International Journal of Economics, Business and Management Research

Vol. 3, No. 06; 2019

ISSN: 2456-7760

ANALYSIS OF HEAVY METAL POLLUTION IN URBAN SURFACE SOIL BASED ON THE OPTIMIZED N. L. NEMEROW MODEL

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Abstract

This study selected eight heavy metal elements in the surface layer as the research object. The mathematical points and single factor-Nemerow Index comprehensive index method are used to classify the sampling points and their pollutant concentrations into the corresponding functional areas to obtain the living area. The average score of the Nemerow Index in five areas, such as industrial area, mountainous area, main road area and Green Belt area. At the same time, combined with the geological accumulation index method, the comprehensive pollution index scores of different functional areas are calculated and the first method is carried out. Comparing and sorting according to the degree of pollution, the two methods obtain the same sorting, that is, the degree of pollution from more serious to slighter is Industrial area > Traffic area > Living area > Green Belt area > Mountainous area. With the help of relevant literature and previous data processing results, the analysis of the heavy metal pollution in the city is carried out, and the conclusions of the corresponding heavy metal pollution are obtained: Industrial production in industrial areas, domestic waste of residents in living quarters, loss during transportation in traffic areas; at the same time, considering that due to differences in altitude, pollutants will accumulate in the southwest. This research model provides an effective reference for the analysis of heavy metal pollution in the surface soil of urban areas in the future.

Keywords: Urban Surface Soil; N. L. Nemerow Index; Single Factor Index; Geological Accumulation Index

1. INTRODUCTION

Heavy metals refer to metals with a specific gravity greater than 5, including gold, silver, copper, etc. Heavy metals accumulate in the human body to a certain extent, causing chronic poisoning. The heavy metals mentioned in terms of environmental pollution mainly refer to heavy elements such as mercury, cadmium, lead, chromium and metalloid-like arsenic. Heavy metals are very difficult to biodegrade, but instead they can be enriched thousands of times under the biomagnification of the food chain and finally enter the human body. Heavy metals can interact strongly with proteins and enzymes in the human body, making them inactive or accumulating in certain organs of the body, causing chronic poisoning.

Soil is an important part of the Earth's surface system natural geographical environment, human agricultural production base. The people eat food for the sky, the food is based on the earth, and human beings live on the earth, always dealing with the soil. Soil quality refers to the ability of the soil to sustain the production of plants and animals, maintain and improve water and gas quality, and human health and life within the boundaries of natural or managed ecosystems (Kong& Liu, 2014).

The original data of the research object is from the National College Students Mathematical Modeling Contest (2011). The sampling points in the original data are from the five main functional areas of the living area, industrial area, mountainous area, main road area and Green Belt area. The location of the sampling point, the altitude and its functional area are listed, the concentration of the eight major heavy metal elements at the sampling point, and the background values of the eight major heavy metal elements.

2. METHODS

2.1 Spatial Distribution of Eight Heavy Metal Elements

2.1.1 The Topographic Map of The City

As mentioned in the introduction, the position coordinates and altitude of 319 sampling points are collected, and each sampling point is one square kilometer, thereby drawing the topographic map of the urban area using MATLAB software.

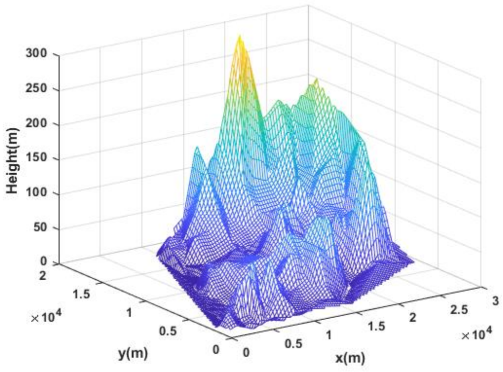


Figure 1 Urban three-dimensional topographic map

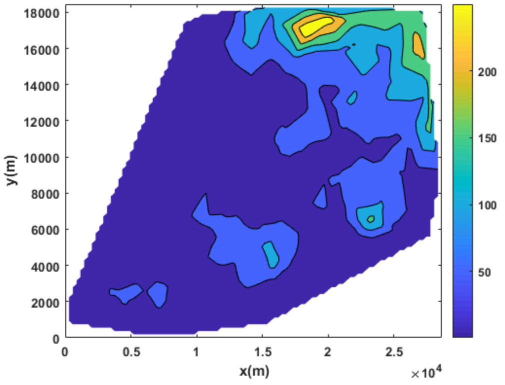


Figure 2 Urban flat topographic map

It can be seen from the topographic map of the urban area that the northeast direction of the urban area is higher, while the southwest direction is lower, but in general, the elevation of the urban area is not high, and the average elevation is less than 50 meters.

