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BASIC CHARACTERISTICS OF NONPOINT SOURCE POLLUTION IN HONG KONG

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Abstract: Harmful eutrophication in coastal waters around Hong Kong is caused by many factors and one of them is the nutrient discharge from nonpoint source pollution (NSP). Based on limited data and information, the characteristics of NSP from Hong Kong streams were investigated in this study. Firstly, the hydrology of Hong Kong streams was analyzed using measurements from hydrological stations. Then, in addition to the determination of the mean concentration and export coefficient for each single land use, the concepts of integrated mean concentration and integrated export coefficient were proposed and applied for each Water Control Zone as well as the whole area of Hong Kong. Finally, the results obtained and further research requirements were briefly discussed.

Key words: Nonpoint source pollution, Runoff coefficient, Nutrients, Integrated mean concentration, Integrated export coefficient, Hong Kong

1. INTRODUCTION

Red tides have been frequently observed over the past two decades in coastal waters (bays) around Hong Kong. One of the main reasons are nutrient discharges from nonpoint source pollution (NSP), especially the nutrients carried by runoff from watersheds. However, only few studies have been carried out in Hong Kong on NSP, for selected sites and storm events (Chen et al., 1999; Lee, 1990; Peart and Jayawardena, 1991), which cannot reflect the general characteristics of NSP for the Hong Kong area.

Based on limited data and information, the characteristics of NSP from Hong Kong streams were investigated in this paper. Firstly, the hydrology of Hong Kong streams is briefly analyzed. Then, apart from the determination of the mean concentration and export coefficient for each single land use, the concepts of integrated mean concentration and integrated export coefficient were proposed and applied for each Water Control Zone as well as the whole area of Hong Kong. Finally, the results obtained and further research requirements were briefly discussed.

2. BASIC CHARACTERISTICS OF NSP IN HONG KONG

2.1 MATERIALS AND DATA SOURCES

The main materials and data sources of this study include monthly river water quality measurements from EPD (Environmental Protection Department, HKSAR); daily and monthly stream flow and monthly rainfall from WSD (Water Supplies Department, HKSAR); and information on land uses as well as water pollution control, e.g. sewerage master plans (SMP), Livestock Waste Control Scheme, etc. from relevant departments of the HKSAR.

To analyze the characteristics of NSP, 37 catchments/rivers, each of which had a water quality station with streamflow measurements near to the outlet, were selected. Usually, the sample frequency is monthly. Sampling stations with less frequent sampling and without flow measurement were not included in the calculation. In total there were 312 sets of usable sample measurements in 1998. The data of 1998 was selected as the basis for analysis basis since the rainfall in 1998 was close to the mean annual rainfall.

2.2 HYDROLOGICAL ANALYSIS OF HONG KONG STREAMS

Storm runoff is the carrier of nonpoint source pollutants. At the same time, the accuracy of load estimation depends strongly on the accuracy of the flow measurement (Li, et al., 2002). In order to obtain reasonable values for runoff, a hydrological analysis for Hong Kong streams, especially of the runoff coefficient, needs to be carried out. There were 11 hydrological stations in Hong Kong in 1997 and 1998. Using monthly data (WSD, 2001), the proportions of annual rainfall and runoff in the wet season (from April 1 to September 30) for the water years 1997 and 1998 (April 1 to next March 31) were determined. The average, maximum, and minimum proportions are shown in Table 1. On average, more than 90% of total rainfall and runoff occur during the wet season. There are no big differences between the years 1997 and 1998, or between rainfall and runoff. This shows that there are very distinct wet and dry seasons in Hong Kong.

Table 1 Proportion of annual rainfall and runoff in the wet season

Water Year	Item	Yearly (mm)	Wet season (mm)	Average (%)	Max. (%)	Min. (%)
1997	rainfall	2944.6	2705.7	92.23	98.83	87.29
1997	runoff	2285.7	2032.1	91.28	96.26	86.71
1998	rainfall	2122.2	1936.5	91.28	95.66	86.55
1998	runoff	1529.8	1277.6	92.86	96.39	88.35

