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RESEARCH ARTICLE

Impact of coal mining subsidence on computed tomography (CT)-measured soil macropores of cultivated land in northern China

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ABSTRACT

Understanding and quantification of the spatial variation and the primary factors that affect soil macropore distribution is helpful to restore soil water and productivity of cultivated land. However, the information of spatial distribution and influencing factors of soil macropores in coal mining subsided areas is still scare. We investigated the soil physicochemical properties and computed tomography (CT)-measured pore parameters at different slope positions and slope aspects (shady slope and sunny slope), and quantified the contribution of influencing factors of soil pore using the model of principal component analysis with multiple linear regression (PCA-MLR). The results showed that pH, electrical conductivity and total P had significant difference between two slope aspects, and the contents of quartz, feldspar, calcite, clay, organic matter and Na ion exhibited significant difference among three slope positions. The number of soil macropores (64.23 ± 50.38), macroporosity (4.09 ± 5.36%), roundness rate (0.85 ± 0.03), and connectivity density (1.04 ± 0.63 cm^{-3}) showed obvious spatial variations in the subsided area. The soil macroporosity on the shady slope was significantly higher than that on the sunny slope. The number of macropores and macroporosity at the top slope position were significantly higher than those at the middle and bottom slope positions. The PCA-MLR model estimated that the factors of soil particle composition and organic matter contributed 43% and 24%, respectively, to the distribution of soil macroporosity. In conclusion, coal mining subsidence had directly and indirectly significant impacts on the spatial distribution of soil macropores. The findings of this study are critical for developing strategies for the conservation of soil water through regulation of soil macropore conditions in mining subsided areas.

Key words: CT scanning, slope aspect, slope position, soil macropores, subsided areas.

INTRODUCTION

Coal mining promotes the growth of the national economy in the world, but it inevitably causes some damage to the ecological environment and severe land subsidence and soil degradation (Ma et al., 2019). More than 95% of China’s coal is produced through underground mining, and this mining approach can alter the surface topographical conditions, leading to significant land subsidence and the generation of a large number of fissures and cracks (Guo et al., 2018), thus affecting soil water storage and transport (Wu et al., 2020; Zhang et al., 2022). Yang and Bian (2022) reported that coal mining subsidence significantly influences the soil water content, organic matter content, cohesion and soil porosity. The soil pore numbers, porosity roundness, and the content of moisture and available P are the main factors influencing the soil productivity (Descalzi et al., 2018; Nasukawa et al., 2019; Jabro and Stevens, 2022). Lechner et al. (2016) demonstrated that coal mining subsidence led to the subsidence influencing soil properties, topography condition, seed germination, crop growth and yields. Because of the uneven distribution of soil moisture or aggravated erosion, land productivity was mainly lost in mining subsidence (Ma et al., 2019; Guo et al., 2021). Therefore, soil water loss in coal mining subsided areas is the most important factor restricting the productivity of cultivated land.

Soil macropores constitute an essential part of soil, providing not only space for soil water, soil gases, and soil organisms but also migration pathways (Zhang et al., 2017). Although soil macropores occupy only a small percentage of the soil volume, they can significantly affect soil water storage, soil water flow and solute transport (Meng et al., 2017; Ma et al., 2021). The properties of soil macropores, such as the macroporosity, macropore number, roundness rate, and connectivity, are considered essential characteristics affecting water flow and solute migration in macropores. The characteristics of soil macropores are influenced by soil properties, topographic conditions, human activities, and land use types (Luo et al., 2010a; 2010b; Guo et al., 2020a). Wang et al. (2021) found that soil organic matter content was the dominant factor influencing the soil macropore characteristics. Ju et al. (2018) found that three topographic conditions (the ditch bottom, ditch edge, and dam land) could significantly affect soil macropore parameters. Guo et al. (2018) noted through a study of soil macropore characteristics in sewage-irrigated areas that sewage irrigation could significantly affect the soil macropore number and macroporosity due to the pore blockage phenomenon triggered by the proliferation effect of microorganisms attributed to the infusion of nutrients in sewage and the dispersion of soil aggregates due to the input of salts. De Lima et al. (2022) found that soil texture and degree of compactness affected pore parameters such as total porosity, and distribution of macropores, mesopores and micropores.

The main methods for the study of soil macropores include the staining tracer method, penetrating curve method, osmometer method, computed tomography (CT) scanning method, and mathematical modelling method. Compared to other methods, CT scanning technology provides the following advantages: (1) Allow observe soil pore structure nondestructively and continuously, (2) has fast imaging speed, and (3) can construct a three-dimensional model of soil structure (Martínez et al., 2017). Budhathoki et al. (2022) quantitatively investigated the parameters of soil macropore number, macroporosity, coarse porosity, and pore fractal dimension in the hillslope pasture field via the CT scanning technique. Therefore, based on CT scanning technology, it is of great importance to thoroughly explore the characteristics of soil macropores to better understand the mechanism of soil water loss in cultivated land in subsidence areas.

We speculate that the change in topographic conditions such as the aspect and position of slope because of coal mining subsidence can directly and indirectly alter the soil macropores. However, until now, less care has been paid on the impacts of coal mining subsidence on soil CT-measured macropores. Therefore, this study aimed: (1) To explore the spatial distribution of soil macropore using CT scanning, (2) to quantify the contribution of the main influencing factors on the spatial distribution using PCA-MLR model, (3) to explore the conceptual model of spatial variation mechanism for the soil macropore.

