mainly refers to the vegetation ecosystem which not only relies on irrigation, precipitation or river bank to recharge but also relies on groundwater; completely independent GDEs is at 3.4~ > 4 m of the GD, mainly refers to the vegetation ecosystem which does not rely on groundwater. According to available data, with the increase of depth, vegetation coverage, wet weight and biomass, their segmentation coefficient of variation have a significant difference; they have fluctuated downward trend, which reveals: (1) the dominant vegetation evolved from the annual shallow-rooted vegetation to the perennial deep rooted vegetation; (2) Differences in surface characteristics of completely dependent, semi-dependent and completely independent GDEs vegetation are significant, which also shows that in addition to the impact of groundwater, the herbaceous vegetation is also affected by the multiple effects of precipitation (Sneva,1982), topography (Hardin and Wistendahl, 1983), man-made and other factors; within the range of groundwater, importance value proportion of the value and diversity index shows the trend of different frequency fluctuations, namely the increasing direction along the depth gradient, showing Mesozoic - in xerophytic - xerophytic vegetation types, quantity and life - form evolution trend. This article was also based on the frequency of appearance and niche theory of dominant species survey sites, using niche breadth and other indicators, analyzed the degree of utilization of herbaceous vegetation on water resources in the study area, obtained niche breadth of a variety of dominant species at different depth gradient. It shows that *Artemisia*, *Echinochloa crusgalli* and *Setairaviridis* constitute a more dominant community of survey sites, and

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can be widely distributed. The overall survey sites niche breadth of dominant species was small, and it also shows that the degree of utilization of water resources is not high; they may be affected by other factors. The evolution of the transition range of herbaceous vegetation in the study area is at about 3.4 m. In this range of more than 3.4 m, a variety of species diversity indexes decreased significantly, proportion and niche breadth were obviously shrunk, vegetation coverage wet weight and biomass firstly decreased.

Conclusions

This paper has attempted to recognize the groundwater as the key factors affecting the activity and distribution of vegetation. The topic is perhaps too obvious, but born under the perspective to explore the pattern of vegetation characteristics under groundwater change conditions in TP. Through correlation analysis, there is a certain relationship between them groundwater and characteristics of vegetation. Following the change of GD, the trend of vegetation characteristics is increasing first, and then decreasing. Different ecotype of dominant vegetation corresponds to different depth of groundwater. Mesophytes, meso-xerophytes and xerophytes have their own depth transition zone which are 1.38~3.43 m, 1.4~3.45 m and 2.4~ > 4 m. The important value proportion, niche breadth and each species diversity index of dominant herbaceous vegetation in each survey point have apparent indication. There is obvious intrinsic link between them and GD. When the groundwater is too shallow, the growth of the height, crown and so on of the herbaceous plants will be inhibited, because the surface due to evaporation and the accumulation of much salt limits the growth of herbs. Our results also suggest that the evolution of the transition range of herbaceous vegetation in TP is at about 3.4 m.

It is well known that groundwater has a significant effect on regional vegetation growth and distribution. Scarcity of water resources, great changes of the groundwater extraction volume and depth are some of the main factors in the evolution of natural vegetation in TP. Because vegetation growth and distribution are affected by many factors, such as climate, grazing and soil, how to determine the impact of groundwater change on vegetation growth and distribution is very important. However, we lack more adequate information and method on the relationship between grassland community characteristics and GD. The depth of groundwater in this study is less than 4.0 m, and whether it still has a good correlation still needs to be further studied under the condition of more than 4.0 m? Moreover, how to determine the water source of natural herbaceous vegetation in agropastoral ecotone in semi-arid region?

Further work needs to be done to determination of critical area of groundwater and water source for different vegetation evolution. Additionally, relationships between GD and vegetation characteristics need to be investigated at high spatial and temporal resolutions.

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