Analysis of Soil Pysical and Chemical Properties in Liangucheng National Reserve in Minqin, China

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Abstract. This study aimed to explore the basic characteristics of soil and improve the natural environment in arid desert areas. The study was conducted in the Liangucheng National Reserve in Minqin, Gansu, and SPSS, EXCEL and GIS software was used to analyze and process data. The semivariogram model and Kriging interpolation method were used to analyze the basic characteristics, mutual relationships, and spatial distribution patterns of the primary physical and chemical properties of the soil in the reserve, including the soil moisture content, conductivity, pH, organic matter, nitrogen, phosphorus, and potassium. The results show that the soil conditions in the reserve are poor, with low water content and nutrient content. The soil characteristics were correlated and were not substantially affected by soil pH and electrical conductivity. Additionally, the measured soil elements had a unique spatial distribution pattern and similarities in their spatial distribution patterns. The spatial correlation between total soil phosphorus and pH was strongest, and the northern part of the reserve, especially near Qingtu Lake, had the best soil conditions, and the central area had the worst soil conditions.

Keywords: Soil physical and chemical properties; geostatistical analysis; spatial distribution pattern; soil conditions; Liangucheng National Reserve.

1. Introduction

Land desertification is one of the ten major environmental problems currently facing humanity[1,2]. Desert ecosystems are distributed in arid areas with very few animals and plants, and the ecological environment is extremely fragile. There are 5.17 × 107 km2 of arid and semi-arid lands worldwide, of which 3.62 × 107 km2 of this land is threatened by desertification, accounting for about a quarter of the land area[3,4] . In China, 27% (2.61 × 106 km2) of the land area has been subjected to desertification. The degradation of the desert ecosystem has become one of the primary ecological and environmental problems in western China, threatening economic and social development.

Soil is an essential component of the earth's surface, and it provides a medium, nutrients, and water for plant growth. Studying soil characteristics can help us better understand the soil environment and improve the environment in a targeted manner. This study used soil moisture content (SMC), soil electrical conductivity (SEC), pH, organic matter (OM), total nitrogen (TN), ammonium nitrogen (NH4+-N), nitrate nitrogen (NO3−-N), total phosphorus (TP), available phosphorus (AP), total potassium (TK), and available potassium (AK) as soil indicators to illustrate soil conditions. Among these, soil solution conductivity can indicate the soil salt content (SSC), which is an important chemical property and soil indicator. OM comprises a small proportion of soil, but it has a substantial influence on soil fertility: soil fertility and OM content are positively correlated within a certain range when other conditions are similar. Nitrogen, phosphorus, and potassium are essential nutrient elements for plants: nitrogen is a component of nucleic acid, chlorophyll, and protein in plants, phosphorus has a significant influence on plant nutrition and is a component of many important organic compounds in plant cells, and potassium primarily exists as ions in plants and is used in plant metabolism[5,6]. Soil spatial heterogeneity (SSH) is also an indicator of soil function, reflecting the soil characteristics and spatial structure of soil indicators and the spatial distribution of plants. Additionally, we can get data for soil sampling and reduce the field workload according to the research about SSH[7]. Soil physical and chemical properties have always been an important part of ecological research[8]. Couto et al.[9]studied the SSH of soil chemical characteristics in Mato Grosso State, Brazil. Additionally, Gao Lu et al. [10]determined the soil characteristics of degraded grassland in Erlitu pasture of Xilin Gol League Zhengxiang White Banner, and they discussed its spatial heterogeneity and impact on soil moisture. Zuber et al.[11] studied changes in the physical and chemical properties of the soil in Illinois in the United States under two methods of rotation and tillage.

The Liangucheng National Reserve is located in Minqin, which is a source of some of the most intense sandstorms in China. Minqin Oasis is the first to be hit by these sandstorms, and the ecology of the area faces a difficult situation. In 2002, the Liangucheng National Reserve was upgraded from a provincial-level to a national-level nature reserve to curb the desertification process and reduce the emergence of new sandy land. This designation has played an important role in improving the natural environment of Minqin and its surrounding areas, maintaining and improving the natural desert ecosystem in the region, reducing natural disasters, and combating desertification and sandstorms. Recently, researchers have analyzed the soil properties of Minqin from different angles[12,13]. Lu Yongqing[14]studied SSH in Minqin, Zhang Kai et al.[15,16]studied the spatial differentiation characteristics of soil properties in the Minqin Oasis desert zone, and Pang Guojin et al.[17]used hyperspectral data to quantitatively analyze the soil salinity in Minqin and established a hyperspectral remote sensing model of soil salinity.

Scholars have conducted research on vegetation, soil, and animals in reserve, but many studies about soil characteristics have focused on the lower Shiyang River or the entire Minqin area[18-20]. Based on soil sampling and determination, this study used a semivariogram model and Kriging interpolation method in classical statistics and geostatistics, combined with GIS software analysis, to quantitatively analyze the basic characteristics, mutual relations, and spatial structure of the main soil characteristics. The distribution pattern provides basic data on the soil characteristics in the protected area and lays the foundation for further research on soil and vegetation in arid desert areas. Additionally, observing and quantitatively studying the soil conditions in the area provides a scientific basis for fixed-point control of deserts and protection of desert ecosystems in arid desert areas, as well as basic data for the ecological restoration and sustainable development of degraded desert systems in protected areas.