Using the data of annual runoff and rainfall from the 11 hydrological stations and their watersheds, the average and area-weighted runoff coefficients of the water years 1997 and 1998 are shown in Table 2. The values of the two years happen to be same since there was no big difference between the annual rainfalls. Usually, the area-weighted mean value will be more reasonable. There were cases of incomplete records for some rainfall stations (WSD, 2001), which might lead to higher values of the runoff coefficient. Compared to the mean annual runoff coefficients of the whole Pearl River, 0.51, and Pearl River Delta, 0.56 (Zhujiang Water Conservancy Committee, 1991), the annual runoff coefficient of 0.66 for Hong Kong appears to be acceptable. Since the rainfall in the water years 1997 and 1998 is close to the long-term mean annual rainfall, the mean runoff coefficient can be taken as 0.66.

Table 2 Estimated runoff coefficients of 11 hydrological stations

Water Year	1997	1998
Average	0.69	0.69
Area-weighted mean	0.66	0.66

2.3 ANALYSIS OF MEAN CONCENTRATION

2.3.1 Mean concentration of each river

To identify the impact of land use and other factors on NSP to provide the basis for the subsequent analysis, it is necessary to calculate the average and flow-weighted mean concentrations for each of the 37 selected rivers. The obtained results show (Li, et al., 2003) that the highest mean concentrations were observed in the New Territories, especially the rivers in Deep Bay Water Control Zone (WCZ), Tuen Mun River in North Western WCZ, and the Lam Tsuen River in Tolo Harbour WCZ; rivers in the other WCZs have much lower concentrations. Actually, the distribution of the mean concentrations in the rivers reflected the comprehensive influences of land use, designated livestock waste control zones, and the progress in the implementation of SMPs in Hong Kong.

2.3.2 Mean concentration in rivers according to different land uses

Based on the official land use classification and the obtained water quality measurements in Hong Kong, the land uses were grouped into five types: urban and town (developed land), agriculture, grassland, scrubland, and woodland. The respective areas were obtained from Hong Kong 1998 (ISD, 2000). Using the land use map and land use data of Hong Kong, the land uses in the catchment areas for the 37 rivers could be identified. In most catchments there are mixed land uses, but catchments with only one type of land use can also be found. Based on the sampling stations representing catchments of single land uses, and using the mean concentration of those rivers, the average concentration in the runoff from each land use type can be estimated (Table 3).

Table 3 Average concentrations for different land uses (mg/l)

Land Use	BOD_5	COD	NH_4	NO_3	TKN	PO_4	TP	TN
Agriculture	28.0	51.1	16.75	0.32	21.32	3.56	4.97	21.64
Town	79.9	99.4	12.26	0.31	17.24	2.03	3.28	17.55
Grassland	10.5	22.3	0.47	1.25	1.29	0.16	0.47	2.54
Shrubland	3.2	14.9	0.29	0.70	0.84	0.11	0.18	1.54
Woodland	1.6	17.6	0.08	0.35	0.41	0.04	0.17	0.77

Compared with the local measurements for the land use of Town (Chen et al., 1999; Lee, 1990), this study found much higher values for total nitrogen (TN) and total phosphorus (TP) concentrations. The average concentration for town/urban land use in Table 3 is derived from the results of Yuen Long Creek and Tuen Mun River. In the Tuen Mun River catchment there were unsewered villages, while in the Yuen Long Creek catchment wastes from livestock farms were discharged (EPD, 2000). Besides, the EMC in Chen's study was obtained from only a few rainfall events, and no heavy storm events were included (Chen et al., 1999).

Compared with literature values, the concentrations for agricultural and town/urban land uses of this study (Table 3) are higher, while the results for grassland and woodland are similar. The values for Agriculture in Table 3 have the same magnitude as those for land with dairy manure application (Novotny and Olem, 1994), which demonstrates the harmful impact of livestock farms on river water quality in the New Territories of Hong Kong.

The following conclusions can be obtained from the above analysis: (1) The concentrations of agricultural land use as shown in Table 3 can be applied mainly to the New Territories, since most agricultural land, including livestock farms, is found there. (2) The concentrations of town/urban land use in Table 3 can be used only for areas with unsewered villages, such as Yuen Long, North District, Tuen Mun, and Tai Po. For other towns and urban areas, the concentrations found in Chen's study can be used. (3) The concentrations of grassland, scrubland and woodland in Table 3 apply to the whole area of the Hong Kong.

