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Characteristics and correlation analysis between soil magnetic susceptibility and heavy metal content in soil along the North shore of Xinjiang Bosten Lake

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Coupling relationship between soil magnetism characteristic and soil heavy metal is one of the hottest topics of current environmental study. Bosten Lake is a major freshwater lake in arid region of Xinjiang, which plays a vital role in regulating this regional ecosystem. In order to explore the soil magnetic susceptibility, soil heavy metal characteristics as well as the correlation between them, in this paper, we selected 10 soil profiles along north shore of Bosten Lake for the determination of soil magnetic susceptibility, and heavy metal content. Through statistic analysis, we can see that: (1) Low frequency magnetic susceptibility of soil along north shore of Bosten Lake gradually increases with the depth of soil layer from 0 to 60cm, and gradually increases to the top value within the soil depth range of 40-60cm, while gradually decreases with the soil depth from 60 to 100cm; According to the variation of magnetic susceptibility content in different soil layers, we can see that within the soil layer with depth range from 0-20cm, 20-40cm, 60-80cm, 80-100cm, it exhibits the intermediate variation, while in the soil layer from 40-60cm, it shows the strong variation. Based on the average value of frequency-dependent magnetic susceptibility, we can see that there are less supper paramagnetic particles within soil layer with depth of 20-40cm, while in other soil layer, the supper paramagnetic particles contents are all over 10%. The analysis result of variation coefficient shows within 20-40cm soil layer, it exhibits medium variation, and in other soil layers, it exhibits strong variation. (2) The content order of heavy metal in soil along the north shore of Bosten Lake is Mn>Cr>Zn>Cu>Ni>As>Pb>Hg, and the vertical distribution rule is that the element Cr and Mn contents gradually increase with the deepening soil layer range from 0-80cm, while gradually decrease with the deepening soil layer range from 80-100cm; There is no obvious change occurring to the Cu content in all soil layer; contents of other elements in 20-40cm soil layer are all lower than that in 0-20cm soil layer. The variation rule of heavy metal content is that Cu, Ni, Pb, Zn, As, Cr show the medium variation, while the Mg and Hg show strong variation. (3) The relation characteristics between heavy metal content and magnetic susceptibility of soil along the north shore of Bosten Lake: the contents of Cu, Mn, Pb, Hg are positively correlated with the low frequency magnetic susceptibility, wherein the Cu element content is related with low frequency magnetic susceptibility in largest degree; Contents of Cr, Pb, Cu, Ni, Zn, Mn are positive correlated with frequency-dependent magnetic susceptibility, wherein the correlation between contents of Mn and Cu elements are mostly and frequency-dependent magnetic susceptibility is the biggest. By above analysis, we can provide scientific reference to regional environmental governance and protection.

Keywords: North shore of Bosten Lake, soil, Magnetic susceptibility, Heavy metal, Correlation.

INTRODUCTION

The soil magnetic susceptibility can reflect informations including soil weathering degree, climate, vegetation, and ecological environment. The diagnose of soil heavy metal pollution by soil magnetism characteristic has become one of most important approaches in soil environmental research [1]. As an important magnetic parameter of environmental magnetism research, the magnetic susceptibility can be put into consideration together with some geochemical elements for exploring the effect of environmental change on magnetic property as well as for analyzing the correlation between magnetic susceptibility and geochemical elements, which is one of the new development tendencies in environmental magnetism study of recent years [2]. As a result, we can indirectly monitor the effect of human activities on environment through analyzing the magnetic characteristics soil particles [3]. Weiguo ZHANG et al who studied the magnetic property of sediments in tidal flat of the Changjiang estuary, believed that the magnetic parameter values of sediments are related with soil heavy metal contents [4]. Due to the magnetic mineral in pollutant source as well as the close relation between magnetic minerals and heavy metals, the magnetic measurement method can be quickly applied in the research of environmental pollution monitoring and environmental evaluation [5]. The magnetic measurement method can achieve an excellent application in monitoring heavy metal pollution in

