Some observations on total carbon and nitrogen in suspended matter in the Kam Tin River, Hong Kong

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Abstract There is little information about the physical and chemical properties of the suspended matter in Hong Kong rivers. Some observations have been made in the Kam Tin basin of total carbon and nitrogen at two sites: an undisturbed upland stream and near Kam Tin in the developed lowlands. Under baseflow conditions at Kam Tin mean suspended C and N contents were 31.8% and 4.2% respectively. At the upland site C and N were lower at 13.2% and 1.1% respectively. During stormflow events C levels at Kam Tin and the upland site were 13.9% and 12.2% respectively and N values were 1.9% and 0.9% respectively. The concentrations of C and N (mg l^{-1}) under both baseflow and stormflow conditions were higher at the downstream lowland site. Seasonal variation under baseflow conditions was detected at Kam Tin while storm-period variation occurred at both sites.

INTRODUCTION

Observations on suspended sediment transport and sedimentation have been undertaken in Hong Kong. One of the most important studies remains that of Lam (1974). For the period October 1971–October 1972, he reported suspended sediment loads of 646.7, 342.9 and 22.9 t year^{-1} for three catchments in the New Territories with areas of 0.282, 0.267 and 0.24 km^2 respectively. The basins had suspended sediment maxima of 132 000, 97 450 and 1753 mg l^{-1} respectively. This variation in suspended sediment was largely controlled by vegetation cover, with the smallest load and lowest maximum concentration being observed in a basin with complete cover, while the higher yields and levels were found in basins containing badlands, areas devoid of vegetation cover. In the basin with the highest sediment yield and concentration, badlands accounted for 40% of the area. The sedimentation rates of various river channels in the territory have been investigated by the Port Works Division (1988). At Tuen Mun, for example, an annual sediment loading of 86 000 t was reported, giving a yield of 5350 t km^{-2} year^{-1}. Dudgeon (1984) reports on the suspended organic matter levels at a number of stations in the Lam Tsuen River during 1978–1979. Suspended organic matter levels were generally higher in the middle and lower course, but even here values were only around 10 mg l^{-1}. At the two uppermost stations values of less than 1 mg l^{-1} were observed. The human impact upon suspended sediment concentrations have been documented by Peart (1997). Under baseflow conditions median suspended sediment concentrations of 4.8 and 1.6 mg l^{-1} were recorded for two undisturbed upland basins. In contrast downstream, near Kam Tin in the developed area of the drainage basin, the median value of suspended sediment was 36.3 mg l^{-1}.

Observations on storm-period suspended sediment concentrations have been reported by Peart *et al.* (1998). Their observations reveal considerable variation in sediment levels both between and within storm events for a small upland basin. Storm-period maxima ranged from over 2500 to 12 mg l^{-1}. Clockwise hysteresis was commonly observed in suspended sediment concentration during storm events. The Environmental Protection Department include suspended solids in their water quality monitoring programme. For example, three monitoring stations are operated in the Ganges basin in the northern New Territories. In 1995 (Environmental Protection Department, 1996) annual median values based on monthly sampling were 87, 145 and 12 mg l^{-1}, respectively, for stations 1, 2 and 3. At the same stations minima were 23, 16 and 5 mg l^{-1} while maxima were 200, 8000 and 800 mg l^{-1}, respectively. In the lower reaches of Fo Tan Nullah at Sha Tin the annual median, minima and maxima were 22, 11 and 37 mg l^{-1}, respectively, while for Kai Tak Nullah at the downstream station annual median, minimum and maximum were 25, 22 and 30 mg l^{-1}, respectively (Environmental Protection Department, 1996).