2.3.3 Integrated mean concentration

Usually, the mean concentration is related to single land use (Novotny and Olem, 1994). But in Hong Kong, there are no measurements of water quality available for single land uses. Actually, the mean concentration of each stream reflects the integrated effect of mixed land uses in its catchment, i.e. it is a kind of integrated or mean concentration for mixed land uses in the catchment. The key point of the concept of integrated mean concentration is that it reflects the influence of mixed land uses. If we extend the concept of catchment to a higher level, such as a WCZ or even the whole regional area of Hong Kong, then we can define the concept of integrated mean concentration for a zone or a region in the same way. Once the integrated mean concentration has been determined, it can be applied to estimating the NPS load at this level if rainfall-runoff is given. On the other hand, since there are many, but extremely small streams in a WCZ or in the whole of Hong Kong, it is not easy to estimate the total load by summarizing the load of each stream. So, the concept of integrated mean concentration for a WCZ is important and practical for water pollution control in Hong Kong.

2.3.3.1 Integrated mean concentration for Hong Kong region

Since the selected 37 rivers /catchments are well representative of Hong Kong region, the integrated flow-weighted mean concentrations of Hong Kong in 1998 can be estimated, and they are shown in Table 4. The calculations were also carried out separately for samples from dry season, wet season, and during flood events, respectively. Flood samples were chosen from monthly measurements by comparing the sampling date with the mean daily flow recorded at the hydrological stations.

Table 4 Integrated flow-weighted mean concentrations of Hong Kong region (mg/l)

Type	BOD_5	COD	NH_4	NO_3	TKN	PO_4	TP	TN
Dry	55.1	86.2	9.78	0.56	13.73	1.79	2.72	14.29
Wet	16.3	24.4	3.81	0.57	5.34	0.76	1.21	5.91
Flood	14.1	22.0	2.32	0.56	3.47	0.52	0.86	4.03
Year	23.4	35.7	4.92	0.57	6.89	0.95	1.49	7.46

Table 4 shows that the water quality during floods is best, followed by the wet season, and is worst in the dry season. Therefore, the overall water quality in Hong Kong region, as exemplified by these 37 rivers, is greatly affected by dilution.

2.3.3.2 Integrated mean concentrations of each Water Control Zone (WCZ)

The integrated mean concentration for each Water Control Zone can be obtained from the concentrations of all rivers in that zone by taking the average flow of each river as its weight (Table 5). Obviously, the worst water quality occurs in Deep Bay WCZ, with its integrated mean concentrations much higher than those of other WCZs.

Table 5 Integrated mean concentrations of each Water Control Zone (mg/l)

Water Control Zone	BOD_5	COD	NH_4	NO_3	TKN	PO_4	TP	TN
Deep Bay	40.5	53.6	9.59	0.33	13.04	1.81	2.77	13.37
Junk Bay	2.3	7.99	0.18	1.79	0.52	0.22	0.27	2.31
North Western	21.7	46.4	2.79	0.97	4.11	0.46	1.00	5.09
Port Shelter	1.0	6.1	0.07	0.57	0.22	0.06	0.07	0.79
Southern	2.5	37.2	0.20	0.16	0.54	0.08	0.15	0.70
Tolo Harbour & Channel	5.1	16.6	0.22	0.77	0.86	0.09	0.26	1.63
Victoria Harbour	8.9	19.2	1.15	1.08	2.09	0.13	0.34	3.17
Western Buffer	2.4	10.9	0.32	1.63	0.74	0.18	0.22	2.38

2.4 ANALYSIS OF EXPORT COEFFICIENTS

Generally, the export coefficient is related to the type of land use in a watershed or a region, and refers to the unit area load of a single land use. When the export coefficient has been determined for each type of land use, the total load of nonpoint source pollution can be easily estimated from the land use data in the region. This approach is very effective for regions with only sparse data on the mean concentration of runoff, hence the export coefficient approach has been widely applied (such as Johnes 1996, Soranno et al.1996). In this section, the export coefficients for different land uses in Hong Kong will be determined. Then the concept of integrated export coefficient will be proposed and applied taking into account the specific conditions in Hong Kong. The water quality data used are taken from section 2.3.

