Postprint: Analysis of Salinity and Halophytic Vegetation Diversity in Uncultivated Saline-Alkali Soils of the Junggar Basin, Xinjiang

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Abstract

This study investigated uncultivated saline-alkali soils in the Junggar Basin, Xinjiang, measuring soil salt content, pH, electrical conductivity, eight major ions, and other indicators. Multivariate statistics and principal component analysis (PCA) were employed to examine the distribution characteristics of saline-alkali soils and halophyte vegetation diversity in the sampling area. The results showed that: (1) The study area was dominated by sulfate-chloride saline soils and sulfate saline soils. Moderate and severe sulfate-chloride saline soils and sulfate saline soils were concentrated in chain-like or belt-like patterns in Changji Hui Autonomous Prefecture and Bortala Mongol Autonomous Prefecture. Soda saline soils and soda alkaline soils in Altay Prefecture exhibited spot-like distributions. (2) Changji Hui Autonomous Prefecture was dominated by euhalophyte vegetation, such as Haloxylon ammodendron and Petrosimonia sibirica; Bortala Mongol Autonomous Prefecture was dominated by salt-secreting vegetation, such as Reaumuria songarica and Alhagi sparsifolia. (3) Quadratic polynomials effectively expressed the relationship between soil salinity and vegetation diversity. The Shannon-Wiener index, Hurlbert index, and Pielou evenness index reached their maximum values when soil salt content was between 5–10 mg · g^{-1}; halophyte species were more abundant and more evenly distributed when pH was in the range of 8.4–9.2. (4) PCA analysis of halophyte dominant species and soil properties indicated that soil salinity was the key factor influencing the distribution of Reaumuria songarica, Haloxylon ammodendron, Salsola collina, and Tamarix chinensis, whereas Suaeda acuminata and Nitraria tangutorum were primarily affected by soil pH and ${CO_3}^{2-}$. This study provides a theoretical basis for the rational utilization of uncultivated land resources and ecological restoration.

Full Text

Analysis of Salinity and Halophytic Vegetation Diversity of Uncultivated Saline-Alkali Soil in the Junggar Basin, Xinjiang

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Abstract

This study investigated uncultivated saline-alkali soils in the Junggar Basin of Xinjiang, measuring soil salt content, pH, electrical conductivity, and eight major ions. Multivariate statistics and principal component analysis (PCA) were employed to examine the distribution characteristics of saline-alkali soils and halophytic vegetation diversity in the sampling area. The results revealed four key findings. First, the study area was dominated by sulfate-chloride and sulfate soils, with moderate to severe sulfate-chloride and sulfate soils distributed in chains or strips concentrated in Changji Hui Autonomous Prefecture and Bortala Mongol Autonomous Prefecture, while soda saline and soda-alkali soils in Altay Prefecture exhibited point distributions. Second, Changji Hui Autonomous Prefecture was dominated by true halophytes such as *Haloxylon ammodendron* and *Petrosimonia sibirica*, whereas Bortala Mongol Autonomous Prefecture featured salt-secreting vegetation like *Reaumuria songarica* and *Alhagi sparsifolia* as dominant species. Third, quadratic polynomial models effectively expressed the relationship between soil salinity and vegetation diversity, with halophytic species being more abundant and evenly distributed when soil salt content ranged from 5-10 mg · g^{-1}, where the Shannon-Wiener, Hurlbert, and Pielou evenness indices reached their maxima; species richness and evenness also peaked within a pH range of 8.4–9.2. Fourth, PCA analysis of dominant halophytic species and soil factors identified soil salinity as the key factor influencing the distribution of *Reaumuria songarica*, *Haloxylon ammodendron*, *Salsola collina*, and *Tamarix chinensis*, while *Suaeda acuminata* and *Nitraria tangutorum* were primarily affected by soil pH and ${CO_3}^{2-}$ content. These findings provide a theoretical basis for the rational utilization of uncultivated land resources and

ecological restoration efforts.

