Journal of Environmental Sciences Vol. 6, No.2, pp. 206–214, 1994 ISSN 1001–0742

Application of face-graph in heavy metal pollution assessment in river sediment

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Abstract—On the basis of sedimentation principles and environmental chemical characteristics of heavy metal, combine international new methods—face graph on heavy metal pollution assessment with multi-variable graph expression, the article made a synthetical assessment study on state of heavy metal pollution and potential ecological risk of Taizi River sediment in Benxi City reach. The results of the study indicated that the state of heavy metal pollution of Taizi River in Benxi City reach is very serious, appropriate counter measures should be taken.
Keywords: face graph; heavy metal pollution; sediment; potential ecological risk index.

1 Introduction

Taizi River situated in the southeast of Liaoning Province with 464 kilometers long, is an important water source in Benxi, Liaoyang and Anshan areas. In the past, Taizi River was a river with high discharge and bioproduction, inland transport was possible. But now, the river was seriously polluted by phenol, cyanogen, oil and heavy metals. The colour of water is black-brown. To investigate the state of heavy metal pollution and potential ecological risk of Taizi River sediment in Benxi City reach, an assessment study on heavy metal pollution and multi-variable graph expression-face graph was carried out.

2 Experimental

2.1 Methodology

A vast amount of scientific studies have indicated that, once heavy metal pollutants emitted by various path into water, most of them are changed rapidly from liquid state to solid state, i.e. they are turned into suspension and sediment. During suspension transport in water current, if the load of suspension exceeds transport capability of water current, suspension will deposit gradually. In addition, in water body polluted by heavy metal pollutant, a few of heavy metals were detected, and it distributed randomly, various from emission state and hydraulic condition. But in sediment, heavy metals accumulate easily and distribute regularly. Because sediment can reflect the state of water system. Sediment is an indicator of heavy metal pollution in water environment (Forstner, 1979), study on sediment can play an important role in determination of complicated hydraulic-chemical action in rivers and lakes.

In this study, sediment can be taken as the object, combine potential ecological risk index method and face graph, make a synthetical assessment state of heavy metal pollution and potential ecological risk of Taizi River sediment in Benxi City reach. The index method and face graph, make a synthetical assessment study on the state of heavy metal pollution and potential ecological risk of Taizi River sediment in Benxi City reach.

2.2. Sampling, treatment and analysis

River in this region are mountain river with high current velocity, and the river beds are composed by wide particulate matter, such as gravel, sands. Heavy metal pollutants accumulate mainly in fine particulate in low current velocity reach. According to this rule, we select area with low current velocity and fine particulate matter for sampling as possible.

There are much pollutant source of waste water in Benxi sector, Taizi River. In order to ensure the representation of sample and its region, sampling site were arranged at the same side of pollutant source beside the river bank. To reflect current state of pollution, samples at sediment surface 0 – 5 cm were selected. For the sake of preventing sample

