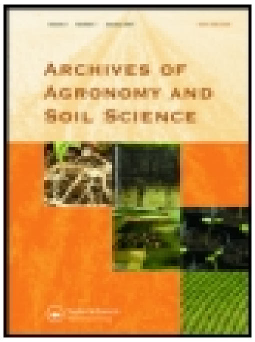

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Change in SOC Content in a Small Karst Basin for the Past 35 Years and its Influencing Factors

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Abstract

To research soil organic carbon (SOC) in a typical small karst basin of western Guizhou in southwest China, data from the second national soil resource survey (1980) and data analysed in the laboratory in 2015 were used. This paper examines the changes in soil organic carbon density (SOCD) and soil organic carbon stock (SOCS) in the topsoil (0-20 cm) over the past 35 years based on soil types, and the primary influencing factors are also discussed. The SOCD and SOCS slightly increased over this period. The SOCD increased from 4.91 kg m^{-2} to 5.13 kg m^{-2}, and the SOCS increased from 368.27×10^3 t to 385.09×10^3 t. The basin sequestered a low level of carbon during this time. Paddy fields were the key contributor to the increases, and the SOCD and SOCS of paddy fields increased by 1.61 kg m^{-2} and 32.39×10^3 t, respectively. Generally, the SOCD and SOCS in the soils from the southern part of Houzhai Basin increased considerably, and those from the northern part of the basin decreased significantly. The spatial variation of SOCD in the Houzhai Basin was mainly due to natural factors. However, the temporal change of SOC was primary caused by human activities.

Key words: Soil organic carbon; dynamic change; natural factors; human disturbance; karst

Introduction

Soil is the largest carbon pool that requires a long turnover period in terrestrial ecosystems, and the soil organic carbon (SOC) pool is the main part of the terrestrial carbon pool (Janzen 2004). It is estimated that there are approximately 1500 Pg C in topsoil in the form of organic matter. The SOC pool is approximately two times as large as the carbon pool in the atmosphere, and it plays a significant role in the global carbon cycle (Lal 2013). A slight change in the soil carbon pool will have a great effect on atmospheric CO_2 concentrations (Ni 2002). A change in the soil carbon pool may lead to deceleration (or acceleration) of the rising CO_2 concentrations caused by human activities.

According to the Fourth Assessment Report of Intergovernmental Panel on Climate Change (2007), enlarging ecosystem carbon pools may be an advisable way to compensate for the carbon emissions needed for economic development. However, a soil carbon pool is the only type of carbon pool that can be disturbed and managed over a short period (Juan et al. 2013). Thus, soil carbon sequestration has become an important way to decelerate and control global warming (Schimel et al. 2001). Many researches have been carried out in recent years that address the dynamics and sequestration of SOC (Batjes 1996; Mao et al. 2015). The majority of these studies addressed SOC changes at a national or regional scale based on long-term field inspections or a comparison of the literature. In addition, most of investigations focused on farmland in non-karst regions, and few studies looked at the SOC changes in karst areas.

Karst landforms cover approximately 22.00 million km^2 or 15% of the Earth's surface (Yuan 2008). A karst landform is distinctive with a weak ecosystem balance. The SOC in a karst region is sensitive to the environment and human disturbance. It is of great importance to study the temporal and spatial characteristics of SOC in karst areas. Guizhou Province, in southwest China, is a typical karst area, and the carbonates are widely distributed (Wei et al. 2006). In the 1980s, many forestlands and grasslands were reclaimed for croplands to resolve the conflict between population growth and low productivity. Due to substantial human disturbance, rocky desertification occurred widely over the past several decades. Land use and vegetation cover have undergone significant changes as well. SOC in this area is likely to have been significantly changed (Zhou et al. 2007). There have been few studies on the SOC pool and influencing factors in karst areas, especially at the basin scale (Zhang et al. 2014).

The Houzhai Basin, located in the western part of Guizhou Province, is a typical small plateau basin with a large area of karst, and rocky desertification is serious problem in this basin. This basin is an excellent choice for studying karst SOC change and influencing factors in this area. Based on the data from the second national soil resource survey carried out in 1980 and the data analysed in the laboratory in 2015, the main objectives of the present study are as follows: (a) to study the spatial discrepancy of SOC contents and soil organic carbon density (SOCD) in the Houzhai Basin over the past 35 years, and (b) to study the primary influencing factors of SOC in other regions with the similar karst feature in the world.

Materials and Methods

Study region

The study region (105°40′43″-105°48′2″E, 26°12′29″-26°17′15″N) is located in Puding County in the central part of Guizhou Province in south-western China, including the three towns of Chengguan (CG), Maguan (MG) and Baiyan (BY), and it covers an area of 75 km^2. The elevation is between 1223.4 and 1567.4 m above sea level, and the air pressure is between 806.1 and 883.8 pa. There are three major categories of soil: Leptosols, Anthrosols and Ferralsols. The land-use types are in

Figure 1.

