Sediment and water quality of the Klagan River tributary in tropical rainforest of Sabah, Borneo Island

MAZLIN B. MOKHTAR
Department of Chemistry, Faculty of Science and Natural Resources, Universiti Kebangsaan Malaysia, Sabah Campus, Locked Bag 62, 88996 Kota Kinabalu, Sabah, Malaysia

ALMAH BT. AWALUDDIN
Marine Science Department, Faculty of Science and Natural Resources, Universiti Kebangsaan Malaysia, Sabah Campus, Locked Bag 62, 88996 Kota Kinabalu, Sabah, Malaysia

ONG ENG TIAN
Department of Chemistry, Faculty of Science and Natural Resources, Universiti Kebangsaan Malaysia, Sabah Campus, Locked Bag 62, 88996 Kota Kinabalu, Sabah, Malaysia

Abstract This study analyzes the sediment and water quality of the Klagan, a river tributary in tropical rainforest of the east Malaysian province of Sabah, Borneo. Hydrological parameters including conductivity, suspended solids, and BOD along a stretch of about 60 km in the upstream and downstream reaches varied in the ranges 100 to 39 000 μmhos cm^{-1}, 29 to 328 mg l^{-1}, and 0.2 to 4.9 mg l^{-1}, respectively. Observations revealed considerable erosion of river banks. Nitrate fluctuated between 0.5 and 2.8 mg l^{-1}. These variations were related to rainfall, farming activity on adjoining land, and mixing of sea water (in deltaic range). Phosphate concentration appeared to be linked to its release from sediment. Phosphate desorption from ferric hydroxide at high pH could not be ruled out. Metal content in the sediment followed the order: Mn > Ni > Cr > Zn > Cu > Co > Pb > Cd. These heavy metals were sediment-water exchangeable.

INTRODUCTION

Borneo, the world's third largest island, is a focus of scientific attention mainly due to its lush tropical rainforest and rich biodiversity. The island presents some peculiar features of its river systems linked to its complex geomorphology, especially the jumble state of Crocker Range of mountains, rainfall pattern, and environmental factor. Klagan River, a tributary of Labuk River in Sabah, northeast Borneo (Fig. 1), was selected for the study of sediment and water quality. Klagan River provides a waterway for transportation and is a source of water for washing, cleaning, and irrigation. It is home to rich populations of fish, prawns, crabs, and other aquatic organisms. The river courses through an uneven terrain largely composed of sandstone, limestone, and basalt. The igneous and metamorphic rocks found in the middle are serpentinite, periodolite, dunite,

