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SPATIAL DISTRIBUTION AND ITS DRIVING FORCES ANALYSIS OF SOIL ORGANIC MATTER IN SEMI-ARID GRASSLAND OPEN-PIT MINING AREAS

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Highlights:
- collected and tested the content of soil organic matter in the open-pit coal mining areas;
- analyzed the spatial distribution of soil organic matter in the semi-arid grassland open-pit coal mining areas;
- quantitative determination of the main driving forces for the spatial distribution of soil organic matter;
- discussed the impact of open-pit coal mining on soil organic matter;
- suggestion for remediation of soil organic matter in mining areas.

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Abstract. Studying the spatial distribution of soil organic matter (SOM) and exploring its driving factors in semi-arid grassland open-pit coal mining areas is crucial for sustaining ecological development and security. Currently, research on SOM in mining areas lacks large-scale investigation, sampling, spatial distribution, and driving force research for semi-arid grassland open-pit coal mining areas, and it is unable to comprehensively grasp the distribution characteristics and driving force of SOM in open-pit coal mines. In view of this, this study took the Shengli Coal Field in Xilinhot City, the hinterland of Xilingol Grassland, as an example to research the spatial distribution and driving forces of SOM in the semi-arid grassland open-pit coal mining area. The results show that: (1) Areas with high SOM content were mainly distributed in the north of open-pit germanium mine, west No. 2 open-pit mine, and No. 1 open-pit mine. Areas with low SOM content were mainly distributed on the east and southeast sides of the city. From the spatial distribution perspective, mining has a certain impact on SOM in the study area. (2) Natural factors have a higher impact on SOM changes than human factors. The order of influence degree of each factor on the spatial distribution of SOM is NDVI > Water > Agriculture > Mine > Town > Industry. The sources of influence on SOM in the research area are relatively complex. (3) The interaction between two factors presents two relationships: nonlinear enhancement and dual-factor enhancement. A single factor is lower than the interaction between various factors. In the interaction between factors, the explanation rate of interaction between Town, Agriculture, Mine, NDVI, Water, and all other factors is above 0.85. This study has important practical significance for soil management in mining areas, ecological restoration, and planning of national land space, etc.

Keywords: soil organic matter, open-pit mining areas, spatial distribution, driving forces, semi-arid grassland.

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1. Introduction

China leads the world in coal production, consumption, and import. Coal is one of the most important basic energy and chemical raw materials in China, and has an important strategic position in the development of the national economy (Edenhofer, 2015). The large-scale exploitation of coal resources, on the one hand, has met the needs of China's economic construction, on the other hand, has also brought a series of ecological and environmental issues. Currently, coal resources in central and eastern China are increasingly depleted production is shrinking, and coal development is accelerating the transfer to western and northern regions such as Inner Mongolia and Xinjiang, where the ecological environment is fragile. Due to the non-selective location of coal mines, the exploitation and utilization of mineral resources inevitably occupy and destroy a large amount of land where coal resources are located, and at the same time affect and pollute the surrounding ecological environment, resulting in serious damage to the original ecological environment and a series of unavoidable ecological environmental problems. According to the different mining methods of coal, coal mining is divided into underground mining and open-pit mining (Wu, 2020). Open-pit mining is the direct stripping of topsoil and overlying strata of the ore layer, exposing the ore layer before mining, and stacking the stripped rock, soil, gangue, tailings, and other wastes in layers inside and outside the mining area to form a stepped pagoda shaped waste dump with alternating platforms and slopes. Open-pit mining coal mining has irreversible effects on the physical, chemical, and biological properties of the soil in the mining area (Feng et al., 2019). The main elements of mine reclamation are soil, plants, water, microorganisms, and so on, among which soil is the most important element of reclamation.

Soil is the life layer in the earth's surface system, with the richest biodiversity and the most active biogeochemical energy exchange and material cycle (transformation). Soil organic matter (SOM) refers to organic compounds that exist in the soil in various forms, including humus (i.e., substances formed by decomposition and transformation of dead residues such as plants, animals, and microorganisms entering the soil) and plant residues (Zhang, 2018). The content of SOM is an important indicator of soil fertility. SOM is not only a supporter of various nutrients required for plant growth but also determines the formation of soil structure and improves soil physical properties (Tao, 2014). SOM is an important source of various nutrients in the soil, providing plants with the nutrients they need, and playing an important role in the formation of soil structure and the improvement of physical properties. It is known as the "nutrient bank" of plants, and its content is an important indicator of soil fertility (Cheng et al., 2009). SOM also plays an important role in improving soil structure and texture, as well as coordinating physical properties such as soil fertilizer, water, heat, and air. Its dynamic changes affect soil fertility characteristics and water salt movement (Wang et al., 2012b). Revealing the spatial distribution and changing characteristics of SOM can ensure soil quality, improve crop yield, and increase soil carbon sink, thereby achieving sustainable development of agriculture and animal husbandry. The spatial distribution of SOM is of great significance to the global carbon cycle, food production, and other issues (Luo et al., 2022). Especially in grassland ecosystems, SOM is the largest organic carbon pool, accounting for about 90% of the entire system's organic carbon. SOM is the center of plant nutrient cycling (Gao et al., 2004).