MATERIALS AND METHODS

Area of study

This study was conducted at the farmland of Jiulishan coal mine (Figure 1), located in Macun District, Jiaozuo City (35°10'-35°21' N, 113°04'-113°26' E), north-western Henan Province, China. Jiaozuo city is famous for its coal mine resources, and is medium-sized city with a population of 3.52 million in 2020. The area exhibits a typical temperate continental climate with warm spring, hot summer, cool autumn, and cold winter seasons. The average annual temperature is 14.2 °C. The average annual precipitation amounts 578 mm. The average number of annual sunshine hours is 2062 h. This area is rich in light and heat resources and is one of the high grain-producing areas in northern China. There has nearly a hundred years of coal mining, which results in land subsided area of about 70 km^2. Consequently, land subsidence in the farmland leads to the loss of irrigation capacity, reduction of soil water-holding capacity and fertility, and deeply decrease of crop yields.

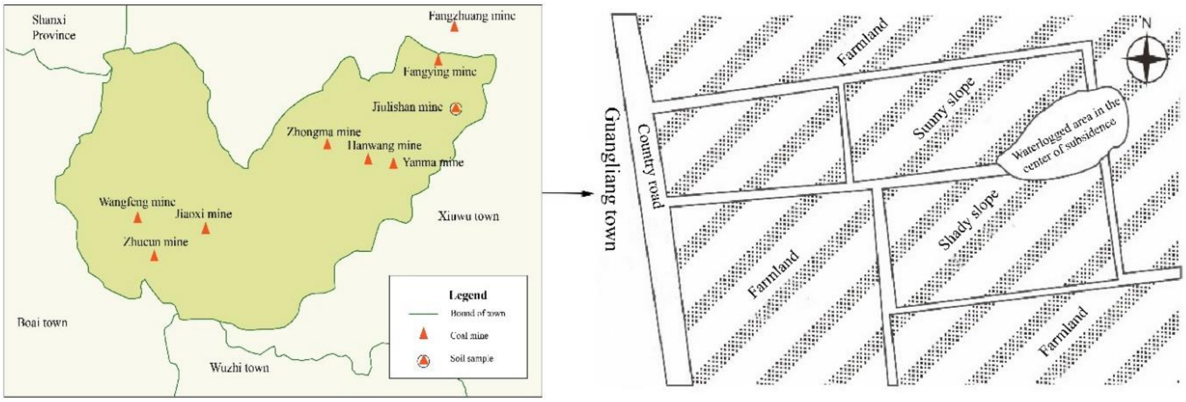

Figure 1. Distribution of soil samples in study area.

The specific study area was located in the farmland, which had high crop yields before coal mining subsidence. The crops grown are wheat and corn in rotation.

Soil sampling

Typical subsidence slopes were selected in the study area, and sampling points were established along different subsidence slope aspects (shady slope and sunny slope) (Figure 1) and at different subsidence slope positions (top, middle, and bottom slope positions). Undisturbed soil column samples were collected with rigid PVC pipes (200 mm long and 150 mm in diameter), and the PVC pipe was inserted slowly and vertically into the soil with a rubber hammer. Then, the penetration of the pipes was operated centimeter by centimeter, and were carefully removed with a shovel. Both ends of each PVC pipe were covered with pipe caps, and three duplicate samples were randomly collected at each sampling point. In addition, disturbed soil samples were collected near each of the above sampling points using a Luoyang shovel, and three replicates were randomly obtained at a depth ranging from 0-20 cm. These samples were air-dried for 7 d, sieved with a 2 mm screen, mixed uniformly, and stored in sealed plastic bags for further physical and chemical properties testing.

Samples analysis

The contents of organic matter and total P were measured with potassium dichromate oxidation and sodium hydroxide digestion, respectively. Electrical conductivity and pH were measured with an electrical conductivity meter (HACH-HQ40d, Hach Company, Loveland, Colorado, USA) and pH electrodes in a soil/water (1:5) suspension, respectively. The Na ions (Na^+), Mg ions (Mg^{2+}) and Ca ions (Ca^{2+}) were determined by ion chromatography system (Dionex ICS-3000, Dionex Corporation, Sunnyvale, California, USA). Mineral composition and particle composition were determined by X-ray diffractometer (D8 Advance, Billerica, Massachusetts, USA) and specific gravity method, respectively (Lu, 2000).

Quantification of soil pore using CT

Computed tomography (CT) scanning was performed with a GE LightSpeed CT medical scanner (General Electric Company, Boston, Massachusetts, USA), and the scanning experiments were completed at the First Affiliated Hospital of the Henan Polytechnic University. The scanning parameters included a 300 mA current, 140 kV voltage and 0.625 mm scanning interval. As a classical medical scanner, the CT-scanning image size was limited to 8 bit and 512 × 512 pixels, and to 0.48 × 0.48 mm resolutions. Because of these limits, the CT-measured pores could not represent total pores in each sample, and the pores identified by the scanner were all large soil pores. Approximately 320 images were obtained for each soil column after CT scanning completion.

The CT-scanning images were analyzed by public software of ImageJ (version 1.51 k; Rasband, W.S., ImageJ, U.S. National Institutes of Health, Bethesda, Maryland, USA) to acquire number of macropores, macroporosity, roundness rate, and connectivity density (Figure 2). To facilitate subsequent CT image processing with ImageJ software, the images were converted into common formats, such as BMP and JPEG. First, the Region of Interest (ROI) tool was used in ImageJ to avoid any possible voids near the pipes during sampling (Hu et al., 2015; Li et al., 2016). Second, the threshold value was set to the standard value (40) to identify the soil macropores (Udawatta and Anderson, 2008). Finally, macropore parameters including number of macropores, macropore area, pore roundness rate and connectivity density were calculated by the ImageJ.