2.1.2 Functional Area Map of the Urban Area

According to the function of the city, the urban area inspected is divided into five major blocks: living area, industrial area, mountainous area, main road area and Green Belt belt. The position coordinates and altitude data 319 sampling points, the sampling points that the ribbon is located, since the position of each sampling point is determined, whereby the respective sampling points classified summary, the urban area map derived.

It is known from the following figure 3 that the spatial distribution map of each functional area in the urban area shows that the living area is evenly distributed at low altitude, and there is basically no living area in the high altitude; the industrial area is mainly distributed in the western part of the urban area; the main road area is evenly distributed. In various parts of the city; parks and green areas are mainly distributed in the southwest and some areas in the middle.

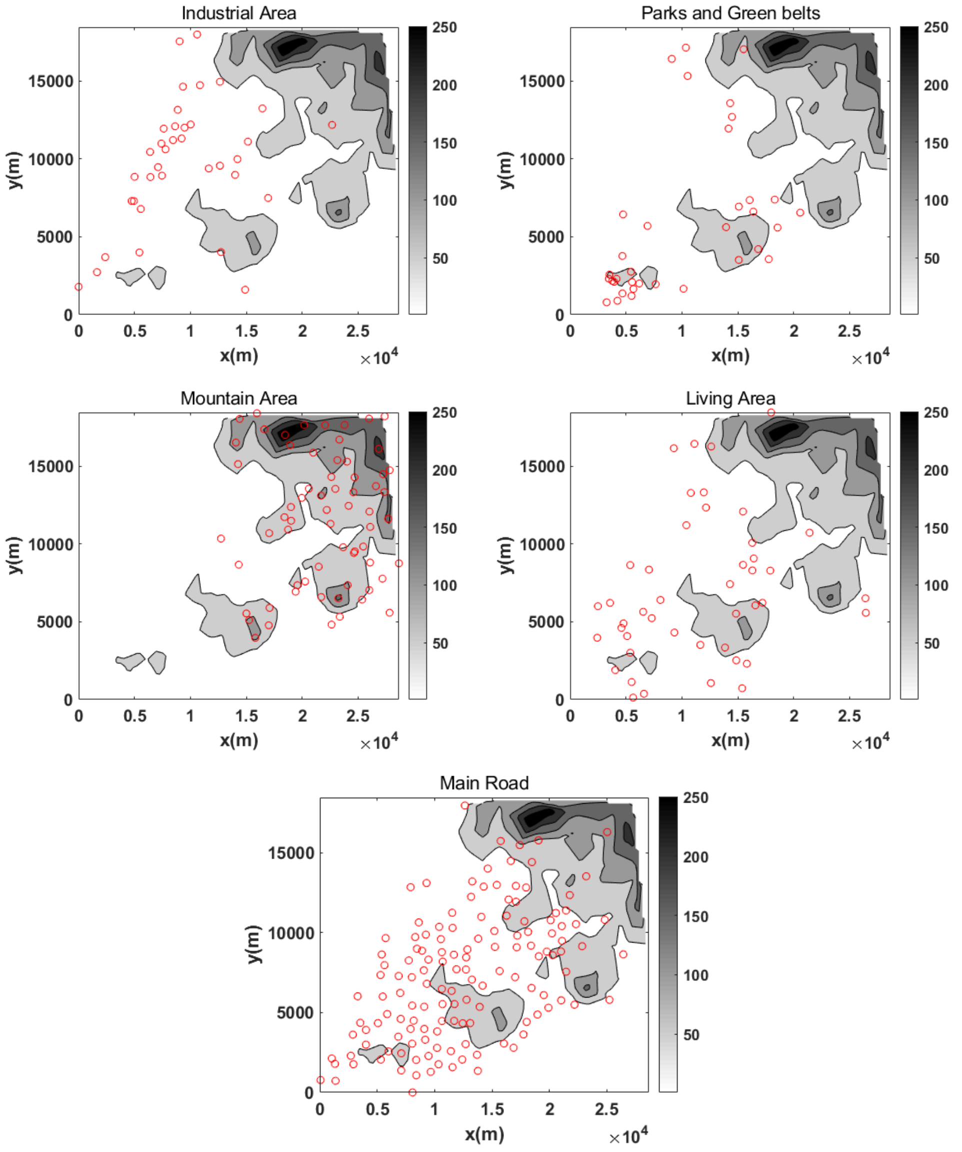
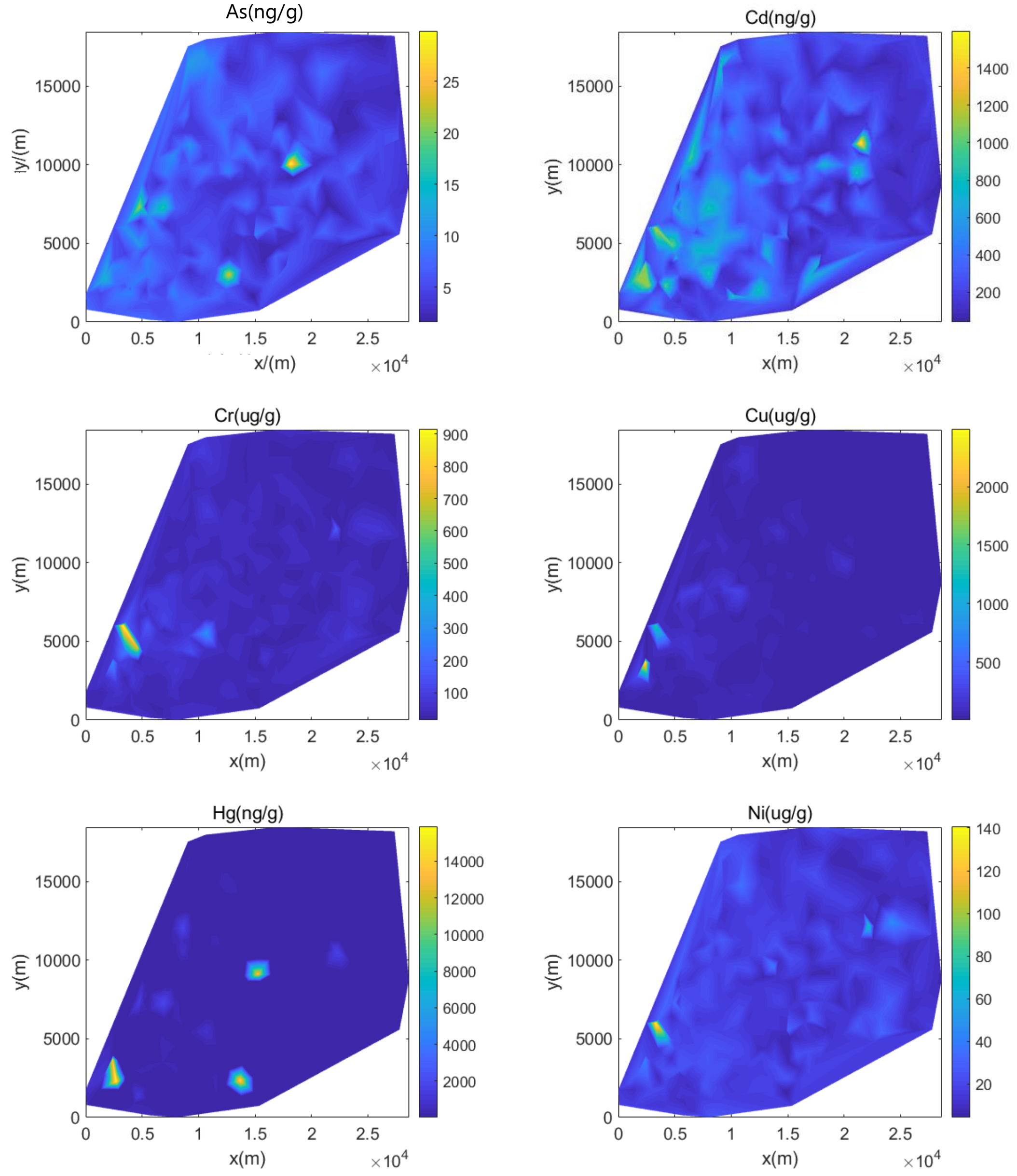