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soil and sediments[6] .As a major component of soil, the magnetic mineral particles exist in soil by large amounts [7]. The magnetic minerals can be divided as naturally formed minerals and man-made minerals [8]. Since secondary pollution will be formed after toxic metal elements entering into water, the monitoring and evaluation of heavy metal pollution in river sediment are of important practical significance [9]. The heavy metal pollution in lake water is mainly caused by industrial pollution, traffic pollution, agricultural pollution and living garbage pollution [10]. The iron particles in industrial waste water greatly affect the source of magnetic materials and material behavior, leading an increased magnetism of the soil, which is far beyond the local soil background value [11]. Large amounts of research results show that for the sediments, soil and street dust that are polluted by various heavy metals, their mass fraction is greatly positively related with their magnetic parameters [12]. Currently, researchers from home and abroad have conducted large amounts of studies on soil heavy metals, which reveals roles of regional climate, environmental conditions and magnetic parameters in effectively indicating the content of certain pollutant in soil, revealing the potential value of magnetic parameters in indicating pollutants[13-15]. Some researches mainly focus on the source and space distribution of pollutants [16], with China's urbanization process is accelerated unceasingly, human activities exert a more and more bigger influence on soil environmental quality [17]. Therefore, it is imperative for us to research and design an more advanced and effective monitoring technique of soil heavy metal pollution [18]. The magnetic susceptibility is closely related with the content of some heavy metals in soil [19], and the heavy metal pollution has been prescribed in China's "twelfth five-year" as a major environmental issue [20]. Large amounts of researches have shown that the magnetic susceptibility χ is positively correlated with contents of Pb, Zn, Cu, Mn [21], and the soil magnetic susceptibility values are obvious positively related with the heavy metal Cu, Zn, Pb [22]. Some researches indicate that in the heavy metal polluted soil, the there is a strong correlation between heavy metal content and soil magnetic parameters [23], also other researches show that regarding the soil being polluted by modern industrial waste, its magnetic susceptibility will increase [24], all these researches play an vital role in evaluating the heavy metal pollution in various regions [25]. Based on above research results, in this paper, we conducted determination on the soil magnetic susceptibility and heave metal content in soil along north shore of Bosten Lake, and analyzed the relation between them for the purpose of knowing the magnetization characteristics of Bosten Lake environment and exploring the correlation between soil magnetic susceptibility and soil heavy metal content. The research result can play a scientific reference in regional environmental governance and protection.

MATERIALS AND METHODS

Overview of the researched area

As the biggest inland freshwater lake, Bosten Lake locates near southern Tianshan piedmont of Bohu County, Bayingolin Mongol Autonomous Prefecture in Xinjiang. Located in east longitude 86°15′-87°00′, north latitude 41°45′-42°15′, it is a mesozoic depression lake, and serves as the main water source for urban and rural people's living as well as the industry and agriculture in Bayingolin. Bosten Lake has vast water area, with length from east to west of 55 km, and width from south to north of 20km. In 2005, the total area of Bosten Lake was registered as 1360.5 square kilometers, which consists of big lakes, small lakes and reed marshes, wherein, the big lakes account for $1036km^2$ with average water depth of 7.38m and total volume of $7.15\times10^9m^3$; The small lake group, composed by 16 small lakes, accounts for 44.5 km^2, with water depth of 2-4m, and volume of $1.2\times10^8m^3$; The total area for reed marshes is $280km^2$, which distributed along the southwest shore to the northwest shore. Bosten Lake area is blessed with sufficient sunshine and abundant heat, and the climate here is of dry air and less rain, the average precipitation for the past few years is 68.2mm, and annual evaporation capacity is 1800-2000mm. In recent years, with the industrial and agricultural development as well as the increasing human activities such as reclamation of lakes, land clearance, heavy grazing, more and more pollutants pouring into the lake, robbed development, irrational utilization of natural resource, the original function of Bosten lake wetland as severely damaged, resulting in destroyed lake ecosystem, extinction of rare species and threatened biodiversity. In addition, due to the higher content of heavy metal, the soil along the lake shores is polluted, negatively affecting the environment.

Collection of soil samples

The soil samples were collected along north shore of Bosten Lake, in Feburary,2014. By randomly setting 10 sites as the sample collection site, each site can be divided into 5 soil layers with depths of 0—20cm, 20---40 cm, 40---60 cm, 60--80 cm, 80--100 cm, respectively, so there should be collecting 50 samples (see Figure 1.)