2. Material and Methods

2.1 Study area

Liangucheng National Reserve is the largest desert nature reserve in China, which is located in the northeastern part of the Hexi Corridor, downstream of the Shiyang River Basin, between the two deserts of Badain Jaran and Tengger, and it surrounds the Minqin Oasis in a semi-ring shape (Figure 1). The geographical coordinates of the reserve are 102° 30′–103° 57′ E, 38° 10′–39° 9′ N, with a total land area of 3898.8 km2, comprising a quarter of the total area of Minqin. The reserve is divided into three parts: core area (1210.6 km2), buffer zone (1516.6km2), and experimental area(1171.6 km2).

The reserve has a high altitude, with the regional elevation of between 1180 and 1550 m, with an average elevation of 1400 m. The reserve has a temperate continental climate, is extremely arid, has been getting drier and drier for many years, has strong evaporation, substantial temperature differences between day and night, and frequent high winds and sandstorms. The annual average rainfall is 110 mm, 80% of which happens in summer and autumn. The drought period is long, and the evaporation is 21 times as much as the precipitation. The annual average temperature is 7.7℃, the extreme minimum temperature is −27.3℃, the extreme maximum temperature is 39.5℃, and average daily difference in temperature is 14℃. Additionally, the relative humidity is 45%, the frost-free period is 137 d, the maximum frozen soil depth is 105 cm, the average annual wind speed is 2.4 m·s−1, the annual average number of windy days is 27.4 d, and the average number of sandstorm days is 25.9 d. The main landforms in the study area can be divided into six types: sandy, floodplain, gobi, hilly, wetland and saline-alkali land. The soil is generally Aridisols[21,20].

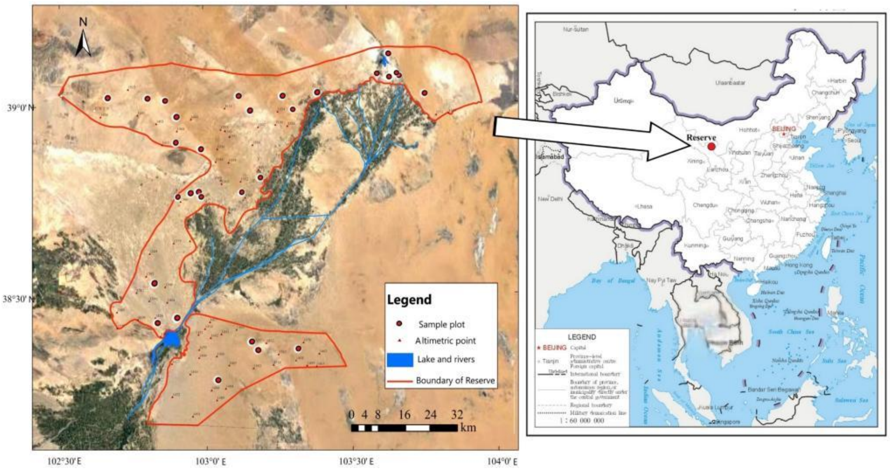

Figure 1. Geographical location map of study area

2.2 Sampling method

Sample plots were established and sample collection was conducted in the reserve in September 2019. Protection status and environmental variables were considered, and local researchers were consulted to help select 30 representative sample plots (5 m × 5 m) within the reserve (Figure 1). GPS positioning equipment was used to record the longitude, latitude, and altitude of each site, along with basic information such as landform and vegetation (Table 1). The sample plots were scattered across all protection types in the reserve and included different landforms. Soil samples were collected in each sample plot following the five-point sampling method. After the sampling point was determined, the soil was sampled with an earth drill with a sampling depth of 0-20 cm. Then, the soil of each sampling site was evenly mixed and sundries such as dead branches, leaves and fine roots were removed. After marking, the soil was put into soil sample bags and brought back to the laboratory to determine the physical and chemical properties of the soil.

2.3 Experimental method

The physical and chemical properties of the soil were determined using numerous approaches: SMC was measured using the drying method(dry at 105℃ to constant weight for 12 h), SEC and pH was determined using the electric potential method (with the ratio of water to soil is 5:1), the OM content was measured using the potassium dichromate oxidation method, the semi-micro Kjeldahl method was used to determine total soil nitrogen, the Nessler colorimetric method was used to determine amounts of ammonium nitrogen, the nitric acid test was used to determine quantities of nitrate nitrogen, the molybdenum blue colorimetric method was used to determine AP, the sodium tetraphenylborate turbidimetric method was used to determine available potassium, TP content was determined using the HClO4-H2SO4 method, and the total potassium content was determined using the flame photometer method.

2.4 Data analysis

Classical statistical methods were used to analyze the basic characteristics of soil properties. Using Excel and SPSS19.0 software were used to conduct basic statistic and correlation analyses on soil characteristics in the reserve and obtain minimum, maximum, average, standard deviation (σ), variance (σ2) and coefficient of variation (CV) statistics, which can reflect the degree of SSH of feature variables.