While monitoring of the concentrations and loads of suspended matter in Hong Kong streams and rivers has been carried out, little attention has been given to the chemical and physical properties of the suspended matter. This is unfortunate given recognition of the role that sediment may play in elemental cycling and transfer of nutrients and pollutants (e.g. Shear & Watson, 1977; Ongley *et al.*, 1981; Meybeck, 1982). Skvortsov (1959) lamented the fact that, while extensive data were available on sediment discharge and transport, information on the composition of suspended

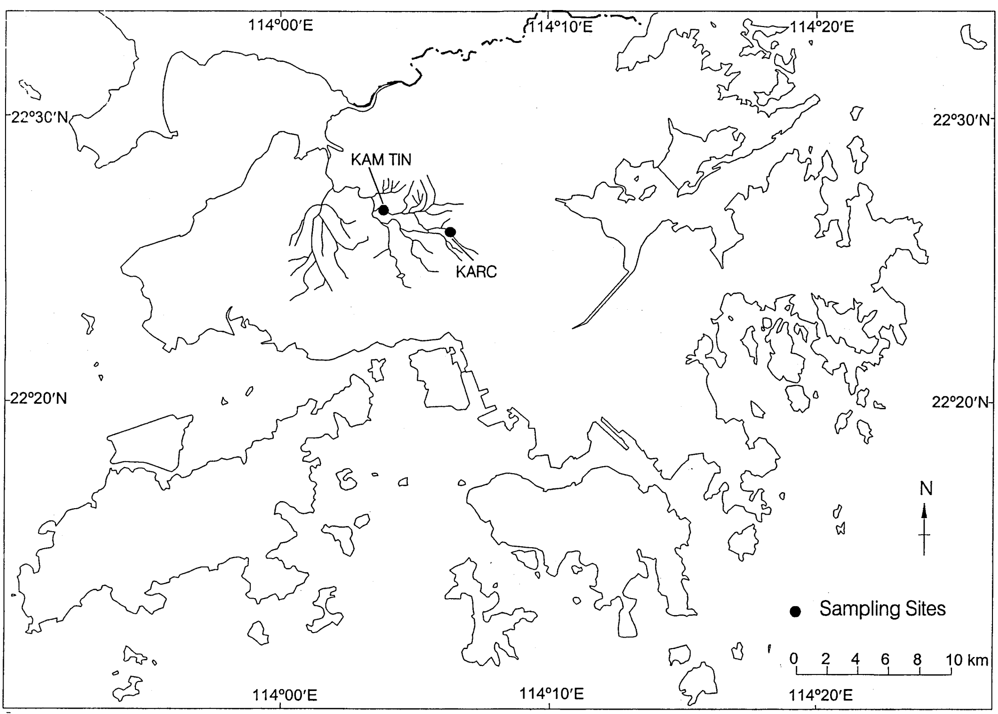

Fig. 1 Location of the sampling sites.

matter was limited. This is the current situation in Hong Kong: very few observations have been made of the properties of suspended matter. This paper reports some observations on total carbon (C) and nitrogen (N) concentrations in suspended matter in the Kam Tin basin in Hong Kong.

STUDY BASIN AND METHODS

The Kam Tin basin is located in the North West New Territories and it drains the slopes of Kai Keung Leng, Tai To Yan and the western slopes of Tai Mo Shan. The solid geology of the basin is dominated by granodiorite along with volcanic and sedimentary rocks of Mesozoic age. The drainage system flows west and discharges into Deep Bay. Topographically the basin consists of steep uplands and a contrasting lowland alluvial plain. The steep upland slopes are well vegetated with grass, ferns, shrubland and woodland. Agriculture has dominated the lowland plain and remains important. However, an increasing area is being occupied by housing (high and low density), open storage and some light industrial uses. Most of the houses and other buildings are not connected to a public sewer system. Near Kam Tin, at the Water Supplies Department gauging station, the basin has an area of 11.72 km^2.