Figure 3 Distribution map of five functional areas

2.1.3 The Spatial Distribution of Eight Heavy Metal Elements

According to the concentration of the eight major heavy metal elements at the sampling point, the concentration of each heavy metal element at each sampling point is known, and the distribution of heavy metal elements corresponds to the urban distribution, which is classified into each functional area, and gets the spatial distribution of each element.



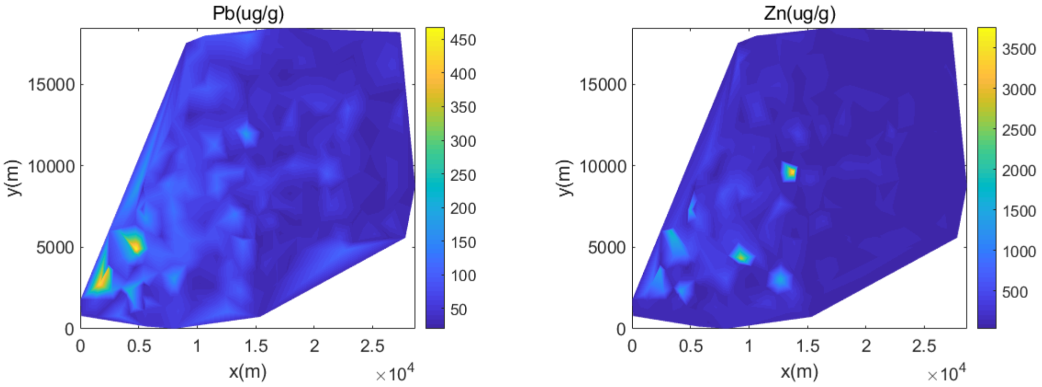


Figure 4 Spatial distribution of eight metal elements

It is known from the spatial distribution of various heavy metal elements that most of the major pollutions are located in the southwest and industrial areas. Moreover, the distribution of chromium, copper, zinc and mercury is more concentrated.