The SSH is analyzed by using a semivariogram model in geostatistics. Its expression is γ(h)=1/2N(h)·∑[Z(xi) -Z(xi+h)]2, where γ(h) is the semi-variation statistic, h is the step size, N(h) is the point logarithm that is away from h, Z(xi) is the actual measured value of the variables considered at point xi, and Z(xi+h) is the actual measured value of the variables considered in point xi+h (the point at a distance of h from point xi).

Table 1. Basic information about the sampling site

Sample number	Longitude /E	Latitude /N	Altitude/ m	Landform	Coverage /%	Main plant types
1	103°38′25″	39°8′49″	1266.13	wetland	100	Agropyron mongolicum Keng
2	103°46′40″	39°1′ 2″	1269.21	sandy	45	Nitraria tangutorum Bor. Reaumuriasongarica (Pall.) Maxim.
3	103°40′25″	39°4′28″	1271.34	saline-alkali land	50	Kalidium foliatum (Pall.) Moq.
4	103°40′15″	39°4′48″	1270.98	saline-alkali land	50	Kalidium foliatum (Pall.) Moq.
5	103°38′56″	39°4′17″	1268.26	sandy	50	Haloxylon ammodendron (C. A. Mey.) Bunge
6	103°36′0″	39°5′55″	1267.31	wetland	100	Agropyron mongolicum Keng
7	103°26′34″	39°2′25″	1283.59	floodplain	45-50	Reaumuriasongarica (Pall.) Maxim. Haloxylon ammodendron (C. A. Mey.) Bunge Nitraria tangutorum Bor.
8	103°20′21″	38°59′40″	1337.00	sandy	35-40	Nitraria tangutorum Bor. Reaumuriasongarica (Pall.) Maxim.
9	103°17′21″	39°1′21″	1280.70	gobi	40	Reaumuriasongarica (Pall.) Maxim. Nitraria sphaerocarpa Maxim.
10	103°13′35″	38°57′2″	1290.00	floodplain	40	Reaumuriasongarica (Pall.) Maxim. Nitraria sphaerocarpa Maxim.
11	103°10′17″	38°58′44″	1296.46	floodplain	50	Nitraria sphaerocarpa Maxim.
12	102°53′7″	38°59′24″	1400.82	gobi	40-45	Zygophyllumxanthoxylon(Bunge) Maxim.

13	102°51′ 32″	39°1′ 38″	1447.48	hilly	5	Caragana korshinskii Kom. Nitraria roborowskii Kom. Stipa capillata L.
14	102°48′ 39″	39°1′ 55″	1438.73	gobi	40-45	Ceratoideslatens(J. F. Gmel.) Reveal et Holmgren
15	102°39′ 10″	39°0′ 57″	1433.08	hilly	25-30	Potaninia mongolica Maxim.
16	102°50′ 52″	38°55′ 6″	1381.73	gobi	35-40	Reaumuriasongarica (Pall.) Maxim. Nitraria tangutorum Bor.
17	102°58′ 40″	38°53′ 16″	1358.37	gobi	35	Ceratoideslatens(J. F. Gmel.) Reveal et Holmgren Reaumuriasongarica (Pall.) Maxim.
18	103°11′ 48″	38°48′ 35″	1301.35	floodplain	45	Calligonummongoli cumTurcz.
19	103°8′ 55″	38°46′ 19″	1310.29	sandy	50	Haloxylon ammodendron (C. A. Mey.) Bunge
20	102°58′ 14″	38°46′ 34″	1313.98	gobi	40	Haloxylon ammodendron (C. A. Mey.) Bunge Nitraria roborowskii Kom.
21	102°59′ 49″	38°45′ 54″	1299.00	floodplain	45	Sophoraalopecuroid esL.
22	102°57′ 4″	38°46′ 24″	1315.45	gobi	45-50	Nitraria roborowskii Kom.
23	102°54′ 23″	38°46′ 2″	1319.38	sandy	35	Haloxylon ammodendron (C. A. Mey.) Bunge
24	102°49′ 34″	38°32′ 22″	1344.07	gobi	35	Ephedra sinica Stapf Nitraria sphaerocarpa Maxim.
25	102°49′ 14″	38°26′ 41″	1364.93	gobi	45	Calligonummongoli cumTurcz. Artemisia frigida Willd.
26	102°54′ 4″	38°28′ 52″	1337.00	sandy	50	Haloxylon ammodendron (C. A. Mey.) Bunge
27	103°1′ 22″	38°16′ 36″	1335.14	sandy	45	Nitraria tangutorum Bor. Reaumuriasongarica (Pall.) Maxim.
28	103°9′ 33″	38°21′ 37″	1497.95	hilly	40	Caragana korshinskii Kom. Nitraria roborowskii

						Kom. Stipa capillata L.
29	103°12′ 2″	38°21′ 31″	1449.19	floodplain	45	Ceratoideslatens(J. F. Gmel.) Reveal et Holmgren Reaumuriasongarica (Pall.) Maxim.
30	103°17′ 30″	38°21′ 37″	1410.60	sandy	18	Artemisia scoparia Waldst. et Kit.