Fig. 1. Distribution of the soil sampling site.

Soil sample analysis method

The collected soil samples were firstly subjected to room dry, and then removed the impurities such as fallen leaves, plant roots, rocks and animal residues, followed by pulverized them into powders which will be selected by 100-mesh nylon mesh for the final samples for the test. The heavy metal Cr, Cu, Mn, Pb, Ni, Zn in the soil samples were put into the hydrochloric acid-nitric acid-hydrofluoric acid microwave digestion system, after being fully digested, removed the acids, and conducted ICP determination; With regard to the element As and Hg, also firstly being digested in hydrochloric acid-nitric acid-hydrofluoric acid microwave digestion system, then removed acids under reflux, and conducted AFS determination instead. The determination method of soil magnetic susceptibility: firstly natural drying the soil sample and then grinding it into powders. Then pick some quantity of powders into the 100cm3 magnetics special sample box, being compacted and sealed, we used Bartington MS2 magnetic susceptibility instrument to determine the low frequency magnetic susceptibility (Xlf,470HZ) and the high frequency magnetic susceptibility(Xhf,4700HZ) . According to the Xlf and Xhf, we calculated the Xfd of the smaple.

RESULTS AND ANALYSIS

Analysis of magnetic susceptibility characteristics of soil along the north shore of Bosten Lake

The Table 1. reflects the statistical characteristic of low frequency magnetic susceptibility of soil along the north shore of Bosten Lake. The low frequency magnetic susceptibility varies from soil layer to soil layer: magnetic susceptibility 1.45-2.43 in 0-20cm soil layer, 1.60-3.45 in 20-40cm soil layer, 2.57-12.56 in 40-60cm soil layer, 1.81-2.62 in 60-80cm soil layer, 1.76-3.05 in 80-100cm soil layer; According to the mean value analysis, we can see the low frequency magnetic susceptibility gradually increase within 0-60cm soil layer, and reaching the peak value within 40-60cm soil layer, while gradually decrease within 60-100cm soil layer; When the coefficient of variation (CV)<10%, it exhibits the weak variation, when Cv=10-100%, it exhibits the medium variation, while Cv>100%, it shows strong variation [1]. Based on this, the variation results of soil low frequency magnetic susceptibility in different soil layers along north Bosten Lake indicate: in soil layers with depth range of 0-20cm, 20-40cm, 60-80cm, 80-100cm, it exhibits medium variation, only in 40-60cm soil layer, it will show strong variation. The possible causes for above result may be diverse, on one hand, due to the water pollution in river basin, the soil properties are inevitably affected, resulting in such variation of low frequency magnetic susceptibility. On the other hand, the underground water level may also exert influence for such results, and the lower-middle part of soil profile is of higher water content, and the soil displays cinerous color. The anaerobic environment caused the reductive dissolution of magnetic minerals, which may be the major cause for the decrease of magnetism in soil profile under 60 cm, which is also similar to the research conclusion by Guo ZHANG et al. [8].

Table. 1. Characteristics of low-frequency magnetic susceptibility.

$X_{lf}/10^{-8}m^3kg^{-1}$	Average	Max	Min	Median	SD	CV
0-20cm	1.45	2.43	0.76	0.95	0.56	0.39
20-40cm	1.60	3.45	0.64	1.47	0.94	0.59
40-60cm	2.57	12.56	0.55	1.76	3.56	1.38
60-80cm	1.81	2.62	0.51	1.90	0.71	0.39
80-100cm	1.76	3.05	0.46	1.41	0.78	0.44

Table 2 reflects the variation of frequency-dependent magnetic susceptibility in different soil layer. The frequency-dependent magnetic susceptibility is used to determine the content of supper paramagnetic particles in soil, and normally when the X_{fd} value is about 5%, it means the content of supper paramagnetic particles is high; when the X_{fd}>10%, the content supper paramagnetic particles is considerably high [8]. According to the average value of frequency-dependent magnetic susceptibility in soil along the north shore of Bosten Lake, we conclude that there is less supper paramagnetic particles in soil layer with depth range from 20-40cm, and in other soil layer, the content of supper paramagnetic particles is over 10%, which is a considerable content. The analysis result of variable coefficient shows that in 20-40cm soil layer, it exhibits medium variation, while in other soil layers, it shows strong variation. The major cause for above results is that the soil in Xinjiang is generally weakly magnetic, the soil-forming process is weak, and the frequency-dependent magnetic susceptibility is normally low. In addition, less human disturbance occurs in north shore of Bosten Lake, which also leads to the low frequency-dependent magnetic susceptibility in soil.