Data source

In this study, the basic data about the soil surface (0-20 cm) were mainly obtained from the second national soil resource survey carried out in 1980. Total of 23 sampling sites were selected in the Houzhai Basin (Table 1). Each soil sample included mixed soil from four or five plots at each location. In 2015, 3180 sampling grids (150 m × 150 m) were designed. The sampling sites were defined as the centre of each sampling grid (Figure 1). A total of 2755 soil samples were taken (425 designed sampling sites were located in areas such as traffic throughways, tractor roads, residential housing, industrial parks, and streams). Soil samples were collected to a depth of 20 cm. Soil samples were collected with a stainless steel shovel and immediately packed in self-zip plastic bags. To avoid cross contamination, the shovel was brushed and then flushed with soil from the subsequent sampling site. Each soil sample included mixed soil from four or five plots at each location.

Sample treatment and determination analysis

General information including soil bulk density (SBD), soil thickness, rock coverage and other indexes were measured at each sampling point and recorded in the field. The soil samples were air dried (about one week), ground to through a 0.2 mm sieve and prepared as required by the laboratory; then, the SOC content was tested and analysed. The SOC was determined via a potassium dichromate method. The soil acreage was calculated using GIS technology and surveying in the field. The rock outcrop was surveyed with a line-transect method. The SOC content was determined by $K_2Cr_2O_7$ oxidation at 170–180 °C followed by titration with $FeSO_4$ (Wang et al. 2010).

Calculations and statistical analysis

To minimize the estimation error of the SOC storage, the error due to rock coverage in the karst area can be reduced by revising its rock outcrop (Zhang et al. 2017). In most of the previous studies, the soil organic carbon density (SOCD) was calculated by the following formula:

$$\mathrm{SOCD}_{i,j} = C_{soc_{i,j}} \times \rho_{i,j} \times T_{i,j} \times 10^{-2} \quad (1)$$

where $\mathrm{SOCD}_{i,j}$ is the SOCD in the *i*th layer of soil type *j* (kg m^{-2}), $C_{soc_{i,j}}$ is the SOC content in the *i*th layer of soil type *j* (g kg^{-1}), $\rho_{i,j}$ is the SBD of the *i*th layer of soil type *j* (g cm^{-3}), $T_{i,j}$ is the soil thickness of the *i*th layer of soil type *j* (cm), and 10^{-2} is the conversion coefficient.

$$\mathrm{SOCS} = \sum_{j=1}^{m}\sum_{i=1}^{n} SOCD_{i,j} \times S_j \times (1\text{-}\delta_j) \times (1-G_j) \times 10^3 \quad (2)$$

where SOCS is the total stock of SOC in the study area (kg), S_j is the soil acreage of soil type *j* (km^2), 10^3 is the unit conversion factor, δ_j is the bare rock rate in the sampling area of soil type *j* (%), and G_j is the percentage of the gravel volume that is greater than 2 mm in soil type *j*. The other indexes are the same as in equation (2).

A semi-variance function (h) was used to describe the spatial heterogeneity of the soil properties. The semi-variance function was used to obtain the variation in the semi-variance function value with an increase in the distance of the sample; the scatter plots were fitted with a Gaussian model and other theoretical models. When the soil properties met a two-order stationary assumption and the intrinsic hypothesis and when the sample size was adequately large, the semi-variance theory variation function (h) formula was used. The semi-variance ($r(h)$) is as follows (Bergstrom et al. 1998):

$$r(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[Z(x_i) - Z(x_i + h) \right]^2 \qquad (3)$$

where Z is the measured soil property, x is the sample location, and *N(h)* is the number of pairs of locations separated by a lag distance h. The semi-variogram expresses the relationship between the semi-variance and the lag distance (h). The relationship typically increases from a value at h = 0 (identified as the nugget) to a maximum value (identified as the sill). The SOCD spatial distribution pattern was determined using a kriging interpolation method with a spatial interpolation grid.

Data analysis

With different levels of SOCD data values for quality control, numerical calculations of the distribution with the four percentile method were conducted to determine the extreme limit and extreme limit values to calculate the maximum and minimum values, mean value, standard deviation, and coefficient of variation. A spatial autocorrelation analysis was conducted using the semi-variance function variables, which must meet the normal distribution data of non-normal distribution; this will cause proportional effects on the variance function and reduce estimation precision. A semi-variogram model, fitted with GS+ software, was used for ordinary kriging interpolation in ArcGIS 9.3 software, rendering an organic carbon density spatial distribution map.

Results and Analysis

Statistical analysis on SBD, rock outcrop and SOC

According to the statistical analysis on SOC content in the Houzhai Basin from 1980 to 2015 shown in Table 2, the SOC content had an average value of 21.98 g kg^{-1} and changed within the range of 1.28 to 86.28 g kg^{-1} in 1980. In 2015, the SOC content had an average value of 25.07 g kg^{-1} and changed within the range of 1.61 to 119.11 g kg^{-1}.