2.2 Degree of Pollution of Heavy Metals in Different Regions

2.2.1 Comprehensive Evaluation Model Based on Single Factor Index Method and Nemerow Index Method

(1) Typical Nemerow Index method

The evaluation of soil environmental quality is generally based on *the standard limits in the Soil Environmental Quality Standard* (GB15618-1955), using the single factor index method or the Nemerow index method. The single factor index method uses the measured data and the standard comparison classification to obtain the evaluation results. The Nemerow index method is developed from the single factor index method and is one of the most commonly used methods for comprehensive pollution index calculation at home and abroad. The method is a weighted multi-factor environmental quality index that takes into account extreme values or outstanding maximum values, and can comprehensively reflect the synergistic effects of various pollutants, thereby more accurately evaluating the pollution degree of various environmental factors (Leiet al., 2002).

The typical Nemerow Index method contains the arithmetic mean and maximum value of the single factor pollution index. The calculation formulas of the single factor pollution index method and the Nemerow index method are as follows:

Single Factor Index method:

$$F_{ij} = C_i / S_{ij} \tag{1}$$

Typical Nemerow Index method:

$$F_j = \sqrt{\frac{F_{j\cdot\max}{}^2 + F_{j\cdot ave}{}^2}{2}} \tag{2}$$

Among the formulas: F_{ij} is the calculated value of the i -th pollution factor under the j -th criterion of the quality standard of an environmental element; F_j is the score calculated according to the j -th standard of the quality of an environmental element; $F_{j\cdot\max}$ is the maximum value of F_{ij} under the j -th standard of the quality standard of an environmental element; $F_{j\cdot ave}$ is the arithmetic mean of F_{ij} under the j -th standard of an environmental element quality standard; i is the number of pollution factors involved, $i=1,2,...,n$; j is the quality category corresponding to the pollution factor selected for the quality standard of an environmental element, $j=1,2,...,\mathrm{m}$; C_i is the measured concentration of the i -th pollution factor; S_{ij} is the standard value of the i -th pollution factor under the j -th standard of an environmental factor quality standard.

The Nemerow index method has the advantages of simple calculation process, clear physical concept and strong operability (Han et al., 2017), but some problems appear in the actual application process, which leads to the evaluation results sometimes failing to accurately and accurately reflect the quality of the evaluated environmental elements. Mainly reflected in the following aspects: (1) In the evaluation, the method only considered the arithmetic mean and maximum value of the single factor pollution index, and the maximum weight is too high; (2) This method did not take into account the toxicity of the contaminated factors involved in the assessment (Han et al., 2017); (3) It did not reveal the impact of the types and quantities of the participating pollution factors on the evaluation values. Therefore, based on method corrections, this paper introduces the calculation of pollution factor weights in different environmental elements.

(2) Calculation of pollution factor weights in different environmental elements introduced based on method correction

In the process of quality evaluation of actual environmental factors, the typical Nemerow index method has a situation of insufficient applicability, which leads to insufficient objective and fair evaluation and insufficient persuasiveness. Therefore, many researchers have improved the method through various channels. Or amendments improve the applicability of the method and obtain more realistic and objective evaluation results.

The introduction of pollution factor weights is a major breakthrough in the correction of the typical Nemerow index method. Due to the different characteristics of environmental factors, the calculation of pollution factor weights is slightly different. For the quality assessment of environmental factors such as surface water and groundwater, the pollution factors are generally more and the categories are scattered, and the evaluation results are more comprehensive. The quality assessment of soils and sediments is mainly for specific pollution factors(Such as heavy metals, polycyclic aromatic hydrocarbons, etc.) with more obvious directivity (Swaine, 2000).

According to the environmental impact proposed by Swaine (2000), we classify mercury (Hg), plum bum (Pb),cadmium (Cd), arsenic (As), chromium (Cr), selenium (Se) as highly toxic elements into Class I, and class low toxic elements of manganese (Mn), molybdenum(Mo), vanadium (V), beryllium (Be), thorium (Th), uranium (U), nickel (Ni), zinc (Zn), and Cuprum

(Cu). Classified as Class II. Class I and Class II have weights of 3 and 2, respectively. Other heavy metal elements such as cobalt (Co), barium (Ba), radium (Ra), antimony (Sb), tin (Sn), titanium (Ti), etc. are classified as Class III. As shown in the table 1:

Table 1Weight of eight heavy metals

	As	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Zn**
Weight	3	3	3	2	3	2	3	2

