Evaluation of Soil Quality and Spatial Characteristics of Urban Garden Green Spaces in Jiaozhou City

Shiyu Zhao[1,†], Chengyuan Jiang[2,†], Xinyu Ma[3], and Mingxiu Gao[1*]

[1]Shandong Agricultural University, College of Resources and Environment, Taishan, Taian, Shandong, China
[2]Yantai Jinshan Heavy Machinery Equipment Co., Ltd, Fushan, Yantai, Shandong, China
[3]Feicheng Agriculture and Rural Bureau, Feicheng, Taian, Shandong, China
[†]These authors contributed equally to this work.

Abstract. Taking the urban garden green spaces(Uggs) in Jiaozhou City as the research object, a soil quality evaluation index system for Uggs was established. The improved Nemerow index method was used to evaluate the soil quality of the total Uggs(TG) and its 4 types(street green space, SG; road green space, RG; comprehensive park, CP; linear park, LP), including entire profile (0-60cm) and layered (0-20, 20-40, 40-60cm). GIS was used to analyze the spatial distribution of soil quality at different layers. The results show that the overall soil quality of Uggs in Jiaozhou City is at a medium to low level. From the perspective of the entire profile, the comprehensive index of soil quality (P_{ijk}) of the total and 4 types of Uggs are 1.10 (TG), 1.06 (CP), 1.04 (SG), 1.05 (LP), and 1.16 (RG), all of which are between 1.0-1.5 and belong to grade III. From a layered perspective, the P_{ijk} of the total and 4 types of Uggs of surface layer are 1.20 (TG), 1.20 (CP), 1.17 (SG), 1.12 (LP), and 1.25 (RG), all of which are at grade III. The P_{ijk} of middle layer are 0.93 (TG), 0.86 (CP), 0.91 (SG), 0.92 (LP), and 0.96 (RG), and the P_{ijk} of bottom layer are 0.89 (TG), 0.84 (CP), 0.88 (SG), 0.83 (LP), and 0.97 (RG); All of which are below 1.00, and at grade IV. In terms of classification, the soil quality of all 3 layers of RG is the highest, but there is no specific pattern in the P_{ijk} of CP, SR, and LP. The soil quality gradually deteriorates from the surface layer downwards. From the perspective of spatial distribution, the soil quality generally follows a pattern of high in the north and west, and low in the south and east, reflecting the outcomes of both natural and anthropogenic influences. The research results can provide scientific basis for soil and Uggs management in Jiaozhou City.

1. Introduction

Urban garden green space (Uggs) is a spatial environment system composed of a certain quantity and quality of various green spaces for urban residents' work and life. It is often distributed in patches or strips within parks, units, residential areas, as well as on both sides of roads and rivers. It can be divided into street green space (SG), road green space (RG), comprehensive park (CP), and linear park (LP) types. The soil in urban green spaces is the basic medium for plant growth, and its quality directly affects plant growth and development as well as urban ecological quality [1]. Therefore, investigating and evaluating the soil quality of Uggs is of great significance for taking targeted measures to improve the soil quality, maintain urban green space ecosystems.

Extensive exploration in the evaluation of soil quality and properties in Uggs has been conducted [1-4]. Tresch et al. established a database of urban gardens in Zurich [2]; Kim et al. proposed key variables for soil quality evaluation of roadside tree systems in Seoul and Suwon city[3]; Li et al. used principal component analysis and weighted composite index to evaluate Uggs soil quality in Qingdao city [4]. In recent years, principal component analysis, weighted composite index, Nemerow index, cluster analysis, fuzzy mathematics, and geostatistical methods have been applied in the evaluation of soil quality in Uggs[4]. The improved Nemerow comprehensive index method mainly considers the limitation of the minimum value of indicators on soil fertility, reflecting the minimum factor law of plant growth, and can better guide soil improvement and utilization. Therefore, it has been applied in the quality characteristics of surface soil in urban scenic areas, parks, and newly built green spaces[5]. Overall, currently, most evaluations of soil quality in Uggs both domestically and internationally only focus on the surface layer of soil, lacking multi-level analysis. Moreover, most studies consider Uggs as a whole, lacking of in-depth classification research. The evaluation of fertility and environmental quality has received more attention, while the systematic integration of soil quality assessment is relatively scarce.