Soil is the foundation of agricultural and animal husbandry production and the key to rebuilding the ecosystem of mining areas. Studying the spatial distribution and driving forces of SOM in mining areas has scientific guiding significance for the practice of land reclamation and ecological reconstruction. Nan Xia et al. conducted spatial analysis of SOM content in desert mining areas and found that the average SOM content in industrial and mining land was the highest at 7.35 g/kg (Xia et al., 2016). Zhang et al. (2018) studied the impact of coal mining subsidence on the spatial variability of SOM content in the loess region. Wang et al. (2012a) studied the succession law of reclaimed soil quality in the open-pit mining mine waste dump in the grassland area. Zhang et al. (2020) studied the spatial distribution of SOM in the coal mining subsidence area of Zhaogu Mine in Henan Province, China. Zhang et al. (2023) believe that the effects of mining activities on the SOM vary depending on the soil depth. Studying the influencing factors and spatiotemporal variability of SOM content in mining areas is not only important for understanding the changing laws of soil quality in mining areas, but also has important guiding significance for the selection of soil covering technology and vegetation types in waste dump sites (Li et al., 2016). Although scholars from various countries have conducted a large amount of research on SOM in mining areas, the current focus is mainly on small-scale research within the mining area, and there is a lack of large-scale investigation, sampling, spatial distribution, and driving force research on SOM in open-pit mining mines in semi-arid grassland areas, which makes it impossible to grasp the overall distribution characteristics of SOM in open-pit mining mines, it is even more difficult to grasp the impact of open-pit coal mining on SOM in surrounding farmland and pastures, especially for open-pit coal mining in ecologically fragile areas such as semi-arid grassland. In view of this, this study aims to (1) determine the content of SOM in the Shengli coalfield and its surrounding area in Xilinhot, Inner Mongolia Autonomous Region, China; (2) analyze the characteristics of the spatial distribution of SOM in the semi-arid grassland open-pit coal mining area; and (3) analyze the driving forces of the spatial distribution of SOM in the semi-arid grassland open-pit coal mining area.

2. Materials and methods

2.1. Study area

The study area is located in Shengli Mining Area, Xilinhot City, Xilingol League, China (Figure 1). Xilinhot City is an important ecological barrier in northern China, belonging to the northern ecological function zone of wind prevention and sand fixation in China's ecological function zoning. Shengli Mining Area is located in the core area of Xilingol Grassland. The geographical coordinates of the study area are 115°24′26″~116°26′30″ E, 43°54′15″~44°13′52″ N. The study area belongs to a temperate semi-arid continental monsoon climate, with short spring and autumn, no intense heat in summer, and long winter. The soil types mainly include chestnut soil, meadow chestnut soil, meadow soil, etc. Some

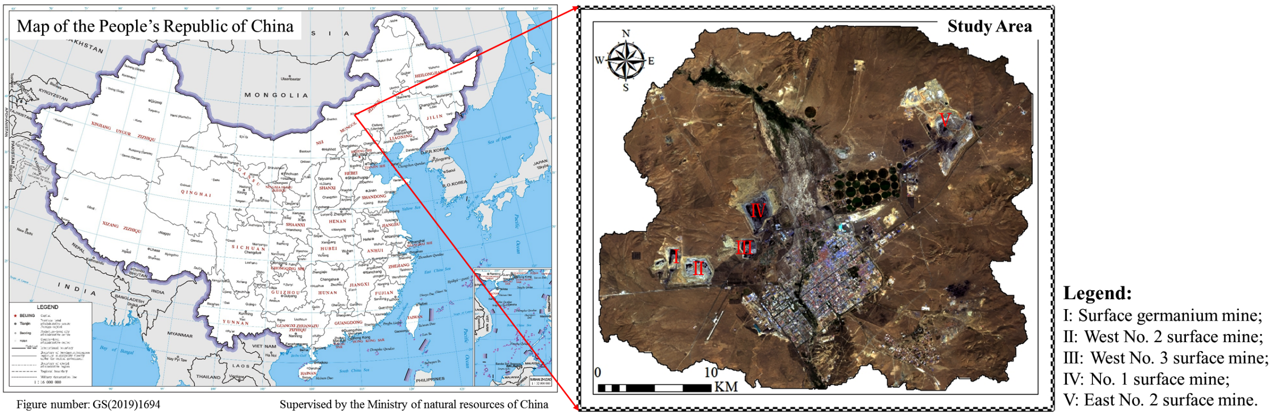

Figure 1. Location of the study area

areas present sandy and gravelly chestnut soil due to grassland degradation, with low SOM content and poor soil fertility. The natural vegetation type is generally dominated by typical grassland vegetation. The geomorphology consists of four geomorphic units: tectonic denudation terrain, denudation accumulation terrain, erosion accumulation terrain, and lava platform.