A sampling programme has been undertaken to monitor the C and N contents of suspended matter at two points in the basin, downstream at Kam Tin and in a small undisturbed upland basin at the Kadoorie Agricultural Research Centre (KARC) (Fig. 1). In the upland basin, due to the generally low suspended sediment concentrations under baseflow conditions, large volume water samples (around 30 l) were collected. At Kam Tin under baseflow conditions a combination of 10 litre and 400–500 ml sample volumes were used depending upon prevailing sediment levels. At both stations storm-period sampling was based upon 400–600 ml volumes. Most of the samples were collected during 1998 and 1999. The suspended sediment was separated by filtration using GF/C filter papers. The filter papers were not pre-ignited because they are composed of 100% borosilicate and are binder free. These were subsequently air dried and the sediment disaggregated before analysis. Suspended matter was not pre-treated to remove carbonates prior to analysis. Carbon and N were measured using a Perkin Elmer model 2400 elemental analyser. Particulate C and N in water can be expressed either as a percentage of the suspended matter or as a mass per unit volume of water: both have been used in this study, but the discussion focuses mainly on % composition.

RESULTS

The mean and median values for the % C, N and the C/N ratio for the wooded upland stream (KARC) exhibit no obvious differences between storm-period samples and those obtained under baseflow conditions (Table 1). However, the interquartile range and coefficient of variation reveal the storm data to be more variable for C. Suspended matter concentrations per unit volume of water are also presented in Table 1. Median values of C and N are 0.39 and 0.03 mg l^{-1}, respectively, for baseflow and they are rather higher under stormflow conditions being 25.6 and 2.28 mg l^{-1} for C and N,

Table 1 Values of C, N and C/N for the upland stream at KARC.

	C (%)	C (mg l^{-1})	N (%)	N (mg l^{-1})	C/N ratio
Baseflow:					
Mean	13.19	0.87	1.11	0.07	12.63
C.V.	11.60	140.20	34.20	128.60	21.00
Median	13.28	0.39	0.98	0.03	13.39
I.Q.R.	2.08	0.35	0.30	0.05	1.80
n	12.00	12.00	12.00	12.00	12.00
Stormflow:					
Mean	12.15	41.13	0.92	2.95	13.36
C.V.	32.80	99.60	30.40	93.20	17.70
Median	11.37	25.58	0.93	2.28	13.06
I.Q.R.	4.74	26.55	0.37	2.05	1.89
n	44.00	44.00	44.00	44.00	44.00

C.V. = coefficient of variation (%); I.Q.R. = inter-quartile range; *n*: sample size.

respectively. The coefficients of variation reveal the concentration data to be more variable than the % composition.

For the storm-period sampling downstream at Kam Tin (Table 2), C has a mean value of 13.9% which is not too dissimilar from that of the upland stream; the median values are also similar at the two sites. However, the coefficient of variation (66.6%) is much higher than that of the upland site at KARC. There is also evidence that N is greatly enriched downstream in the suspended matter with the mean value (1.94%) being approximately double that at the upland site. The C/N ratio as defined by both mean and median values is much lower at Kam Tin in comparison to the upland site; variability as given by the coefficient of variation is similar at both sites. When consideration is given to the concentration data presented in Table 2 both C and N are much higher under stormflow conditions at Kam Tin in comparison to the upland stream at KARC. The median value of C is approximately double that of the upland stream while at Kam Tin median N is three times higher than in the headwaters.

Baseflow C and N, in %, along with the C/N ratio descriptive statistics are given in Table 3 for the Kam Tin sampling station. Compared to the upland stream, the mean values for C and N of 31.83 and 4.22%, respectively, are at least double those of the upland basin. The C/N ratio at Kam Tin, with an average of 7.62, is lower than that of the upland basin, which has a value of 12.63. The median values of % C, % N and C/N show a similar difference between the two stations. Total % C has a higher coefficient of variation at the Kam Tin station and a greater interquartile range. In contrast, based upon the coefficient of variation, % N and the C/N ratio are more variable in the upland stream. However, the interquartile range of N (%) at Kam Tin is the highest of the two monitoring points. Under baseflow conditions when consideration is given to the concentration of particulate C and N in the water their levels are very much elevated at the downstream, lowland sampling station at Kam Tin. For example, the average concentration of N at Kam Tin is 132 times greater than that at KARC.

At the Kam Tin station, the baseflow samples have been subdivided into two periods, October–March and April–September inclusive, which represent the winter

Table 2 Values of C, N and C/N from storm hydrographs at Kam Tin.