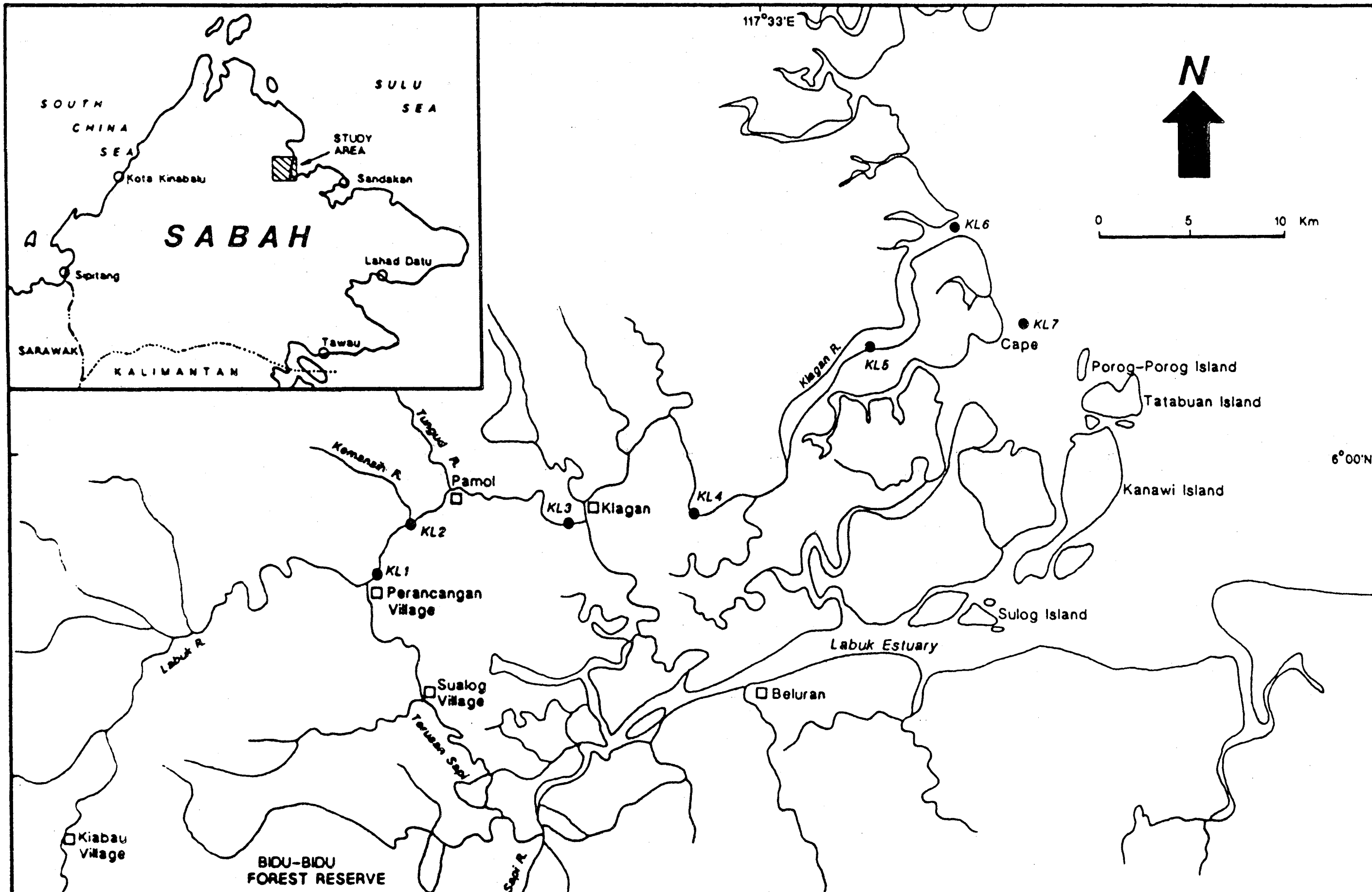

Fig. 1 Map showing drainage system of the study area.

ademelite, dolerite, and pyrosenite. Alluvial deposits, peat, sand, mud, and clay are conspicuous in the downstream section. This study was designed to gather information on water-quality and sediment characteristics of the afore-described riverine ecosystem. The quality of water is influenced by sediment, nature of rocks of the area, and in the future perhaps, by proposed copper mining. Now that copper mining has been proposed in the Bidu Bidu Hill area, which is in the Sandakan residency and is drained by the Klagan River, the monitoring of sediment and water quality of this riverine system has assumed utmost importance. It is likely that the vast amounts of natural resources of Bidu Bidu region will attract industrial exploitation. Hence, a study of this type may be necessary to suggest environmentally friendly measures of sustainable development.

DATA

The data are based on samples collected from seven stations along the Klagan River in upstream and downstream ranges over a distance of 62 km. Information on these sites is given below.

KL1: At Tambidong-bidong village, where the Klagan separates from the Labuk River. The river banks are low, steep, and covered by shrubs and banana plants. Riverine sediment is muddy. Fishing pressure is high.

KL2: In the area where the Klagan River gives off the Kemansih branch. The banks are muddy, have a sharp slope, and support shrubs and fruit trees.

KL3: In Klagan Jaya Village. The sloping and muddy banks of the Klagan River are covered by green foliage. The water is turbid. Fishing and transport of timber takes place in this segment.

KL4: This station is in Bukit Besi fishing village. The banks are muddy and sloppy. Big logs are employed as bridges across the river.

KL5: In Bukit Mendagu. The spot receives considerable freshwater from the nearby waterfall. There is no defined bank because of thick growth of palm trees and mangroves. Sediment is muddy and sandy.

KL6: This site is in lower reaches of the Klagan River and has estuarine features with a lush growth of mangrove on the bank. Sediment is muddy and sandy. Trawling is carried out in the area.

