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CHEMICAL CHARACTERISTICS OF WATER ENVIRONMENT IN LIMNIC WETLANDS IN THE WESTERN SONGNEN PLAIN, CHINA

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ABSTRACT: In the western Songnen Plain in China, the alkalization degree of water bodies is high in the limnic wetlands. Generally, pH is above 8.0, and the hydrochemical types belong to $HCO_3^{2-} - Na^+$. Through analysis on the basic saline variables such as CO_3^{2-}, HCO_3^{2-}, Cl^-, Ca^{2+}, Mg^{2+}, SO_4^{2-}, Na^+ etc. and the composed variables such as $(Cl^- + SO_4^{2-})/HCO_3^{2-}$ and $Na^+/(Ca^{2+} + Mg^{2+})$, the relationships between different variables were found, and the discriminant function and critical region map based on the pH value are obtained, and the function could be applied as one of the significant study methods on the investigation of saline-alkaline water-body. The relative analysis shows that the correlations are different among different salt variables, and some of them reaches significant level ($\alpha = 0.01$). Specially, in the western Songnen Plain, the lithofacies material of soil is mainly formed by the weathering of basalt and granite, and they are deposited inside the plain through running water transportation, so the $NaAlO_2$, Na_2SiO_3 and $NaHSiO_3$ in them can react with water and carbonate to form soda, which leads to the high correlations between Na^+ and CO_3^{2-}, HCO_3^{2-}, Cl^-, SO_4^{2-}, and the correlation between Na^+ and $Na^+/(Ca^{2+} + Mg^{2+})$ is the highest. Moreover, because of high evaporation, the salts that are in the groundwater is congregated on the earth's surface, the dissoluble salts (Cl^-, SO_4^{2-}) turn into lake, which accounts for the reason for the high correlation between Cl^- and SO_4^{2-}.

KEY WORDS: limnic wetlands; hydrochemical types; correlation analysis; discriminantion analysis

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Due to regional hydrogeologic and climatic conditions, in the western Songnen Plain, the most distinct characteristic of water environment in limnic wetlands is that many water bodies have high salt contents and pH values, and some limnic wetlands belong to salt marshes. The limnic wetlands of this region are special nature complex. It is important for the utilization of wetland resources and the integrated development of saline-alkaline soil to study chemical characteristics of water environment in this region.

1 NATURAL ENVIRONMENT CHARACTERISTICS OF THE WESTERN SONGNEN PLAIN

The western Songnen Plain lies to the east of the Da Hinggan Mountains, its east is adjacent to the

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Second Songhua River, its south borders on watershed between the Songhua River and the Liaohe River, its north adjacent to Qiqihar region. Its total area is $5 \times 10^4 km^2$. The Songnen Plain is an alluvial low plain. It is located in the Songliao sunken lowland, which began to subside chronically since the Mesozoic, and its bed rock is embeded deeply(WANG, 1992). Its top is covered with the Quaternary period fluviolacustrine facies sediments, which has high salt saturation in the rock, and its water solution is alkaline, the pH value is above 8.5. Among its salt components, the cations are mainly Na^+, and the anions are HCO_3^- mainly(LI *et al.*, 1997). Due to wind erosion, many free hillocks and closed shallow dish lowlands are distributed alternately in its middle part.

Climate type of the Songnen Plain belongs to continental monsoon climate, between winter and summer, seasonal winds have distinct alternation, and temperature is obvious different. In conclusion, the spring is dry, windy and lack of rainfall, the summer has abundant rainfall, the autumn has relatively mild rainfall and abundant sunshine, the winter is cold and long. The average precipitation through a year is 429.8mm. Many rainfalls are shower, precipitation in July and August accounts often 50% of that of the whole year, and the precipitation of spring (March – May) accounts only 10% of that in a year, less than 40mm.