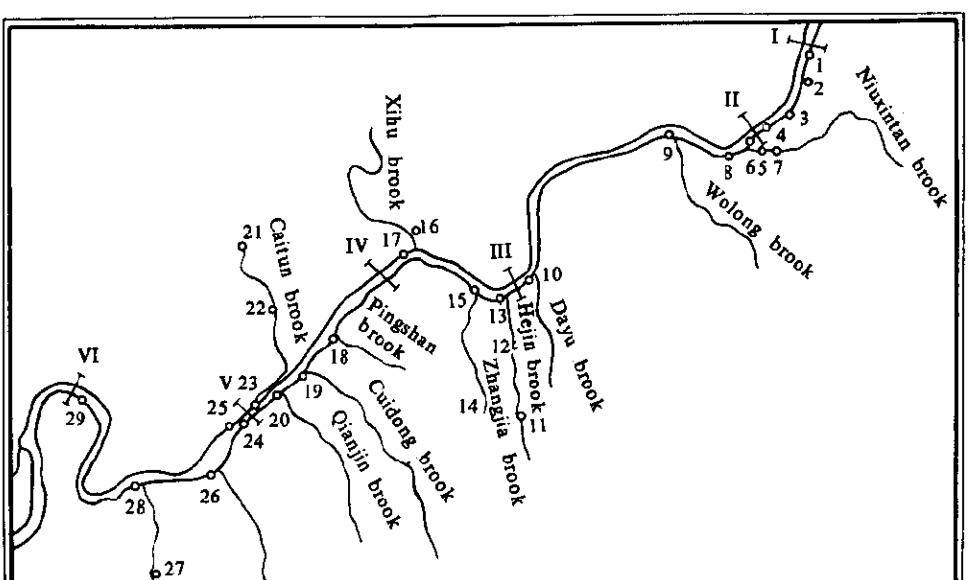

Fig. 1 Sediment sampling sites in Taizi River, Benxi City reach

Table 1 Determining subject and methods of sediment samples

Determining subject	Sample	Method
Cu, Zn, Cr	HNO_3, $HClO_4$, HF	AAS
Cd, Pb	HNO_3, $HClO_4$, HF	AAS
Hg	HNO_3, H_2SO_4, V_2O_5	Flameless AA
As	HNO_3, H_2SO_4, $HClO_4$	Ag-DDC

from pollution by sampling machine, sample that contact with metal implement were removed carefully, and the other were brought to laboratory in polyethylene bag for analysis. Sample were air-dried at room temperature. Because of the size of sediment exert an influence on content of heavy metal, size correction was taken in this study. Samples ($<50\mu m$) were grounded and analysed. Fig.1 shows the location of sampling. Table 1 shows subject and methods of determination, and Table 2 shows the results of the determination.

3. Face graph and its assessment methods

3.1 Face graph

In data processes of previous scientific research, planes were usually used to express data object. When there are only two variable in sample, plane right angle coordination can be used to trace, and when there are three variables in sample, the 3-dimension coordination can be traced. But this expression is not convenient when there are more than three variables in sample. At actual scientific research, the number of variables to process is almost more than three, the data can not be expressed by tracing. In this study, the relationship and characteristics between samples are expressed by graph expression for multi-variable.

Face graph was raised by Chernoff (Chernoff, 1973). In face graph, a face expresses a sample, and the size and shape on a part of face graph express a variable. This methods has not been used in environmental scientific research so far. Usually parts of face graph are composed by 18 variables (Fang, 1989). If there are not more than 18 variables, same parts of face graph can be fixed.

To make data in the range of [*aj*, *bj*], a regular variation is necessary for original data before graph. For the j variable in j sample X_{ij}, regular variation formula is:

$$X_{ij}=a_j+(b_j-a_j)\times\frac{X_{ij}-X_{\min j}}{X_{\max j}-X_{\min j}}\ ,\ i=1,2,\cdots n \tag{1}$$

where X_{ij} is variate data for graph; a_j, b_j is upper and lower limit of graphing data; $X_{\min j}$ is minimum of j variable in all samples; $X_{\max j}$ is maximum of j variable in all samples.

To express the content of each polluting element, the form of reference is changed (Fang, 1989). Face graph is consisted of 15 variables, 7 of them are fixed. Table 3 presents the meaning of each variable.

Table 2 Determination result of heavy metal pollution element

(Unit: mg/kg)

	Cu	Cd	Pb	Zn	Cr	As	Hg
1	36.26	0.083	17.96	126.10	31.05	4.65	0.106
2	63.63	0.084	30.97	172.46	34.37	4.69	0.254
3	49.30	0.099	30.16	207.44	34.17	5.51	0.342
4	99.52	0.247	46.40	171.17	31.96	6.44	0.622
5	136.00	0.161	46.60	191.24	38.15	6.60	0.231
6	139.20	0.271	39.55	181.36	36.79	8.07	0.434
7	74.54	0.137	60.33	196.39	37.30	10.06	0.203
8	118.60	0.396	82.59	434.64	33.09	10.75	1.512
9	80.84	0.197	84.55	475.30	34.86	6.15	1.159
10	110.14	0.117	201.24	450.42	19.01	8.54	0.816
11	2088.26	0.315	204.29	699.36	29.92	5.44	5.204
12	6786.54	1.537	217.52	405.26	41.17	10.35	1.935
13	10711.14	0.272	1261.45	325.10	53.14	10.23	1.685
14	400.77	0.488	3457.40	847.18	49.62	10.09	0.019
15	961.54	0.293	93.63	567.22	38.46	8.22	1.044
16	77.03	1.223	15042.46	121.32	12.84	7.76	0.492
17	58.57	0.114	56.50	257.86	43.17	6.15	1.209
18	135.64	0.865	2039.06	526.66	54.03	14.33	0.447
19	460.83	0.410	630.92	377.04	64.29	16.76	0.320
20	101.67	0.766	457.12	1208.35	38.57	16.77	0.815
21	2178.94	0.524	9930.58	440.16	45.18	13.40	0.070
22	1266.07	0.313	69.15	280.10	49.90	5.55	0.861
23	2936.94	3.310	156.58	525.76	51.41	7.45	1.676
24	104.68	0.945	1567.66	468.08	42.76	8.68	0.416
25	2181.34	93.950	131.26	602.60	48.75	16.85	0.270
26	165.11	1.687	447.94	1447.94	53.75	7.48	0.431
27	174.75	5.578	93.95	422.02	48.53	19.77	0.704
28	184.95	0.572	175.83	661.79	46.61	18.06	0.695
29	177.85	1.601	176.78	812.31	46.41	12.63	1.253