For a long time, urban greening has been strengthened in Jiaozhou City, Shandong Province, China. In 2016, it launched the “Construction of National Forest City” and formulated the “Overall Plan for National Forest City

* Corresponding author: mxgao@sdau.edu.cn

Construction in Jiaozhou City", constructing a forest ecological spatial layout of "one shield, one core, one belt, two corridors, and multiple clusters". In 2018, Jiaozhou City became the core area of the Shanghai Cooperation Organization(SCO) Local Economic and Trade Cooperation Demonstration Zone, with a construction area of 61.1km^2, including Jiaozhou Economic and Technological Development Zone and Conceptual Planning New Area. The "Five New Cities" of SCO International City, Airport New City, Hub Port New City, Caos New City and Banqiao New City were arranged in groups to create a new platform for international cooperation of the "the Belt and Road" and create a high-quality ecological environment. In 2024, the green coverage rate of urban built-up areas has reached 44.9%, higher than the national average (43.3%), Shandong Province (43.9%). Since 2020, the excellent air quality rate in urban areas has been 80.2%~88.7%, with an average of 84.56%, higher than that of Shandong Province (70.98%). It has successively won honors of National Forest City, National Civilized City, National Greening Model City, National Ecological Demonstration Zone. Although it has obtained many achievements above, becoming a typical representative of Uggs construction, there has been a lack of systematic evaluation and research on Uggs soil quality. Therefore, this article intends to take the central urban area of Jiaozhou as the study area, use on-site survey and laboratory analysis methods to obtain soil information, construct an evaluation index system for soil quality of Uggs, comprehensively analyze the total and different types and layers of soil quality based on the improved Nemerow index method and GIS. The aim is to provide scientific basis for improving the soil management and maintenance level of Uggs in Jiaozhou.

2 Materials and methods

2.1. Overview of the study area

Jiaozhou City is located in the southeast of the Shandong Peninsula(36°00′-36°30′N, 119°37′ -120°12′E), with a land area of 1324km^2. The population is 1.05 million, with an urbanization rate of 65.72%. The area of Uggs in the built-up area reaches 3950.1 hm^2. The per capita park green space is 13.2m^2. There are 23 parks in the city with an area of 667.2 hm^2.It belongs to warm temperate marine climate, with an average annual temperature of 11-14 ℃. The survey covers the central urban area of Jiaozhou City, from Dagu River in the east to Xiaoxin River in the west, 3 km north of Beihuan Road in the north, and Jiaohuang Highway in the south, with a total area of 8540.6 hm^2. The terrain types in the survey area are mainly plains and low hills. The soil types are mainly brown soil and alluvial soil.

2.2 Data source

2.2.1 Sample sites layout

According to the "Overall Plan for National Forest City Construction in Jiaozhou City", the survey area was determined based on the boundaries of the central urban area and the scope of Uggs maintenance. Based on the types, areas, distribution characteristics, and vegetation conditions of Uggs, 180 survey sites were set up, taking into account the principles of uniformity and representativeness. There were 31, 81, 37, and 31 sample sites for SG, RG, CP, and LP, respectively.

2.2.2 Sample collection

At each sampling point, a soil drill was used to extract 2kg of soil from the surface (0-20cm), middle (20-40cm), and bottom (40-60cm) layer, respectively. For each sample, impurities such as roots and stones were removed, mixed well, and the quartering method was used to take about 1kg of soil sample. Bulk density samples from each layer were collected using a 100cm^3 ring knife. Samples were sealed in plastic bags, numbered and labelled, separately. Omap interactive map (V9.9.3) were used to record the coordinates of sample sites. EC110 portable conductivity meter (Range 0.00-199.9ms/cm, accuracy ± 2%) was used to measure the soil conductivity of each soil layer. SC900 soil compactor(Range 0-7000kPa, resolution: 2.5cm depth, 35kPa pressure) was used to measure soil compaction. In the laboratory, soil samples were spread out on clean plastic clothes. Large soil blocks were crushed, impurities were removed, and naturally air dried. After grinding, soil samples passed through 1 and 0.5mm sieves were prepared and bagged for future use, respectively.

