A study of anthropogenic, marine and other influences upon water chemistry in Hong Kong rivers

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Abstract

A six-year river data water quality set obtained by the Hong Kong Environmental Protection Department (HKEPD) at 82 monitoring sites are used to study, at the regional scale, the spatial controls and influences upon water chemistry in HK rivers. Univariate statistics and factor analysis of the elements have been applied to analyze 27 determinands of surface water quality (pH, water temperature (Temp), flow, Salinity (Sal), Total Solids (TS), Conductivity (COND), Cl, TOC, BOD_5, COD, DOmg/L, DO%, NH_4, NO_2, NO_3, TKN, TP, PO_4, Al, Fe, Zn, Mn, Pb, Cd, Cr, Cu, Ni). The statistical results show that nutrients, aggregate organics and metals have greater variation than physical parameters which are less influenced by anthropogenic factors. These determinands can also be explained by four principle factors, representing nutrient and organic contamination, marine influences and heavy metal contamination. Finally, the local rivers can be classified into four groups, based on the factor scores derived from the factor analysis. These results may contribute to the improvement of landuse planning and sewerage design in the future.
Keywords: river-water chemistry; marine influence, nutrient and heavy metal contamination.

1   Introduction

It is well recognized that the water-quality determinands in rivers can reflect many factors and processes functioning in the drainage basins and catchment systems, such as atmospheric deposition, soil erosion, weathering of crustal minerals, biomass characteristics and anthropogenic inputs (Berner and Berner

[2], Markrich and Brown [11], Meybeck [12]). Furthermore, previous studies have shown that the regional monitoring and research of water-quality elements in rivers can contribute to the reduction of river contamination, the formulation of water resources management programs, the design of effective monitoring networks and the investigation of environmental effects brought by socio-economic components, such as the change of landuse (Gueguen *et al.* [7]; Meybeck [12], Pekey *et al.* [14]). Therefore, river research and monitoring in a regional context is common in most countries, such as the Joint Danube Survey (JDS) in Europe (Woitke *et al.* [17]).

Hong Kong is a metropolitan city with a high population density and intense land competition. Although more than a hundred of streams and rivers are observed in this small area (1102km^2), river research at the regional scale is rare, except three pieces of research conducted by Binnie & Consultant Engineers in 1974, the Environmental Protection Agency in 1981 and Li *et al.* [10]. However, the researchers ignored most water-quality determinands except organic and nutrient content. Also, these studies did not apply multivariate statistical techniques to investigate the spatial variation and the factors governing the relationship/association of these elements.

In this regard, the primary aim of this study is to examine the inter-relationship between water-quality determinands and to identify the spatial controls upon water quality at the regional scale. This study helps to fill in the research gap of a regional river study in Hong Kong, and provide a basis for contamination- abatement and may help formulate a better management plan for the local river environment.

2   Materials and methods

2.1 Study sites

Hong Kong (HK, latitude: 22°9′ ~ 22 ^{o}37′N; longitude: 113 ^{o}52′ ~ 114 ^{o}30′E) is located at the South East coast of China in Guangdong Province. It consists of Hong Kong Island, Kowloon Peninsula, the New Territories, and 235 islands. Its population is over 6.8 million and the land area is 1102 km^2. The geology in HK is straightforward as it is dominated by volcanic rocks and granites. About 20% of total land area is developed while the remaining 80% is steep hillsides covered with secondary grasslands and shrublands (Lee *et al.* [9]). Major rivers in HK number only 10, but there are around 600 small streams or creeks. Most rivers and streams originate in the mountains and hills, then flow through the built-up area and/or alluvial plain in the North and West. There is no natural lake in HK, but some man-made storage reservoirs exist (UNESCAP [16]).

In 2003, more than half of the monitored rivers were recorded as 'excellent' or 'good' in terms of the Water Quality Index (EPD [6]). However, the mainstreams in HK are still under the pressure of channelisation (DSD [4]), sewage disposal (Sin *et al.* [15], sedimentation (Peart [13]) as well as different kinds of contamination.