Due to relative little amount of rainfall, water system is not fully developed. There are 54 rivers with their lengths more than 10km and basin areas above $20km^2$ in the region. The Tao'er River and Huolin River have important influence on water quantity balance of limnic wetlands. As a result of low physiognomy, the Songhua River, Nenjiang River and their branches form centripetal water systems in the Songnen Plain. Drainage of surface water is not free, and the Huolin River valley is mainly an inner land stream area. According to statistics, there are more than 700 lakes in this area, of which over 200 lakes have basin areas of more than $1km^2$, and the salt concentration is high in many lakes with alkali water(ZHAN, 1997). As the results of watercourse evolution, in this region, many lakes are residues of ancient riverways, and some yoke lakes and the seeper depression are formed by wind erosion during the Neotectonic Movement accompanying the formation of Songliao Watershed(LI *et al.*, 1996). Most of limnic wetlands are closely related to surface stream, only few lakes have direct and close relation with groundwater. Furthermore, movement and enrichment of elements have consanguineous relationships with the stream, and surface geochemical actions are special.

Saline-alkaline soil in this region is universally developed, saline-alkaline soil supply the salt sources for water environment. Well developed plants are adapted the high salt environment and many vegetation complexes are flourishing.

2 SOURCES AND MOVEMENT OF WATER IN SALINE-ALKALI LIMNIC WETLANDS

Water sources of limnic wetlands in this region include mainly rainfall, surface stream and groundwater.

Water amount received by limnic wetlands are determined by precipitation, catchment area of limnic wetlands and local physiognomy conditions.

Annual rainfall of the Songnen Plain has a tendency to decrease gradually from the southeast to the northwest, and in the west part rainfall varies greatly. In high water year, precipitation can reach more than 600mm, while low water year, it is less than 200mm, and in common water year, it is about 400mm. Variation of rainfall change range in a year is wide with 70% precipitation centralized from May to August. Specially, rainfall is the only source of low-lying wetlands (10 – 100ha) formed by wind erosion(QIU, 1996) which are distributed mainly in Anguang-Sheli zone, around Qiqihar and Tailai-Dorbod zone.

Surface stream is main supply source for most of limnic wetlands in this region. When plentiful rainfall occurs, in limnic wetland valleys which have great catchment area, surface stream can supply water to them along natural slope or downstream lakes along seasonal rivers. For example, in the Zhalong wetland of Shuangyang River downstream, in flood season, river table is high, which submerges alluvial flat and supply water to limnic wetlands. Some wetlands, such as wetlands in the Huolin River downstream, are floodplain of

seasonal flood discharge way, they can get water supplies from seasonal river flood. Some yoke lakes become temporary flood way during flood year and get the supply from river water.

Some limnic wetlands are located in the geotectonic rupture zone or the front edge of alluvial or pluvial fan. With lithology change of aquifer, groundwater table rises and serves as a water source to supply adjacent limnic wetlands, such as the Daqintala limnic wetlands.

Altogether, water supply amount of limnic wetlands in the western Songnen Plain is mostly from surface stream, then rainfall, and only few limnic wetlands get water from groundwater. In the point of number, limnic wetlands supplied by rainfall are most, then, surface stream, and the third, groundwater. Most of limnic wetlands have two or more supply sources. Because of spatial and temporal variation of water sources, lake water table changes annually. In high water years or seasons, due to high lake water table, many lakes connect with each other, and at the same time, a great of water can dilute salt content of limnic wetlands. In low water year, the situation is contrary.

The wetland water is consumed naturally through vertical and horizontal direction. In the vertical direction, water is consumed through evapotranspiration, water surface evaporation, infiltrating to supply groundwater. In the horizontal direction, water is consumed through supplying downstream lakes. Evapotranspiration and water surface evaporation are determined by coverage percentage of vegetation, biomass, temperature, dridity and wind velocity. Vegetation transpiration centralizes mainly through May to September. Water surface evaporation can keep for a whole year, but maximum evaporation occurs at the joint time of spring and summer. In winter, due to low temperature, short sunshine and freezing coverage on the water surface, evaporation amount is little. In flood season, wetland receive superfluous water from river, and in low water season, remaining water in limnic wetlands recharges to river or downstream lakes through surface stream or infiltrating. Through this process, not only the demand water of limnic wetlands ecological system is satisfied, but also the river flood is adjusted. In addition, the limnic wetlands water is consumed by social-economic development more and more in recent years.