2.2. Data source and processing

The data sources are shown in Table 1. ENVI 5.1 software is used for remote sensing image preprocessing. The Normalized Difference Vegetation Index (NDVI) is calculated using the band operation method (Equation (1)). The land classification system and data in 2017 were based on existing research results (Wu et al., 2021, 2022) (Figure 2). The Distance To the Nearest (DTN) townland, the DTN agricultural land, the DTN industrial storage land, the DTN mining land, the DTN road network land, and the DTN water land are obtained using the European distance method in ArcGIS spatial analysis. The mining land consists of open-pit, waste dump, and mining industrial square land in the mining area. The slope and aspect are calculated using Topographic Modeling in ENVI.

Table 1. Data source

Name	Source
DEM	Geographical State Monitoring Cloud Platform website
Landsat 8	US Geological Survey website

$$NDVI = \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + \rho_{Red}}, \quad (1)$$

where ρ_{Red} stands for the red band, ρ_{NIR} stands for the near-infrared band.

2.3. Collection and testing of soil samples

152 surface soil samples were collected in August 2017 (Figure 3). In this study, a dedicated soil sampler was used to collect soil samples. The depth of the soil samples is 0–20 cm. Mark the polythene bags containing the soil samples and take photographs of the site. SOM was determined by the potassium dichromate-external heating method.

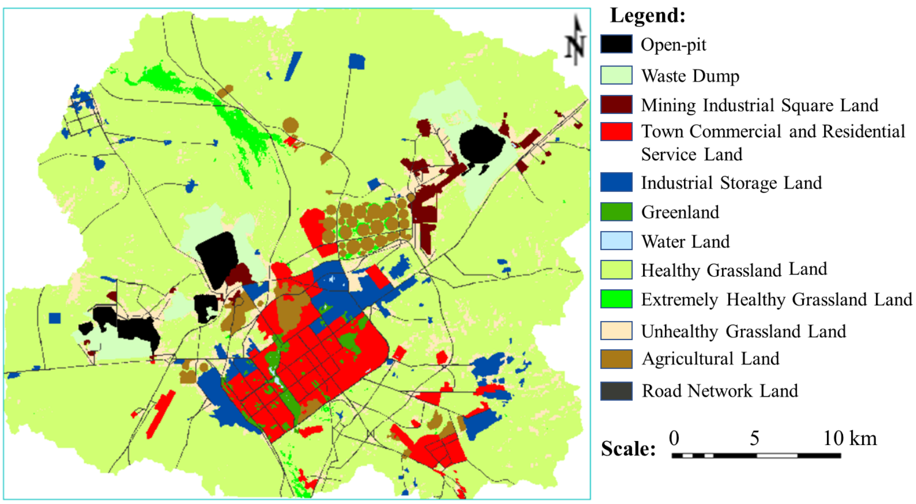

Figure 2. Land use classification map of the study area

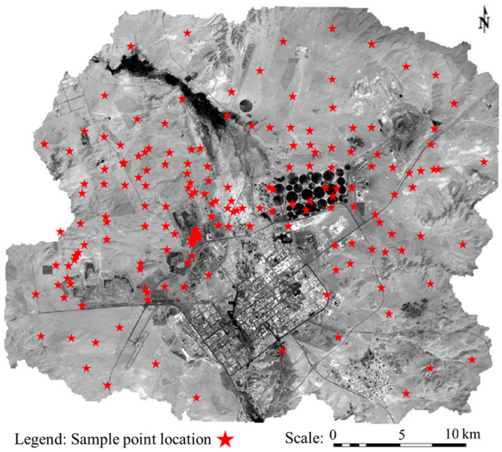

Figure 3. Spatial distribution of soil sample plots

2.4. Making of the spatial distribution map of soil heavy metals

SOM data were identified as outliers using the mean ±3 times the standard deviation, and data outside this range were marked as outliers and replaced with the maximum and minimum values of the normal data, respectively. SPSS software was used to conduct descriptive statistical analysis, K-S test, and one-way analysis of variance on the sample data. Canoco software was used to analyze the typical correspondence between terrain factors and SOM. Semi-variance function analysis and theoretical model fitting were carried out through the geo-statistical software GS+9.0. Conduct trend effect analysis, Kriging interpolation, and cross-validation on the ArcGIS platform, as well as map editing to produce a spatial distribution map of SOM (Zhao et al., 2020).

2.5. Analysis method for driving forces of spatial distribution of SOM of open-pit coal mining area

According to the characteristics of the study area and the needs of this study, elevation, slope, aspect, vegetation (NDVI), and DTN water are selected as natural driving factors in this study. The DTN mining land, the nearest townland, the nearest industrial storage land, the nearest agricultural land, and the nearest road network land are selected as human driving factors. The geographic detector is a new spatial statistical method that was first proposed by Jinfeng Wang et al. to detect spatial heterogeneity and reveal driving factors (Wang & Xu, 2017; Wang et al., 2016b). This study mainly applies its two functions of factor detection and interaction detection to carry out research.