The semivariogram model requires the data to conform to a normal distribution. The single-sample Shapiro-Wilk test was used to perform a normal distribution test on each index. It was used to transform the data that did not obey the conditions of a normal distribution and then geostatistical analysis was conducted. The semivariogram model was used to obtain five parameters, including variable range (A0), nugget value (C0), partial sill value (C), sill value (C0 + C) and nugget coefficient (C0/(C0+C)) to show the extent of the autocorrelation of the spatial variables. Using ArcMap10.3 software, the SSH of each indicator was determined using the Kriging interpolation method, and the spatial distribution map of soil characteristics was made[22].

3. Results and Discussion

3.1 Basic characteristics of soil properties

The experimental data (Table 2) were statistically analyzed to determine basic changes in the soil characteristics in the protected area. In summary, the soil was alkaline soil, the SEC varied widely, the water content and various nutrient contents were low, and the soil conditions were poor. Therefore, protection is still needed.

Table 2. Essential features of soil properties in Liangucheng National Reserve

Soil Properties	Minimum	Max	Median	Mean	Standard Deviation	Variance	Coefficient of Variation
SMC %	1.50	12.50	3.282	3.98	0.024	0.001	0.602
OM ‰	3.48	17.68	12.07	10.84	4.139	17.13	0.382
pH	7.25	8.66	8.08	8.02	0.343	0.118	0.043
TN g/kg	0.1	1.13	0.35	0.42	0.251	0.063	0.600
NH4+-N mg/kg	7.4	22.38	12.235	12.67	3.315	10.987	0.262
NO3−-N mg/kg	0.01	542	9.47	46.34	114.865	13194.074	2.479
TP g/kg	0.01	0.68	0.24	0.26	0.144	0.021	0.551
AP mg/kg	3.31	26.07	7.285	8.91	5.303	28.127	0.595
TK g/kg	1.07	5.16	2.72	2.81	1.102	1.215	0.392
AK mg/kg	90.72	537.5	217.425	235.71	97.976	9599.266	0.416
SEC us/cm	2.05	1877	111.4	288.56	477.831	228322.674	1.656

According to existing studies, when the CV is 0 to 0.15, the soil properties have weak variability; when the CV is 0.16 to 0.35, there is a moderate degree of variability; when the CV exceeds 0.36, the variability is relatively strong[23]. The CV of soil pH was very small, and its variability was low, showing that the pH value was relatively consistent. Soil NH4+-N had a moderate degree of variation. Also, SMC, OM, TN, NO3−-N, TP, AP, TK, AK, and SEC all showed strong variability.

Among them, the soil physical and chemical properties with relatively large variation were nitrate nitrogen and electrical conductivity, of which the CV was greater than 1.5. Among all the measured indicators in this study, nitrate nitrogen had the strongest variability, which was quite different in the protected area and fluctuated sharply.

3.2 Correlation analysis of soil properties

Correlation analysis between characteristics of various soils was conducted, and the results are shown in Table 3. Soil moisture is a direct source of plant moisture, which determines plant growth and is of great significance. SMC was positively correlated with OM content and had a very positive correlation with AP. The reason for this could be that the study area has severe land desertification, extremely low water content, poor soil structure, and no fertility retention capacity, which makes the soil barren and is not conducive to the formation and accumulation of organic nutrients. Areas with low OM content and high water content have relatively better soil conditions, increased soil cohesiveness, relatively better soil structure, and improved fertility retention capacity.

Table 3. Correlation analysis of soil properties in Liangucheng National Reserve

Soil Properties	SMC	OM	pH	TN	NH4+-N	NO3−-N	TP	AP	TK	AK	SEC
SMC	1	0.449*	−0.217	0.362	−0.261	0.195	−0.224	0.764**	0.151	0.236	−0.096
OM		1	0.121	0.295	−0.433	0.222	−0.098	0.397	0.268	0.342	−0.109
pH			1	−0.368	−0.124	−0.072	0.350	−0.113	−0.306	0.040	−0.117
TN				1	−0.095	0.594**	−0.616**	0.425*	0.297	0.499*	−0.054
NH4+-N					1	−0.102	−0.067	−0.304	−0.005	−0.096	−0.064
NO3−-N						1	−0.392	0.457*	−0.006	0.479*	−0.049
TP							1	−0.253	−0.157	−0.177	0.095
AP								1	−0.319	0.490*	0.083
TK									1	0.312	−0.035
AK										1	0.020
SEC											1

* Significantly correlated at the 0.05 level

** Significantly correlated at 0.01 level

Except for NH4+-N and TP, the content of soil OM was positively correlated with the other indicators. OM is the primary source of soil nutrients, which can boost plant growth, improve soil structure and properties, enhance soil permeability, water retention, and fertilizer capacity, and reduce nutrient loss. Therefore, soil nutrients in areas with high OM content are relatively better.

N, P, and K are the three most nutritious elements needed by plants. According to the correlation analysis, there were correlations between soil N, P, and K. Additionally, there was an evident positive correlation between TN and NO_3^--N, a distinctly negative correlation with TP, and a significant positive relationship between AP and AK. There is a clear positive correlation among the three indicators of NO_3^--N, AP, and AK. Except for individual indicators, soil N, P, and K were closely related and together constituted a soil nutrient environment. There was a negative correlation between NH_4^+-N and other soil indicators, and the correlation coefficients were all small (−0.005–−0.433). This could be because the content of NH_4^+-N in the soil is low. The numerical range of the measured physical and chemical indicators was low (the full range was 14.98 mg/kg), there was little difference between sampling points, and the correlation was not clear.