3.2 Methodology in assessment

On the basis of sedimentation principles and environmental chemical characteristics of heavy metal, this article made a synthetical assessment study on the

Table 3 Meaning of each variable in face graph

Variable	Element	Range	Definition of face graph	Approxinate meaning
X1	PERI	0.7 – 1.5	Centrifugal ratio of face	Narrower face means stronger PERI
X2	Cr	1.3 – 3.0	Length of eyebrow	Longer eyebrow means higher Cr content
X3		0 – 45	Angle of eyebrow	Fixed
X4		0.2 – 1.0	Centrifugal ratio of eyes	Fixed
X5	As	8.0 – 30	Size of eyes	Bigger eyes means higher As content
X6	Hg	8.0 – 18.0	Size of ears	Bigger ears means higher Hg content
X7	Pb	2.0 – 8.0	Length of nose	Longer nose means higher Pb content
X8		1.0 – 5.0	Height of nose	Fixed
X9	Zn	1.0 – 8.0	Size of mouth	Bigger mouth means higher Zn content
X10		0 – 45	Angle of mouth	Fixed
X11		1.0 – 3.0	Height of eyes	Fixed
X12		1.0 – 4.0	Distance between two eyes	Fixed
X13		0.0 – 1.0	Site of eyeballs	Fixed
X14	Cu	0.0 – 5.0	Amount of hair	More hairs means higher Cu content
X15	Cd	0.0 – 20.0	Amount of beard	Much beard means higher Cd content

state of heavy metal pollution and potential ecological risk of Taizi River sediment in Benxi City Reach, apply *PERI* (the potential ecological risk index) which was raised by Professor Lars Hakanson (Lars Hakanson, 1980). The calculating formula of *PERI* is as follows:

$$PERI=\sum_{j=1}^{n} E_r^i=\sum_{j=1}^{n} T_r^i \times C_j^i=\sum_{j=1}^{n} T_r^i \times \frac{C_{surface}^i}{C_n^i} \quad ,$$

where $C_{surface}^i$ is concentration of heavy metal in the surface of sediment; C_c^i is parameter needed in calculation; C_j^i is pollution for the given heavy metal; T_r^i is toxic response factor for the given heavy metal; E_r^i is potential ecological risk factor for the given heavy metal; *PERI* is potential ecological risk index for several heavy metals involved.

3.3 Selection of parameter needed in calculation

Currently, the selection of parameter needed in calculation is different for domestic and foreign scholars, some use average heavy metal content in shale, while others use average heavy metal content in global sediment, and Hakanson raised that, take the pre-industrial highest background value of global sediment as the parameter needed in calculation. The latter is adopted in this study because it can reflect actual level of river pollution more exactly. The preindustrial highest level of river pollution background values (ppm) of global sediment are as follows: Cu, 50; Cd, 1.0; Pb, 70; Zn, 175; Cr, 90; As, 15; Hg, 0.25 (Lars Hakanson, 1980).