Keywords: uncultivated saline-alkali soil; salinity; halophytic vegetation diversity; Junggar Basin

1.1 Study Area Overview

The Junggar Basin in Xinjiang is situated between the Altai Mountains and Tianshan Mountains, extending from 82°07 52.6 -90°53 54.5 E and 44°07 17.6 -47°09 04.3 N, with terrain gradually decreasing from west to east. The region experiences substantial interannual precipitation variation and temperature fluctuations, with an average annual evaporation of 1828 mm far exceeding the average annual precipitation of 416 mm, characteristic of a typical temperate continental arid climate. Extensive salt accumulation occurs in the basin' s soils due to poor leaching, forming two major tectonic erosion depressions known as Lupotan and Yanchiwa. Halophytic vegetation is widely distributed throughout the sampling area, with shrubs and herbs such as *Tamarix chinensis*, *Haloxylon ammodendron*, *Reaumuria songarica*, and *Salsola collina* serving as dominant species, accompanied by *Phragmites australis* and *Seriphidium nitrosum*. The unique combination of topography, soil types (gray desert soil, aeolian sandy soil), and climatic conditions has created distinctive soil salinization phenomena in this region.

1.2 Sample Collection and Processing

This study selected natural, uncultivated, and undisturbed saline-alkali lands in the Junggar Basin, with sampling sites determined through field surveys. Based on administrative regions, soil samples were collected from four major areas in the basin: Changji Hui Autonomous Prefecture, Altay Prefecture, Tacheng City, and Bortala Mongol Autonomous Prefecture, totaling 49 sampling points (Fig. 1). At each point, soil samples were taken from two layers (0–20 cm and 20–40 cm), with 500 g collected per layer and three replicates per layer. Soil from each layer was thoroughly mixed, placed in sample bags, air-dried naturally, and cleared of plant and animal residues and stones before being ground and passed through a 2 mm sieve. Soil extracts were prepared at a 1:5 soil-to-water ratio for determination of eight major ions, pH, electrical conductivity, and salt content. Soil salt content was measured using a soil salinity analyzer (DDSJ-308A), pH was determined by potentiometry (TPY-16A), and the eight ions were analyzed as follows: K^+ and Na^+ by flame photometry, Ca^{2+} and Mg^{2+} by EDTA titration, ${CO_3}^{2-}$ and ${HCO_3}^-$ by double indicator titration, Cl^- by $AgNO_3$ titration, and ${SO_4}^{2-}$ by $BaSO_4$ turbidimetry, following the methods described in reference [21].

Plant surveys were conducted at the uncultivated saline-alkali soil sampling points by establishing 10 m$\times$10 m quadrats, with 49 quadrats set up in total. Within each quadrat, a 1 m$\times$1 m subplot was used to identify halophytic species, record individual plant numbers, and document environmental characteristics [22].

1.3 Analysis Methods for Soil Salinization

Based on the U.S. soil salinity classification system, saline-alkali soils were classified as saline when electrical conductivity (EC) exceeded 4 $dS \cdot m^{-1}$ and as alkaline when pH was below 8.5. Soil salinization levels were categorized as: non-salinized (<5 $mg \cdot g^{-1}$), lightly salinized (5–10 $mg \cdot g^{-1}$), moderately salinized (10–15 $mg \cdot g^{-1}$), and heavily salinized (15–20 $mg \cdot g^{-1}$). Soil types were further classified by ion composition: $Cl^-/SO_4^{2-} < 0.2$ indicated soda saline soil, 0.2–1.0 indicated sulfate soil, 1.0–4.0 indicated chloride-sulfate soil, and >4.0 indicated chloride soil. Soda-alkali and soda saline soils were distinguished by exchangeable sodium percentage (ESP): >5.0 indicated soda-alkali soil, while 1.0–5.0 indicated soda saline soil [23].

1.4 Analysis Methods for Halophytic Vegetation Diversity

Halophytic vegetation in the uncultivated saline-alkali soils of the Junggar Basin was identified based on literature records, with the selection criterion being species capable of growing in habitats with salt content exceeding 0.5%. Vegetation coverage was estimated visually as the ratio of the vertical projection area of aboveground plant parts to the quadrat area. Diversity indices were calculated as follows: the Shannon-Wiener index represents species richness, the Hurlbert index represents the probability of interspecific encounter (species diversity), and the Pielou evenness index reflects the distribution pattern of different species [24].

The formulas are: - Shannon-Wiener diversity index (H): H = - (ni/N)ln(ni/N) - Hurlbert diversity index (d): d = (N-1)/ln(N) - Pielou evenness index (J): J = H/ln(m)

where N is the total number of species surveyed, ni is the number of individuals of the ith species, and m is the number of species in the quadrat.

1.5 Data Processing and Statistical Analysis

Statistical analyses were performed using SPSS 21.0, sampling point distribution maps were created with ArcGIS 10.2, and figures were generated using Origin 8.0 and the "vegan" package in R-3.6.2.