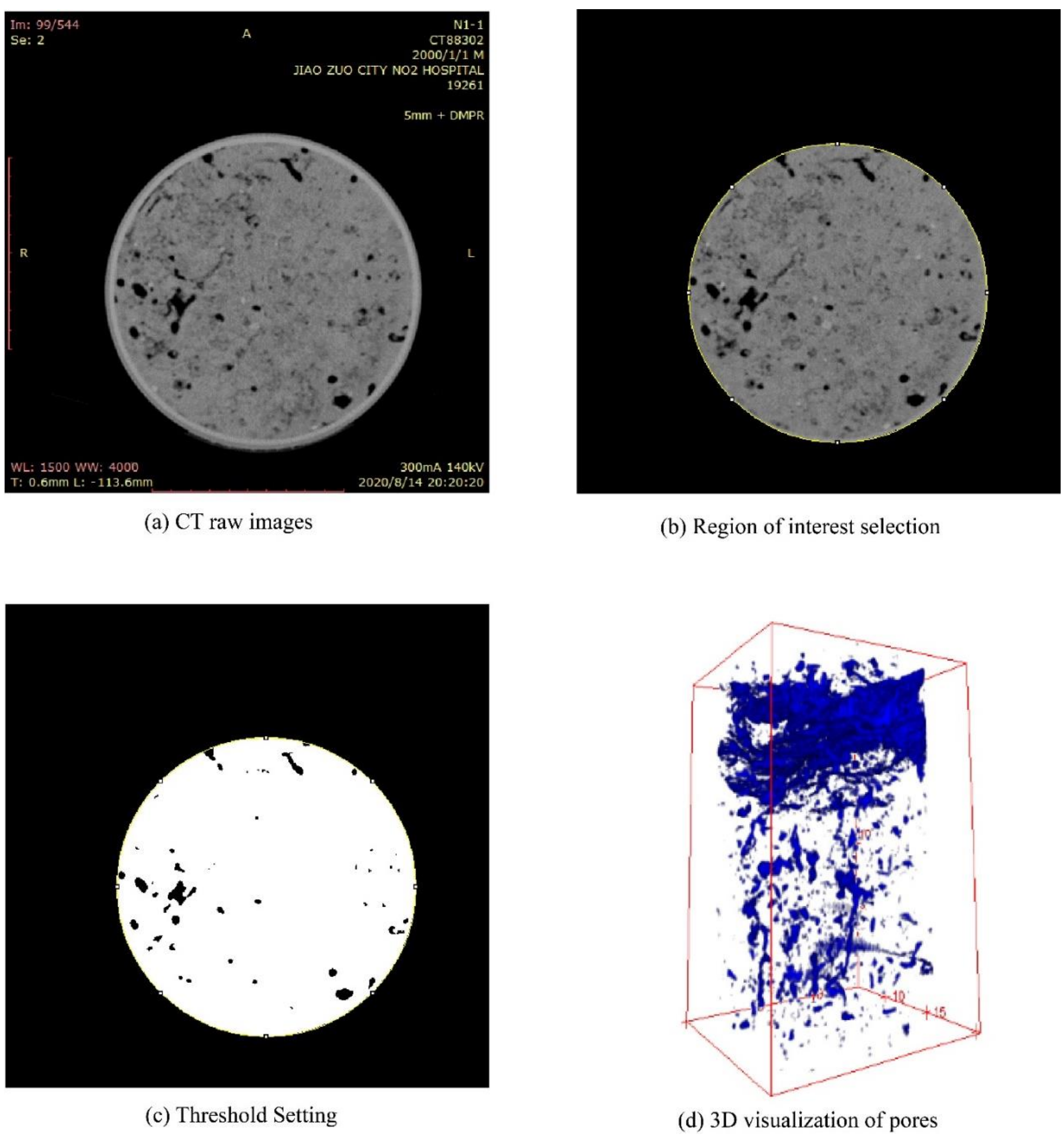

Figure 2. Computed tomography (CT) image processing process.

Statistical analysis
Difference in the physicochemical and macropore properties for three slope positions were analyzed using one-way ANOVA, and difference for two slope aspects were analyzed using T-test. Correlation coefficients were calculated to determine the relations among the physicochemical indicators. Contribution rate of main influencing factors on the macroporosity distribution were calculated using principal component analysis (PCA)-multiple linear regression (MLR) model. The statistical analyses were performed using SPSS 13.0 (IBM, Armonk, New York, USA).

RESULTS

Spatial variation of soil physicochemical properties in the coal mining subsided area
The characteristics of soil physicochemical properties in the study area are presented in Figure 3. The average contents of quartz, feldspar, calcite, clay, silt, sand, electrical conductivity (EC), organic matter, total P, pH, Na, Mg and Ca ions were 51.67%, 22.50%, 19.00%, 22.60%, 39.73%, 37.67%, 1.92 mS cm^{-1}, 21.56 g kg^{-1}, 0.24 g kg^{-1}, 8.23, 59.69 mg kg^{-1}, 24.20 mg kg^{-1}, and 184.46 mg kg^{-1}, respectively. The feldspar, clay, EC, Na, Mg and Ca ions exhibited high coefficient of variation (CV) values (> 35%).

The results of T-test showed that the contents of pH, EC and total P under two slope aspects exhibited significant difference. The results of ANOVA showed that the contents of quartz, feldspar, calcite, clay, organic matter and Na ion under three slope positions exhibited significant difference. These results exhibited obviously spatial variability of soil physicochemical properties in the subsided area.