(1) Spatial differentiation and factor detection. The spatial heterogeneity of detection y(SOM) and the extent to which detection of each factor explains the spatial heterogeneity of the attribute y(SOM). Measured with a q value, the expression is:

$$q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2}, \tag{2}$$

where q represents the interpretation rate of the influencing factor, with a value range of 0 to 1. The larger the q value, the stronger the interpretation rate. The X and Y variables are superimposed in the Y direction to form an L layer, represented by h = 1, 2, 3,..., L. N_h and N are the sample numbers of the subregion h and the entire region, respectively. σ_h^2 and σ^2 is the discrete variance of the subregion h and the entire region Y, respectively

(2) Interaction detection. Identify the interactions between different independent variable factors, that is, evaluate whether the combined effects of factors X_1 and X_2 will increase or decrease the explanatory power of the dependent variable y. The evaluation method is to first calculate the q values of the two factors X_1 and X_2 for y: $q(X_1)$ and $q(X_2)$, and calculate the q values when they interact: $q(X_1 \cap X_2)$, and compare $q(X_1)$, $q(X_2)$, and $q(X_1 \cap X_2)$. Table 2 shows the relationship between the two factors.

Table 2. Types of interaction between two covariates

Interaction types	Judgement criteria
Enhance, bivariate	$q(X_1 \cap X_2) > q(X_1)$ and $q(X_2)$
Enhance, nonlinear	$q(X_1 \cap X_2) > q(X_1) + q(X_2)$
Weaken, univariate	$q(X_1 \cap X_2) < q(X_1)$ or $q(X_2)$
Weaken, nonlinear	$q(X_1 \cap X_2) < q(X_1)$ and $q(X_2)$
Independent	$q(X_1 \cap X_2) = q(X_1) + q(X_2)$

X_1 and X_2 represent the impact factors of vegetation degradation. The symbol "∩" represents the interaction between X_1 and X_2.

3. Results

3.1. Spatial distribution of SOM in the open-pit coal mining area

In this study, the natural breakpoint method was used to divide SOM spatial distribution into three parts: low, modeled, and high-content regions of SOM. The basic idea of the natural breakpoint method is to minimize the average deviation between each category and the average value of the category and to maximize the deviation between each category and the average value of other categories (Ding et al., 2019). As can be seen from Figure 4, areas with high SOM content are mainly distributed in the north of open-pit germanium mine, west No. 2 open-pit mine, and No. 1 open-pit mine. Areas with low SOM content are mainly distributed on the east and southeast sides of the city. Overall, the SOM in areas far from the city is relatively high. The reason behind this is that areas far from cities are mainly pastures, so animal manure can increase SOM content. As can be seen from Table 3, the spatial distribution of SOM content shows a normal distribution pattern. The area of the Modify Content Regions of SOM

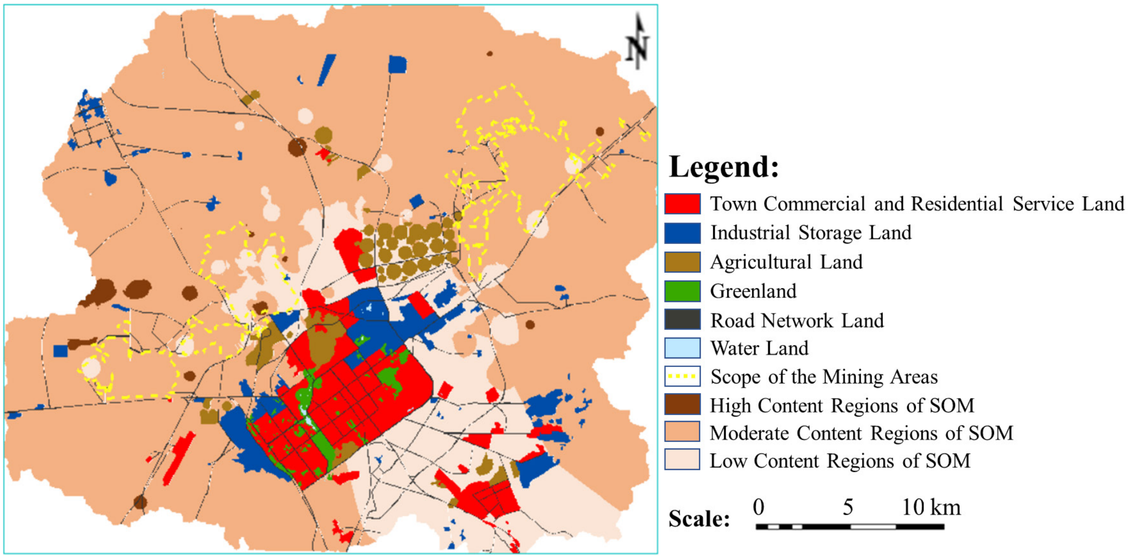

Figure 4. Spatial distribution map of SOM

is the largest, 5 times the area of the Low Content Regions of SOM, and 93 times the area of the High Content Regions of SOM. The distribution of High Content Regions of SOM is relatively scattered, while the distribution of Low Content Regions of SOM is relatively centralized. From the spatial distribution perspective, mining has a certain impact on SOM in the study area.