2.2 Description of dataset

The Hong Kong Environmental Protection Department (HKEPD) has carried out a river monitoring programme since 1986, but the dataset in this research covers the 1998 – 2003 period (6-years), which are available on the EPD's website. For each of the sites, samples are normally collected on a monthly-basis, so the sampling number is 72 (except two stations with $N=56$)

To date, the HKEPD's dataset potentially contains 46 water-quality determinands for each sample. Owing to the problem of missing values, only 27 determinands, each of which have at least 30% of total possible observations, are selected for use in this study. These determinands include *physical properties*, *aggregate organics*, *nutrients* and *total fraction heavy metals*. The list of these determinands is given in table 1, and the details of field and analytical methods are provided in the HKEPD's annual report (EPD [6]).

2.3 Statistical treatment of data

Univariate statistics (arithmetic mean, geometric mean, standard deviation, relative standard deviation) are calculated for each variable. For the multivariate analyses, the geometric mean is used for minimizing the influences of extreme outliers (Pekey *et al.* [14]).

The dataset has also been standardized using Z-score transformation, so as to remove the scaling effects among different determinands and to fulfill the assumption of cluster and factor analysis (Helsel and Hirsch [8]).

Before the Q-mode factor analysis was carried out, the dataset were examined by two tests: the Karser-Meyer-Olkin Measure (KMO) of Sampling Adequacy and Barlett's Test of Sphericity. Then, varimax rotation and regression factor scores are conducted on the factor analysis results.

3 Results and discussion

3.1 General characteristics of water-quality determinands in HK

The summary descriptive statistics (arithmetic and geometric means) of water-quality determinands for the 82 monitoring stations are given in table 1. For nutrients, the total average of PO_4, NO_3, and NH_4 in the sampled rivers/streams are 0.645 mg/L, 1.006 mg/L and 3.189 mg/L respectively, which are higher than other rivers/streams in the world based upon literature cited in Markich and Brown [11] and Zhang *et al.* [18]. For heavy metals, the total average of Cu, Zn, Pb, Cd and Ni are 8.80 µg/L, 79.79µg/L, 6.34µg/L, 0.61µg/L and 7.00µg/L respectively, which are also higher than those rivers in other countries, based upon the literature cited in Audry *et al.* [1], Gueguen *et al.* [7], Markich and Brown [11]. These results may highlight the problems of excessive nutrients and metals in HK rivers.

The extent of variation among the various water-quality determinands is also different. Table 1 gives the relative standard deviation (RSD) of each determinand. It is found that the RSD for the majority of physical elements

(6.691 % ~ 277. 618 %) is lower than that of most nutrients (123.173 % ~ 290.762 %), aggregate organics (178.143% ~ 231.869 %) and heavy metals (159.183% ~1172.461%). This result confirms that the concentrations of these water-quality determinands are highly variable among the inland rivers and streams, even though the land area of HK is not large. It is believed that this variability may reflect anthropogenic and other impacts, which are discussed in the following section.

Table 1: Descriptive statistics of physiochemical variables among 82 monitoring stations in HK.