2.1 Analysis of Ion Characteristics of Soil Salinization

Statistical analysis of soil salinity, pH, and base ions in the Junggar Basin is presented in Table 1. Soil salt content ranged from 0.12-64.36 $mg \cdot g^{-1}$, averaging 7.53 $mg \cdot g^{-1}$, indicating a salinization tendency. Soil pH ranged from 7.95–10.23, showing alkaline conditions. The average ion contents of Cl^- and SO_4^{2-} were significantly higher than other ions, confirming that chloride and sulfate soils dominate the study area. The coefficient of variation (CV) measures the dispersion of base ions: $CV \leq 0.1$ indicates weak variation, $0.1 < CV \leq 1.0$

indicates moderate variation, and CV > 1.0 indicates strong variation [25]. The pH showed small variation amplitude, while soil salinity and base ions exhibited uniform distribution across the study area, though soil salinity displayed obvious heterogeneity. Overall, soil salt content showed strong variation (CV > 1.0).

Comparing soil salt content and base ion characteristics across different soil layers (Table 2) revealed that the average contents of salt, pH, and the eight major ions were similar between the 0–20 cm and 20–40 cm layers. However, the average contents of salt, Cl^-, and ${SO_4}^{2-}$ in the 0–20 cm layer were higher than in the 20–40 cm layer, indicating surface enrichment of soil salts. Conversely, the average Ca^{2+} and Mg^{2+} contents were higher in the 20–40 cm layer. Correlation analysis (Tables 3 and 4) showed that in the 0–20 cm layer, soil salinity was significantly positively correlated with Cl^- and ${SO_4}^{2-}$, while in the 20–40 cm layer, soil salinity was positively correlated with Cl^- and ${SO_4}^{2-}$, non-significantly positively correlated with Ca^{2+} and Mg^{2+}, and negatively correlated with pH.

2.2 Distribution Characteristics of Soil Salinization

The classification of soil salinization degrees is illustrated in Fig. 2. Moderate and severe salinization accounted for large proportions of the sampling area at 34.5% and 26.5%, respectively, distributed in chains or strips across the Junggar Basin. Light salinization comprised 11.9% and exhibited point distributions. Overall, saline soils accounted for 92.9% of the area. The classification of saline-alkali soil types is shown in Fig. 3, with saline soils distributed in strips and alkali soils scattered in points throughout the basin. Classification based on anion proportions ($Cl^-/{SO_4}^{2-}$) indicated that sulfate-chloride and sulfate soils were predominant, with soda-alkali soils as secondary types.

Regional differences in soil mineral content created distinct distribution patterns of soil types. In Changji Hui Autonomous Prefecture and Bortala Mongol Autonomous Prefecture, where soil minerals were dominated by chlorides and sulfates, sulfate-chloride and sulfate soils were distributed in interlocking strips, primarily supporting true halophytes and salt-secreting plants. Soda-alkali and saline soils occurred as continuous patches in Changji Hui Autonomous Prefecture but as scattered spots in Tacheng City. Statistical analysis of soil type proportions (Fig. 3) revealed that Changji Hui Autonomous Prefecture had high proportions of sulfate-chloride soils (Fig. 3a), Bortala Mongol Autonomous Prefecture showed the highest proportion of sulfate soils (Fig. 3b), and Altay Prefecture had high proportions of soda-alkali soils (Fig. 3c).

2.3 Relationship Analysis Between Halophytic Vegetation and Soil Salinity, pH, and Base Ions

Vegetation survey results (Table 5) showed that dominant plant communities in the uncultivated saline-alkali soils of the Junggar Basin consisted mainly of annual and perennial herbs and small shrubs. Dominant shrub species included *Reaumuria songarica*, *Haloxylon ammodendron*, *Anabasis salsa*, *Halocnemum* *strobilaceum*, *Ajania fruticulosa*, and *Kalidium caspicum*, while dominant herb species comprised *Petrosimonia sibirica*, *Halogeton glomeratus*, *Salsola collina*, *Alhagi sparsifolia*, and *Seriphidium kaschgaricum*. As soil salinization degree intensified, species numbers in the Chenopodiaceae, Polygonaceae, and Tamaricaceae families increased, while Asteraceae species decreased.