Table 2. Characteristics of frequency magnetic susceptibility.

$X_{fd}/10^{-8}m^3kg^{-1}$	Max	Min	Average	Median	SD	CV
0-20cm	0.91	0.07	0.29	0.21	0.32	1.10
20-40cm	0.05	0.01	0.02	0.02	0.01	0.50
40-60cm	0.99	0.03	0.26	0.05	0.37	1.42
60-80cm	0.99	0.01	0.23	0.02	0.38	1.65
80-100cm	0.97	0.01	0.25	0.07	0.37	1.48

Statistical characteristics of soil environment background value of Bosten Lake Wetland

Table 3. shows the statistical content of soil environment background value of Bosten Lake wetland area, and the statistical results show: the order of heavy metal content is : Mn>Cr>Zn>Cu>Ni>As>Pb>Hg, Mn top the rank, and the content of Hg element is the lowest. the vertical distribution rule of these 8 elements is: In the depth of 0-80cm, the content of Cr and Mn increase with the deepening of soil layer, while in depth 80-100cm, their content become less; There is no obvious change to Cu content, which stays within the range of 21.83-24.69mg/kg; With regard to other elements, their contents in soil depth of 20-40cm are lower than that in soil depth of 0-20cm.According to the classification of variable coefficients, when Cv<10%, it means lower variation, Cv=10-100% represents the medium variation, while when Cv>100%, it means strong variation. As for the heavy metal soil pollution in the Northern shore of Bosten Lake, the variation rule is: Cu, Ni, Pb, Zn, As, Cr is in the range of medium variation, while Mg and Hg show the strong variation. The above characteristics and mechanism of soil heavy metal pollution in north shore of Bosten Lake are caused by complex factors including internal factors and external factors. The internal factor is the mainly the landform of Yanqi basin, while the external factors are the three major pollution source including farmland drainage, industrial wastewater and domestic wastewater, Among which, the farmland drainage is the major cause for salt pollution of Bosten Lake, and the other two are the main cause for the eutrophication of Bosten Lake. The objective reason is the insufficient coming water from the upstream Kaidu River, and the subjective reason is due to the extensive production mode and unreasonable production structure, resulting in a unoptimistic environmental governance situation.

Table 3. Environmental background concentrations in the soils.