3 CHEMICAL CHARACTERISTICS OF WETLAND WATER ENVIRONMENT

Water chemical characteristics of limnic wetlands in the western Songnen Plain are affected synthetically by water supply modes, replenishment quantity, drainage modes, drainage quantity and climate. Due to long-term and great area subsidence, sediments contained by river water are deposited constantly, and river bed is silted and upraised to lead to riverway swing, which restrains free running water and forms some inner land basins. Moreover, because of dry climate, intense evaporation and mankind disturbance, in many limnic wetlands, water amount input into limnic wetlands is less than output, which results in salt contents in limnic wetlands increases gradually. While due to the difference of supply and drainage modes and natural environment, the salt contents of limnic wetlands are quite different. Generally, salt content is higher in inner valley than that in outer valley; that of limnic wetlands supplied by groundwater is lower than that supplied by surface stream; that of limnic wetlands that have supply relationship with river is lower than that has no such relationship. Table 1 shows chemical characteristics of river water, and Table 2 lists chemical characteristics of some typical limnic wetlands.

From Table 2, we can see that the pH of limnic wetlands is higher than that of rivers and water is alkali, the hydrochemical type is soda-Na. Comparatively, the contents of Na^+, F^- and Cl^- are higher than those of the Second Songhua River, the Nenjiang River, the Tao'er River and the Huolin River(Table 1). The contents of Na^+, F^- and Cl^- of Hua'ao limnic wetlands, Na^+、F^-、HCO_3^-、Cl^-、CO_3^{2-} of Dabusu limnic wetlands, Na^+ of Shisan limnic wetlands, Na^+, F^- and Cl^- of Changcheng limnic wetlands are distinctly higher than those of rivers in this area. Mineral degree, total hardness and total alkalin-

Table 1 The hydrochemical characteristics of main rivers in the western Songnen Plain(mg/L)

Rivers	pH	K^+	Na^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	SO_4^{2-}	Alkalinity*	Hydrochemical type
Second Songhua River	7.3	1.68	10.50	84.50	13.60	11.63	151.89	3.40	2.49	$HCO_3^- - Ca^{2+}$
Nenjiang River	8.3	0.69	33.72	16.03	3.65	8.88	139.08	1.40	2.28	$HCO_3^- - Na^+ \cdot Ca^{2+}$
Tao'er River	7.6	1.80	8.00	43.50	20.00	8.70	209.50	2.00	3.43	$HCO_3^- - Ca^{2+} \cdot Mg^{2+}$
Huolin River	8.5	2.13	59.35	56.11	18.24	150.73	280.60	1.70	5.80	$HCO_3^- \cdot Cl^- - Ca^{2+} \cdot Na^+$

* unit: me/L

Table 2 The geochemical characteristics of limnic wetlands in the western Songnen Plain(mg/L)

Limnic wetlands	pH	K^+	Na^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	CO_3^{2-}	SO_4^{2-}	Alkalinity*	Hydrochemical type
Qagan Lake	7.4	3.14	297.30	17.06	15.73	145.57	501.02	111.27	46.28	11.92	$HCO_3^- \cdot Cl^- - Na^+$
Yueliang Lake	8.2	1.36	46.30	29.10	12.90	17.02	167.00	4.62	12.60	2.89	$HCO_3^- - Na^+ \cdot Ca^{2+}$
Lianhuan Lake	8.8	3.46	198.32	16.03	9.73	12.43	600.24	0.00	1.96	9.84	$HCO_3^- - Na^+$
Hua'ao Lake	9.8	5.60	2222.50	23.60	10.07	4559.20	1186.20	297.80	22.50	29.37	$Cl^- \cdot HCO_3^- - Na^+$
Dabusu Lake	9.4	2.80	243.50	40.00	84.00	2674.20	26443.50	20999	1303.50	1133.50	$CO_3^{2-} \cdot HCO_3^- - Na^+ \cdot Mg^{2+}$
Shisan Lake	9.5	11.20	1467.50	109.00	27.50	2361.20	607.60	27.23	10.00	10.87	$Cl^- - Na^+$
Zhalong Wetland	8.8	3.46	198.32	16.03	9.73	12.43	600.24	0.00	1.96	9.84	$HCO_3^- - Na^+$
Tailai Wetland	8.9	1.51	32.10	12.02	7.30	21.30	117.12	0.00	1.64	1.92	$HCO_3^- - Na^+$
Changcheng Lake	10.2	1569.83		169.44	113.76	2833.07	262.15	26.32	1812.33	5.17	$Cl^- \cdot SO_4^{2-} - Na^+$
Sanba Lake	9.7	1643.42		203.12	146.53	3964.31	122.09	31.27	1882.41	3.04	$Cl^- \cdot SO_4^{2-} - Na^+$
Qingxue Lake	9.8	1766.76		224.56	123.18	2866.44	196.37	43.22	1728.15	4.66	$Cl^- \cdot SO_4^{2-} - Na^+$
Liuhetang Lake	10.1	1625.57		256.15	564.84	2562.93	166.64	54.74	476.84	4.56	$Cl^- \cdot Na^+ - Mg^+$