SEC can reflect soil salinity. Generally, areas with high electrical conductivity have high soil salinity. The correlation coefficient between electrical conductivity and other indicators was between −0.117 and 0.095, which shows that the relationship between soil salinity and other soil physical and chemical properties was very small.

3.3 Geostatistical analysis of soil properties

The spatial heterogeneity of soil's physical and chemical properties is an important attribute of soil. Various substances have a specific spatial structure in the soil and are not randomly distributed in the soil space. The soil environment, landform, vegetation, and other conditions within a certain range are the same, and the content of various soil factors within this range is also similar and has a certain spatial dependence. Geostatistics can quantitatively analyze the spatial heterogeneity of soil traits and the degree of spatial autocorrelation.

The Shapiro-Wilk test was used to perform a normal distribution test on each index (Table 4). The data followed normal distribution when P is larger than 0.05. The data that did not obey the conditions of a normal distribution was transformed and the indices of the protected area conformed to the conditions of a normal distribution after transformation. The normal distribution map of the transformed data is shown in the Figure 2. The soil spatial distribution of Liangucheng National Reserve was analyzed using the semivariogram model in geostatistics, and the results are shown in Figure 3 and Table 5.

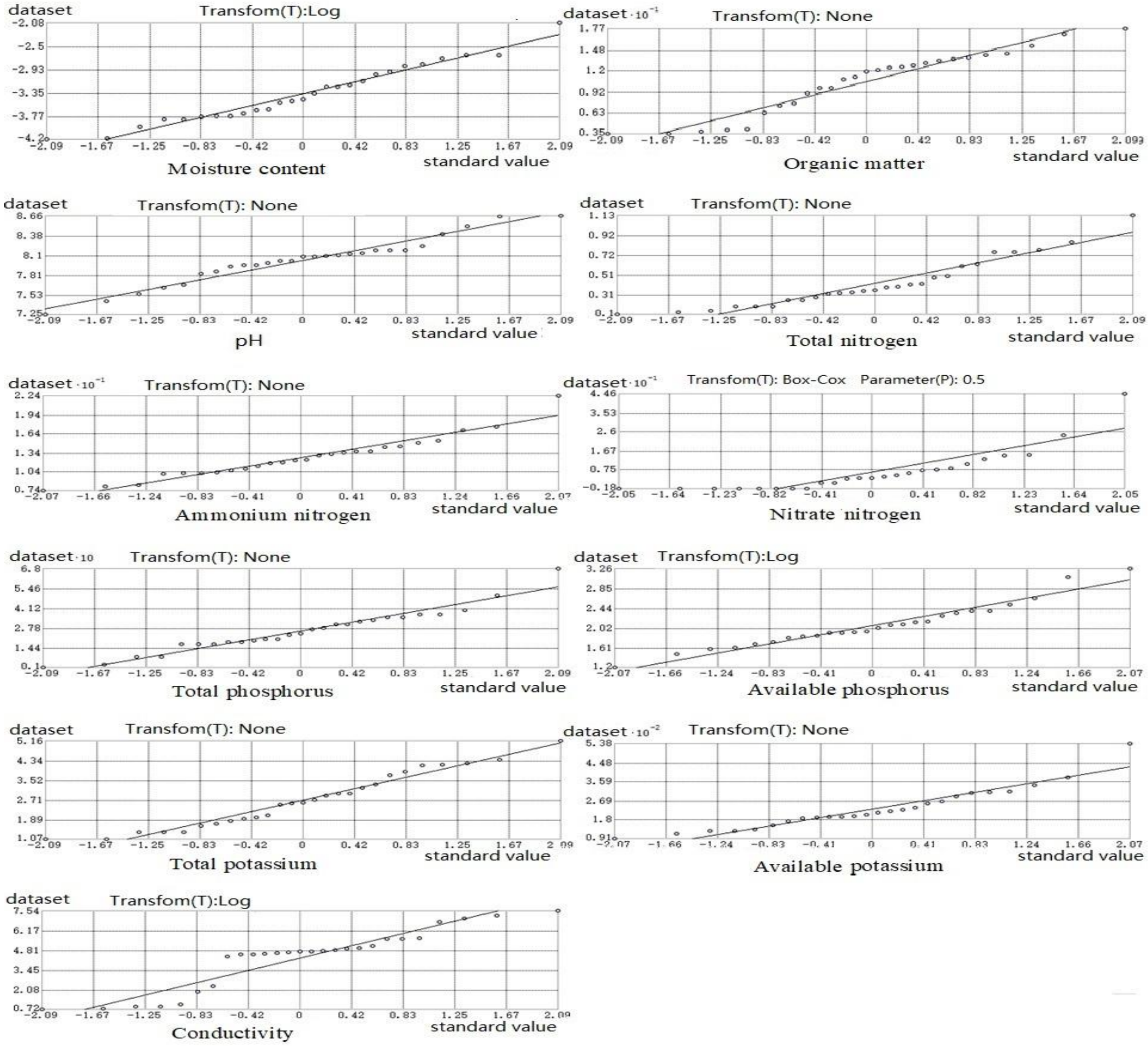

Figure 2. Normal distribution map of soil properties after data conversion

Table 4.Test results of normality on soil properties in the reserve

	SMC	OM	pH	TN	NH4+-N	NO3−-N	TP	AP	TK	AK	SEC
Statistic	0.797	0.933	0.963	0.917	0.948	0.433	0.927	0.765	0.964	0.927	0.624
P	0.001	0.124	0.519	0.057	0.269	0.001	0.094	0.001	0.538	0.094	0.001