	C (%)	C (mg l^{-1})	N (%)	N (mg l^{-1})	C/N ratio
Mean	13.90	67.97	1.94	9.30	7.32
C.V.	66.60	145.80	65.5	125.90	17.60
Median	12.29	51.68	1.70	7.38	7.56
I.Q.R.	12.08	45.78	1.57	5.44	0.82
n	58.00	58.00	58.00	58.00	58.00

C.V. = coefficient of variation (%); I.Q.R. = inter-quartile range; *n*: sample size.

Table 3 Values of C, N and C/N under baseflow conditions at Kam Tin.

	C (%)	C (mg l^{-1})	N (%)	N (mg l^{-1})	C/N ratio
All data:					
Mean	31.83	71.87	4.22	9.24	7.62
C.V.	15.50	115.30	18.50	111.40	7.70
Median	33.02	55.26	4.27	6.89	7.77
I.Q.R.	3.01	54.65	0.59	7.10	0.75
n	53.00	53.00	53.00	53.00	53.00
Summer baseflow:					
Mean	29.73	73.82	3.82	9.33	7.85
C.V.	21.60	79.60	23.80	78.20	5.60
Median	31.91	62.95	4.00	7.95	7.96
I.Q.R.	5.20	66.30	0.90	8.25	0.63
n	22.00	22.00	22.00	22.00	22.00
Winter baseflow:					
Mean	33.32	70.49	4.50	9.18	7.46
C.V.	8.30	138.10	11.80	131.70	8.40
Median	33.70	51.06	4.36	6.33	7.65
I.Q.R.	2.18	47.41	0.72	6.97	0.94
n	31.00	31.00	31.00	31.00	31.00

C.V. = coefficient of variation (%); I.Q.R. = inter-quartile range; *n*: sample size.

dry and summer wet seasons respectively. The descriptive statistics are presented in Table 3. ANOVA reveals a significant difference between the two sampling periods for % N at the 0.001 level, C (%) at the 0.01 level and C/N only at the 0.05 significance level. Figure 2 presents the % C and N for both baseflow and stormflow samples at Kam Tin and evidences a clear seasonal pattern, both determinands being reduced during the summer wet season.

It is worthwhile comparing four samples obtained under baseflow conditions at the Kam Tin site when excavators were working within the channel as part of a drainage maintenance or improvement scheme. These samples have very low C values (ranging from 4.05 to 6.26%) and N levels (0.65 to 1.49%) compared to the more typical baseflow samples of the main data set. Their C/N ratio which averaged 5.35 is also lower than the other baseflow samples.

There is some evidence of storm-period variation in the data sets of the two stations. For example, at the upland site four samples obtained during the storm of 6 September 1998 revealed that C ranged from 12.31 to 14.95% and N from 0.94 to 1.05%. At the same site samples obtained during the storm of 7 June 1999 had C values ranging from 7.79 to 15.99% with N varying from 0.70 to 1.42%. During this