Temporal and spatial changes in SOCD over the past 35 years

Change in SOCD

For the past 35 years, the SOCD of topsoil (0-20 cm) in the Houzhai Basin has undergone a light increase. It had a slight increase of 4.29% from 4.91 kg m^{-2} in 1980 to 5.13 kg m^{-2} in 2015 (Table 3). The increment in Anthrosols SOCD was at a maximum at 1.61 kg/m^2, followed by the Ferralsols SOCD at 0.91 kg m^{-2}; however, the Leptosols SOCD decreased by 0.65 kg m^{-2}. The topsoil organic carbon density of the Houzhai Basin had an average change of 0.01 (0.006) kg m^{-2} y^{-1}, and Anthrosols had the largest average increase at 0.05 kg m^{-2} y^{-1}, followed by Ferralsols (0.03 kg m^{-2} y^{-1}); however, Leptosols had an average decrease in SOCD of -0.02 kg m^{-2} y^{-1}. Although the decrease in paddy SOCD was far less than the increase on an average basis, the area of Leptosols was approximately 1.2 times as much as the area of other types of soil, the change in the carbon pool of the whole region was subject to the soils of the larger area, leading to the slight increase in the topsoil organic carbon density of the Houzhai Basin.

Spatial distribution of SOCD

Table 4 includes the optimum semi-variance function of the SOCD of the Houzhai Basin over the two periods and its parameters. Within the fitting accuracy, the residual sum of squares (RSS) was close to 0, and the R square (R^2) was close to 1, showing that the fitting semi-variance functions may well reflect the spatial structure features of SOCD. The optimum theoretical model of SOCD semi-variance function was an exponential model and a spherical model in 1980 and 2015, respectively. A large nugget (C_0) variance shows that a process should not be neglected at a small scale. A high value of $C_0/(C_1+C_0)$ suggests that the spatial variation from random factors is large. Otherwise, the spatial variation from structural factors is large. When it is adjacent to 1, the variation is considered constant on the whole scale. When $C_0/(C_1+C_0) < 25\%$, the spatial variation is considered significant; when it is between 25% and 75%, the spatial variation is considered moderate; when $C_0/(C_1+C_0) > 75\%$, the spatial variation is considered slight. As $C_0/(C_1+C_0)$ of SOCD was 21% and 30% in 1980 and 2015, respectively, the SOCD was considered to have a significant spatial variation in 1980 and a moderate spatial variation in 2015.

In 1980, the SOCD of the Houzhai Basin was low and mainly changed within the range of 2.43 to 3.46 kg m^{-2}. In the eastern and south-eastern marginal areas, the SOCD was high (exceeded 10.54 kg m^{-2} partly). In 2015, the SOCD was still high in the eastern and south-eastern marginal areas of the study region, but in the south, and compared with that in 1980, the SOCD greatly increased. In the Houzhai Basin, Anthrosols were mainly distributed in the south of the Houzhai basin, and the highly fertile Anthrosols contained rich mineral nutrients, with a wealth of organic matter added by the human use, thus making the SOCD increase. However, Leptosols soils were mainly distributed throughout most of the high-altitude north-eastern area, and since their original vegetation cover types were mostly weeds and bushes in the early 1980s, the soils were mostly humified and contained rich organic matter. However, through planting as a part of reclamation over the past 35 years, the undisturbed soils were damaged, and the content of organic matter decreased, leaving a reduction in the SOCD. This process is the reason for the difference in the spatial distribution.

Changes in soil organic carbon storage over the past 35 years

The study suggested an overall increase in SOCS of the surface layer (0-20 cm) of Houzhai Basin. Specifically, SOCS increased to 385.09×10^3 t in 2015 from 368.27×10^3 t in 1980, representing an overall growth rate of 4.6%. Among the different soil types, Anthrosols, with an increase of 37.09% ($\Delta T = 32.39 \times 10^3$ t), made the greatest contribution to the growth in SOCS (Table 5), followed by Ferralsols ($\Delta T = 11.72 \times 10^3$ t), whereas the Leptosols ($\Delta T = -27.3 \times 10^3$ t) decreased. Table 5 indicates a severe carbon loss of 54.12% due to Leptosols in the past 35 years. Therefore, efficiently controlling the loss of Leptosols could be a feasible way to improving the SOCS in Houzhai Basin. The carbon loss phenomenon mainly occurred in the north and west of the basin in a centralized and scattering pattern, respectively (Figure 3); carbon sequestration was observed in the regions along Yelang Lake in the south; the SOCS of soils in the southeast and a small part of the central basin primarily maintained a relatively balanced condition (with the change in SOCS ranging from -5% to 5%).

Since the peripheral regions of Yelang Lake in the south have distinct geographical advantages, in terms of its combination of the good soil characteristics and influence of human activities, compared to other regions, a favourable environment for increases in SOC stocks has been created.

