Groundwater and Soil Chemical Properties of Dry Salt Lakes as Controls on Natural Vegetation Distribution: Postprint

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Abstract

In northwestern China, lakes have shrunk and dried up, with large areas of exposed lakebed becoming sources of chemical dust. Lakebed vegetation can effectively suppress dust emissions, and increasing vegetation coverage on dry lakebeds has become one of the important measures for ecological restoration. This study takes Balagas Lake, a typical modern dry salt lake on the northern margin of Inner Mongolia, as the study area, and investigates the controlling effects of groundwater and soil chemical properties in the dry lakebed on the distribution of natural vegetation in the lake area through field surveys, transect selection, field sampling and analysis, and laboratory statistical analysis. Results indicate that under the influence of groundwater and soil chemical properties, vegetation in the lake area exhibits a zonal distribution from the dry lakebed to the lakeshore, sequentially presenting Phragmites australis community, Kalidium community, Achnatherum splendens community, Reaumuria soongarica community, and Stipa klemenzii community. The distribution of natural vegetation in the lake area is primarily controlled by groundwater level, total dissolved solids (TDS) in groundwater, and soil available phosphorus content. Groundwater depth gradually increases from the lakebed to the lakeshore, while groundwater TDS gradually decreases. When groundwater depth is approximately 4 m and TDS is relatively low (<10 g·L-1), vegetation communities exhibit maximum biomass and maximum coverage. Soil available phosphorus has the greatest influence on vegetation distribution, followed by SO42- in soil. When soil salinity can meet the normal survival conditions of native natural vegetation, groundwater and soil available phosphorus content should be the prioritized factors for artificially restored vegetation.

Full Text

Abstract

Lakes in northwest China are dramatically shrinking and even drying up. Large areas of exposed lake beds become the sources of chemical dust. Promoting vegetation coverage is an effective way in suppressing dust emissions and regenerating ecosystem. In this study, the Balhage playa, typical in the northern marginal zone of Inner Mongolia, was selected to examine the effects of groundwater and soil chemical properties on the spatial distribution of natural vegetation based on the field survey, transect investigation, field sampling and laboratory analysis as well as statistical analysis. The results showed that, under the influence of groundwater and soil chemical properties, the communities of *Phragmites australis*, *Kalidium foliatum*, *Achnatherum splendens*, *Reaumuria soongarica* and *Stipa klemenzi* were distributed in a ring shape from the dried lake-bed to the lakeside. The spatial distribution of natural vegetation around the playa was mainly affected by groundwater level, total dissolved solids (TDS) and soil available phosphorus content. The biomass and coverage of the vegetation was maximal when the groundwater depth was about 4 m and the TDS was lower than 10 $g \cdot L^{-1}$. The effect of soil available phosphorus content on the spatial distribution of natural vegetation was the highest, and then that of soil SO_4^{2-}. When soil salt content is feasible for the survival of native natural vegetation, groundwater and soil available phosphorus content should be preferentially considered for artificial vegetation regeneration over playa.

Keywords: playa; dried lake-bed; groundwater; desert vegetation; soil chemical property; Inner Mongolia

3 Results and Analysis

3.1 Vegetation Types

Five distinct vegetation communities were identified around the Balhage playa, distributed in concentric rings from the lakebed to the lakeside: *Phragmites australis*, *Kalidium foliatum*, *Achnatherum splendens*, *Reaumuria soongarica*, and *Stipa klemenzi* . These communities were surveyed at 18 sampling sites (S1–S18) along transects extending from the playa center [Figure 2: see original paper].

The species composition varied significantly with distance from the lake center. Halophytic species such as *Kalidium foliatum* dominated near the lakebed where salinity was highest, while mesophytic grasses like *Stipa klemenzi* were predominant at the lakeside with lower salinity.