The range of variation reflects the spatial distance of the largest variation in spatial heterogeneity. The smaller the value, the greater the variability. The range of soil physical and chemical properties in the reserve was 160.0–1356.7 m, and most values were concentrated between 200 and 600 m. The ranges of soil pH and soil available potassium were lowest at 160.0 m and 176.0 m, respectively. The variation range of ammonium nitrogen, nitrate nitrogen, and available potassium content were the largest, all of which were 1356.7 m.

The C0 reflects the variability and measurement error of variables under the smallest sampling scale caused by experimental errors and spatial variation of natural phenomena. The C0 of soil properties in the protected area varied greatly, ranging from 0.0258 to 7.368. Except for electrical conductivity and ammonium nitrogen content (>4), the nugget values of other indicators were all lower than 1.1. Among them, the nugget value of soil TP content was the smallest, the nugget value of ammonium nitrogen was the largest, and the random variation was the highest.

Table 5. Basic parameters of spatial correlation degree of soil physical and chemical properties

Soil Properties	Variation/a (km)	Nugget Value/C0	Partial Sill Value/C	Abutment Value/C0+C	C0/C0+C (%)
SMC	0.5529	0.7167	0.1957	0.9124	78.55
OM	0.16	0.6398	0.5352	1.175	54.45
pH	0.16	0.058	1.3689	1.4269	4.06
TN	0.2146	0.1197	0.2525	0.3722	32.16
NH4+-N	1.3567	7.368	4.8422	12.2102	60.34
NO3−-N	1.3567	1.0013	0.0573	1.0586	94.59
TP	0.2959	0.0258	1.3216	1.3474	1.91
AP	0.3711	0.1091	0.0965	0.2056	53.06
TK	0.3318	0.72	0.8747	1.5947	45.15
AK	1.3567	1.0359	0.0013	1.0372	99.87
SEC	0.2959	4.2178	0.2414	4.4592	94.59