Element group	Physiochemical elements	Sampling number	Geometric mean	Arithmetic mean	Std. Deviation	Relative S.D (RSD, in %)
Physical elements	Cl (mg/L)	3927	210.640	2502.081	4354.071	174.018
	TS (mg/L)	5675	490.156	3801.625	8210.261	215.967
	EC µS/cm)	5675	608.166	5015.756	10282.71	205.008
	Sal (mg/L)	3950	0.751	4.312	7.332	170.033
	pH	5675	7.495	7.512	0.503	6.691
	DO (mg/L)	5675	6.961	7.473	2.24	29.968
	DO (%)	5675	84.735	90.739	26.49	29.194
	Temp (°C)	5675	24.296	24.722	4.423	17.89
	Flow (L/s)	3338	0.059	0.19136	0.531	277.618
Nutrients	TP (mg/L)	5239	0.294	1.025	2.979	290.762
	PO$_4$ (mg/L)	5424	0.129	0.645	1.711	265.304
	TKN (mg/L)	5449	1.017	4.338	10.426	240.312
	NO$_3$ (mg/L)	5520	0.037	1.006	1.24	123.173
	NO$_2$ (mg/L)	5061	0.499	0.158	0.367	232.791
	NH$_4$ (mg/L)	5441	0.401	3.189	8.432	264.394
Aggregate organics	COD (mg/L)	5335	13.716	25.368	46.602	183.706
	BOD (mg/L)	4031	5.514	13.566	31.456	231.869
	TOC (mg/L)	5311	4.096	6.854	12.21	178.143
Heavy metals	Zn (µg/L)	4843	32.897	79.787	523.905	656.627
	Pb (µg/L)	3751	2.918	6.344	20.487	322.953
	Ni (µg/L)	3081	3.503	6.998	17.4	248.652
	Mn (µg/L)	5215	102.251	191.045	385.838	201.962
	Fe (µg/L)	5454	345.351	613.587	976.726	159.183
	Cu (µg/L)	4696	4.426	8.797	23.826	270.828
	Cr (µg/L)	1783	2.471	3.485	9.639	276.584
	Cd (µg/L)	1896	0.204	0.344	0.608	176.45
	Al (µg/L)	4609	157.889	450.907	5286.709	1172.461

3.2 Factor Analysis on water-quality determinands

Factor analysis has been carried out to examine the inter-relationship among the water-quality determinands. All 27 parameters were included in the preliminary stage of analysis, but the Measures of Sampling Adequacy (MSA) indicated the need for the variable selection, which reduced the dataset to 17 determinands (Table 2). The factor analysis shows good results, explaining 85.881% of the total variance of the whole dataset. Reflected by the extracted communities,

these factors can solve 59.20% ~ 98.94% of variance in each variable. Finally, the KMO test and Barlett's Test of Sphericity confirm that the standardized dataset is adequate for conducting factor analysis (KMO=0.755) and subject to the normal distribution (Approx Chi-sq= 3284.269, p-value =0.000).

The results of the factor analysis are summarized in table 2. Factor 1, explaining 43.192 % of factor variance, has a high factor loading of TKN, TP, PO_4, NH_4, TOC, COD, and BOD_5. Factor 2, explaining 26.318 % of variance, includes Sal, COND, Cl. The third and fourth factors, accounting for 10.270 % and 6.100 % of factor variance, contain Al, Pb, Cr, Mn, Zn.

Table 2:   Factor analysis result of 17 water-quality determinands on four factors after Varimax rotation with Kaiser Normalization (Bold-faced values represent strong loadings).

	Component			
	1	2	3	4
TKN	**.965**	-.073	.091	.121
TP	**.958**	-.107	-.009	.051
NH_4	**.951**	-.094	.065	.114
TOC	**.937**	.002	.220	.139
PO_4	**.932**	-.109	-.081	.011
COD	**.915**	.216	.219	.127
BOD_5	**.817**	-.047	.286	.102
DOmg/L	-.776	-.297	-.161	-.291
SAL	-.013	**.995**	.003	-.011
COND	.000	**.994**	.007	-.004
Cl	-.009	**.993**	.008	-.007
TS	-.023	**.992**	.001	-.015
Al	.192	.009	**.917**	.037
Pb	.300	-.173	**.748**	.297
Cr	-.029	.514	**.613**	-.073
Mn	.151	.093	.003	**.749**
Zn	.153	-.141	.152	**.730**
Eigenvalues	7.343	4.474	1.746	1.037
% of Variance	43.192	26.318	10.270	6.100
Cumulative %	43.192	69.510	79.781	85.881

Factor 1 is related to nutrient and organic contamination. In unpolluted rivers, the concentration of PO_4 and NH_4 are very low (<0.020 mg/L and <0.2mg/L respectively; Chapman and Kimstach [3]); therefore, very high concentrations of N and P may indicate that there are excessive nutrients coming from anthropogenic inputs, including agricultural runoff with fertilizers, livestock wastes and municipal wastes. Similarly, in rivers with high organic loading (one example is TOC), the biodegradation of organic matter by bacteria or chemical oxidants will consume dissolved oxygen; therefore, in sewage or industrial effluents, the TOC, BOD and COD may be over 100 mg/L while DO may reduce to 0% (Chapman and Kimstach [3]).