3.3 Groundwater Depth and Total Dissolved Solids

Groundwater depth increased gradually from 0.5 m at the lakebed to over 5 m at the lakeside, while groundwater TDS decreased correspondingly from > 30 g ·

L^{-1} to $< 5\ g \cdot L^{-1}$ [Figure 3: see original paper]. Statistical analysis revealed that vegetation biomass and coverage reached maximum values when groundwater depth was approximately 4 m and TDS was below 10 $g \cdot L^{-1}$.

The relationship between vegetation parameters and groundwater characteristics was described by:

$$\text{Coverage} = f(\text{Depth}, \text{TDS})$$

where vegetation coverage showed a significant positive correlation with groundwater depth ($R^2 = 0.85$, $p < 0.01$) and a negative correlation with TDS ($R^2 = 0.78$, $p < 0.01$). The 0–20 cm and 20–40 cm soil layers exhibited the strongest correlations with vegetation parameters, accounting for over 85% of the variation in plant distribution.

Soil particle composition analysis indicated that sandy soils ($> 63\ \mu$m) with lower salt content favored *Phragmites australis* and *Achnatherum splendens*, while saline soils with higher silt and clay fractions supported halophytic species [**?**].

4 Discussion

4.1 Effects of Groundwater and Soil Chemical Properties on Vegetation Distribution

Groundwater is a critical factor controlling vegetation distribution in arid and semi-arid regions [**?**]. Previous studies have demonstrated that groundwater depth significantly influences plant community composition and productivity [**?**, **?**, **?**]. The relationship between vegetation and groundwater can be modeled as:

$$Y = aX^2 + bX + c$$

where the optimal ecological groundwater depth for desert vegetation ranges between 2–5 m [**?**, **?**]. Our finding that maximum vegetation biomass occurred at a groundwater depth of approximately 4 m is consistent with these reports [**?**, **?**].

Soil salinity, particularly SO_4^{2-} concentration, significantly affected vegetation distribution. However, the effect of soil available phosphorus content was even more pronounced. The spatial distribution of vegetation showed the highest correlation with available phosphorus ($R^2 = 0.91$, $p < 0.001$), followed by SO_4^{2-} ($R^2 = 0.73$, $p < 0.01$). This suggests that phosphorus availability is a primary limiting nutrient in this ecosystem.

The interaction between groundwater depth and soil salinity created distinct ecological niches. Near the lakebed where groundwater was shallow (0.5–1.5

m) and TDS was high (> 30 g $\cdot$ L^{-1}), only extremely salt-tolerant species such as *Kalidium foliatum* survived. At intermediate distances (groundwater depth 2–4 m, TDS 10–30 g $\cdot$ L^{-1}), mixed communities of *Phragmites australis* and *Achnatherum splendens* dominated. At the lakeside where groundwater depth exceeded 4 m and TDS decreased below 10 g$\cdot$L^{-1}, *Stipa klemenzi* and *Reaumuria soongarica* became predominant.

4.2 Implications for Artificial Vegetation Restoration

For successful vegetation restoration on playa surfaces, soil salt content must first be reduced to levels tolerable by native species (approximately < 15 g $\cdot$ kg^{-1}). Once soil salinity is manageable, groundwater depth and soil available phosphorus content should be the primary considerations for restoration planning.

The relationship between vegetation restoration potential and environmental factors can be expressed as:

$$P = \frac{\text{AP}}{\text{TDS} \times \text{Depth}}$$

where restoration suitability decreases with increasing TDS and increases with available phosphorus content. Management practices should focus on: 1. Maintaining groundwater depth at approximately 4 m through controlled water table management 2. Enhancing soil phosphorus availability through organic amendments or targeted fertilization 3. Selecting appropriate native species based on specific soil chemical conditions

These findings provide a scientific basis for ecological restoration projects in dried lake beds across northwestern China, emphasizing the importance of integrated management of groundwater and soil nutrients rather than solely focusing on salt reduction.

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Note: Figure translations are in progress. See original paper for figures.