Regional variations in soil mineral content influenced both soil type distribution and halophytic vegetation coverage, as vegetation type indirectly reflects soil salinity [26]. The relationship between soil salinization and halophytic vegetation coverage is depicted in Fig. 4. The average vegetation coverage in the Junggar Basin was 26.5%, dominated by true halophytes and salt-secreting plants. Correlation analysis between soil salinity, pH, base ion content, and halophytic vegetation diversity (Figs. 5 and 6) demonstrated that quadratic polynomial regression effectively expressed the relationship between halophytic vegetation and soil salinity. When soil salt content ranged from 5-10 $mg \cdot g^{-1}$, the Shannon-Wiener, Hurlbert, and Pielou evenness indices all reached maximum values. The Hurlbert index showed similar trends with soil salinity. Regression analysis revealed that halophytic vegetation richness and evenness in the Junggar Basin exhibited quadratic relationships with uncultivated saline-alkali soil salinity. Within the pH range of 8.4-9.2, halophytic species were relatively abundant and evenly distributed, though the correlation was not significant. The Shannon-Wiener and Hurlbert indices showed linear correlations with soil base ion content (Fig. 6), but no significant relationships with Ca^{2+} and Mg^{2+}.

3 Discussion

Tectonic movements formed the Junggar Basin, where arid climate, low precipitation, and enclosed topography have created unique salinization landscapes. Soil salts exhibited surface enrichment across different soil depths, and both soil salinity and base ions displayed spatial heterogeneity. The predominance of chloride-sulfate soils in Changji Hui Autonomous Prefecture aligns with findings from Wang et al. [27] on soil salinity characteristics in the Weigan River Oasis and Zhang et al. [28] on soil salinization in Qitai. In Altay Prefecture, the north-high-south-low terrain [29] facilitates downstream migration of soda-alkali soils from upstream areas, where they accumulate in chains on the soil surface.

Our results indicate that Chenopodiaceae species serve as the dominant constructive species in uncultivated saline-alkali soils of the Junggar Basin, with Chenopodiaceae species numbers increasing as soil salinity rises while Asteraceae species decline. This pattern resembles findings by Qian et al. [30] on desert vegetation coverage characteristics in marginal areas of the Junggar Basin and reflects long-term vegetation adaptation to saline-alkali environments. As soil salinity increases, halophytic vegetation shifts from salt-resistant (salt-excluding) to true halophyte (salt-accumulating) types. Species richness and evenness indices did not follow linear relationships with soil salinization degree but rather quadratic polynomial curves. Within the 5-10 $mg \cdot g^{-1}$ salinity range, Shannon-Wiener and Pielou evenness indices increased gradually, while species richness declined when salinity exceeded 10 mg · g^{-1}. This aligns with most studies suggesting that moderate saline habitat disturbance enhances plant diversity in desert ecosystems [30-31,14]. This phenomenon may occur because halophytic vegetation has an optimal salinity range for each habitat type; beyond this range, species abundance and diversity decrease. Additionally, interspecific competition and community retrogressive succession contribute to reduced diversity [32]. From a pH perspective, uncultivated saline-alkali soils showed a U-shaped correlation with vegetation community diversity, though not significant, indicating that pH is not a direct factor affecting species richness and diversity but may indirectly influence plant life forms and constructive species through other soil indicators (nutrients, salinity, moisture) [33]. PCA analysis of dominant halophytic species and soil factors confirmed that soil salinity and ${CO_3}^{2-}$ are the primary factors influencing the distribution of dominant species in uncultivated salinized landscapes. Similar conclusions were reached in studies on the relationship between plant community diversity and soil factors in Fukang desert areas, plant diversity in Heihe wetlands in arid and semi-arid regions, and spatial heterogeneity of non-agricultural saline-alkali lands in the Manas River Basin in Xinjiang, all identifying soil salinity and pH as key factors affecting desert landscape vegetation diversity [15,31,34].

4 Conclusions

As a reserve land resource, uncultivated saline-alkali soils in the Junggar Basin were studied to characterize their spatial distribution and halophytic vegetation coverage, yielding the following conclusions:

1. The uncultivated saline-alkali soils of the Junggar Basin exhibited average ion contents in the order ${SO_4}^{2-} > Cl^-$, with sulfate-chloride and soda-alkali soils accounting for 46.9% and 26.5% of the area, respectively. Changji Hui Autonomous Prefecture featured sulfate-chloride soils, Bortala Mongol Autonomous Prefecture was dominated by sulfate soils, and soda-alkali soils were distributed throughout the entire sampling area.