2.2.3 Experimental Analysis Methods

The soil sample analysis was conducted in the soil science laboratory of Shandong Agricultural University according to the methods in the "Technical Specifications for Soil Analysis" [6]. Soil bulk density was determined using the ring knife method and calculated the result based on the weight of dry soil. The pH was measured using an acidimeter (Leici PHS-3C, range -2.00~18.00, accuracy 0.01) and potentiometric method (water soil ratio=2.5:1). The soil salinity was determined using a 1:5 soil water ratio extraction, drying–weighing method. A relationship model between salinity and conductivity was established, the on-site conductivity was converted to salinity[7]. Organic matter was determined using potassium dichromate oxidation volumetric method. Total nitrogen was determined using concentrated sulfuric acid digestion and an automatic Kjeldahl nitrogen analyzer (Haineng K1160, range 0.1~240mg N, titration accuracy 0.2~1.0 μL/step, Repeatability standard deviation (RSD) ≤0.5%). Alkaline nitrogen was determined using alkaline diffusion method. Available phosphorus was determined using 0.5mol/L $NaHCO_3$ leaching molybdenum antimony colorimetric method and a spectrophotometer (Puxi TU-1950, wavelength range 190~900nm, accuracy 0.3nm; photometric range -4.0~4.0Abs, accuracy 0.002Abs) with a 1cm diameter colorimetric dish to measure the absorbance at a wavelength of 700nm, and a standard curve was drawn and the available phosphorus content was calculated. Available potassium was determined using a 1mol/L NH_4AC extraction and flame photometer

(Youke FP6400, linear error: K ≤ 0.005mmol/L), and a standard curve was plotted to calculate the content of available potassium. The quality of all measurement results was controlled according to the precision specified in the reference[6], and the parallel measurement results all meet the standard requirements for allowable deviation.

2.3 Research Methods

2.3.1 Evaluation of soil quality in Uggs

Based on the principles of availability, systematicity and independence, evaluation indicators were selected from 3 attributes of soil physics, chemistry, and nutrients to construct an evaluation index system (Table 1). A membership function model to calculate the membership degree values of each evaluation indicator was established, to eliminate the influence of differences in metrics between indicators. The soil quality of Uggs in Jiaozhou City was evaluated through an improved Nemerow index method, and the soil quality status and the differences in soil quality at different levels were analyzed.

1) Soil quality indicator membership function model: When soil attribute indicators are positively or negatively correlated with soil quality, P_i is calculated using the following formula (1), (2), respectively:

$$P_i = \begin{cases} P_i = C_i/X_a & (C_i \le X_a) \\ P_i = 1 + (C_i - X_a)/(X_c - X_a) & (X_a < C_i \le X_c) \\ P_i = 2 + (C_i - X_c)/(X_p - X_c) & (X_c < C_i \le X_p) \\ P_i = 3 & (C_i > X_p) \end{cases} \quad (1)$$

$$P_i = \begin{cases} P_i = 3 & (C_i \le X_p) \\ P_i = 2 + (X_c - C_i)/(X_c - X_p) & (X_p < C_i \le X_c) \\ P_i = 1 + (X_a - C_i)/(X_a - X_c) & (X_c < C_i \le X_a) \\ P_i = X_a/C_i & (C_i > X_a) \end{cases} \quad (2)$$

In the formula, P_i is the single factor quality score of soil quality index; C_i is the measured value of quality index i; X is the grading standard for the indicator, X_a, X_c, and X_p are mainly determined based on the Second National Soil Survey standard combined with the actual situation in Jiaozhou City (Table 1).

Table 1. Classification standard values of soil indicators.

Indicators	X_a	X_c	X_p	Attribute
Bulk density (g/cm^3)	1.45	1.35	1.25	-
Compactness (kPa)	2000	800	300	-
pH (>7)	9.5	8.5	7.5	-
pH (<7)	4.5	5.5	6.5	+
Salinity (g/kg)	1.5	0.5	0.3	-
Organic matter (g/kg)	10	20	30	+
Total nitrogen (g/kg)	0.75	1.5	2	+
Alkaline nitrogen (mg/kg)	60	90	120	+
Available phosphorus (mg/kg)	5	12	20	+
Available potassium (mg/kg)	50	100	150	+

2) The improved Nemerow index method formula (3) is as follows[8]:

$$P_{ijk} = \sqrt{\frac{P_{ijkave}^2 + P_{ijkmin}^2}{2}} \cdot \frac{n-1}{n} \quad (3)$$

In the formula, P_{ijk} is the comprehensive index of soil quality in Uggs; i, j, and k represent soil attributes, green space types, and soil layers, respectively; In this article, i=1, 2, 3,…, n; N is the number of soil quality evaluation indicators, with n=9; j=5, namely, SG, RG, CP, LP, and TG (Total Uggs) respectively; k=4, representing the surface, middle, bottom, and entire profile respectively; P_{ijkave} is the average quality score of soil i attribute index at k layer in j type Uggs; P_{ijkmim} is the minimum value of the single factor quality score of soil i attribute in k layer of j type Uggs. Formula (3) replaces P_{imax} in the original Nemero formula with P_{imim}, highlighting the impact of the worst indicator on soil quality. The correction term (n-1)/n enhances the credibility of the evaluation results. The more attribute indicators involved in the evaluation, the closer (n-1)/n is to 1, and the higher the credibility. Based on the soil quality index value, the soil quality is divided into four levels (Table 2).