Affecting factors of soil organic carbon

The Pearson correlation analysis showed some significant positive correlations between SOC content and slope gradient and altitude and rock outcrop ($p < 0.01$) (Table 6), a negative correlation between SOC content and soil depth ($p < 0.01$), a significant negative correlation between SOC content and SBD ($p < 0.05$), an insignificant correlation between SOC content and rock fragment content. There were significant positive correlations between SOC density and SBD and soil depth ($p < 0.01$), a significant negative correlation between SOC density and rock fragment content ($p < 0.01$), and insignificant correlations between SOC density and slope gradient, altitude and rock outcrop. The relevant analyses suggest that slope gradient and altitude have significant positive correlations with SOC content ($p < 0.01$). Thus, the regions in the basin at a higher altitude and greater slope gradient are richer in SOC content because most of these regions are situated in mountainous areas with favourable vegetation cover and greater inputs of SOC content compared to other regions. However, affected by soil depth and SBD, SOCD had insignificant correlations with altitude and slope gradient; there exists a significant negative correlation between soil depth and SOC content ($p < 0.01$), because thinner soil depth makes it easier to input litter and other organic matter, resulting in high natural SOC content. In contrast, organic matter in soils having thick horizons is likely to have large-scale dispersion, which is the reason for the low SOC content in the soils (Li et al. 2007). There is a significant positive correlation between soil depth and SOCD ($p < 0.01$). SBD of soils has a significant negative correlation with SOC content. SBD reflects the porosity of soils, with lighter SBD having a greater porosity and a good structure with a reasonable arrangement of pores, which are usually fertile soils rich in organic carbon.

Discussion

Natural factors influencing the change in SOC content

As an important part of soil, SOC is always in a dynamic state of constant accumulation and degradation due to changing natural factors such as edaphic and environmental factors (Six et al. 2000). The SOC balance, to a certain extent, is affected by organic matter input and output and changes based on the influencing factors of SOC formation and degradation in the natural environment (Li et al. 2009).

For topsoil, edaphic factors are mainly represented by SBD, gravel and rock outcrops, and these factors are related to the SOCS (Dalal et al. 2001). These factors influence the total soil bulk. In addition, these factors are of importance in arrangement of land use which is related to the input and output of organic matter and the primary dynamic force for mineralization of soil organic matter (SOM) (Jiang et al. 2000). SBD and gravel are important items to soil micro-circumstance. It is well known that SBD reflects the pore condition of soil to some extent. Soils with small bulk density have large porosity, good structure and reasonable pore size; the soil is often more fertile; and organic carbon content is high (He et al. 2008). High gravel, generally, leads to low SBD increasing the SOC content. However, an increase in gravel also leads to a decrease in the total amount of soil affecting the SOCD and SOCS. Rock outcrop relates to organic matter translation (Abid et al. 2008). High rock outcrop leads to organic matter concentrated in a smaller range coupled with the surface of the litter of the soils, and the SOC content increases. On the other hand, organic matter is dispersed into a larger range, and then, the organic carbon content is low (Bai et al. 2014).

Altitude and slope gradient are two main environmental factors affecting SOC. As mentioned above, there are considerable differences in the SOC content at different altitudes and slope gradients (Liu et al. 2014). Altitude is the dominant environmental factors in determining hydrothermal conditions and vegetation coverage, which are important to SOC input and mineralization. Slope gradients mainly influence the distribution stability of SOC on slopes and lead to SOC redistribution, especially in mountainous areas. Previous studies have shown that long and gentle slopes benefit SOC accumulation, while short slopes facilitate SOC transfer and SOC enrichment in the middle or lower areas. As the slope gradient increases, soil erosion is enhanced, resulting in a substantial loss of surface soil rich in nutrients and in a reduction of SOC content (Lorenz et al. 2014). Flat slopes play an important part in SOC accumulation. There is a significant positive correlation between rock outcrop and SOC content ($p < 0.01$), which is in line with the study results provided by Wu Min et al. Similar to soil depth, if soils have a high rock outcrop, organic matter will be accumulated in a considerably small area. Furthermore, the SOC content increases due to soil erosion of litter on rock surfaces. In contrast, organic matter is scattered in a wider range of soils with a low rock outcrop, leading to low SOC content.

Anthropogenic factors in change of SOC content

Anthrosols and Ferralsols are in paddy fields and dry lands, and through field exploration and interviews, farmland (paddy field and dry land) was found to be the most common land-use type, where chemical and organic fertilizers used were more often than in other types of soil, greatly increasing the SOC content and thus leaving the SOCD rapidly improved (Wang et al. 2017).