Table 3. Area and proportion of low, moderate, and high content regions of SOM

Types	Low content regions of SOM	Moderate content regions of SOM	High content regions of SOM
Areas (km^2)	142.05	706.57	7.60
Proportion	13.91%	69.18%	0.74%

3.2. Driving forces analysis of the spatial distribution of soil organic matter

(1) Single-factor analysis of detection factors
From Figure 5, it can be seen that NDVI, the DTN townland, the DTN agricultural land, the DTN mining land, and the DTN water all exceed 0.8 for the *q* value of SOM, indicating that NDVI, town, agriculture, mining, and water have a strong driving effect on the spatial distribution of SOM. The DTN industrial storage land has a *q* value of more than 0.6, indicating that industry has a significant driving effect on the spatial distribution of SOM. The *q* values of distance, elevation, slope, and aspect to the nearest road network land are all less than 0.4, indicating that these four driving factors have no significant driving effect on the spatial distribution of SOM.

From the perspective of the entire study area, natural factors have a higher impact on SOM changes than human factors. Li et al. (2024) obtained similar results.The order of the impact of each factor on the spatial distribution of SOM is: NDVI(0.995009) > Water(0.921762) > Agriculture(0.870131) > Mining(0.842113) > Town(0.830109) > Industry(0.647151). Among natural factors, NDVI and water area have the most significant impact. The *q* values of NDVI and water area are 1.00 and 0.92, respectively, with an interpretation rate of over 90%. Among human factors, agriculture, mining, and town have a significant impact on the spatial distribution of SOM, with *q* values of 0.87, 0.84, and 0.83, respectively, with an explanatory power of over 80% (Figure 5). Water bodies and areas with high vegetation coverage will attract animals, thereby increasing SOM content. Continuous fertilization of agricultural

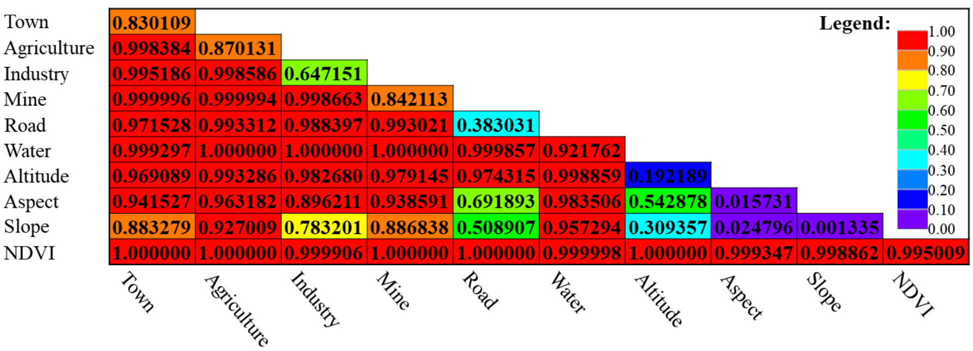

Figure 5. Interaction detector results of spatial distribution driving factors of SOM

land can also increase SOM content. Continuous human disturbance around urban and industrial areas can cause soil compaction, leading to a decrease in SOM content. It can be seen that the sources of influence on SOM in the research area are relatively complex.

(2) Analysis of interaction between detection factors

As can be seen from Figure 5, the interaction between the two factors shows two relationships, namely non-linear enhancement and two-factor enhancement, with no independently acting factors. In the interaction between factors, the explanation rate of interaction between Town, Agriculture, Mine, NDVI, Water, and all other factors is above 0.85. The eight groups with an interpretation rate of 1.000000 for the spatial distribution of SOM by the interaction between two factors are Town ∩ NDVI, Agriculture ∩ Water, Agriculture ∩ NDVI, Industry ∩ Water, Mine ∩ Water, Mine ∩ NDVI, Road ∩ NDVI, and Altitude ∩ NDVI. The results show that Town, NDVI, Agriculture, Water, Industry, Mine, Road, and Altitude interact together to affect the spatial variation of SOM in the study area.