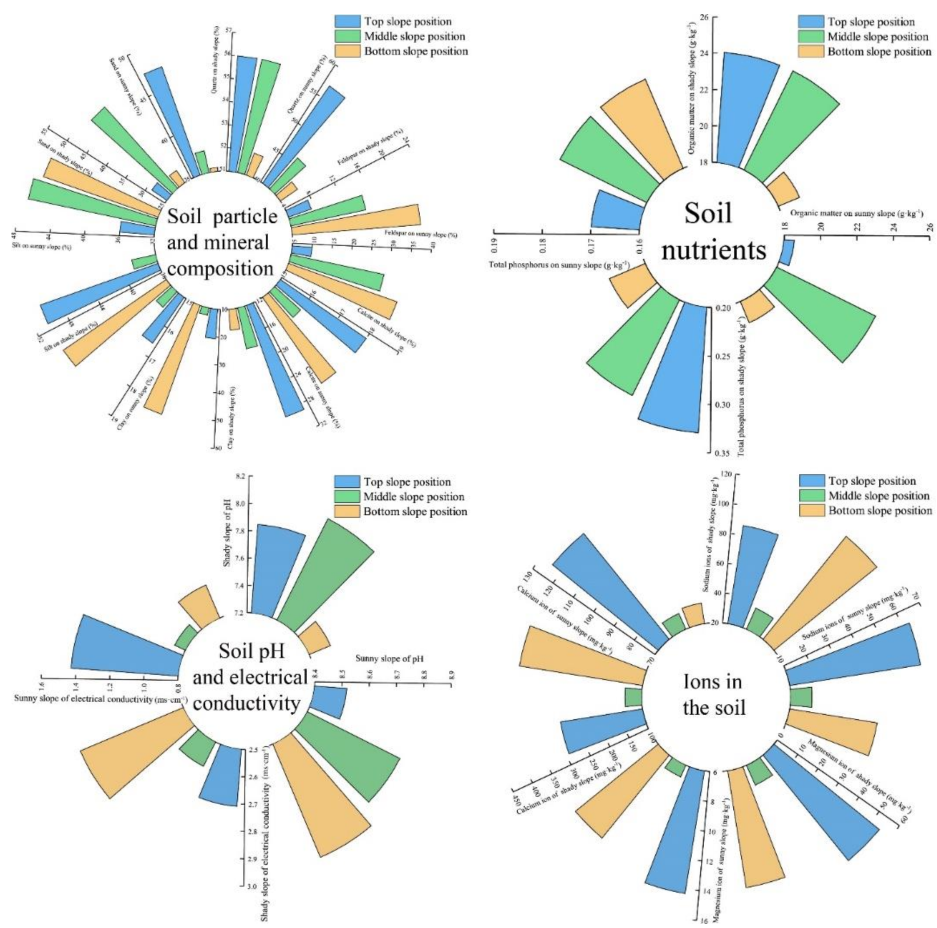

Figure 3. Physical and chemical properties of soils in subsidence area.

Variation in soil macropore properties under different slope aspects

The number of soil macropores (64.23 ± 50.38), macroporosity (4.09 ± 5.36%), roundness rate (0.85 ± 0.03) and connectivity density (1.04 ± 0.63 cm^{-3}) in the coal mining subsidence area obviously varied in space (Figure 4). The number of soil macropores was the largest in the 0-5 cm layer, followed by the 10-15 cm layer, and this quantity was the smallest in the 15-20 cm layer on both shady and sunny slopes. The soil macroporosity on shady slopes was the highest in the 5-10 cm layer, which was 78%, 28% and 91% higher than that in the 0-5, 10-15 and 15-20 cm layers, respectively. The soil macroporosity on sunny slopes was the highest in the 0-5 cm layer, which was 54%, 39% and 25% higher than that in the 5-10, 10-15 and 15-20 cm layers, respectively. The soil pore roundness rate on shady slopes was the highest in the 15-20 cm layer and the lowest in the 5-10 cm layer, whereas the soil pore roundness rate on sunny slopes was the highest in the 15-20 cm layer and the lowest in the 0-5 cm layer. The soil pore connectivity density on shady slopes was the highest in the 0-5 cm layer and the lowest in the 5-10 cm layer, while the soil pore connectivity density on sunny slopes was the highest in the 5-10 cm layer and the lowest in the 15-20 cm layer. The number of macropores (0-5 and 10-15 cm), macroporosity (5-10, 10-15 and 15-20 cm) and pore roundness rate significantly ($P < 0.05$) differed between the two slope aspects. This indicated that the slope aspects significantly influenced the soil macropore parameters.