Toxic response factor can reflect the risk of heavy metal to ecological system from the viewpoint of principle of element abundance and degree of element release. Namely, smaller abundance of an element or bigger release degree means stronger potential ecological toxticity. According to this, after a series of processed of basic data, Hakanson determined the order of heavy metal toxicity level: Hg > Cd > As > Pb = Cu > Cr > Zn, regular processed toxicity factor: Hg = 40, Cd = 30, As = 10, Pb = Cu = 5, Cr = 2, Zn = 1 (Lars Hakanson, 1980).

3.5 Degree of potential ecological risk factor and pollution level for individual heavy metal:

$E_r^i < 40$: low ecological risk; $40 \leqslant E_r^i < 80$: moderate ecological risk; $80 \leqslant E_r^i < 160$: considerable ecological risk; $160 \leqslant E_r^i < 320$: high ecological risk; $E_r^i \geqslant 320$: very high ecological risk.

Degree of potential ecological risk index and pollution level for all heavy metals involved: $PERI < 150$: low ecological risk; $150 < PERI \leqslant 300$: moderate ecological risk; $300 \leqslant PERI < 600$: considerable ecological risk; $PERI$: $\geqslant 600$, high ecological risk.

4 Results and discussion

Seven elements in samples from 29 location in Benxi City reach of Taizi River were analysed and determined, Table 2 shows the results and Fig. 2 shows the face graph drew according to processed original date from Table 3. Table 4 shows the results of *PERI* calculated as the methodology in assessment.

Compare face graph with data of each sample, we can find that pollution state of each sample is reflected on its corresponding face graph. Potential ecological risk index and pollution level of heavy metals such as Cu, Cd, Pb, Zn, Cr, As and Hg are expressed in face graph by hair, beard, nose, mouth, eyebrow, eyeballs and ears, respectively.

The relatively heavy metal pollution degree of each site is shown in Fig. 2. Face 1 is a control area on the upperstream of Taizi River, can be compared with other sites. For example, face 12, 13 with the most hairs, indicate that Cu pollution in these two disposition point is the most serious; face 26 with the most beard indicate that Cd pollution in this site is the most serious. Similarly, Pb pollution in sites 16 and 21 and Zn pollution in sites 26 and 20 are most serious, As pollution

Table 4 Results of potential ecological risk index (*PERI*)

Sample No.	Cu	Cd	Pb	Zn	Cr	As	Hg	RI
1	3.63	2.49	1.28	0.72	0.69	3.10	16.95	28.86
2	6.36	2.52	2.21	0.99	0.76	3.13	40.64	56.61
3	4.93	2.97	2.15	1.19	0.76	3.67	54.70	70.37
4	9.95	7.41	3.31	0.98	0.71	4.29	99.52	126.17
5	13.60	4.83	3.32	1.09	0.85	4.40	36.96	65.06
6	13.92	8.13	2.82	1.04	0.82	5.38	69.44	101.55
7	7.45	4.11	4.31	1.12	0.83	6.71	32.48	57.01
8	11.86	8.88	5.90	2.48	0.74	7.17	241.92	278.95
9	8.08	5.91	6.04	2.72	0.77	4.10	185.44	213.06
10	11.01	3.51	14.37	2.57	0.44	5.69	130.56	168.15
11	208.83	9.45	14.59	4.00	0.66	3.63	832.64	1073.80
12	678.65	46.11	15.54	2.32	0.91	6.90	309.60	1060.03
13	1071.14	8.16	90.10	1.86	1.18	6.82	269.60	1448.86
14	40.08	14.64	246.96	4.84	1.10	6.73	3.04	317.39
15	96.15	8.79	6.69	3.24	0.85	5.48	167.04	288.24
16	7.70	36.69	1074.46	0.69	0.29	5.17	78.72	1203.72
17	5.86	3.42	4.04	1.47	0.96	4.10	192.96	212.81
18	13.56	25.95	145.65	3.01	1.20	9.55	71.52	270.44
19	46.08	12.30	45.07	2.15	1.43	11.17	51.20	169.40
20	10.17	22.98	21.65	6.90	0.8C	11.18	130.40	204.14
21	217.89	15.72	709.33	2.52	1.00	8.93	11.20	966.56
22	126.61	9.39	4.94	1.60	1.09	3.70	137.76	285.09
23	293.69	99.30	11.18	3.00	1.14	4.97	168.16	581.44
24	10.47	28.35	111.98	2.67	0.85	0.79	66.56	221.67
25	218.13	50.61	9.38	3.44	1.08	11.23	43.20	337.07
26	16.51	167.34	32.00	8.27	1.19	4.99	68.96	299.26
27	17.48	29.76	6.71	2.41	1.08	13.18	112.64	183.26
28	18.49	17.16	12.56	3.78	1.04	12.04	111.20	176.27
29	17.79	48.03	12.63	4.46	1.03	8.42	200.48	292.84

in sites 27 and 28 is serious, Hg pollution in site 11 is very serious and Cr pollution is not serious in this area.