Step 1: Calculate the F_{ij}

According to the Single factor index method(1), we substitute the data of the concentrations of the eight major heavy metal elements at the sampling point into Equation (1), the results are shown in Table 2:

Table 2 Single factor index results for eight heavy metals in five functional areas

	As	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Zn**
Living Area	0.25	0.97	0.23	0.49	0.19	0.37	0.23	0.95
Industrial Area	0.29	1.31	0.18	1.28	1.28	0.40	0.31	1.11
Mountain Area	0.16	0.51	0.13	0.17	0.08	0.31	0.12	0.29
Traffic Area	0.23	1.20	0.19	0.62	0.89	0.35	0.21	0.97
Green Belt Area	0.25	0.94	0.15	0.30	0.23	0.31	0.20	0.62

Step 2: Determine the weight matrix

Based on the single factor index results of the eight heavy metals in Table 2, the weight matrix is calculated:

$$W_{ij} = [3 \quad 3 \quad 3 \quad 2 \quad 3 \quad 2 \quad 3 \quad 2] \tag{3}$$

Then matrix normalize the data:

$$W_{ij} = [1/7 \quad 1/7 \quad 1/7 \quad 2/21 \quad 1/7 \quad 2/21 \quad 1/7 \quad 2/21] \tag{4}$$

Step 3: Revised $F_{j \cdot ave}$

The revised formula is:

$$F'_{j \cdot ave} = \sum_{i=1}^{n} F_{ij} W_{ij} \tag{5}$$

Among the formulas: W_{ij} is the weight of the i-th pollution factor calculated under the j-th standard of an environmental factor quality standard; $F'_{j\cdot ave}$ is the arithmetic mean of F_{ij} under the j-th standard of the quality standard of an environmental element after correction; F_{ij} is the calculated value of the i-th pollution factor under the j-th standard of the quality standard of an environmental element.

Step 4: Calculate F_j

$$F_j = \sqrt{\frac{{F_{j\cdot\max}}^2 + {F'_{j\cdot ave}}^2}{2}} \qquad (6)$$

In the formula: F_j is the score calculated according to the j-th standard of the quality of an environmental element.

Based on the model established above, we get the following calculations: ：

Table 3 Nemerow scores and pollution levels in five functional areas

Functional Area	Average Nemerow score	Degree of pollution
Living Area	0.99	Warning line
Industrial Area	1.67	Light pollution
Mountain Area	0.43	Safety
Traffic Area	1.56	Light pollution
Green Belt Area	1.80	Warning line

Degree of Pollution：< 0.5: Safe; 0.5-1: Warning Line; 1-2: Light pollution; 2-3: Moderate Pollution ; >3: Serious pollution

According to the calculation result of F_j, the average score of the Nemerow index method in the urban area is drawn by using MATLAB software. As shown in Figure 5 below:

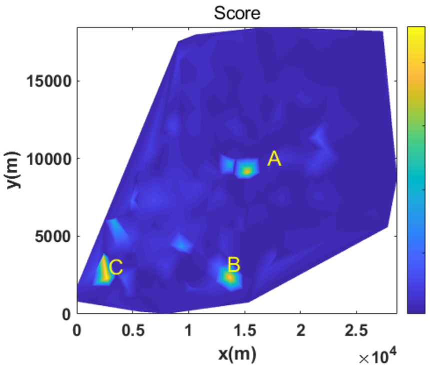


Figure 5 Score of the Nemerow Index in the urban area

The higher the score calculated by the Nemerow index method, the more serious the pollution in the area. It can be seen from observation of Figure 5 that the pollution levels in the central, southern and south western parts of the city are the most serious.

The scores calculated by the Nemerow index method are classified into five functional areas, and the average scores of the five functional areas are obtained, that is, the degree of pollution. As shown in Figure 6:

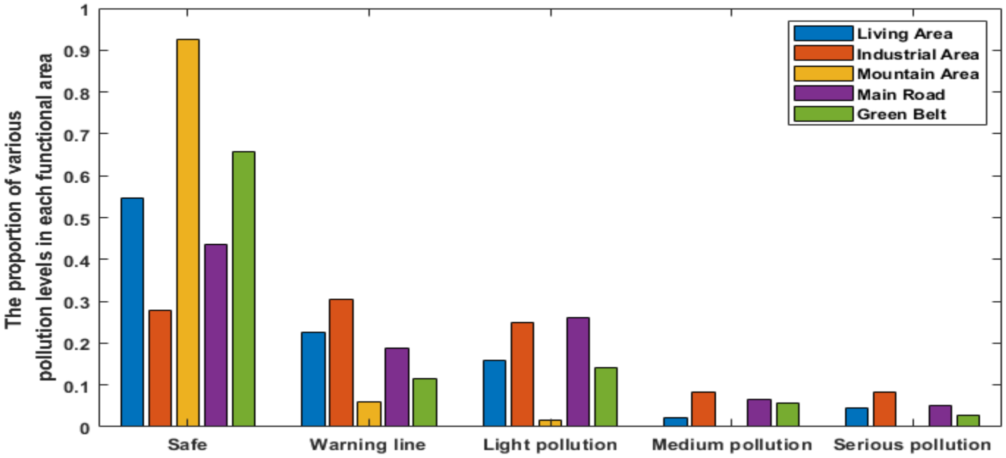


Figure 6 Distribution of pollution levels in five functional areas

It can be clearly seen that the industrial area of the urban area is the most polluted, followed by the traffic area, the living area is medium, the environmental condition of the park area is good, and the mountain environment is the least polluted.