4. Discussion

4.1. Analysis of influencing factors of SOM

According to the results of this study, NDVI, water, mine, town, agriculture, and industry all have an impact on SOM. Vegetation is the nutrient source of SOM, and the quantity and quality of its inputs have an important effect on the formation and transformation of SOM (Kirchmann et al., 2004). In the grassland environment, a large number of dead roots of herbaceous plants enter the recycling and transformation process of organic matter in the soil every year (Fang & Lin, 2024; Han et al., 2022). The water conditions in semi-arid grassland areas directly affect plant growth and residue input, as well as indirectly affect the decomposition and accumulation of SOM by influencing microbial activity. Under the condition of insufficient water, the grassland ecosystem is more conducive to the preservation and accumulation of SOM. The reduction of litter input, destruction of aggregates, and disturbance of microbial communities caused by tillage activities are the main factors hindering the formation and transformation of SOM in farmland (Liu et al., 2010). In farmland, different cover crops also play an important role in the formation process of SOM (Fang & Lin, 2024). As a comprehensive reflection of land activities, land use can change land productivity, soil quality, and fertility, thereby affecting SOM. The impact of the town on SOM is mainly reflected in the decrease in soil organic carbon density and soil fertility. The impact of industrial activities on soil organic matter is mainly reflected in soil pollution, which not only directly affects soil quality and agricultural production, but also has a significant impact on global climate change.

4.2. Effects of coal open-pit mining on surface soil organic matter

The semi-arid grassland has a flat terrain, and the greatest impact of open-pit coal mining on ecology is the changes in topography and geomorphology. As the elevation of the open-pit continues to decrease, surrounding surface water and groundwater converge towards the pit, indirectly affecting the ecological function of the surrounding area, and further affecting the content of surface SOM. The external waste dump has a high terrain and unstable geological structure, which is extremely prone to water and soil loss, and will also affect the ecological functions of the surrounding areas, further affecting the content of organic matter in the surface soil. Dust will be generated during coal excavation, transportation, and production, and substances such as heavy metals in the dust will also have an impact on the content of organic matter in the surface soil in the surrounding area.

Water is the source of life, especially in semi-arid grassland areas. Water is the most critical factor affecting landscape ecological health. Groundwater is a key factor for maintaining surface water resources and biological growth in semi-arid grassland. The drainage of groundwater from open-pit coal mining has led to the gradual drainage of the phreatic aquifer in the semi-arid grassland, and the water replenishment, runoff, and drainage conditions of the groundwater have also changed. The groundwater level has decreased, resulting in a decrease in the runoff of surface rivers in the semi-arid grassland, a cutoff of surface water, a decrease in the ability to conserve and regulate water sources, a gradual shrinkage of wetlands, a sharp decline in biomass, and gradual degradation of grasslands, further affecting the organic matter content of surface soil.

At the same time, the open-pit mining process generally adopts ultra-large off-highway truck drainage and ultra-large wheel bulldozers for leveling. The use of large-scale heavy machinery leads to the crushing of reconstructed soil, the disturbance of soil internal structure, the decrease of soil pore number, the decrease of connectivity and water seepage capacity, and the increase of soil bulk density (Liu et al., 2016; Bai & Zhao, 2001). Studies have shown that the reduction of soil porosity is a substantial problem causing soil compaction, which directly changes the biology, physical, and chemical properties of soil, water transport, and SOM status (Zhang et al., 2016).

4.3. Remediation of soil organic matter in mining areas

The ultimate goal of studying the spatial distribution and driving forces of SOM in open-pit coal mining areas is to guide the improvement and remediation of soil in mining areas. Open pit mining destroys the structure of the surface soil layer and vegetation distribution, greatly damaging land resources. Through reclamation of the mining area land, it can improve the soil structure and biology, physical and chemical properties (Wang et al., 2012a).

Remediation measures for SOM in mining areas mainly include physical, chemical, biological, and engineering measures (Wang et al., 2016a). Physical measures include topsoil removal, guest soil removal, deep tillage, and soil plowing. Chemical measures include acid, alkali, and salt to improve soil acidification. Biological measures include the application of organic fertilizers, sawdust, manure, organic sludge, etc. Engineering measures can be summarized as an integrated process of "stripping-disposal-reclamation". Shengli Coal Field is adjacent to the northern suburb of Xilinhot City. Urban sludge and its compost are good organic fertilizers and soil conditioners, which have broad application prospects in soil improvement and remediation in open-pit coal mines. At the same time, it can also solve the problem of urban sludge disposal, with good environmental, ecological, economic, and social comprehensive benefits through treating waste and turning waste into treasure (Gao et al., 2016). Bryophytes play an important role in vegetation restoration and soil nutrient enrichment in mining areas. Bryophytes can serve as pioneer species in damaged mines, overcoming extreme environments such as heavy metal pollution, poor soil, nutrient imbalance, and drought in mining areas and settling well. The accumulated bryophytes and humus can create conditions for the settlement of other species (Chen & Zhang, 2010). Bryophytes can also form moss crusts, which can greatly improve the ability of soil in coal mine reclamation areas to resist wind and rain erosion (Feng et al., 2022). Therefore, it is possible to consider using bryophytes to increase the content of SOM in the mining area.