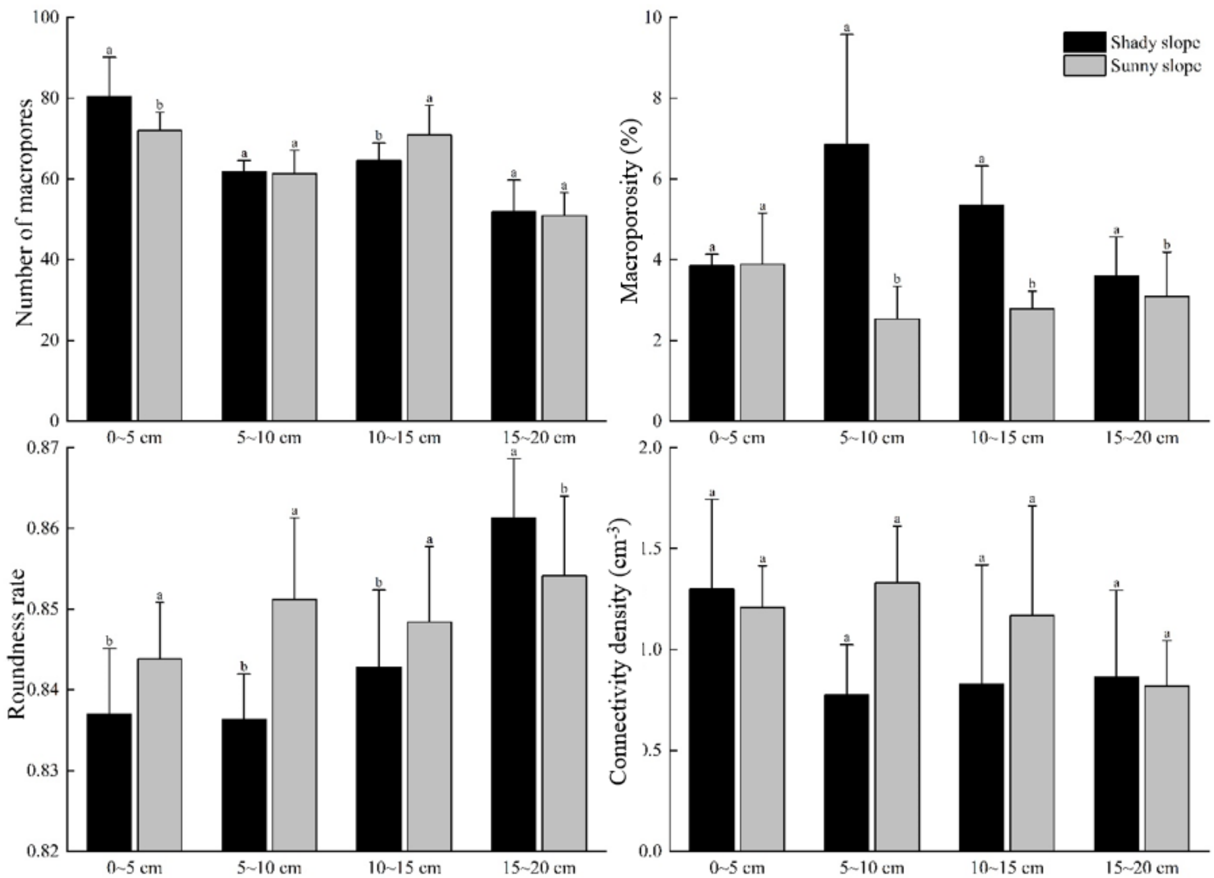

Figure 4. Characteristics of soil macropore under different slope aspect in coal mining subsidence area. Different letters represent significant differences ($P < 0.05$).

Variation in soil macropore properties under different slope positions

In the 0-5, 5-10, and 15-20 cm layers, the number of macropores was the largest at the top slope position, the second largest at the bottom slope position, and the smallest at the middle slope position (Figure 5). In the 0-5, 10-15, and 15-20 cm layers, the macroporosity was the largest at the top slope position, the second largest at the bottom slope position, and the smallest at the middle slope position. In the 5-10 and 15-20 cm layers, the soil pore roundness rate was the highest at the top slope position, followed by the middle slope position, and it was the lowest at the bottom slope position. In the 0-5 and 5-10 cm layers, the soil pore connectivity density was the highest at the middle slope position, followed by the bottom slope position, and the soil pore connectivity density was the lowest at the top slope position. The number of soil macropores, macroporosity, and pore roundness rate (5-10, 10-15, and 15-20 cm layers) significantly ($P < 0.05$) differed among the various slope positions, and the soil macropore number and macroporosity (0-5, 10-15, and 15-20 cm layers) were significantly higher at the top slope position than those at the middle and bottom slope positions. This indicated that the slope position significantly influenced the soil macropore parameters.