Table 2. Grade standards of soil quality.

Grade	I	II	III	IV
Soil Quality Index	P≥2.0	1.5≤P<2.0	1.0≤P<1.5	p<1.0

2.3.2 Spatial differentiation analysis of soil quality

Based on the ArcGIS 10.2 software, the inverse distance weighting method was used to interpolate and map the soil quality indices of each layer, and the spatial characteristics of soil quality of 3 layers was analyzed.

3. Results

3.1 Comprehensive quality characteristics of Uggs soil in Jiaozhou City

Using the improved Nemerow index method, the soil quality of the entire profile (0-60cm) of Uggs in Jiaozhou City was evaluated. Four types of Uggs, including CP, SG, LP, and RG, as well as the overall single factor quality index and soil quality comprehensive index(P_{ijk}) of all Uggs, were obtained. The results are shown in Table 3.

Table 3. Soil quality index of Uggs in Jiaozhou City

Quality index	CP	SG	LP	RG	TG
Bulk density (g/cm^3)	1.02	0.93	1.04	1.15	1.06
Compactness (kPa)	1.68	1.84	1.87	1.66	1.73
pH	2.17	2.24	2.10	1.90	2.06
Salinity (g/kg)	0.97	0.94	0.87	1.25	1.07
Organic matter (g/kg)	0.76	0.65	0.66	0.89	0.79
Total nitrogen (g/kg)	0.88	0.75	0.73	0.90	0.85
Alkaline nitrogen (mg/kg)	0.83	0.81	0.84	1.15	0.98
Available phosphorus (mg/kg)	1.70	1.79	1.49	1.73	1.70
Available potassium (mg/kg)	2.58	2.65	2.80	2.85	2.75
Quality comprehensive index	1.06	1.04	1.05	1.16	1.10

SG, RG, CP, LP and TG are street green space, road green space, comprehensive park, linear park, and total garden green spaces, respectively. The same applies to Table 4.

As shown in Table 3, the P_{ijk} of total Uggs in Jiaozhou City is 1.10, which is at the lower level of grade III. The P_{ijk} of different types of green spaces ranges from 1.04 to 1.16, and is also at the lower level of grade III. The P_{ijk} ranking for various types is as follows: RG(1.16)>CP (1.06)>LP (1.05)>SG (1.04). The reasons may be: 1) In recent years, the economic development and urban construction speed of Jiaozhou City have been accelerating, with a large number of newly built Uggs, and most of them have poor soil quality foundations; 2) In the management of Uggs, attention is often paid to visible parts such as plant planting, pruning, and garbage cleaning, and insufficient attention has been paid to soil improvement and fertilization; 3) RGs are mostly shrubbery, with difficult removal of dead branches and leaves, and accumulation of organic matter. In addition, animal feces, organic waste, and even atmospheric deposition promote the accumulation of soil nutrients, resulting in high quality index; 4) Although the CP is well managed, it also attaches great importance to aesthetics, timely cleaning of dead branches and leaves, insufficient accumulation of organic matter, and lack of fertilization, so the quality is not high. 5) SGs are often subject to more human trampling, resulting in compacted soil, poor plant growth, and limited nutrient accumulation, resulting in a lower quality index.

3.2 Soil quality and spatial distribution characteristics at different layers

3.2.1 Characteristics of soil quality at different layers

The improved Nemerow index method was used to obtain single factor quality scores and P_{ijk} for 4 types and total Uggs, as well as 3 layers. The P_{ijk} was classified and statistically mapped, and the results are shown in Table 4 and Figure 1.