2. Halophytic species such as *Haloxylon ammodendron*, *Tamarix chinensis*, *Reaumuria songarica*, and *Salsola collina* were widely distributed in Changji Hui Autonomous Prefecture. Bortala Mongol Autonomous Prefecture was dominated by *Reaumuria songarica* and *Alhagi sparsifolia*, while Altay Prefecture featured salt-alkali tolerant *Seriphidium kaschgaricum* as the dominant species. In Tacheng City, the dominant halophytes were *Nitraria tangutorum* and *Achnatherum splendens*.

3. Within the uncultivated saline-alkali soil landscape of the Junggar Basin, soil salinity and halophytic vegetation diversity exhibited a quadratic curve relationship, while vegetation richness showed a U-shaped correlation with soil salinity.

References

[6] Wang J, Ding J, Abulimiti A, et al. Quantitative estimation of soil salinity by means of different modeling methods and visible infrared (VIS NIR) spectroscopy, Ebinur Lake Wetland, northwest China[J]. PeerJ, 2018, 6: e4703, doi: 10.7717/peerj.4703.

[8] Acosta J A, Faz A, Jansen B, et al. Assessment of salinity status in intensively cultivated soils under semiarid climate, Murcia, SE Spain[J]. Journal of Arid Environments, 2011, 75(11): 1056-1066.

[11] Zhao Yong, Abuduwaili J, Yimit H. The occurrence, sources and spatial characteristics of soil salt and assessment of soil salinization risk in Yanqi Basin, northwest China[J]. PloS One, 2014, 9(9): e106079, doi: 10.1371/journal.pone.0106079.

[15] Zhao S, Liu J J, Banerjee S, et al. Soil pH is equally important as salinity in shaping bacterial communities in saline soils under halophytic vegetation[J]. Scientific Reports, 2018, 8(1): 4550-4561.

[16] Zhao Xuan, Hao Qili, Sun Yingying. Spatial heterogeneity of soil salinization and its influencing factors in the typical region of the Mu Us Desert Loess Plateau transitional zone, northwest China[J]. Chinese Journal of Applied Ecology, 2017, 28(6): 1761-1768.

[21] Bao Shidan. Methods of soil agricultural chemical analysis[M]. Beijing: China Agricultural Science and Technology Press, 2000: 20-23.

[22] Zhang Linjing, Yue Ming, Gu Fengxue, et al. Coupling relationship between plant communities species diversity and soil factors in ecotone between desert and oasis in Fukang, Xinjiang[J]. Chinese Journal of Applied Ecology, 2002, 13(6): 658-662.

[23] Xi Jinbiao, Zhang Fusuo, Mao Daru, et al. Species diversity and distribution of halophytic vegetation in Xinjiang[J]. Scientia Silvae Sinicae, 2006, 42(10): 6-12.

[24] Zhang Xueni, Lü Guanghui, Yang Xiaodong, et al. Responses of desert plant diversity, community and interspecific association to soil salinity gradient[J]. Acta Ecologica Sinica, 2013, 33(18): 5714-5722.

[25] Musa Asigul, Abliz Abdulla, Halik Wahap, et al. Spatial heterogeneity of soil salinity, pH and base cations in Keriya Oasis of Xinjiang[J]. Soils, 2017, 49(5): 1007-1014.

[26] Wang Panpan, Li Yanhong, Zhang Xiaomeng. Responses of plant diversity changes in the wetland of Lake Ebinur to salinity environment gradient[J]. Ecology and Environmental Sciences, 2015, 24(1): 29-33.

[27] Wang Dandan, Yu Zhitong, Cheng Meng, et al. Characteristics of soil salinity under different land use types in Weigan River Oasis[J]. Arid Land Geogra-

phy, 2018, 41(2): 349-357.

[28] Zhang Fang. Characteristics of soil salinization and remote sensing monitoring in Qitai Oasis, Xinjiang[D]. Urumqi: Xinjiang University, 2011.

[29] Dawutikhan Yerbori, Tiegs Nurjiang. Analysis of climatic conditions and variation characteristics of precipitation in Altay region[J]. The Farmers Consultant, 2019(7): 166.

[30] Qian Yibing, Zhang Liyun, Wu Zhaoning, et al. Characteristics of eco-environment in the margin regions of the Junggar Basin, Xinjiang[J]. Arid Land Geography, 2003, 26(1): 30-36.