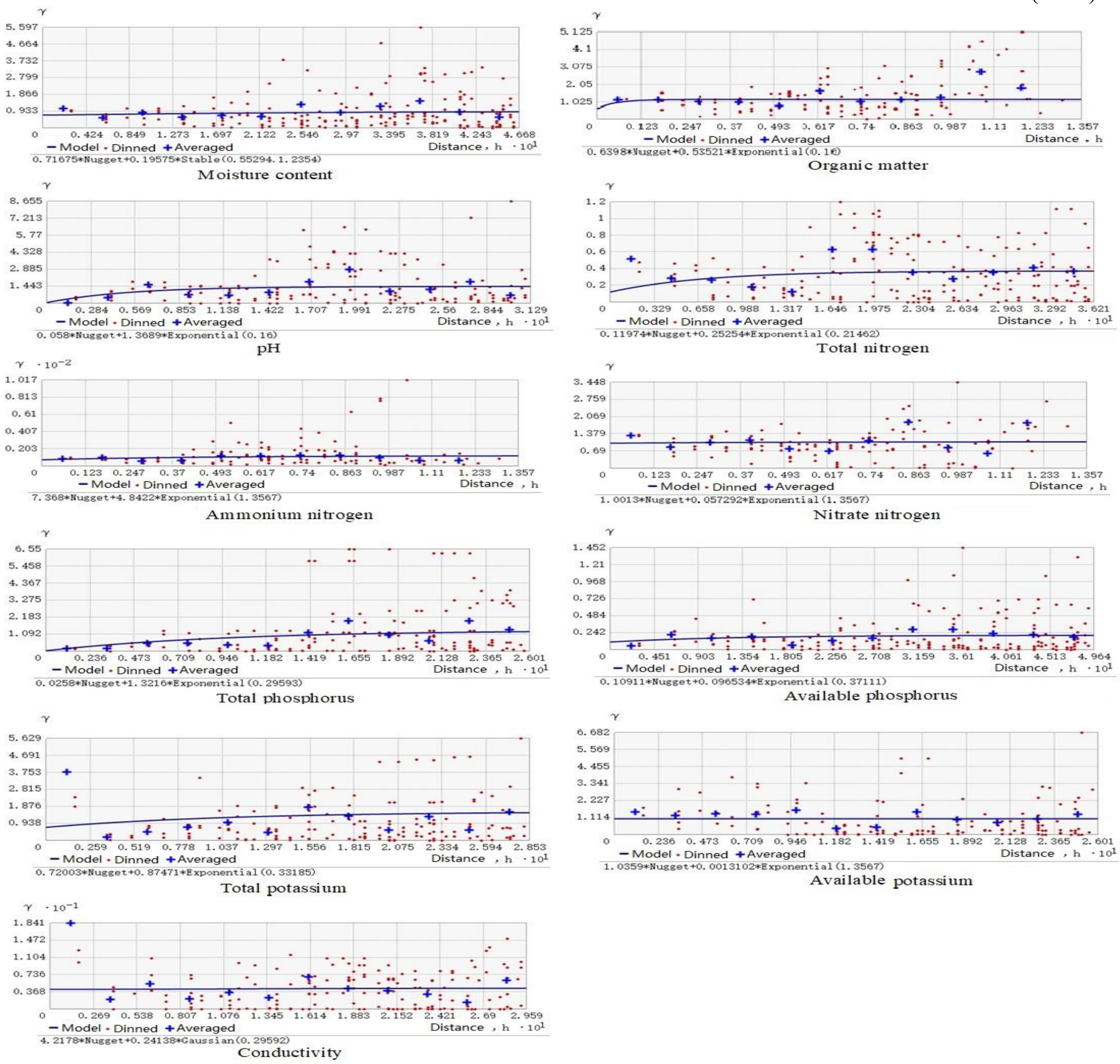

Figure 3. Semivariogram model of soil properties in the reserve

The partial sill value (C) is the spatial structure value, reflecting the structural variation caused by the spatial topography, climate, and soil parent material. The range of the partial abutment value of soil properties in the protected area was 0.0013–4.8422. The difference was similar to the nugget value. Except for the content of ammonium nitrogen, the maximum partial abutment value of other indicators was 1.3689 for pH, and the partial abutment value of the soil's available potassium content was the lowest.

The sill value C0+C manifests the overall characteristics of regionalized variables. The abutment value of each soil property in the protected area ranges from 0.2065 to 12.2102. The abutment value of ammonium nitrogen is higher than other indicators, indicating that the total variation degree is high. The abutment value of soil physical and chemical properties, except for ammonium nitrogen and electrical conductivity, is less than 1.6, and the abutment value of effective phosphorus content was the lowest, and its total variation was the lowest.

The nugget coefficient (C0/(C0+C)) reflects the random variation to the total variation. The smaller the ratio, the smaller the degree of spatial variation caused by random factors, and the stronger the spatial correlation of soil features. When C0/(C0+C) <25%, it indicates that the soil properties have a strong spatial correlation rather than a random distribution. When 25%< C0/(C0+C)<75%, it indicates that the spatial relationship of the soil property is at a medium level. When C0/(C0+C) >75%, it indicates that the spatial correlation degree of the soil properties is very low, and the spatial distribution is relatively random. The nugget coefficient is between 1.91% and 99.87%. Among them, the nugget coefficients of soil TP and pH are less than 5%, which has a strong spatial correlation. The nugget coefficients of OM, TN, NH4+-N, AP, and TK were between 32.16% and 60.34%, which is a moderate spatial correlation, and the nugget coefficients of water content, NO3−-N, AK and SEC were greater than 75%, and the degree of spatial correlation was very low. These findings indicate that the spatial distribution patterns of these soil characteristics are very random. Among them, the nugget coefficients of NO3−-N, AK, and SEC were higher than 90%. There are some possible reasons that the soil surface water content was greatly affected by the surrounding environment, climate and sampling time, and the change was large: there are saline-alkali soils in the reserve, resulting in some index values being very high, resulting in the data in other plots being different, and faults appear.

3.4 Spatial distribution pattern of soil properties

The spatial interpolation method can predict indicator values in other regions using information from sampling locations. The soil features at each sampling point were used as the baseline data. A semivariogram model and the Kriging interpolation method were used to construct the spatial distribution pattern of the soil properties in the reserve (Figure 4). The soil characteristics had evident patterns in their spatial distributions. Different physical and chemical properties formed a heterogeneous patch near Qingtu Lake in the northeast of the reserve. Some indicators were concentrated in the southeast or southwest of the reserve, indicating that regional soil properties are spatially structured.

SMC was high in the north and northeast of the reserve, the pH range was small, the soil pH was similar, and the pH in the northwest was relatively high. Additionally, the salt content (conductivity) was high in the northeast and southwest, the N, P, K, and OM soil content was higher in the north of the reserve, while the soil NH4+-N and TK content was higher in the southeast. The content of NO3−-N and TP was higher in the southwest. Overall, the soil conditions in the north of the reserve were better than those in the south, and the soil conditions in the middle of the reserve were the worst. The analysis showed that there are two water areas in the Liangucheng National Reserve, namely the Hongyashan Reservoir in the southwest and Qingtu Lake in the northeast. Most reserve areas belong to the desert ecosystem, and water conditions have become the primary factor affecting vegetation growth. Water, directly and indirectly, affects soil conditions: the saline-alkali land in the reserve is close to the water area, so the highest salt content is where the water area is located.