Land uses considerably shape variations in SOC contents levels. Our previous study results show that mean SOC contents levels of different land uses in the Houzhai Basin decline in the following order: forest land > uncultivated land > grassland > cropland. The SOCD of different land use declines in the following order: cropland > grassland > forestland > uncultivated land. Many experiments have demonstrated that the types and quantity of fertilizers used have significant effects on SOC formation and accumulation (Wu et al. 2015). The use of organic fertilizers and crop and straw returning can facilitate SOC accumulation, and yet, long-term use of a single fertilizer can lead to reductions in SOC. Since the 1980s, the use of fertilizers in Guizhou Province has significantly increased while the cultivated area with green manure and the application of organic fertilizers to farmlands also have substantially increased, including a greater input of organic fertilizers into cultivation of certain farmlands, which is possibly one of the reasons why the SOC content of the farmlands has increased since the 1980s. At the same time, there are dramatic changes in the industrial structures and vegetation policies of many Leptosols soil regions (Hui et al. 2014). To pursue greater economic benefits, many slope cultivated lands no longer grow rape and other crops but vegetables, fruit trees or other cash crops; after long-term aridity, the hydrothermal condition has been substantially changed. Greater soil aeration has improved the activity of soil microorganisms and has accelerated SOM mineralization, leading to rapid a decline of the SOC content in Leptosol soil (Zheng et al. 2016).

In addition to the use of fertilizers, human activities also play an important role in the SOC change of farmlands. Although in the past 35 years, human activities have exerted no adverse impact on the total surface SOC inventories of farmlands in Puding County, the effects of human activities on the SOC inventories of different types of farmlands vary (Ying et al. 2016). Among the soil types in Houzhai Basin, Anthrosols had the most significant increase in surface SOCD because, on the one hand, during the growing period, Anthrosols are in a flooded anaerobic condition that facilitates surface SOC accumulation by suppressing microbial activity and slowing mineralization and decomposition of organic matter (Yu et al. 2007). On the other hand, there are a substantial number of organic substances added to Anthrosols through crop and straw returning, which, in combination with the local farmers' habit of using green manure to grow paddies, help increase surface SOC, to a certain degree. In addition, the Leptosol surface SOCD of upland soil in Houzhai Basin has significantly declined because this type of soil is mostly located in the mountainous areas with high altitudes, steep banks and primary vegetation composed of shrubs, copses and weeds that contain rich surface SOC in a natural condition. However, the primary vegetation has been destroyed by human activities such as cultivation and farming, making the topsoil a less efficient protective layer for vegetation. Moreover, the topsoil has been in a loose condition over the long term due to frequent ploughing. Consequently, topsoil erosion has deteriorated, and the surface SOCD has dramatically declined (Xu et al. 2013).

In summary, high diversity of geographic characters leads to the spatial heterogeneity of SOCD in the Houzhai Basin. However, the temporal change of SOC content or stock was, probably, caused by human activities. Before the year of 1980, a large part of land in the basin was claimed for cropland to satisfy the need of food production. Then, the SOC content and SOC stock in the Houzhai Basin were decreased. Since the 1990s, a great number of rural labours rushed into developed cites, such as Fujian, Ningbo, Shanghai, et al. Therefore, some croplands were abandoned and became different forestlands or grasslands, and SOC content in these lands increased. Consequently, the SOC stock in the Houzhai Basin increased as well.

Conclusions

According to the results of this study, both the SOC contents and SOCD of topsoil (0-20 cm) in Houzhai Basin have increased during the past 35 years (1980-2015). The mean content of SOC increased from 21.98 g kg^{-1} to 25.07 g kg^{-1}, and the mean SOCD increased from 4.91 kg m^{-2} to 5.13 kg m^{-2}. The total SOCS of the basin increased from 3.68 × 10^{11} g to 3.85 × 10^{11} g. Based on geostatistics of GIS system, it is found that the spatial characteristics of SOCD in the Houzhai basin changed. In the east part of Houzhai Basin, SOCD became higher in comparison with other parts during this period. However, the north, west north and south parts of this basin became lower in comparison with east part. We believed that land uses considerably shape variations in SOC level. The east part of Houzhai Basin is mainly peak cluster depression region, and most lands in this part are different forestlands in which SOC are tend to accumulate. Most lands in the other parts are different croplands with high intensity of human disturbance.

In addition, the present indicates the Houzhai River is a carbon sink during the past several decades. There is about 22.00 million km^2 land in the world. To decrease the atmospheric CO_2 concentration and alleviate the pressure of global warming, further insight studies should be carried to reveal the mechanism of carbon sink in karst area.

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Tables Captions:

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Table 2. Statistical information of SBD, rock outcrop and SOC in 1980 and in 2015.

Table 3. The topsoil SOCD (0-20 cm) of the Houzhai basin for the past 35 years (1980-2015).

Table 4. Semi-variogram theoretical models and parameters of SOCD.

Table 5. The SOCS of the surface layer for the past 35 years of Houzhai basin (1980-2015).

Table 6. Correlations between SOC/SOCD and different factors.

Figure Captions:

Figure 1. The distribution of sample sites in 2015 (a), in 1980 (b) and land use (c) in the Houzhai Basin.