* units: me/L

ity of limnic wetlands are comparatively higher. In the western Songnen Plain, alkalization of many inland limnic wetlands is serious, only in few large lakes that have supply relationship with rivers, such as Yueliang Lake, Lianhuan Lake and Qagan Lake, this situation is slight. Moreover, alkalization of a few lakes are more serious, and their functions of irrigation and drinking have lost. Commonly, in the western Songnen Plain, some natural limnic wetlands are affected by human activities, climate and surface geo-chemical factors, alkalization is serious. Specially, it is obvious in the Huolin River valley, the midstream valleys of the Tao'er River and the Nenjiang River. In some slight alkali areas, the periodical water supplied from river dilutes the salt contents of limnic wetlands, and reed and other swamp vegetation grow well.

According to the contribution of main salt components to regional alkalization, the main hydrochemical variables can be classified into two groups, i.e. fundamental variables, such as CO_3^{2-}, HCO^{3-}, Cl^-, Ca^{2+}, Mg^{2+}, SO_4^{2-}、Na^+ etc. and derived variables, such as $(Cl^- + SO_4^{2-})/HCO_3^{2-}$, Cl^-/SO_4^{2-}, $Na^+/(Ca^{2+} + Mg^{2+})$ etc. (SHI, 1991). Due to identical source and comparable character of elemnets, some variables have correlation with each other. The correlation among different components are analyzed (Table 3).

From Table 3, it is clear that the correlation is different among different components, and the relativity among some components reaches significant correlation ($\alpha = 0.01$). Specially, in the western Songnen Plain, mainly, the lithofacies (soil) are weathering material of basalt and granite. They are accumulated by the way of running water transportation, and the $NaAlO_2$, Na_2SiO_3 and $NaHSiO_3$ in them can react with water and carbonate to form soda, which lead to correlation coefficients between Na^+ and CO_3^{2-}, HCO_3^{2-}, Cl^-, SO_4^{2-}, and between Na^+ and $Na^+/(Ca^{2+} + Mg^{2+})$ are higher.

Moreover, because of high evaporation, salt in the groundwater is moved upward and accumulated on the surface soil. Dissoluble salts (Cl^-, SO_4^{2-}) turn into lake and this can be attributed to the high correlation between Cl^- and SO_4^{2-}.

Because pH reflects synthetically alkalization of water body in a certain degree(ZHANG, 1996), on the basis of correlative analysis, saline-alkaline components in the water bodies are classified by step discrimination analysis according to pH value. The discrimination rule

Table 3 The relationship matrix of saline-alkalization variables of water bodies in the western Songnen Plain

	CO_3^{2-}	HCO_3^{2-}	Cl^-	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Na^+	$(Cl^- + SO_4^{2-})/HCO_3^{2-}$	Cl^-/SO_4^{2-}	$Na^+/(Ca^{2+}+Mg^{2+})$
CO_3^{2-}	1.000	++	++	−	+	++	++	+		++
HCO_3^{2-}	0.713	1.000	+		+	+	++			+
Cl^-	0.832	0.470	1.000	−	+	++	++	++		+
Ca^{2+}	−0.442	−0.293	−0.213	1.000						
Mg^{2+}	0.436	0.555	0.495	−0.062	1.000	+	+			
SO_4^{2-}	0.750	0.573	0.718	−0.303	0.531	1.000	++	+		+
Na^+	0.940	0.829	0.871	−0.361	0.531	0.756	1.000	+		++
$(Cl^- + SO_4^{2-})/HCO_3^{2-}$	0.570	0.034	0.816	−0.055	0.032	0.402	0.552	1.000		++
Cl^-/SO_4^{2-}	−0.043	0.060	0.091	0.226	0.017	−0.206	0.061	0.111	1.000	
$Na^+/(Ca^{2+}+Mg^{2+})$	0.782	0.442	0.659	−0.411	−0.093	0.436	0.729	0.720	0.035	1.000