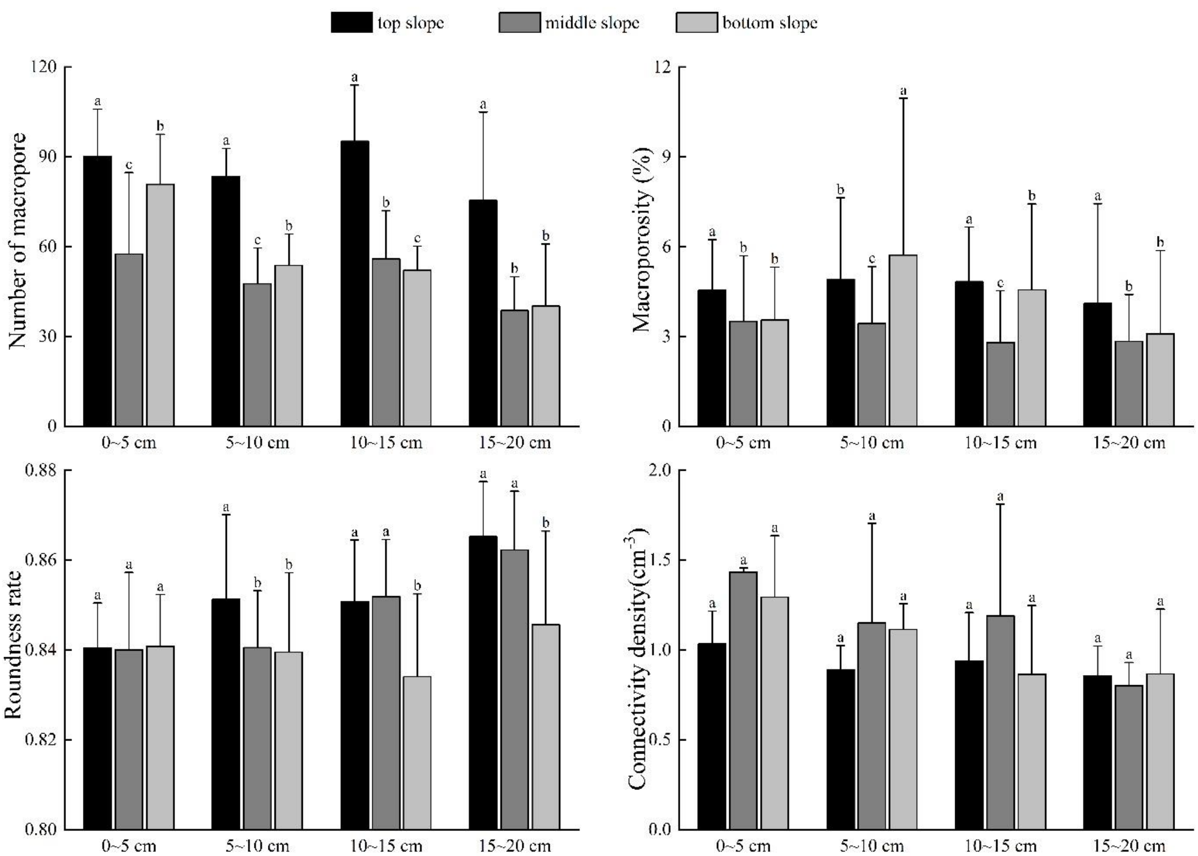

Figure 5. Characteristics of soil macropore under different slope positions in coal mining subsidence area. Different letters represent significant differences ($P < 0.05$).

Contribution of main influencing factors to the soil macroporosity distribution

The influencing factors of soil macropores characteristics mainly included soil physicochemical properties and topographic conditions. The soil physicochemical properties included soil organic matter, particle composition, Na, Mg, Ca ions, EC, pH and mineral composition. The topographic condition included the slope aspects and slope position. The slope aspects and slope position were quantified, in which values of 1 and 2 were assigned to shady and sunny slopes, respectively, and values of 1, 2 and 3 were assigned to the top, middle and bottom slope positions, respectively.

Four principal components had eigenvalues greater than 1 and a cumulative variance contribution of 98% (Table 1). In the first principal component, the soil pH attained the highest factor loading value and was therefore selected first. Although the difference between the factor loading values of EC, Ca^{2+}, Na^+ and soil pH did not exceed 10%, there occurred a significant correlation ($P < 0.01$) between the EC, Ca^{2+} and soil pH (Figure 6). Therefore, two variables (Na^+ and pH) were selected, and this factor could be considered the “soil pH and salinity” factor. In the second principal component, the slope position obtained the highest factor loading value. Moreover, the difference between the factor loading values of the quartz content and slope position did not exceed 10%, and nonsignificant correlation existed between these variables. Therefore, these two variables (slope position and quartz content) were selected, and this factor could be regarded as the “topography and mineral composition” factor. In the third principal component, organic matter exhibited the highest factor loading value, and the difference in loading value between this factor and the other factors exceeded 10%. Therefore, only one variable (organic matter) was selected, and this factor could be regarded as the “soil organic matter” factor. In the fourth principal component, sand achieved the highest factor loading value, and the difference in loading value between this factor and the other factors exceeded 10%. Therefore, only one variable (sand) was selected, and this factor could be considered the “soil particle composition” factor. In summary, the four principal components represented four types of influencing factors, namely, F_1 (soil pH and salinity), F_2 (topography and mineral composition), F_3 (organic matter), and F_4 (particle composition), which are the main factors influencing the soil macropore characteristics.

Table 1. Principal component analysis of influencing factors of soil macropore characteristics. Bolded values are considered highly weighted when within 10% of variation of the absolute values of the highest factor loading in each principal component.

Project	First principal component	Second principal component	Third principal component	Fourth principal component
Eigenvalue	7.142	3.408	2.928	1.224
Variance contribution rate	47.613	22.720	19.517	8.160
Cumulative variance contribution rate	47.613	70.333	89.849	98.009
Factor load				
Quartz	0.558	**0.821**	0.018	-0.112
Feldspar	-0.450	-0.791	0.411	-0.006
Calcite	-0.057	0.707	-0.670	0.199
Clay	0.739	-0.489	-0.427	-0.040
Powder	-0.567	0.130	0.624	0.499
Sand	-0.510	0.643	-0.077	-**0.558**
Electrical conductivity	**0.932**	0.132	0.242	-0.219
Organic matter	-0.031	0.183	**0.909**	0.005
Total phosphorus	0.642	0.219	0.713	-0.090
pH	-**0.981**	-0.005	-0.056	0.172
Sodium ion	0.890	-0.078	-0.334	0.254
Magnesium ion	**0.876**	-0.117	0.056	0.461
Calcium ions	**0.976**	-0.143	-0.073	0.118
Slope direction	-0.862	-0.048	-0.438	0.247
Slope position	0.005	-**0.893**	-0.154	-0.416