2.2.2 Comprehensive Evaluation Model Based on the Cumulative Index of Geology (2010)

To evaluate the pollution of heavy metals, in addition to considering the background values of anthropogenic pollution and environmental geochemistry, consideration should also be given to changes in background values that may be caused by natural diagenesis. The geological accumulation index method takes into account the natural diagenetic factors and makes up for the shortcomings of the Nemerow comprehensive index method. The calculation formula is:

$$I_{geo} = \log_2\left(\frac{C_n}{1.5BE_n}\right) \qquad （7）$$

In the formula: I_{geo} represents the geological accumulation index; C_n represents the measured value of the element n in the sample (mg/kg); BE_n indicates the geochemical background value (mg/kg); The index of 1.5 is a correction index that takes into account changes in background values due to diagenesis.

Step 1: Classify sampling points into 5 functional areas

According to the concentration of the eight major heavy metal elements at the sampling point, the data is classified into five functional areas, as shown in Table 4:

Table 4 Geological accumulation index values of different heavy metals in five sampling points

	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Living Area	9.17	0.287	43.94	45.77	0.168	19.7	62.74	223.16
				…				
	5.72	0.193	80.35	26.57	0.111	19.8	57.64	89.08
Industrial Area	6.56	0.223	40.08	25.17	0.95	15.4	32.28	117.35
				…				
	14.08	1.092	67.96	308.61	1.04	28.2	434.8	966.73
Mountain Area	4.09	0.127	27.58	23.99	0.03	11.93	57.47	85.61
				…				
	2.72	0.070	19.45	9.12	0.015	7.09	22.73	32.86
Traffic Area	7.84	0.153	44.31	20.56	0.266	18.2	35.38	72.35
				…				
	5.93	0.146	45.05	22.51	0.086	17.2	36.18	94.59
Green Belt Area	5.93	0.201	45.19	24.9	0.259	14.6	35.88	102.65
				…				
	3.3	0.212	50.13	38.62	0.139	10.6	66.98	186.22

Step 2: Calculate the mean value of geological accumulation index of each heavy metal element in five functional zones

The calculation formula is:

$$\overline{I_{geo}} = \frac{1}{n}\sum_{i=1}^{n} I_{geo} \qquad (8)$$

In summary, the geological accumulation index of each heavy metal element is as follows:

Table 5 Geological accumulation index values of different heavy metals in five functional zones

	As	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Zn**
Living Area	0.13	0.34	0.15	0.88	0.20	-0.08	0.24	0.47
Industrial Area	0.21	0.80	-0.03	1.38	1.32	-0.03	0.67	0.86
Mountain Area	-0.53	-0.53	-0.45	-0.39	-0.60	-0.46	-0.46	-0.59
Traffic Area	-0.06	0.60	0.03	1.07	0.46	-0.18	0.28	0.65
Green Belt Area	0.14	0.18	-0.17	0.40	0.20	-0.34	0.13	0.05

Under each functional area, the eight heavy metal elements were averaged to obtain the results as shown in Table 6:

Table 6 Mean value of geological accumulation index of five functional areas

Functional Area	**Mean value of geological accumulation index**	**Degree of pollution**
Living Area	0.29	No pollution to moderate pollution
Industrial Area	0.65	No pollution to moderate pollution
Mountain Area	-0.50	No pollution
Traffic Area	0.36	No pollution to moderate pollution
Green Belt Area	0.07	No pollution to moderate pollution

Pollution degree index: < 0: No pollution; 0-1: No pollution to medium pollution; 1-2: Medium pollution; 2-3: Medium pollution to serious pollution; 3-4: Serious pollution; 4-5: Serious pollution to extremely serious pollution; > 5: Extremely serious pollution.

The higher the geological accumulation index, the more serious the pollution. It can be seen from the table that the industrial area is the most polluted, the traffic area is second, the living area is medium, the Green Belt area has better environmental conditions, and the mountainous environment is the best.