++ $\alpha = 0.01$, significant positive correlation;
+ $\alpha = 0.05$ positive correlation;
− $\alpha = 0.05$ negative correlation.

is that water bodies are classified into 1, 2 and 3 according to pH 7 − 8, 8 − 9 and 9 − 10. Through analysis and simulation, the following discrimination function and regional map(Fig. 1) are obtained.

Type Discrimination Functions:

Type 1

$$Y_1 = -0.116[CO_3^{2-}] - 0.172[SO_4^{2-}] + 0.019[Na^+] - 4.121$$

Type 2

$$Y_2 = -0.0348[CO_3^{2-}] + 0.225[SO_4^{2-}] + 0.0029[Na^+] - 1.343$$

Type 3

$$Y_3 = -0.0065[CO_3^{2-}] + 0.0569[SO_4^{2-}] + 0.00533[Na^+] - 2.986$$

Canonical Discriminant Functions:

$$X = 0.048[CO_3^{2-}] + 0.120[SO_4^{2-}] - 0.006[Na^+] + 0.011$$

$$Y = -0.001[CO_3^{2-}] - 0.169[SO_4^{2-}] + 0.005[Na^+] - 0.505$$

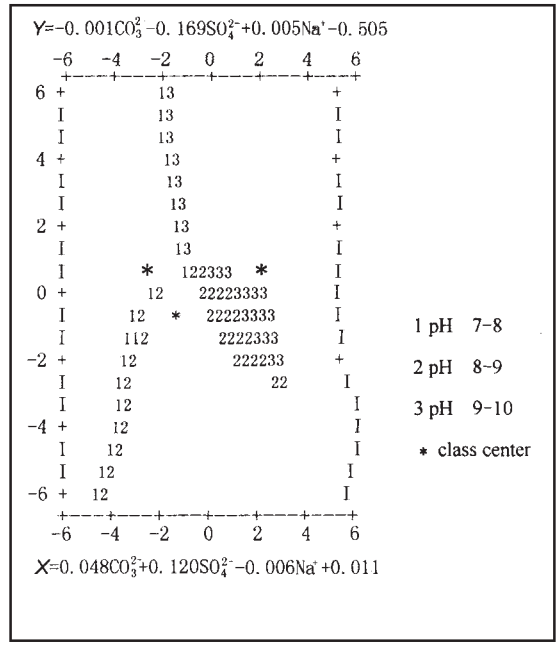

Fig. 1 Discrimination of hydrochemical characteristics in the western Songnen Plain

where, the unit of $[CO_3^{2-}]$, $[SO_4^{2-}]$ and $[Na^+]$ is mg/L.

Through the above analysis, the alkalescence of water bodies in the western Songnen Plain can be expressed by the concentration of CO_3^{2-}, SO_4^{2-} and Na^+, by which Y_1, Y_2 and Y_3 are calculated, and the biggest $Y(Y_1, Y_2, Y_3)$ is the pH range of water body. According to Fig. 1, saline-alkali situation is classified for different water bodies

4 CONCLUSIONS

In the western Songnen Plain, the limnic wetlands are significant natural landscapes that are formed under special geological and geographical environment and land hydrologic conditions. Hydrochemical characteristics of limnic wetland have intimate relationship with its causes of formation and element character.

This analysis is an effective way to explain difference of element source, movement and accumulation under special conditions. In this paper, through the analysis of water source and movement of limnic wetlands, the movement laws of saline-alkaline components are clarified in the region. Finally, high correlation between CO_3^{2-}, HCO_3^{2-}, Cl^-, SO_4^{2-}, Na^+, $(Cl^- + SO_4^{2-})/HCO_3^{2-}$ and $Na^+/(Ca^{2+} + Mg^{2+})$ is obtained, and the causes are discussed.

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