Figure 2. Temporal and spatial distribution of SOCD in the Houzhai basin (a. the SOCD spatial distribution in 1980; b. the SOCD spatial distribution in 2015).

Figure 3. Amplitude in soil organic carbon storage (SOCS) in the past 35 years.

Table 1. Sampling sites of different soil types in 1980 and in 2015.

Soil types	Area (km^2)	Sampling numbers	
		1980	2015
Anthrosols	20.12	8	1010
Leptosols	42.00	9	1288
Ferralsols	12.88	6	457
Total	75.00	23	2755

Table 2. Statistical information of SBD, rock outcrop and SOC in 1980 and in 2015.

	SBD (g cm^{-3})		Rock outcrop (%)		SOC (g kg^{-1})	
	1980	2015	1980	2015	1980	2015
Range	0.86-1.47	0.79-1.43	0-97	0-95	1.28-86.28	1.61-119.11
Mean	1.28	1.22	20.78	15.94	21.98	25.07
Standard deviation	0.38	0.22	28.37	22.29	16.90	13.93
Variance	29.69	18.03	136.52	139.83	76.89	55.56
Kurtosis	0.04	1.90	0.36	0.79	0.87	2.69
Skewness	0.59	-0.96	0.08	1.33	0.28	1.66

Table 3. The topsoil SOCD (0-20 cm) of the Houzhai basin for the past 35 years (1980-2015).

Soil types	Percentage (%)	SOCD1980	SOCD2015	∆SOCD (kg m^{-2})	SOCD Amplitude (%)	∆SOCD (kg m^{-2} y^{-1})
		Mean ± standard error (kg m^{-2})				
Anthrosols	26.83	4.34±0.23	5.95±0.22	1.61	27.1	0.05
Leptosols	56.00	5.57±0.18	4.92±0.23	-0.65	-13.2	-0.02
Ferralsols	17.17	3.65±0.37	4.56±0.31	0.91	20.0	0.03
Total	100	4.91±0.21	5.13±0.19	0.22	4.3	0.01

Note: SOCD1980 is the topsoil (0-20 cm) soil organic carbon density of 1980, SOCD2015 is the topsoil (0-20 cm) soil organic carbon density of 2015; ∆SOCD is the topsoil (0-20 cm) soil carbon increment per unit area (kg m^{-2}); ∆SOCD/t is the topsoil soil (0-20 cm) annual variation of soil organic carbon density (kg m^{-2} y^{-1}).

Table 4. Semi-variogram theoretical models and parameters of SOCD.

Time	Model type	Nugget (C_0)	Sill (C_0+ C_1)	C_0/C_0+C	Partial base value (C_1)	Range (m)	R^2	RSS
1980	Index	1.12	5.23	0.21	0.04	2210.6	0.89	1.05×10^{-5}
2015	spherical	0.93	3.05	0.30	0.04	2326.3	0.83	2.35×10^{-5}

Note: C_0 refers to the nugget variance; (C_1+C_0) refers to the sill that shows the total variation of system; C_0/(C_1+C_0) refers to the degree of spatial variation.

Table 5. The SOCS of the surface layer for the past 35 years of Houzhai basin (1980-2015).

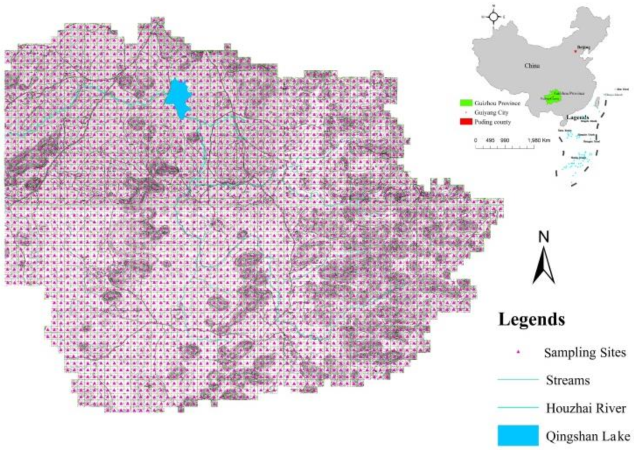
Soil type	Area (km^2)	T1980 ($\times10^3$ t)	T2015 ($\times10^3$ t)	ΔT ($\times10^3$ t)	ΔT/T1980 (%)	Lost carbon (%)	Fixed carbon (%)	Relative balance (%)
Anthrosols	20.12	87.32	119.71	32.39	37.1	17.8	80.2	2.0
Leptosols	42.00	233.94	206.64	-27.30	-11. 7	54.1	41.9	4.0
Ferralsols	12.88	47.01	58.73	11.72	24.9	16.0	45.6	38.5
Total	75.00	368.27	385.09	16.82	4.6	38.3	58.1	13.6

Note: T1980、T2015 are the SOCS of the surface layer of 1980 and 2015; ΔT is the SOCS change of the surface layer; ΔT/T1980 is the ratio of soil organic carbon storage to the carbon storage in 1980; Lost carbon, fixed carbon and relative balance indicate that the SOCS amplitude is less than -5%, greater than 5% and between 3 and 5% in 1980-2015 years respectively.