Using MATLAB software to draw the corresponding pollution levels of each region is shown in Figure7:

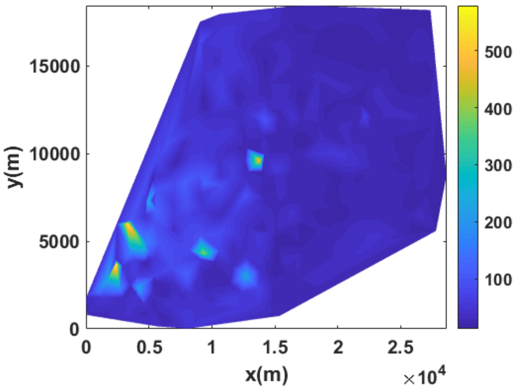


Figure 7 Urban geological accumulation index distribution map

It can be seen from Figure 7 that the pollution degree of the western and southwestern parts of the urban area is the most serious, and it tends to radiate to the surroundings.

According to the results of the integrated Nemerow index method and the geological accumulation index method, the pollution levels in the central, southern and southwestern parts of the city are the most serious, and the environmental conditions in the eastern and northern parts are the best. However, in terms of the accuracy of the results, it is obvious that the Nemerow index method is more accurate than the geological accumulation index method, and it can accurately depict the pollution level of each region. For example, under the Nemerow index method, the pollution level of the living area is a warning line; while the pollution level of the living area under the geological accumulation index method is no pollution to moderate pollution, the former is more accurate. Therefore, this article is based on the Nemerow index method.

2.3 Analysis of the main causes of heavy metal pollution

After the distribution of heavy pollutants is obtained, the following will analyze the location of the five functional zones in the urban area, the layout of the urban area and the overall situation of the urban area, and analyze the causes of heavy metal pollution in the urban area.

2.3.1 The Causes of Heavy Metal Pollution by Using the Regional Positioning of the City

Living Area: The content of copper in the living area is relatively high, which may be closely related to people's disposal of copper household goods. At the same time, the content of nickel and lead in the living area is relatively high, reflecting the residents' discarding to some extent. In the case of nickel batteries, batteries, etc.; high levels of chromium reflect the discharge of domestic sewage.

Industrial Area: In the industrial zone, the four elements of cadmium, copper, mercury and zinc all reached the highest content. The pollution of cadmium, copper and zinc comes from human exploitation of cadmium, copper and zinc minerals respectively; mercury pollution mainly comes from industrial discharge of wastewater.

Traffic Area: The content of cadmium, copper, lead and zinc in the traffic area is relatively high. Lead is mainly related to the combustion of leaded gasoline; cadmium, copper and zinc are related to the dust generated by the abrasion of automobile tires on traffic roads; in addition, heavy metal elements in automobile tire additives may also affect the heavy metal content in the soil.

Green Belt Area: The cadmium, lead and zinc content in the green area of the park is relatively high, which may be related to the dust generated by the wear of automobile tires passing through the road.

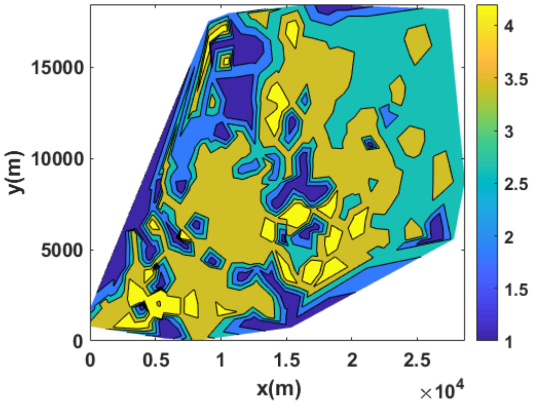


Figure 8 Urban area layout map

As can be seen from Figure 8, in addition to a large number of mountainous areas in the north, the urban area is composed of a main road area and a Green Belt area surrounded by living areas and industrial areas. According to the analysis of the distribution of heavy pollutants, the mountainous areas in the east are in a safe state; while the living areas and Green Belt areas north of the mountainous areas are in a warning line; the industrial and transportation areas between the two are mildly polluted. Thus, the entire regional layout can be divided into a warning line, light pollution and a safe state.

2.3.2 Determine the Cause of Heavy Metal Pollution by the Geographical Characteristics of The City.

According to the distribution of altitude, the pollution level of the urban area is shown in Figure 9:

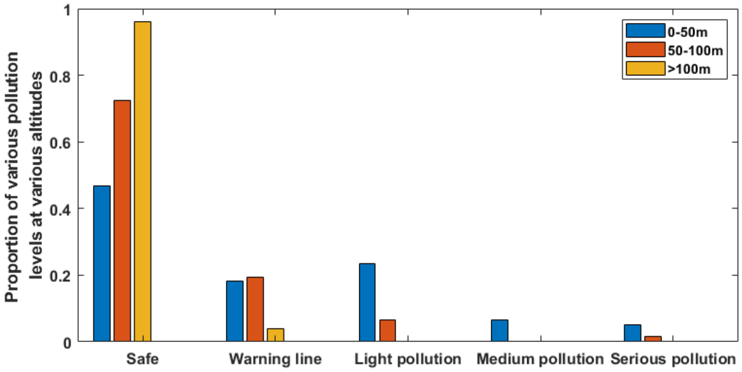


Figure 9 Ratio of various pollution levels at various altitudes

Then, due to the consideration of the distribution of altitude, using the Nemerow index method, the pollution level of the urban area is shown in Table 7:

Table 7 Evaluation of the pollution degree of Nemerow score at different altitudes

Altitude(m)	Mean of the Nemerow score	Degree of pollution
<50	1.4159	Light pollution
50-100	0.5999	Warning line
>100	0.4373	Safety

Pollution degree index: < 0.5: Safe; 0.5-1: warning line; 1-2: light pollution; 2-3: Medium pollution; > 3: Serious pollution

Based on Tables 7 and Figure 9 and the urban terrain, it is known that in the northeast-south westward terrain elevation, pollutants spread along the terrain in the natural physical and chemical migration of wind and water handling, and thus mainly accumulate in the south western part of the urban area; At the same time, because the south western region is a living area and a Green Belt area, the concentration of pollutants in the southwest is one of the most serious parts of the entire urban area.

3. CONCLUSIONS

In this paper, firstly we use the mathematical statistics, single factor-Nemerow Index comprehensive index method, geological accumulation index method and other methods to describe the pollution distribution of heavy metal pollutants in the urban area, and comprehensively evaluate the pollution degree of each area. Comparing the two methods leads to the same sorted result, that is, the order of pollution from more serious to slight is: Industrial Area > Traffic Area > Living Area > Green Belt Area > Mountainous Area.

The analysis of the heavy metal pollution in the urban area was carried out by means of the relevant literature and the results of previous data processing. First, according to the distribution map of 8 kinds of heavy pollutants, the functional areas to which the more polluted areas belong are known. Then, combined with the geographical difference in the urban area, the transmission route of heavy metal pollution is estimated. Finally, the conclusions of the corresponding heavy metal pollution are drawn: industrial production in industrial areas, domestic waste in residential areas, and loss during transportation in the main road area; at the same time, considering the difference in altitude, pollutants will accumulate in the southwest. section.

The advantages of this model are obvious: on the one hand, the single factor index method combined with the Nemerow Index method is used to establish a comprehensive evaluation model for soil heavy metal pollution. In particular, the model introduces pollution factor weights according to the environmental impact proposed by Swaine. The Nemerow index method has been amended to highlight the pollution effects of heavy metal elements that affect the ecology. Therefore, the model has carried out a good degree of depiction of heavy metal pollution in various parts of the city. On the other hand, through the geological accumulation index method, the natural diagenetic factors are taken into consideration, and the pollution degree of each region is obtained. The evaluation makes up for the deficiency of the Nemerow comprehensive index method. Finally, the results of the two evaluation method models are comprehensively analyzed to achieve the complementary advantages of the model.

REFERENCES

Kong, F. B., Liu,Y.. (2014). Comparison of Single Factor Index Method and Nemerow Index Method in Soil Environmental Quality Assessment. *Journal of Gansu Science and Technology*, 30(3): 21-22.

China Society for Industrial and Applied Mathematics. (2011). China Undergraduate Mathematical Contest Question in Modelling. Retrieved July17, 2018, from http:// Www.mcm.edu.cn/html_cn/node/a1ffc4c5587c8a6f96eacefb8dbcc34e.html, 2011.

Gary F. Bennett. (2007). N.L. Nemerow Industrial Waste Treatment: Contemporary Practice and Vision for the Future. *Journal of Hazardous Materials*, 132(1): 601-602.

National Environmental Protection Agency. (1995). GB15618-1955, Environmental quality standard for soils. *Environmental protection law of the People's Republic of China*, 2-6.

Lei, G. J., Chen, Z.L., Liu,Q. X., et al. (2013). Evaluation of Heavy Metal Pollution Degree and Potential Ecological Hazards in Soils of Guangzhou Suburbs. *China Environmental Science*, 33(s1): 49-53.

Han, S.X., Wang, L. H., Zhao,C.S..(2017). Applicability and Amendment Principle of Nemerow Index Method in Environmental Quality Assessment. *Journal of Agro-Environment Science*, 36(10): 2153-2160.

Gu, C. J., Pan, Y., Pan, M. J..(2002). Application and Existing Problems of Nemerow Index Method in Groundwater Quality Evaluation. *Environmental Protection Science*, 28(1): 45-47.

Swaine D J. Why trace elements are important. (2000). *Fuel Processing Technology*, s 65–66(1): 21-33.

Zhang, J. H., Zha, A. N., Wang, Z. F., et al. (2010). Differences between Nemerow Index and Geological Accumulation Index in Soil Heavy Metal Evaluation——Taking the Xiaoqinling Gold Belt as an Example. *Gold*, 31(8) :43-46.