4.4. Limitations and uncertainties

A total of 152 sample points were collected and tested in this study. If more sample points were collected, more accurate results of the spatial distribution of SOM would be obtained. The research area is a regional complex inlaid by various ecosystems such as industry (including thermal power plants, cement plants, etc.), agriculture, animal husbandry, mining (including coal, petroleum, germanium, etc.), and cities. This study only uses the method of geographical detectors to analyze the driving forces of the spatial distribution of SOM, without in-depth research on the impact mechanism of various natural and human factors on the spatial distribution of SOM. In addition, continuous collection of SOM data for many years and analysis of the spatial distribution and driving forces of SOM in mining areas in time series can reveal more problems. However, these limitations and uncertainties are not large enough to affect the general results of this study.

5. Conclusions

This study took the Shengli Coal Field in Xilinhot City, the hinterland of Xilingol Grassland, as an example to study the spatial distribution and driving forces of SOM in the semi-arid grassland open-pit coal mining area. The results showed that: (1) The spatial distribution of SOM showed a normal pattern, and the area of Moderate Content Regions of SOM was the largest, which was 5 times that of Low Content Regions of SOM, 93 times that of High Content Regions of SOM. The distribution of High Content Regions of SOM was relatively scattered, while the distribution of Low Content Regions of SOM was relatively centralized. Areas with high SOM are mainly distributed in the north of open-pit germanium mine, west No. 2 open-pit mine, and No. 1 open-pit mine. Areas with low SOM content are mainly distributed on the east and southeast sides of the city. From the spatial distribution perspective, mining has a certain impact on SOM in the study area. (2) Natural factors have a higher impact on SOM changes than human factors. The driving factors that affect the spatial distribution of SOM include vegetation, water, mining, town, agriculture, and industry. The order of impact of each factor on the spatial distribution of SOM is NDVI > Water > Agriculture > Mining > Town > Industry. The sources of influence on SOM in the research area are relatively complex. (3) The interaction between two factors presents two relationships: nonlinear enhancement and dual-factor enhancement. A single factor is lower than the interaction between various factors. In the interaction between factors, the explanation rate of interaction between Town, Agriculture, Mine, NDVI, Water, and all other factors is above 0.85.

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Author's contributions

Dejun Yang and Yongjun Yang constructed the review. Ziqiang Dai collected the literature and helped in the drafting of the manuscript. Zhenhua Wu and Xiaoying Wang wrote and revised the manuscript. Qiao Yu and Weibo Ma advised and supervised the project. Zhenhua Wu provided funding.

Disclosure statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Availability of data and materials

The datasets during and/or analyzed during the current study available from the corresponding author on reasonable request.

References

Bai, Z., & Zhao, J. (2001). Land reclamation, ecological restoration and sustainable development in the areas of mining and project construction. *Science and Technology Review*, *16*, 49–52.

Chen, X., & Zhang, Z. (2010). Bryophytes on karst rocky desertification in Laowanchang Gold Mine of Guizhou province, P. R. China. *Journal of Guizhou Normal University (Natural Science Edition)*, *4*, 144–148.

Cheng, P., Wu, J., Li, D., & He, T. (2009). Quantitative prediction of soil organic matter content using hyper spectral remote sensing and geo-statistics. *Transactions of the Chinese Society of Agricultural Engineering*, *25*, 142–147.

Ding, Y., Zhang, M., Qian, X., Li, C., Chen, S., & Wang, W. (2019). Using the geographical detector technique to explore the impact of socioeconomic factors on $PM_{2.5}$ concentrations in China. *Journal of Cleaner Production*, *211*, 1480–1490. https://doi.org/10.1016/j.jclepro.2018.11.159

Edenhofer, O. (2015). King coal and the queen of subsidies. *Science*, *349*, 1286–1287. https://doi.org/10.1126/science.aad0674

Fang, J., & Lin, C. (2024). A review of the formation and transformation process of soil organic matter and its influencing factors. *Journal of Subtropical Resources and Environment*, *19*, 24–34.

Feng, C., Gan, Y., He, X., Lei, S., Cheng, W., Huang, J., & Kou, J. (2022). Bryophyte diversity of a grassland mining area and its relationship with soil physical and chemical properties. *Journal of East China Normal University (Natural Science)*, 76–84.

Feng, Y., Wang, J., Bai, Z., & Reading, L. (2019). Effects of surface coal mining and land reclamation on soil properties: A review. *Earth-Science Reviews*, *191*, 12–25. https://doi.org/10.1016/j.earscirev.2019.02.015

Gao, Y., Han, X.-G., & Wang, S. (2004). The effects of grazing on grassland soils. *Acta Ecologica Sinica*, *24*, 790–797.

Gao, Y., Yu, Y., Wang, J., & Liu, M. (2016). *Ecological restoration in coal mining area*. Science Press.

Han, S., Wang, E., Chen, X., & Fu, Y. (2022). Accumulation of SOM fractions to croplands and plantations converted from cropland with black soil. *Land Degradation & Development*, *33*, 638–648. https://doi.org/10.1002/ldr.4187

Kirchmann, H., Haberhauer, G., Kandeler, E., Sessitsch, A., & Gerzabek, M. H. (2004). Effects of level and quality of organic matter input on carbon storage and biological activity in soil: Synthesis of a long-term experiment. *Global Biogeochemical Cycles*, *18*, 1–15. https://doi.org/10.1029/2003GB002204

Li, B., Wang, J., Wang, H., & Bai, Z. (2016). Progress on measurement and factors of soil organic carbon in mineral area. *Soils*, *3*, 434–441.