2.4.1 Load estimation and export coefficients

The first step in export coefficient analysis is the load estimation. Based on a previous comparison of different methods for load estimation (Li, et al., 2002), the most appropriate method selected here is that the load is estimated as the flow-weighted mean concentration times the annual mean discharge. Since there are no complete hydrological data available for the sampled water quality stations, the average sample flow is used instead of the annual mean flow. The annual load of nutrients in 1998 for each of the 37 catchments is thus calculated. Dividing the load by the upstream catchment area of the respective water quality station, the export coefficient of each catchment can be obtained.

2.4.2 Influence of catchwater area of reservoirs

The total catchwater area of reservoirs in Hong Kong takes up about 1/3 of the total land area. Among the 37 streams, there are some streams where a part of the catchment area of a water quality station belongs to a reservoir catchwater area. This will lead to smaller values of export coefficients for the influenced streams. Therefore, a correction must be applied to the catchwater area of reservoirs. In view of the unavailability of specific data, it is assumed that the water diversion system collects and transports 70% of the total annual runoff generated from the water gathering grounds to the reservoirs. Hence the effective area monitored by a river water quality station in a reservoir catchwater area can be expressed as:

$$Effective\ Area = Area * (1 - 0.7 * R)$$

Where, $Area$ is the total upstream area of the water quality station; and, R is the ratio of reservoir catchwater area over total upstream area.

Using the effective area, the export coefficients obtained are more reasonable, and the results from the 37 catchments are used as the basis for the following analysis.

2.4.3 Export coefficients for different land uses

Using the same representative streams and sampling stations for different land uses as for the analysis of mean concentration, the average export coefficient of each land use type can be obtained (Table 6).

Table 6 Average export coefficients for different land uses (kg/ha.year)

Land use	BOD_5	COD	NH_4	TKN	NO_3	TN	TP
Agriculture	160.1	302.2	92.69	118.60	2.37	120.98	28.21
Town	1290.9	1298.6	147.17	212.26	2.92	215.18	36.24
Grassland	118.6	317.9	6.39	19.67	13.92	33.59	4.09
Scrubland	46.9	208.0	4.47	12.51	8.61	21.12	2.22
Woodland	42.5	517.5	2.36	9.56	6.68	16.25	3.30

The results of this study (Table 6) show larger values than the values reported in literature (Novotny and Olem, 1994; Frink, 1991). Possible reasons include: no single land use measurements of NSP in Hong Kong; the representative stations for grassland, scrubland and woodland are near dense population areas; and the influence of catchwater areas of reservoirs. Of course, the higher values for Agriculture and Town were also caused by the impact of unsewered villages and wastes from livestock farms, as mentioned above.

2.4.4 Integrated export coefficients

The above analysis demonstrates that, on the basis of the limited available data in Hong Kong, it is difficult to obtain reasonable export coefficients for each type of single land use. Yet, one of the most important advantages of the export coefficient approach is that it can easily predict the effect of land use changes. In Hong Kong the land uses changed very slowly in recent years, e.g. the land cover of woodland, scrubland and grassland remained fairly stable for the least 10 years. Hence it is possible, on the basis of the traditional concept of export coefficients, to estimate the pollutant load from nonpoint sources in a simple manner.

It is well known that the export coefficient always relates to single land use. But actually the export coefficient of each stream reflects the integrated effects of mixed land uses in its catchment. We can therefore define and analyze the concept of integrated export coefficient for mixed land uses at the level of catchment, WCZ, or the whole region, similarly to the above analysis of mean concentration.

For Hong Kong, the 37 catchments distributed widely in the whole territory are well representative. The integrated export coefficient can be obtained by taking the simple average or area-weighted mean coefficients of the 37 catchments (Table 7). Table 7 shows that the average values for TN and TP are lower than the area-weighted mean average values, while the reverse holds for NO_3.

Table 7 Integrated export coefficients of the whole of Hong Kong, 1998 (kg/ha.year)

Concentration	BOD_5	COD	NH_4	NO_3	TKN	TP	TN
Average	153.9	318.9	20.2	8.3	32.1	6.9	40.4
Area-weighted mean	193.4	310.1	42.4	4.9	59.3	12.9	64.2

In each of the eight WCZs, there is at least one representative catchment. The integrated export coefficients for each WCZ can be estimated from the values of the streams within the WCZ, with area-weighted mean (Table 8).