[31] Zhao Xiaoying, He Xuemin, Yang Xiaodong, et al. Effects of soil moisture and salt on desert plant biodiversity in Ebinur Lake Basin of Xinjiang, China[J]. Journal of Arid Land Resources and Environment, 2017, 31(6): 76-82.

[32] Zhu Hongwei, Xia Jun, Cao Guodong, et al. Dynamic change of soil salinity in salinization abandoned farm land and affecting factors[J]. Soils, 2013, 45(2): 339-345.

[33] Wu Hao, Ma Xinxin, Xiao Nannan, et al. Effects of soil physical properties on morphological traits of constructive trees and species diversity of pine oak mixed forest in Qinling Mountains[J]. Soils, 2020, 52(5): 1068-1075.

[34] Zhao Min, Zhao Ruifeng, Zhang Lihua, et al. Plant diversity and its relationship with soil factors in the middle reaches of the Heihe River based on the soil salinity gradient[J]. Acta Ecologica Sinica, 2019, 39(11): 4116-4126.

Figures

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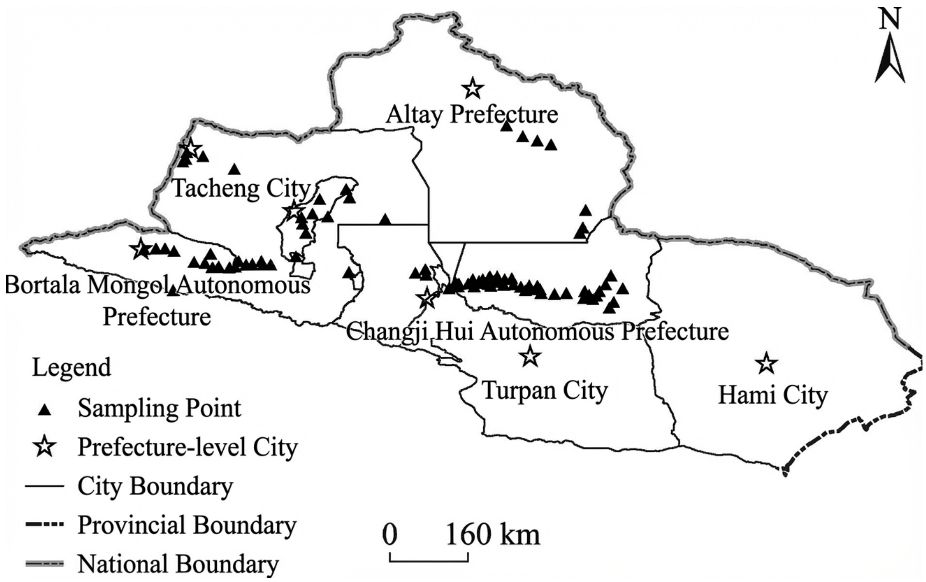
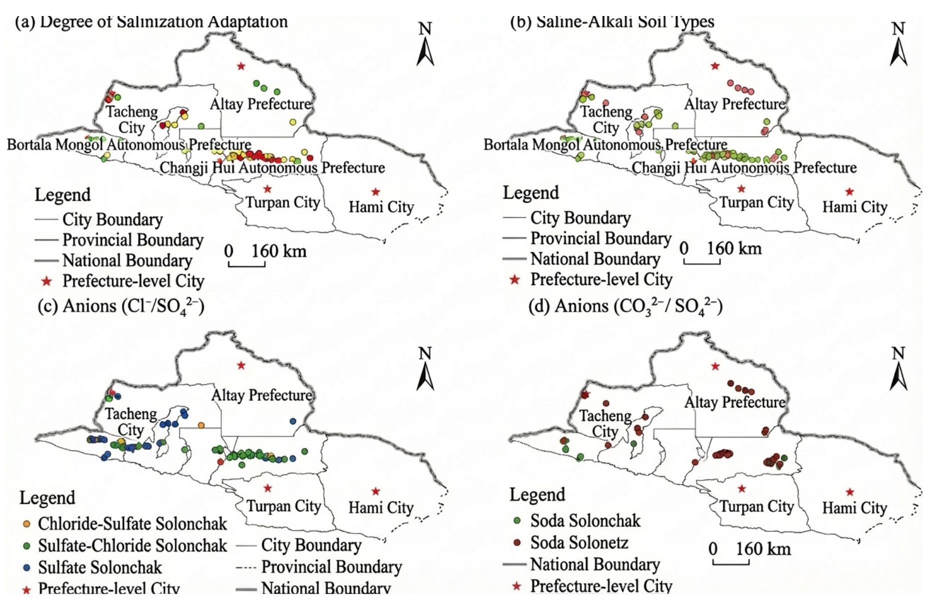