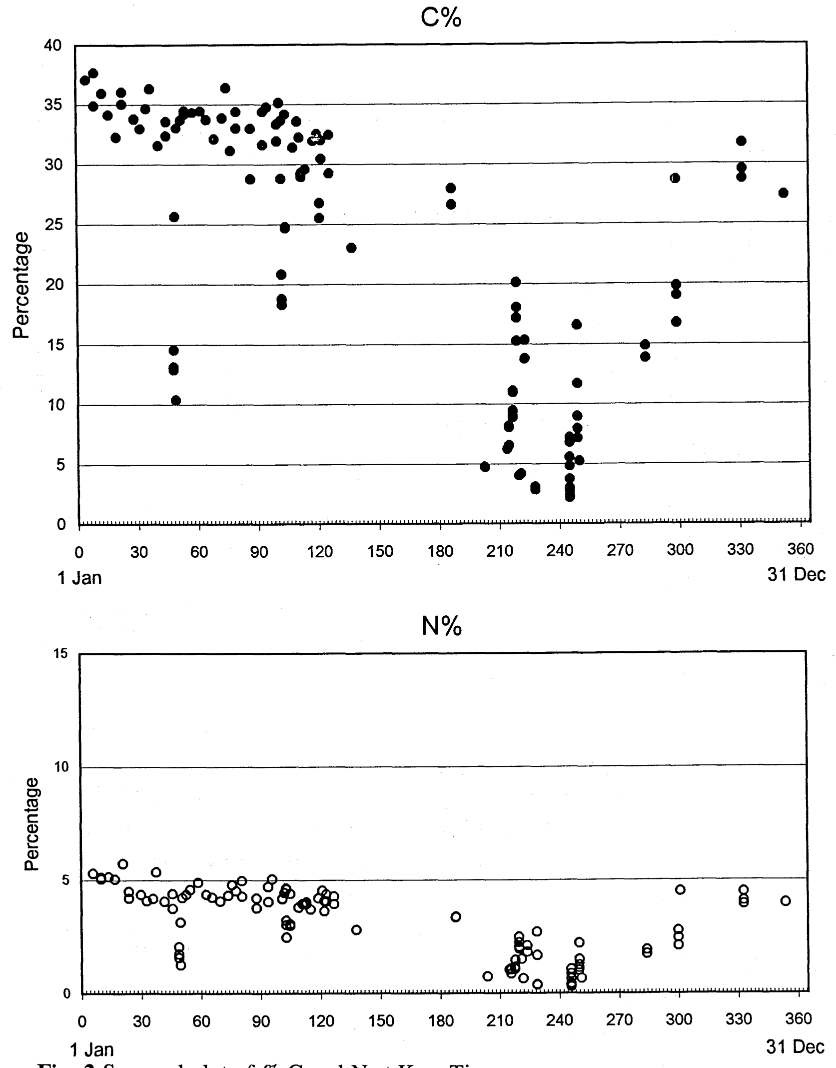

Fig. 2 Seasonal plot of % C and N at Kam Tin.

storm the concentration of C ranged from 21.88 to 38.66 mg l^{-1} while N varied from 1.95 to 3.58 mg l^{-1}. At Kam Tin six samples obtained during the storm of 5 August 1999 had C values ranging from 8.85 to 11.06%, while 1.07–1.46% describes the range of N. During the storm of September 1998, 10 storm-period samples were obtained and C ranged from 2.18 to 7.16% and N from 0.3 to 1.07%. Both these storms have levels of C and N that are well below the mean value of these determinands. Storm-period variation in particulate C and N concentration is also observed in these storms at the Kam Tin station. For example, on 5 August 1999, N varied from 4.38 to 11.11 mg l^{-1}. At the Kam Tin site 10 samples were identified as being from small storms. They have mean C, N and C/N ratio values of 29.15, 4.11 and 7.11%, respectively. The values for C and N are considerably higher than the storm-period average and more closely resemble the samples obtained under baseflow conditions.

DISCUSSION

The only outcrops of carbonaceous rocks (the carbonaceous siltstone of the Mai Po Member of the Lok Ma Chau Formation) and seams of graphite (also associated with the Mai Po Member) in the North West New Territories lie outside the study basin (cf. Langford *et al.*, 1989). In addition, the marble associated with the Yuen Long Formation is both buried beneath alluvial sediments and situated to the west of the basin (cf. Langford *et al.*, 1989). Consequently, it is believed that the C reported in this study is mainly organic in nature.

Little attention has been given in Hong Kong to the measurement of suspended sediment properties other than concentration. Dudgeon (1984) provides some early observations on the organic content of suspended matter in Hong Kong while Peart *et al.* (1998) provide limited evidence of storm-period variation in organic content of suspended matter. In a study of the Lam Tsuen River, Peart (1995) reports organic C and N levels of suspended sediment. They had mean values of 1.12 and 0.14%, respectively. The relatively low organic carbon levels may reflect a contribution from substrate material derived from cut and fill slopes associated with roadworks.