Table 3:   The classification of Hong Kong rivers/streams and their stations based on Q-mode factor analysis.

Group	Stations	River or stream
1 (10)*	KT1, KT2, YL3, YL4, TN1, RB2, RB3, IN1, FVR1, TSR1	Kam Tin River, Lower Yuen Long Creek, Upper Tuen Mun River, Fariview Park Nullah, Lower River Beas, Lower River Indus, Lower Tin Shui Wai Nullah
2 (14)*	GR1, GR2, YL1, YL2, KN1, KN2, KN3, KN4, KN5, KN7, JR6, JR3, RB1, DB6	River Ganges, Upper Yuen Long Creek, Kai Tak Nullah, Tsueng Lan Shue River, Upper River Beas, Ngau Hom Ha Stream
3 (14)*	IN2, GR3, KW3, TN2, TN3, TN4, TN5, TR12C, TR12E, TSR2, TR17, TR19, TR19A, TR19C	Middle River Indus, Upper River Ganges, Kau Wa Keng Stream, Tuen Mun River, Tin Shui Wai Nullah, Middle Tai Po Kau, Fo Tan Nullah, Tin Sum Nullah, Upper Tin Shui Wai Nullah
4 (43)*	AN1, AN2, DB1, DB2, DB3, DB5, DB6, DB8, IN3, JR11, KY1, MW1, MW2, MW3, MW4, MW5, TC1, TC2, TC3, TN6, TR4, TR6, TR12B, TR12D, TR12, TR12G, TR12H, TR12I, TR13, TR14, TR17L, TR19I, TR23A, TR23L, TW1, TW2, TW3, PR1, PR2, PR5, PR6, PR7, PR8	Pai Min Kok Stream, Tai Shui Hang, Tsang Kok, Pak Nai, Sheung Pak Nai stream, Sha Kok Mei, Ho Chung and Tai Chung Hau Stream, Tung Chung River, Mui Wo River, Upper Tai Po Kau river, Siu Lek Yuen Nullah, Kwun Yam Stream, Sam Dip Tam Stream

Due to the problem of missing value, the factor scores for TR12F cannot be calculated.
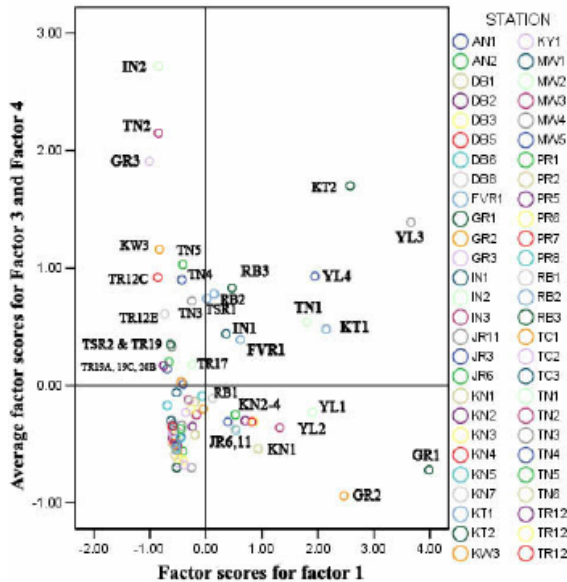* Number of stations

Figure 1:   The classification and factor scores of 82 river monitoring stations in Hong Kong.