Li, Y., Li, Z., Zheng, S., Lin, J., Yang, S., Zhao, L., & Zhang, X. (2024). Elucidating the spatial differentiation of soil organic matter and influencing factors within the Yihe River Basin. *Environmental Science*, 1–17.

Liu, T., Wang, J., Qin, Q., Wang, H., & Bai, Z. (2016). Review on the study of the effect of mechanical compaction on soil pore characteristics in the mining area. *Chinese Journal of Soil Science*, *47*, 233–238.

Liu, W., Su, Y., Yang, R., Wang, X., & Yang, X. (2010). Land use effects on soil organic carbon, nitrogen and salinity in saline-alkaline wetland. *Sciences in Cold and Arid Regions*, *2*, 263–270

Luo, C., Zhang, X., Meng, X., Zhu, H., Ni, C., Chen, M., & Liu, H. (2022). Regional mapping of soil organic matter content using multitemporal synthetic Landsat 8 images in Google Earth Engine. *Catena*, *209*, Article 105842. https://doi.org/10.1016/j.catena.2021.105842

Tao, L. (2014). *Analysis an characteristics of soil arganie matter in opencast using graund hyperspectral data*. Xinjiang University.

Wang, J., & Xu, C. (2017). Geodetector: Principle and prospective. *Acta Geographica Sinica*, *72*, 116–134.

Wang, J., Yang, R., & Bai, Z. (2012). Succession law and model of reclaimed soil quality of opencast coal mine dump in grassland. *Transactions of the Chinese Society of Agricultural Engineering*, *28*, 229–235.

Wang, J., Bai, Z., Yang, R., & Qin, Q. (2016). *Theory and method of quantitative characterization of reconstructed soil properties in open pit coal mine in Loess Region*. Science Press.

Wang, J.-F., Zhang, T.-L., & Fu, B.-J. (2016). A measure of spatial stratified heterogeneity. *Ecological Indicators*, *67*, 250–256. https://doi.org/10.1016/j.ecolind.2016.02.052

Wang, X., Yang, J., Jin, W., Liu, G.-M., Liu, M., Yao, R., & Yu, S. (2012). Change of soil organic carbon reserve in northern Manasi county in last 30 years. *Transactions of the Chinese Society of Agricultural Engineering*, *28*, 223–229.

Wu, Z. (2020). *Study on landscape pattern optimization of large-scale surface coal base in semi-arid steppe based on 3S integrated technology*. China University of Mining and Technology.

Wu, Z., Lei, S., Yan, Q., Bian, Z., & Lu, Q. (2021). Landscape ecological network construction controlling surface coal mining effect on landscape ecology: A case study of a mining city in semi-arid steppe. *Ecological Indicators*, *133*, Article 108403. https://doi.org/10.1016/j.ecolind.2021.108403

Wu, Z., Lu, Q., Lei, S., & Yan, Q. (2022). Study on landscape ecological classification and landscape types evolution: A case study of a mining city in semi-arid steppe. *Sustainability*, *13*, 9541–9561. https://doi.org/10.3390/su13179541

Xia, N., Tiyip, T., Ding, J., Nurmemet, Y., Zhang, D., & Liu, F. (2016). Estimation model of soil organic matter in desert mining area based on multispectral image data. *Transactions of the Chinese Society of Agricultural Engineering*, *32*, 263–267.

Zhang, H. (2018). *Environmental pedology*. Chemical Industry Press.

Zhang, H., Liu, W., Zhang, H., Fan, L., & Ma, S. (2020). Spatial distribution of soil organic matter in a coal mining subsidence area. *Acta Agriculturae Scandinavica, Section B – Soil & Plant Science*, *70*, 117–127. https://doi.org/10.1080/09064710.2019.1676916

Zhang, J., Wei, R., & Guo, Q. (2023). Impacts of mining activities on the spatial distribution and source apportionment of soil organic matter in a karst farmland. *Science of the Total Environment*, *882*, Article 163627. https://doi.org/10.1016/j.scitotenv.2023.163627

Zhang, L., Wang, J., & Liu, T. (2016). Landscape reconstruction and recreation of damaged land in opencast coal mine: A review. *Advances in Earth Science*, *31*, 1235–1246.

Zhang, Y., Wang, J., & Zhu, Y. (2018). Effects of land subsidence caused by coal mining on the spatial variation of soil total nitrogen and organic matter concentrations in loess area. *Chinese Journal of Ecology*, *6*, 1676–1684.

Zhao, Y., Lei, S., & Liu, Y. (2020). Spatial variability and influencing factors of soil nutrients in Shengli mining area. *Soils*, *52*, 356–364.