Table 4. Soil quality index of different layers

Layer(cm)	Quality index	CP	SG	LP	RG	TG
Surface (0-20)	Bulk density (g/cm^3)	1.18	1.01	1.08	1.29	1.19
	Compactness (kPa)	2.05	2.26	2.10	1.84	2.00
	pH	2.23	2.36	2.17	2.02	2.14
	Salinity (g/kg)	1.03	0.97	0.98	1.34	1.16
	Organic matter (g/kg)	0.91	0.75	0.74	0.98	0.88
	Total nitrogen (g/kg)	1.06	0.84	0.82	0.98	0.94
	Alkaline nitrogen (mg/kg)	0.97	0.95	1.04	1.24	1.10
	Available phosphorus (mg/kg)	2.01	2.11	1.60	2.04	1.97
	Available potassium (mg/kg)	2.72	2.65	2.84	2.91	2.82
	Quality comprehensive index	1.20	1.17	1.12	1.25	1.20
Middle (20-40)	Bulk density (g/cm^3)	1.04	0.86	0.99	1.11	1.02
	Compactness (kPa)	1.40	1.50	1.69	1.51	1.52
	pH	2.03	2.16	1.90	1.71	1.91
	Salinity (g/kg)	0.86	0.78	0.83	1.05	0.91
	Organic matter (g/kg)	0.50	0.48	0.56	0.67	0.59
	Total nitrogen (g/kg)	0.55	0.63	0.57	0.69	0.64
	Alkaline nitrogen (mg/kg)	0.52	0.57	0.65	0.88	0.72
	Available phosphorus (mg/kg)	1.19	1.50	1.38	1.27	1.34
	Available potassium (mg/kg)	2.21	2.48	2.60	2.55	2.47
	Quality comprehensive index	0.86	0.91	0.92	0.96	0.93
Bottom (40-60)	Bulk density (g/cm^3)	1.05	0.86	1.04	1.26	1.08
	Compactness (kPa)	1.39	1.50	1.39	1.51	1.47
	pH	2.07	1.95	1.83	1.66	1.87
	Salinity (g/kg)	0.83	0.80	0.67	0.90	0.82
	Organic matter (g/kg)	0.39	0.47	0.45	0.70	0.54
	Total nitrogen (g/kg)	0.52	0.57	0.53	0.75	0.63
	Alkaline nitrogen (mg/kg)	0.54	0.54	0.55	0.88	0.69
	Available phosphorus (mg/kg)	1.34	1.61	1.09	1.28	1.35
	Available potassium (mg/kg)	2.19	2.42	2.56	2.63	2.46
	Quality comprehensive index	0.84	0.88	0.83	0.97	0.89

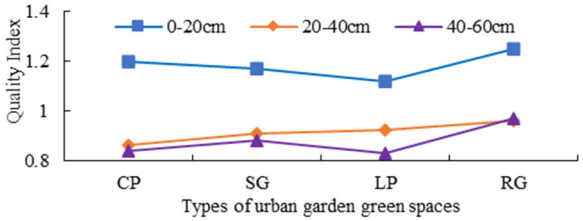


Fig. 1. Soil quality comprehensive index of different layers

As shown in Table 4 and Figure 1, 1) Surface layer: The P_{ijk} of total Uggs is 1.20, and the quality index of different types of green spaces ranges from 1.17 to 1.25, all at grade III; The soil quality index for various types of green spaces is in the order of RG (1.25)>CP(1.20)>SG (1.17)>LP(1.12). 2) Middle layer: The P_{ijk} of total green spaces is 0.93, and the quality index of different types of green spaces ranges from 0.86 to 0.96, all at grade IV; The soil quality index for various types of green spaces is in the order of RG(0.96)>LP(0.92)>SG(0.91)>CP(0.86). 3) Bottom layer: The P_{ijk} of total green spaces is 0.89, and the quality index of different types of green spaces ranges from 0.83 to 0.97, all at grade IV; The soil quality index for various types is in the order of RG (0.97)>SG (0.88)>CP (0.84)>LP (0.83).

Overall, the quality index of RG is the highest among all 3 layers (Figure 1), but there is no specific pattern in the quality levels of CP, SG, and LP. Layered comparison shows that the soil quality of the entire profile of Uggs in Jiaozhou City is: Surface>Middle>Bottom, and the patterns are the same for CP, SG, and LP; Although RGs have Surface>Bottom>Middle, there is little correlation between bottom and middle. It can be seen that the soil quality of Uggs in Jiaozhou City gradually deteriorates from the surface layer downwards.