The data presented in this paper provide further evidence of the need to consider aspects of suspended sediment transport in addition to concentration in Hong Kong. Considerable amounts of C and N are present in the suspended matter of the two sampling sites in the Kam Tin basin. The spatial and temporal variation evidenced by the data between the upland and lowland sites is also noteworthy. Spatial variability of the concentration of suspended organic matter has been evidenced by Dudgeon (1984, 1995) in Hong Kong. Subramanian & Ittekkot (1991) present evidence of considerable spatial variability of particulate organic carbon (%) in the Brahmaputra and of more limited variability in the Ganges. Other researchers have reported seasonal variation in suspended organic matter expressed as % (e.g. Skvortsov, 1959; Ongley *et al.*, 1981; Subramanian & Ittekkot, 1991), while storm-period variation is widely reported in the literature. For example, Walling & Kane (1982) report intra-storm variation of % C and N for three rivers in Devon, England. Working in the River Dart and Jackmoor Brook basins in southwest England, Walling & Kane (1984) provide evidence of both inter- and intra-storm-period variation in C, N and the C/N ratio. Symader *et al.* (1992) report storm-period variation of % organic carbon for a small catchment near Trier, Germany. Storm-period variations have also been reported as concentrations (cf. Mitchell *et al.*, 1997).

Subramanian & Ittekkot (1991) report temporal variation of particulate organic carbon at the annual scale for the Indus River. It would seem worthwhile investigating this aspect in the Kam Tin basin. However, this may be dependent upon funding.

The nature of the C/N ratio along with the % of C and N may help elucidate the source of the suspended matter. For example, Martins & Probst (1991) have speculated on the role of autochthonous and allochthonous sources of particulate organic carbon of the Niger River. Dudgeon (1983) has shown that, for a small wooded drainage basin in Hong Kong much of the organic material is provided by litterfall into the stream; allochthonous sources dominate. This may be the source of the high C levels reported for the baseflow sediments at the upland site when no rainsplash erosion would be active to dilute the organic matter with inorganic soil material. Surface soil has an organic carbon content of around 5% in the upland basin while nitrogen is about 0.45%, based on fieldwork by the author. These values are low in comparison to the suspended matter, if most of the C and N in the sediment is derived from organic material.

The Kam Tin basin has a history of pollution by livestock waste (Binnie & Partners, 1974). Farmers have traditionally disposed of waste by washing it into the river. Pig waste has a low C/N ratio of 4.4. (cf. Chan *et al.*, 1994). Baseflow and stormflow mean C/N ratios for the Kam Tin station of 7.62 and 7.32 respectively suggest that pig waste is not the sole source of suspended matter in the river. In recent years a pig-on-litter system of management has been encouraged to reduce the pollution problem. The clean litter (sawdust) has a C/N ratio of around 60 but after exposure to pig waste stabilizes at around 20–30 after 5–6 weeks (Chan *et al.*, 1994). A ratio of 20–30 is far too high for sawdust litter to be the source of the suspended matter. The probability of other sources or transformation in the fluvial system must be recognized. The change in C, N and C/N ratio in baseflow samples at Kam Tin when excavators were working in the channel provides a further example of the process information provided by elemental composition data.

The presence of N in the suspended matter indicates that any study of nutrients in Hong Kong ought to include the particulate phase. Other studies have recognized or evidenced the necessity of including the particulate phase in any investigation of nutrient transport and production in the fluvial system (e.g. Meybeck, 1982; Mitchell *et al.*, 1997).

CONCLUSION

The % C and N of suspended matter, along with their ratio, have been presented for two monitoring stations in the Kam Tin river basin. Information of the concentration of C and N per unit volume of water have also been presented. Spatial and temporal variation has been outlined. Data from both sites indicate that there is a need to monitor the chemical nature of suspended matter. This is because such information may be important for elucidating the sediment source and the dynamics of sediment production in Hong Kong fluvial systems. It is also important in terms of elemental cycling and nutrient budgeting.

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