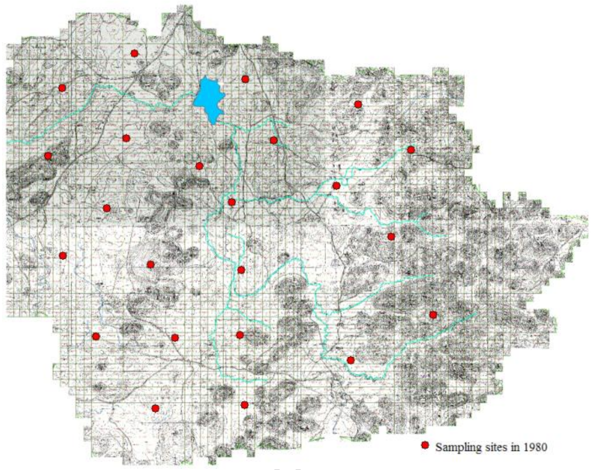
Table 6. Correlations between SOC/SOCD and different factors.

Exponential	SOC	SOCD
Slope gradient	0.99**	-0.58
Altitude	0.99**	-0.20
Soil depth	-0.91**	0.86**
SBD	-0.83*	0.97**
Gravel	0.51	-0.98**
Rock outcrop	0.98**	0.08

Note: ** Significant at 0.01 level, * Significant at 0.05 level



(a)



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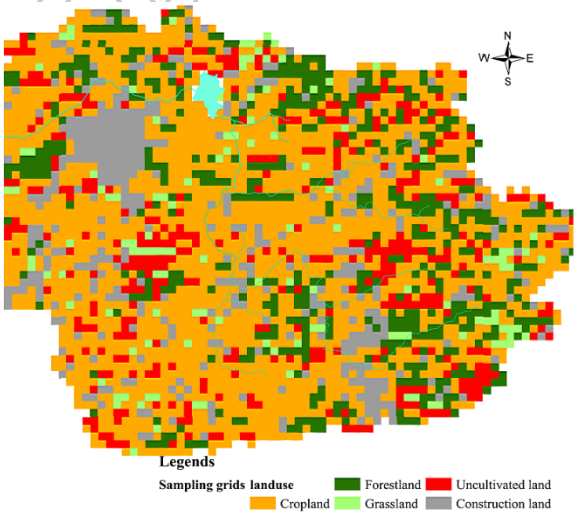
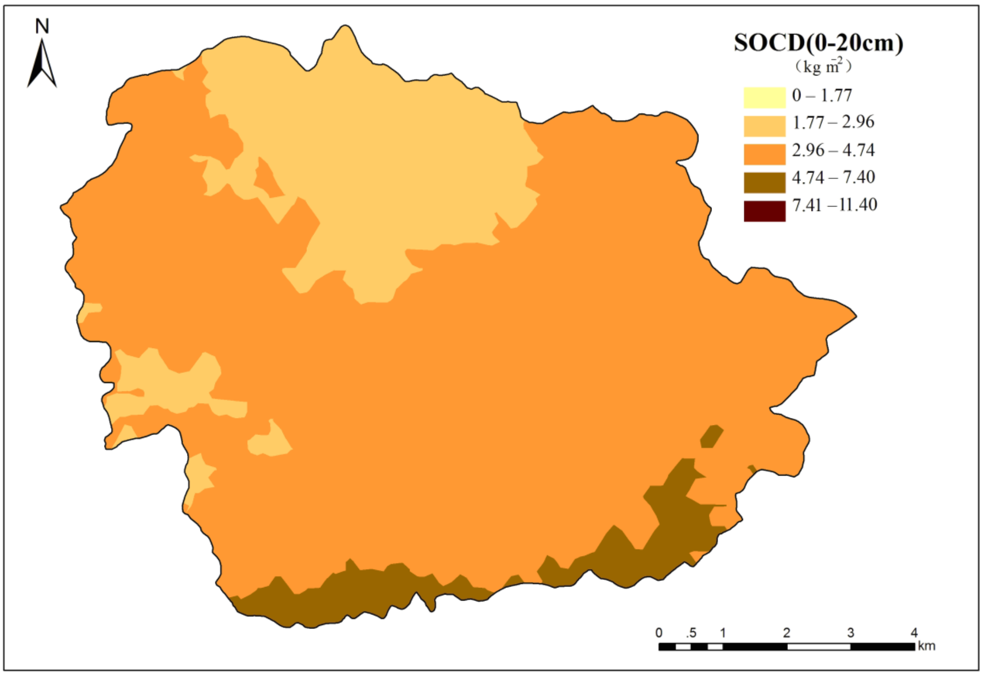


(c)

Figure 1. The distribution of sample sites in 2015 (a), in 1980 (b) and land use (c) in the Houzhai Basin.