Indicators	Depth	No.	Average	Max	Min	Medin	SD	Cv
Cr	0-20	10	49.81	87.88	30.58	51.33	1.52	3.05
	20-40	10	50.18	66.56	21.43	48.33	1.85	3.68
	40-60	10	56.45	75.76	41.38	60.24	3.79	6.71
	60-80	10	60.61	95.89	27.8	58.83	2.08	3.43
	80-100	10	56.11	65.74	44.66	60.49	4.38	7.8
Cu	0-20	10	21.94	55.76	16.06	29.5	7.56	34.45
	20-40	10	22.83	43.53	13.15	20.06	2.77	12.1
	40-60	10	21.83	29.28	13.5	21.02	0.81	3.7
	60-80	10	23.2	31.13	14.48	26.75	3.55	15.3
	80-100	10	24.69	36.28	14.87	23.24	1.45	5.9
Mn	0-20	10	410.25	719.38	262.25	424.75	14.5	735.3
	20-40	10	472.01	662.63	281.25	432.88	39.13	82.9
	40-60	10	484.25	642.63	407.25	497.15	12.93	26.7
	60-80	10	1121.2	673.93	253	535.94	585.26	56.19
	80-100	10	468.9	550.88	255.25	5406.69	37.79	77.61
Ni	0-20	10	19.52	23.26	10.93	19.58	0.06	3.07
	20-40	10	18.08	26.68	10.06	20.45	2.37	13.1
	40-60	10	21.79	29.81	12.75	25.14	3.35	10.78
	60-80	10	23.2	36.39	18.6	24.52	1.32	5.69
	80-100	10	22.02	27.93	17.53	23.98	3.78	17.17
Pb	0-20	10	9.18	17.96	-2.96	8.7	6.633	72.19
	20-40	10	4.64	19.125	-2.96	0.78	6.56	141.14
	40-60	10	8.76	25.325	0.05	7.85	7.16	81.74
	60-80	10	11.96	30.93	1.025	9.4	8.08	67.5
	80-100	10	9.825	19.68	3.1875	5.71	4.46	45.74
Zn	0-20	10	52.6	85.62	26.96	45.78	16	30.37
	20-40	10	45.78	67.95	25.66	44.85	13.94	30.46
	40-60	10	58.7	92.83	34.16	81.01	20.33	34.63
	60-80	10	56.67	89.96	31.12	42.25	17.52	30.91
	80-100	10	62.62	148.87	33.2	48.31	31.76	50.72
Hg	0-20	10	0.97	5.91	0	0.75	1.8	141.57
	20-40	10	0.86	4.24	0.074	2.7	1.22	141.58
	40-60	10	0.37	1.25	0	1.04	0.45	196.14
	60-80	10	0.56	3.81	0	0.11	1.167	206.43
	80-100	10	0.37	0.84	0	0.421	0.3	82.31
As	0-20	10	9.75	16.26	6.79	10.89	2.84	29.2
	20-40	10	9.39	12.5	6.2	9.08	1.86	19.82
	40-60	10	10.87	18.39	7.45	11.18	2.99	27.57
	60-80	10	9.85	15.86	0	10.52	4.35	44.21
	80-100	10	10.93	32.06	0.67	7.29	8.28	75.73

Analysis of correlation between soil magnetic susceptibility and heavy metal content in soil along Northern shore of Bosten Lake

Table 4. reflects the correlation between soil low frequency magnetic susceptibility and heavy metal content in soil along north shore of Bosten Lake. When $|r|=1$, it means the two variables are in completely linear correlation. When $r=0$, there is no linear correlation between the two variables. Normally it can be divided into 3 levels: $|r|<0.4$ represents low degree linear correlation; $0.4\leq|r|<0.7$ represents significant linear correlation; $0.7\leq|r|<1$ represents high degree linear correlation [26]. On this basis, the analysis result of correlation between soil low frequency magnetic susceptibility and heavy metal content in soil along north shore of Bosten Lake: the correlation coefficient between Element Cr and soil low frequency magnetic susceptibility shows a gradually increasing trend, reaching its highest value in 80-100cm soil layer, representing high degree linear correlation. The same situation happens to the variation of correlation coefficient between Ni and soil low frequency magnetic susceptibility; Cu content is significantly related to the soil low frequency magnetic susceptibility, while Hg content is low degree related to the soil low frequency magnetic

susceptibility; Mn content is significantly related to the soil low frequency magnetic susceptibility only in 80-100cm soil layer, while in other soil layers, low degree correlation exists. Regarding the contents of Zn, Hg, As, they share the equal correlation with soil low frequency magnetic susceptibility, reaching peak value of linear correlation coefficient in 40-60cm soil layer, which is the significant linear correlation.

Table 4. Correlation analysis between low frequency magnetic susceptibility and heavy metal contents.

depth	Cr	Cu	Mn	Ni	Pb	Zn	Hg	As
X_{lf} 0-20cm	0	0.57	0.14	0	0.24	0	0.1	0
X_{lf} 20-40cm	0.14	0.37	0.36	0.28	0.14	0.24	0.22	0.22
X_{lf} 40-60cm	0.1	0.53	0.36	0.24	0.68	0.48	0.32	0.45
X_{lf} 60-80cm	0.2	0.48；	0.32	0.35	0.22	0.33	0.14	0.22
X_{lf} 80-100cm	0.7	0.65	0.42	0.62	0.1	0.2	0.25	0