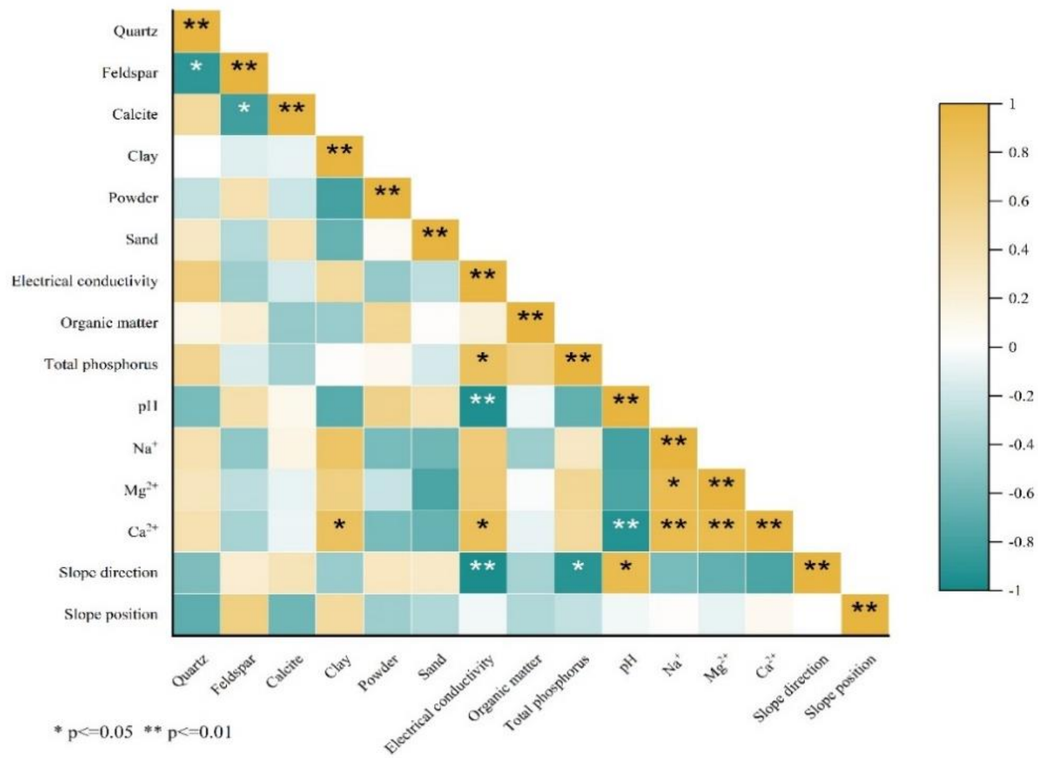

Figure 6. Heat map of correlation of indicators in soils.

Based on principal component analysis (PCA), multiple linear regression (MLR) was performed to obtain the degree of influence of each factor on the macroporosity. With the use of standardized soil macroporosity parameters as the dependent variables (Y^*) and standardized principal component scores as the independent variables (F_1, F_2, F_3, and F_4), a regression equation for the soil macroporosity could be obtained via MLR analysis ($P < 0.05$, Table 2).

$$\text{Macroporosity:}\ Y^* = 0.189F_1 + 0.207F_2 + 0.294F_3 - 0.531F$$

Table 2. Regression analysis of principal component and its effects on soil microporosity.

Main factor	Regression coefficients	P	Contribution rate (%)
F_1	0.189	0.024	15
F_2	0.207	0.031	17
F_3	0.294	0.024	24
F_4	-0.531	0.020	43

Through this regression equation, the influence degree of the four influencing factors on the soil macroporosity could be obtained, among which the F_4 factor exhibited the highest impact degree (43%), the F_3 factor attained the second highest impact degree (24%), and the F_1 factor achieved the lowest impact degree (15%).

DISCUSSION

Effects of coal mining subsidence on soil physicochemical and macropore properties

Coal mining subsidence has significantly altered the topographic condition (slope position, slope aspects, etc.), which can profoundly affect the distribution of physical, chemical and biological properties (Hishi et al., 2014; Zou et al., 2015). In the present study, the results of T-test analysis showed that slope aspect significantly affected on the contents of pH, EC and total P. In addition, the results of ANOVA exhibited that slope position significantly influence the contents of quartz, feldspar, calcite, clay, organic matter and Na ion (Figure 3). The reason was that topographic condition can impact the spatial distribution of abiotic resources such as solar radiation, light, temperature, and angle between the wind and ground (Hishi et al., 2014; Miller and Chanasyk, 2015; Zou et al., 2015). Previous studies of Cui et al. (2020) and Budhathoki et al. (2022) reported that that slope position had obvious effects on the soil macropores. Our results were similar with these reports.

In the present study, the number of soil macropores, macroporosity and pore roundness rate (5-10, 10-15 and 15-20 cm) significantly differed among the various slope positions. Furthermore, the number of soil macropores and macroporosity (0-5, 10-15 and 15-20 cm) at the top slope position were significantly higher than those at the middle and bottom slope positions. The main reasons are as follows: (1) The soil layer at the top of the subsidence area was seriously fractured, with displacement variations and a relatively loose soil structure, resulting in an increased soil porosity at the top of the subsidence area, while the bottom of the subsidence area occurred close to the subsidence center, with a relatively narrow displacement distribution and a relatively compact soil structure (Budhathoki et al., 2022). (2) Coal mining subsidence resulted in the trend with sand occurring relatively concentrated at the top of the slope, while soil fine particles mostly gathered at the slope bottom. In addition, we also found that the slope aspect had obvious effects on the soil macropores. The number of soil macropores (0-5 and 10-15 cm), macroporosity (5-10, 10-15 and 15-20 cm) and pore roundness rate exhibited significant differences among the various slope aspects. The reason for this phenomenon is that the slope aspect can cause differences in light, wind speed, temperature and other factors, which in turn can cause differences in the soil physical, chemical and microbiological properties along the slope.

Previous studies have showed that soil macropores can be influenced by factors such as soil properties, topographic conditions, human activities, and land use type (Luo et al., 2010a; Guo et al., 2020a). In this study, the PCA-MLR model was used to quantify the influencing factors of soil macropores. This model, as an important receptor model (Salim et al., 2019), has been widely applied in quantitative analysis of influencing factors (Guo et al., 2020b). We found that the important factors influencing the soil macroporosity were F_1 (soil pH and salinity), F_2 (topography and mineral composition), F_3 (organic matter) and F_4 (particle composition), and their contributions were 15%, 17%, 24% and 43%, respectively, with F_4 (particle composition) and F_3 (organic matter) as the dominant factors. The reasons for this finding should be as follows: (1) Soil organic matter can improve soil microbial metabolism, thus promoting the development of agglomerates and improving the soil structure; (2) soil texture plays an important role in the dynamic process of soil pore structure and pore connectivity (Luo et al., 2010a; Guo et al., 2020a). Luo et al. (2010a) reported that the soil organic matter content and particle composition are important influencing factors of soil macropore parameters, and their results strongly supported our findings obtained with the PCA-MLR model in this study.