Factor 2 may indicate the influence of seawater through marine aerosol deposition or seawater intrusion. Compared with river water, seawater has the following distinctive characteristics: strong ionic strength with high total dissolved solids (TDS) and COND (>1 mS/cm), high salinity with abundant Na and Cl. Furthermore, estuarine reaches which receive sediment and solids from both river deposits and tidal mixing particles, usually have higher total solids (TS) concentrations (Eisma [5]). Therefore, rivers or aquifers affected by seawater may show certain characteristics/endmembers of seawater. However, these endemembers are not enough to 'certify' the marine influences, because Cl and TS may also come from the primary sewage treatment plants which apply Ferric Chloride for waste removal (DSD [4]). Other determinands or indicators like Sodium (Na)/Cl, Cl/Iodine (I) may need to be adopted to confirm the influences of seawater (Sin *et al.* [15]), but they are not included in the HKEPD's dataset.

Finally, factors 3 and 4 are composed of 5 types of heavy metals, indicating the potential of heavy metal contamination. Similar to nutrient and organic wastes, the concentration of heavy metals is low in unpolluted rivers (0.1 – 0.001 µm) unless they are affected by domestic or industrial activities (Chapman and Kimstach [3]). For example, Cu, Zn, Pb, Ni, Cd, Cr are common materials in textile dyes, electroplating, galvanizing battery manufacture and plastic fabrication, which are also popular types of industry in HK (Zhou *et al.* [19]). To sum up, factors 1, 3 and 4 are mostly related to the anthropogenic inputs of chemical elements to the streams/rivers.

To examine the spatial controls of the anthropogenic influence governing the distribution of these determinands, the regression factor scores based on the results of the factor analysis are calculated for each individual monitoring site. Since factor 2 (the marine influences) may be caused by natural influences tidal effects, its factor scores are omitted. Also, as both the third and fourth factors of table 2 reflect the same type of human impact (heavy metal contamination), their factor scores are averaged. As a result, four groups of rivers and associated factor scores are identified, which are given in table 3 and shown in figure 1. The final groupings are discussed below.

Group 1: Multiple types of contamination

In this group, 10 river stations have positive factor scores for factor 1 and average scores for both factors 3 and 4, indicating that they are affected by multiple types of contamination (nutrient, aggregate organic and heavy metal contamination). These stations also have higher concentrations of most nutrients, aggregate organics and some heavy metals. In HK, they are mainly located at the edge of newtowns that receive diverse sources of contaminants.

Group 2: High nutrient and organic values, less heavy metal contamination

In this group, 14 river stations have positive scores for factor 1 but negative average scores for both factors 3 and 4. These results indicate that the dominating types of human impact in these stations are nutrient and organic contamination rather than heavy metal contamination; some peak concentrations

of nutrients and aggregate organics can be observed in the monitoring stations of this group. Most of these stations are found in rural area or old-developed downtown of Hong Kong.

Group 3: High heavy metal contamination, lower nutrient and organic contamination
In this group, 14 river stations have positive average scores for both factors 3 and 4 but negative scores for factor 1. These results mean that heavy metal contamination is more significant than nutrient and organic contamination at these monitoring stations, and the peak concentration of heavy metals may exist at these monitoring sites/rivers. Nearly all of these stations are located near to the factory areas and/or heavy traffic roads.

Group 4: Less-contaminated rivers
In this group, 43 river stations do not reveal the influences of nutrient, organic and heavy metal contamination, or these influences are masked by other factors such as seawater or geological minerals. All of them have negative average scores for both factor 1, factors 3 and 4. These streams/rivers, which have the lowest concentrations of nutrients, aggregate organics and heavy metals, are mainly found inside the remote area or country park of HK.

4　Conclusion

Although the land area in HK is small (1102 km^2), the concentration of physical, nutrient, aggregate organics and heavy metal elements vary greatly among different watercourses. The factor analysis identifies marine and anthropogenic influences upon the interrelationship of water-quality determinands, and classifies the local watercourses into four groups: some of them either have nutrient and organic contamination (Group 2) or heavy metal contamination (Group 3), while the others either suffer multiple types of contamination (Group 1) or have a low contamination problem (Group 4). The spatial location of the sites in each group supports the interpretation of the spatial controls upon the groups.

Acknowledgements

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