Table 5 reflects the characteristics of correlation between soil low frequency magnetic susceptibility and heavy metal content in soil along north shore of Bosten Lake. Contents of Cr, Pb, Hg are in low degree correlation with soil low frequency magnetic susceptibility; Mn and As share the equal variation trend of correlation with soil low frequency magnetic susceptibility, reaching peak value of correlation coefficient in 20-40cm soil layer which represents the significant linear correlation, while in other soil layers, low degree linear correlation exists. The correlation coefficient between Zn content and soil frequency-dependent magnetic susceptibility shows a gradually decreasing trend, reaching the peak value of correlation coefficient in 80-100cm soil layer, which represents the significant correlation. In 0-20cm, 40-60cm, 80-100cm soil layers, the Cu content is significantly correlated with the frequency-dependent magnetic susceptibility, while in other soil layers, the low degree linear correlation exists; In 40-60cm and 80-100cm soil layers, Ni content is significantly linear related to the soil frequency-dependent magnetic susceptibility.

Table 5. Correlation analysis between frequency magnetic susceptibility and heavy metal content.

depth	Cr	Cu	Mn	Ni	Pb	Zn	Hg	As
X_{fd} 0-20cm	0.22	0.52	0.33	0.27	0.1	0.26	0.22	0
X_{fd} 20-40cm	0.14	0.24	0.56	0.2	0.1	0.37	0	0.55
X_{fd} 40-60cm	0.26	0.66	0.45	0.46	0.1	0.28	0.3	0
X_{fd} 60-80cm	0.24	0.6	0.33	0.4	0.29	0.56	0.2	0.32
X_{fd} 80-100cm	0.37	0.39	0.51	0.51	0.1	0.68	0.14	0.32

RESULTS AND CONCLUSION

(1) The characteristics of magnetic susceptibility of soil in north shore of Bosten Lake are: differentiation characteristics of low frequency magnetic susceptibility vary from soil layer to soil layer, in 0-60cm soil layer, it gradually increases, reaching its peak value in 40-60cm soil layer, and then gradually decreases in 60-100cm soil layer; The variation result of magnetic susceptibility and heavy metals contents show: In 0-20cm, 20-40cm, 60-80cm, 80-100cm soil layers, it exhibits medium variation, only in 40-60cm soil layer, it exhibits strong variation. Through determining the average value of frequency-dependent magnetic susceptibility, we find that the 20-40cm soil layer contains less superparamagnetic particles, while in other soil layers, the contents of superparamagnetic particles are all over 10%, which is a considerable value. The analysis results of variation coefficient show that in 20-40cm soil layer, it exhibits medium variation, while in other soil layers, it exhibits strong variation. (2) The characteristics of heavy metals contents in soil along north shore of Bosten Like show that the order of heavy metals contents is Mn>Cr>Zn>Cu>Ni>As>Pb>Hg, wherein the Mn element tops the rank, while the Hg content is the lowest. The vertical distribution rule of heavy metals shows that the Contents of Cr and Mn increase with the deepening of the soil layer depth of 0-80cm, while gradually decrease with the deepening of the soil layer depth of 80-100cm; There is no significant variation occurs to the content of Cu in all soil layers; The contents of other elements in 20-40cm soil layer are generally lower than that in 0-20cm soil layer. The variation trend of heavy metals contents is: contents of Cu, Ni, Pb, Zn, As, Cr show medium variation, while the contents of Mg and Hg show strong variation. (3) The correlation between soil magnetic susceptibility and heavy metal content in soil along north shore of Bosten Lake shows that the contents of Cu, Mn, Pb, Hg are positively related to the low

frequency magnetic susceptibility, wherein the Cu content is related in largest degree; There is no correlation between other four heavy metal elements and magnetic susceptibility of surface soil; The correlation results between soil frequency-dependent magnetic susceptibility and heavy metal contents in soil show contents of Cr, Pb, Cu, Ni, Zn, Mn are positively related with soil frequency-dependent magnetic susceptibility, wherein the correlation coefficient between Mn and Cu contents and soil frequency-dependent magnetic susceptibility is the highest in each soil layer.

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