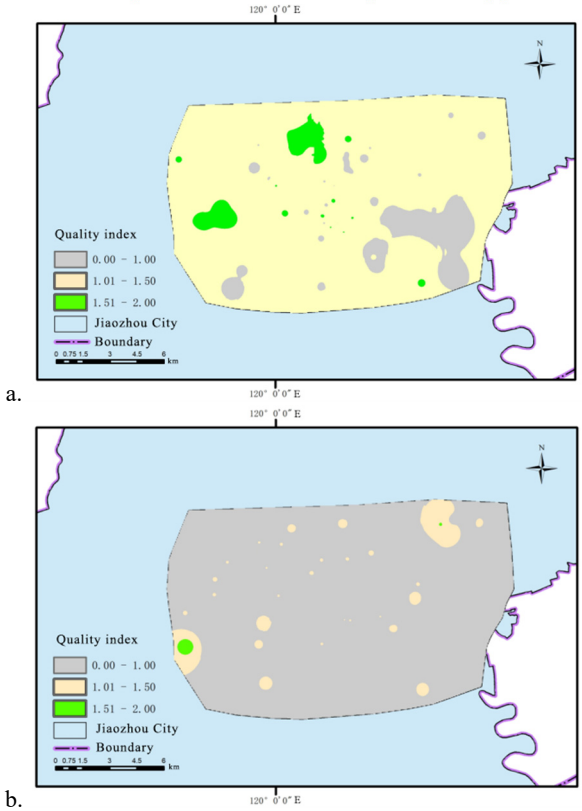
3.2.2 Spatial differentiation characteristics of soil quality at different layers

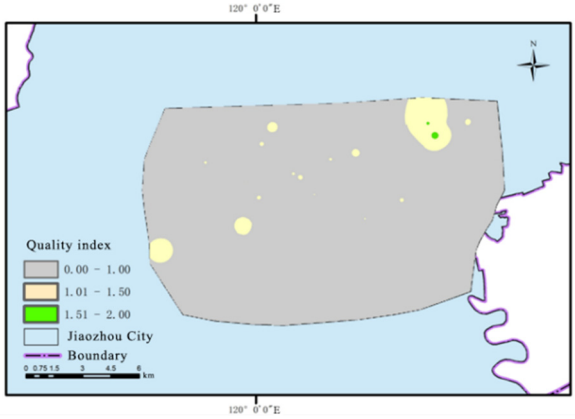
Based on the improved Nemerow index method, the soil quality index of each layer sample point was calculated. ArcGIS software was used to interpolate the spatial distribution of soil quality at 3 layers using the inverse

distance weighting method. The soil quality grades were matched according to Table 2, and the results are shown in Figure 2.

From Figure 2, it can be seen that the soil quality index of each layer did not reach grade I (P>2.0), but was at grade II or below. The vast majority of the surface layer is at grade III (1.0-1.5), with a patchy distribution of grade II in the western and northern regions; The IV grade is concentrated in the southeast. The middle and bottom layers are mainly classified as grade IV, with only sporadic distribution of grade III and II, indicating worse soil quality in the middle and bottom layers.

Overall, the soil quality index of Uggs in Jiaozhou City generally follows a pattern of high in the north and low in the south, and high in the west and low in the east. This is related to the fact that the terrain in the central urban area decreases from south to north and from west to east. The north and west are mainly plains with good soil conditions, while the south is low hills with poor soil conditions. The eastern part is the Dagu River, and the southeastern part is the Shaohai Park. The terrain is low-lying and close to Jiaozhou Bay, with high soil salt content and pH, which affects soil quality. The soil in local areas is influenced by the soil foundation quality, construction project quality, and management level of local green spaces, showing significant differences in soil quality compared to adjacent areas. It can be seen that the spatial differences in soil quality of Uggs in Jiaozhou City are influenced by both natural and human factors. In the future, In the future, the management and protection efforts should be strengthened, and measures such as soil fertilization and conditioning should be taken to continuously improve soil quality and create better growth conditions for plants in Uggs.





a, b and c are the surface(0-20cm), middle(20-40cm), and bottom(40-60cm) layers, respectively.

Fig. 2. Spatial distribution of soil quality comprehensive index.

4. Conclusion

The improved Nemerow index method was used to evaluate the total and classification types of Uggs soil in Jiaozhou City, both in entire profile and layered, and the spatial differentiation characteristics of soil quality at different layers were analyzed with GIS. The results show that, the entire profile soil quality index for both the total and different types of Uggs is between 1.0-1.5, belonging to grade III; The surface soil quality of both the total and 4 types of Uggs is at grade III, while the middle and bottom layers are at grade IV; The soil quality of RG is the highest among the 3 layers, but there is no specific pattern in the CP, SG, and LP. The soil quality gradually deteriorates from the surface layer downwards, and generally follows a pattern of high in the north and low in the south, and high in the west and low in the east, reflecting the outcomes of both natural and anthropogenic influences.

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