Mechanism of variation in soil macropores and its potential environmental significance in coal mining subsided area

Based on the above results, we found that coal mining subsidence had direct and indirect effects on the soil macropores. The direct effects were that topographic conditions had a significant impact on soil macropores. The indirect effects were that topographic conditions obviously influenced soil physicochemical properties, and then they had a significant impact on soil macropores. Furthermore, it was noted that the indirect effects were apparently higher than the direct effects according to the results of PCA-MLR model. Consequently, we attempted to establish a conceptual model of the spatial variation in soil macropore characteristics in coal mining subsided areas (Figure 7). The conceptual model could be expressed as follows: Coal mining subsidence altered the ground surface topographic conditions, which caused an increase in soil sinking and an obvious change in soil pores and soil compaction. Additionally, the different slope aspect and slope position in the subsided area caused local changes in the temperature, wind speed and other conditions, which intensified the heterogeneity in the spatial distribution of soil physical and chemical properties, especially the variability of the soil particle composition and organic matter content. Eventually, this resulted in significant spatial variability of the soil macropore characteristics in the subsided area. The spatial variability of the soil macropore parameters could inevitably affect the soil water availability, distribution and migration characteristics, causing an uneven soil water distribution or an increased loss and reduced land productivity.

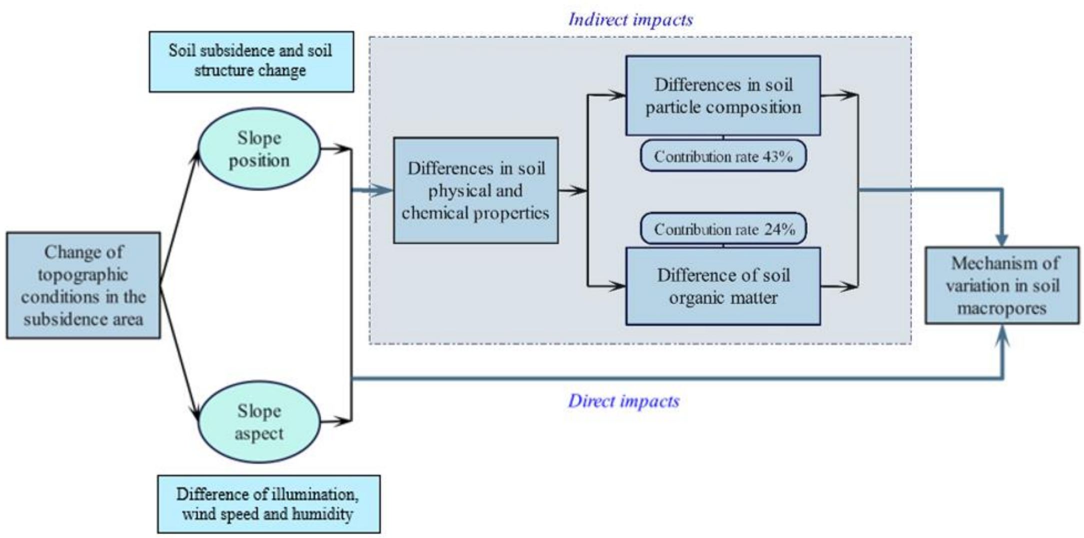

Figure 7. Conceptual model of spatial variation of soil macropore characteristics in subsidence area.

The above conceptual model could provide a new perspective for land management in subsidence areas: Soil macropores could be adopted as an entry point, the factors influencing soil macropores could be investigated, and targeted water loss control pathways could be explored through soil macropore regulation. Choosing the Jiaozuo mining area in this study as an example, coal mining led to the formation of notable coal mining subsidence. The area contained high-yield farmland before subsidence, while land reclamation after subsidence remained at the level of planting on slopes, the soil water loss problem was very prominent, and the planting benefits were low. According to the degradation status of the mining area, soil macropores could be regulated in the following two aspects: (1) The fertilization strategy mainly involving organic fertilizers supplemented by chemical fertilizers should be adopted to improve the soil agglomeration state through long-term application of organic fertilizers. (2) The construction of protective forests and the transformation of micro terraces should be realized to reduce the transport of fine particulate matter by wind and water forces in subsidence land areas, thus improving the soil texture conditions and pore characteristics. In addition, different microregional land restoration and soil improvement strategies could be adopted considering the specific conditions of the soil pore characteristics in subsidence areas at different slope positions and along various slope aspects.

CONCLUSIONS

In this study, we investigated the spatially variable characteristics of soil macropores in a subsidence area. The soil macropore parameters significantly differed among the different slope positions and slope aspects. The soil particle composition and organic matter content were identified as the main factors influencing the macropore distribution via the principal component analysis with multiple linear regression (PCA-MLR) model. Their contributions reached 43% and 24%, respectively. The above results showed that the topographic conditions and soil physicochemical properties in the subsidence area significantly impacted the spatial distribution of soil macropores. In addition, more long-term studies are needed to better understand the mechanisms of the spatial variation in soil macropore characteristics in subsidence areas.

Author contributions

Conceptualization: G.X-M. Methodology: G.X-M. Validation: Z.Q., G.X-M. Formal analysis: Z.Q., G.X-M. Investigation: Z.Q., L.L. Resources: Z.Q. Data curation: Z.Q., L.L. Writing-original draft: Z.Q. Writing-review & editing: G.X-M. Visualization: Z.Q., L.L. Supervision: G.X-M. Project administration: G.X-M. Funding acquisition: G.X-M. All co-authors reviewed the final version and approved the manuscript before submission.

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