Potential ecological risk index (*PERI*) of each site can be made out object in Fig. 2. For example, face 13 with the narrowest face shape, indicates that potential ecological risk in this site is very high. Potential risk in site 11, 12, 16, 21 and 23 is very high, too. Potential ecological risk in site 2, 3, 4, 5, 6 and 7 is low or moderate. The other disposition point are considerable.

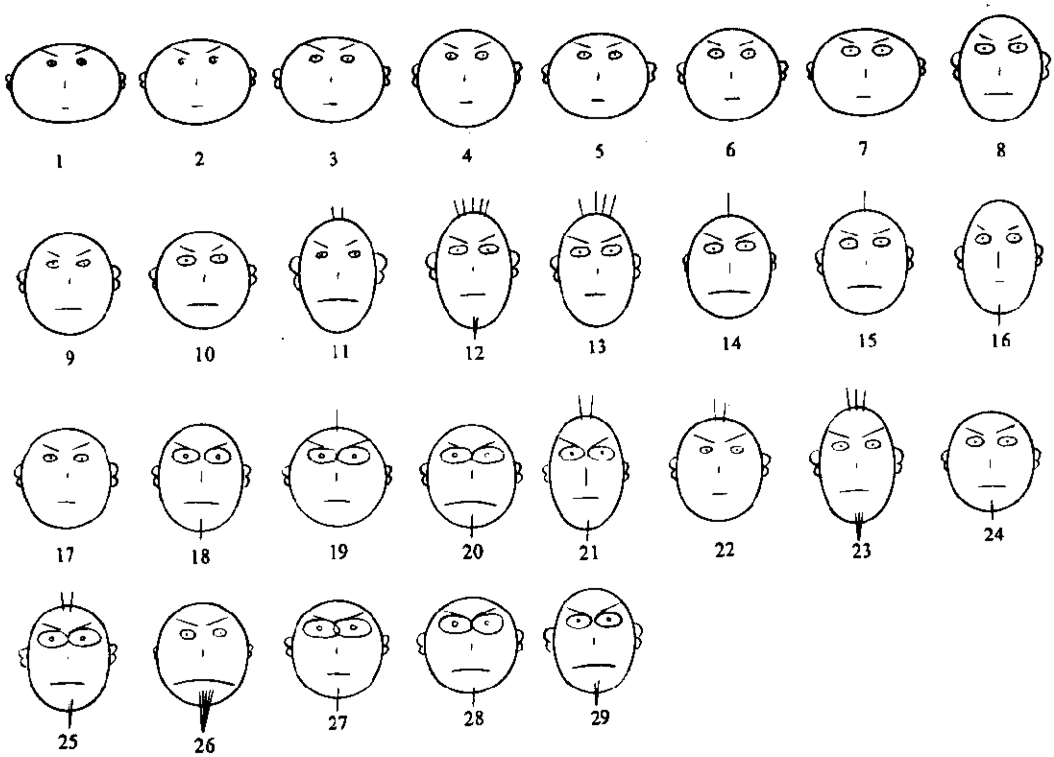

Fig. 2 Face graph

5 Conclusions

Heavy metal pollution of Taizi River sediment in Benxi City reach is very serious. The pollution order of its tributaries can be arranged as: Hejin, Xihu, Caitunmeini (high potential ecological risk), Erjiao, Zhangjia brook (considerable potential ecological risk), Ergang emitance, Pingshan, Qianjin, Wolong, Cuidong (moderate potential ecological risk), and Niuxintai brook (low potential ecological risk).

The order of heavy metal pollution degree of Taizi River sediment in Benxi City reach is Cu > Pb > Hg > Cd > As > Zn > Cr.

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(Received December 31, 1992)