Table 8 Export coefficients of each Water Control Zone (kg/ha.year)

Order	WCZ	BOD_5	COD	NH_4	TKN	NO_3	TN	TP
1	Deep Bay	272.8	361.2	64.67	87.96	2.24	90.2	18.70
2	Junk Bay	63.2	217.4	4.98	14.33	49.29	63.6	7.54
3	North Western	115.3	247.2	14.87	21.89	5.18	27.1	5.34
4	Port Shelter	30.4	179.4	1.93	6.50	16.74	23.2	1.93
5	Southern	32.6	491.2	2.64	7.10	2.13	9.2	2.02
6	Tolo Harbour & Channel	56.7	186.0	2.46	9.56	8.61	18.2	2.88
7	Victoria Harbour	28.8	62.3	3.73	6.76	3.50	10.3	1.09
8	Western Buffer	5.0	22.5	0.66	1.53	3.37	4.9	0.45

2.5 COMPARISON OF RESULTS

Since the sampled flow data lead to smaller values of load estimation (Li, et al., 2002), the above results of the export coefficients will most likely be smaller than the actual values. There are much more uncertainty factors in the analysis of export coefficients than in the analysis of mean concentration. In addition, the sample measurements of concentrations reflect the actual influences from all factors in the upland area. Therefore, the estimated values of the mean concentrations are recommended for the calculation of loads because they appear to be more reasonable than the values of the export coefficients.

2.6 OTHER CHARACTERISTICS

Some other characteristics related to NSP in Hong Kong include: more than 200 islands and many streams with small catchment area, short course, and low flow rate; very high annual precipitation (mean annual value, 2214mm) and rainfall intensity; separate drainage systems for rainfall runoff and sewage; and very high population density in urban and new towns.

3. DISCUSSION AND PERSPECTIVE

3.1 DISCUSSION

- The rainfall in 1998, 2334mm, was close to the long-term mean annual value (2214mm). If the current land use pattern and pollution control measures do not change, the NSP loads of wetter years or drier years will be much higher or lower, respectively, than in 1998.
- The shortcomings of the measurements of NSP in Hong Kong are too short measurement series for too few storm events, especially no heavy storm events. Therefore, the measured concentrations of urban storm runoff in 1998 did not reflect the real conditions and might be smaller than the actual values (Chen et al., 1999). In addition, there are almost no water quality stations in the urban and town areas.
- The results of the mean concentration approach appear to be the most reasonable.

3.2 RECOMMENDATIONS AND PERSPECTIVE

- Woodlands, scrubland and grassland cover the major part of Hong Kong's land area, 739 km2 or 67.3 %, of which the country parks and natural reserves occupy 415 km^2. This is beneficial to the control of NSP since human activities are strictly limited in these areas.
- Hong Kong has more than 200 islands and a long shoreline. The urban area and new towns are mainly located along the shoreline. Therefore, the nonpoint source loads are discharged into the coastal waters separately along the shorelines, which can reduce the impact of NSP to a certain degree.
- The catchwater area of the reservoirs, occupying about 1/3 of the area of Hong Kong, disturbs the natural watersheds and river systems. Hong Kong's sewage collection and transport systems as well as the Dongjiang-Shenzhen Water Supply Scheme have similar impacts. In addition, the streams in Hong Kong are very small. Therefore, it is more important to study the NSP for each Water Control Zone or for the whole region rather than for each stream.
- At present, the key to NSP control in Hong Kong is the waste from livestock farms and unsewered villages.
- With the full implementation of the Sewerage Master Plans and Livestock Waste Control Scheme, the NSP will mainly originate from urban/town areas with very high population density. It is therefore important to systematically investigate the NSP in these areas, including its monitoring, modeling, prediction, control, and management.
- In the future, it is necessary to prepare and implement a monitoring plan for different land uses in Hong Kong and in urban/town areas, to monitor water quality at all hydrological stations, to increase the number of water quality stations in catchwater areas of reservoirs, and to study the influence of hydrological conditions on NSP, such as different rainfall years, storm magnitudes, etc.

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