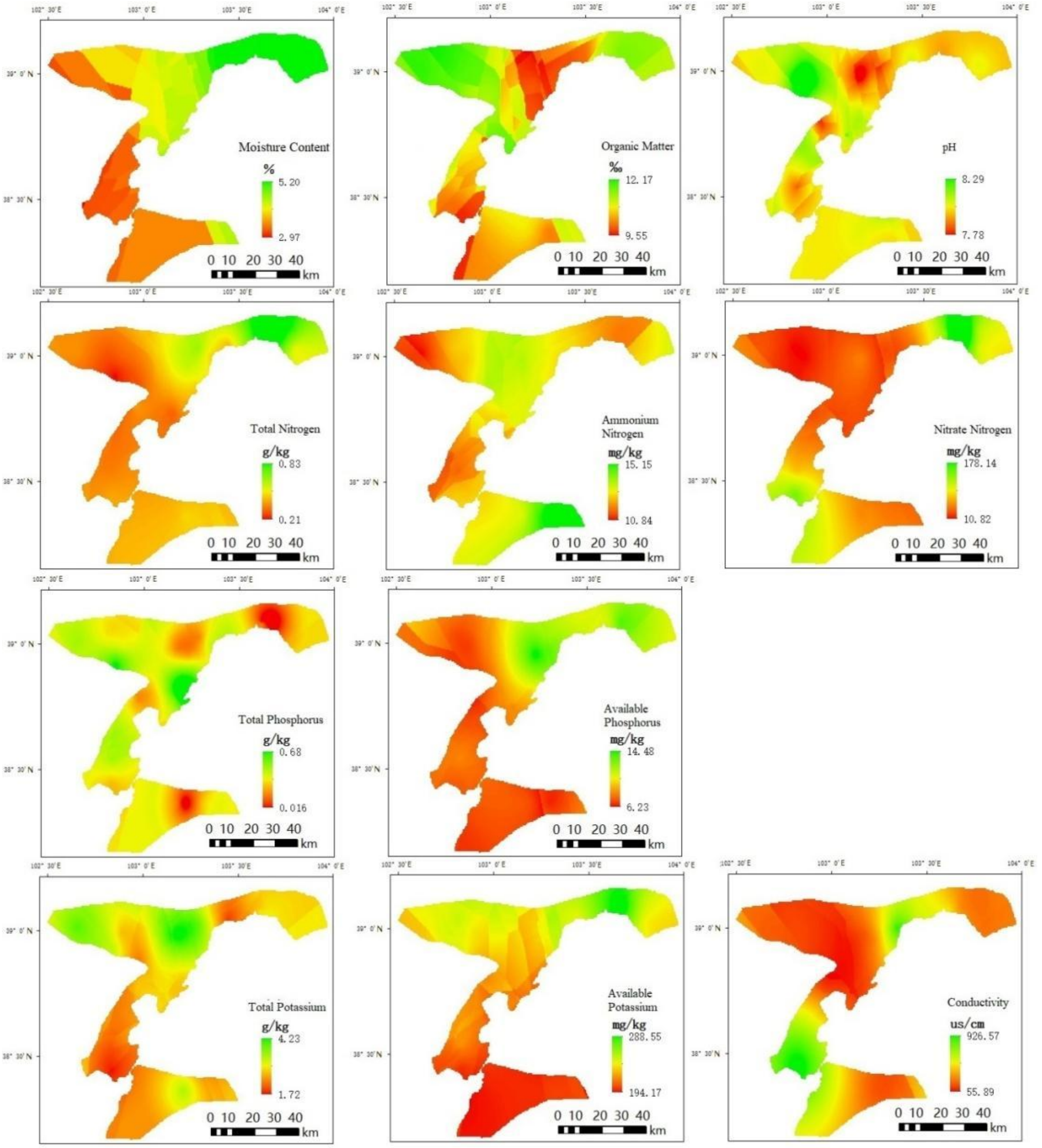

Figure 4. Spatial distribution of soil physical and chemical properties in the reserve

4. Summary

The soil water content in the protected area was very low, the salt content varied widely, and the concentrations of various nutrients were low. The soil conditions in the protected area were poor, and protection is still needed. Except for pH and electrical conductivity, all soil indicators were significantly correlated. The soil features of the study area were correlated and not substantially affected by soil pH and electrical conductivity.

This study used Kriging interpolation to conduct geostatistical analysis and develop the spatial distribution map of the soil features: SMC, SEC, pH, OM, N, P, and K. We found that each of the soil elements had a specific spatial distribution. Even in a desert area with limited vegetation types, the soil features were still spatially heterogeneous.

The spatial distribution patterns of soil TP and pH had the strongest correlation based on geostatistical analysis, and the nugget coefficient of nitrate nitrogen, available potassium, and electrical conductivity was higher than 90%. However, the spatial distribution pattern of these three indicators was regular, and their values were larger near the saline-alkali soil. This could be because the content of nitrate nitrogen, available potassium, and salt in saline-alkali land is relatively high, making the measurements from the other plots very different. These differences made the nugget coefficient very high.

The spatial autocorrelation range of soil features was mostly concentrated between 200 and 600 m. In follow-up research, we suggest that the soil characteristics are selected as the separation distance of the sampling points according to the studied soil features to reduce the workload and speed up the research progress.

The spatial distribution patterns of various soil properties were similar, but the specific distribution patterns were not consistent. The specific location, shape, size, and change trend of heterogeneous patches with different soil properties were different. In general, the northern part of the reserve, especially near Qingtu Lake, had the best soil conditions, and the central part had the worst soil conditions. Different soil chemistry could be regulated by different ecological processes and environmental factors. The reasons for the differences should be explored in subsequent studies and determine the factors affecting the ecological processes affecting soil chemistry.

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