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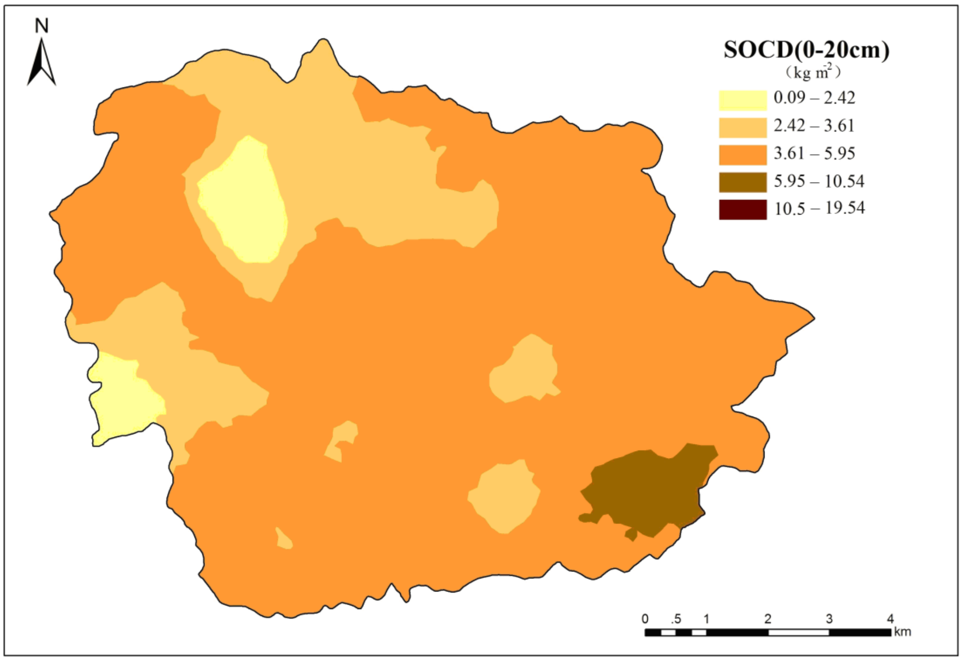

(b)

Figure 2. Temporal and spatial distribution of SOCD in the Houzhai basin (a. the SOCD spatial distribution in 1980; b. the SOCD spatial distribution in 2015).

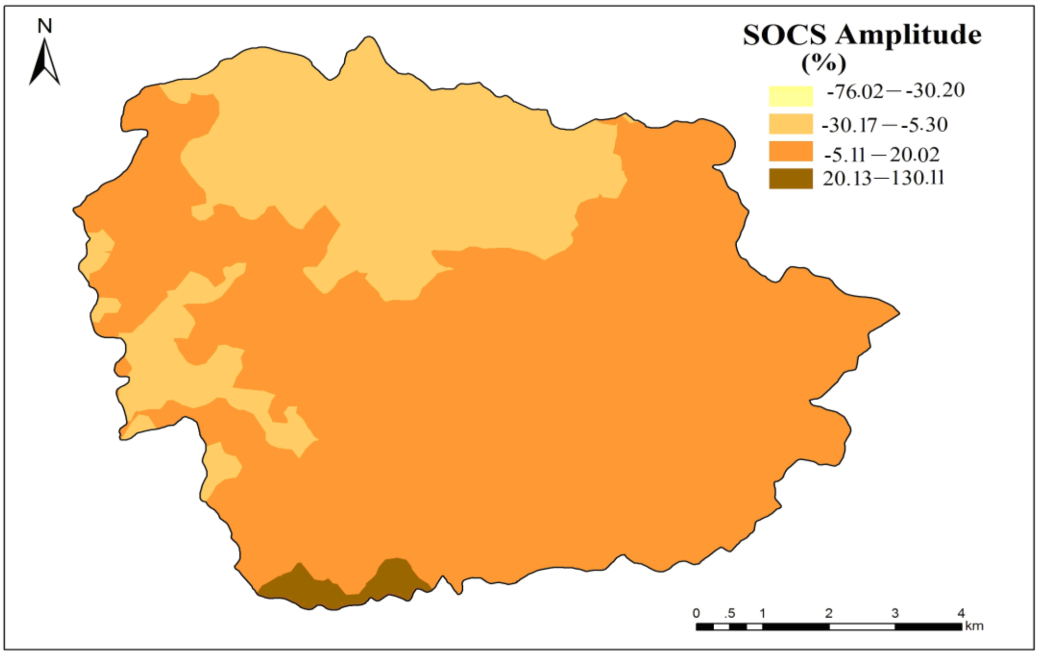

Figure 3. Amplitude in soil organic carbon storage (SOCS) in the past 35 years.