Figure 1: Figure 1



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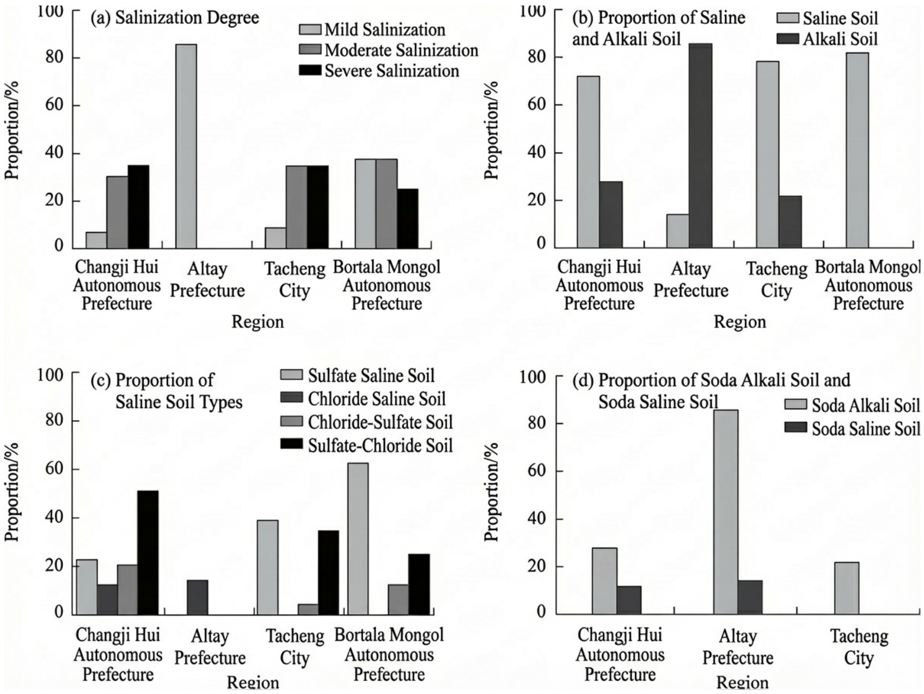

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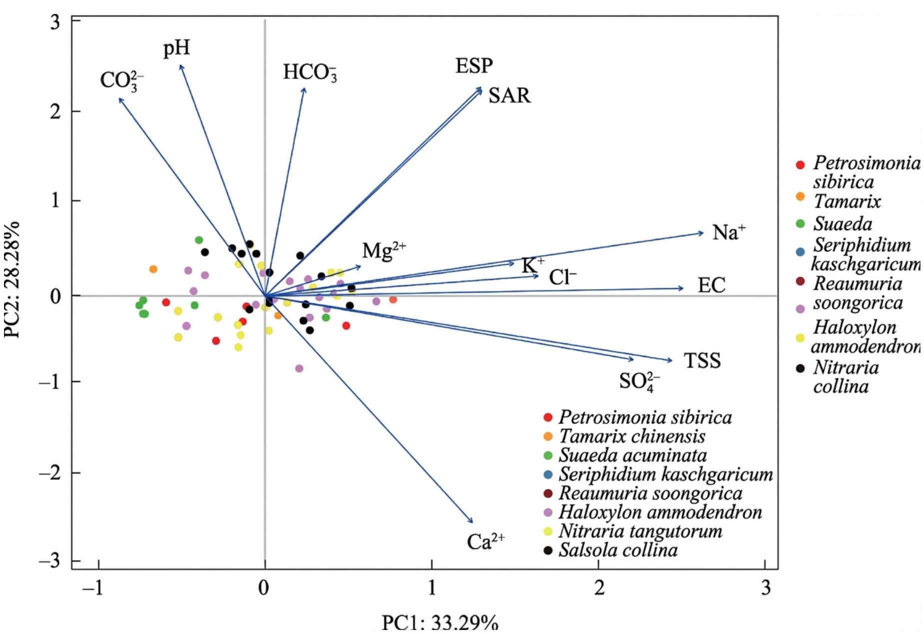

Figure 4: Figure 7