KL7: The site is virtually at a bay, some 210° north of Cape and 20° northeast of Poroq-Poroq Island. The area is characterized by muddy and sandy sediment and strong wave activity. Fishery resources are rich.

Data on chemical parameters of water and heavy metals of sediment are presented in Tables 1 and 2.

METHODS

Temperature, pH, conductivity, salinity, and dissolved oxygen (DO) of the water were measured in the field using accurate instrumentation. Concentration of suspended solids, nitrate, phosphate, sulfate, and biochemical oxygen demand (BOD) were determined according to the methods recommended by APHA (1985).

Sampling was carried out 2-7 August, 24-30 August, and 3-8 December 1991. Surface-water samples were collected and kept in glass bottles for phosphate and BOD

Table 1 Water-quality parameters of the Klagan River stations that were measured *in situ.*

Date	Station	Cond. (μmho cm^{-1})	Sal. (ppt)	T (°C)	pH	DO (mg l^{-1})	NO_3 (mg l^{-1})	PO_4 (mg l^{-1})	SO_4 (mg l^{-1})	BOD (mg l^{-1})	SS (mg l^{-1})
2-7	KL1	110	0.0	27.0	7.5	7.00	2.7	0.04	1.0	0.2	253
Aug.	KL2	109	0.0	28.0	7.5	6.40	2.3	0.03	3.0	1.1	233
1991	KL3	100	0.0	27.5	7.6	7.00	2.7	0.04	6.0	2.4	295
	KL4	105	0.0	27.3	6.6	6.00	2.5	0.04	3.0	2.4	114
	KL5	11 000	6.5	29.2	5.25	5.25	1.9	0.05	325	1.1	206
	KL6	30 000	16.0	30.7	7.4	5.48	1.8	0.06	950	3.0	327
	KL7	31 000	17.0	31.5	7.9	6.36	1.3	0.04	2000	4.3	328
24-30	KL1	139	0.0	29.2	7.2	7.65	2.7	0.08	4.0	0.9	56
Aug.	KL2	140	0.0	30.1	6.9	7.26	2.8	0.04	7.0	0.7	41
1991	KL3	119	0.0	28.8	6.5	5.92	2.4	0.06	7.0	1.5	52
	KL4	11 000	6.0	30.0	6.8	5.30	1.8	0.07	17.0	1.0	29
	KL5	20 000	12.5	30.9	8.1	6.90	2.2	0.06	675	2.1	35
	KL6	37 900	23.0	30.7	7.9	7.77	1.8	0.06	2750	3.3	54
	KL7	39 000	22.0	30.4	8.0	6.93	1.8	0.10	2350	4.9	69
3-8	KL1	130	0.0	28.0	6.5	7.49	1.0	0.05	1.0	1.5	128
Dec.	KL2	125	0.0	28.0	6.5	7.26	1.1	0.05	1.0	1.2	68
1991	KL3	112	0.0	27.0	6.5	6.83	1.1	0.04	7.0	0.8	144
	KL4	148	0.0	26.0	6.6	5.44	1.0	0.04	13.0	2.7	148
	KL5	800	0.5	28.0	6.7	5.85	0.6	0.06	425	2.5	176
	KL6	12 000	10.0	28.0	6.9	6.25	0.6	0.05	875	2.3	124
	KL7	20 500	12.0	28.0	9.9	6.64	0.5	0.5	1125	3.7	96

Table 2 The mean metal content (μg g^{-1}) in sediment (total of the five fractions) of the Klagan River.

Station	Cd	Co	Cr	Cu	Mn	Ni	Pb	Zn
KL1	4.16	34.0	70.9	30.5	338	155	18.6	51.2
KL2	3.88	33.7	90.3	36.0	308	167	26.2	58.8
KL3	4.54	27.9	60.6	31.8	299	120	32.0	53.9
KL4	3.50	27.8	53.6	41.0	193	111	10.2	50.6
KL5	4.20	28.3	69.6	45.1	189	132	10.3	58.0
KL6	4.15	24.0	52.9	38.6	144	94	13.1	43.5
KL7	4.24	22.5	52.2	32.2	225	93	22.9	47.0

analyses, or in polythene bottles for analyses of nitrate, sulfate, suspended solids, and soluble metals. These water samples were preserved in acid; the type of acid depended on the parameter to be analyzed. BOD glass bottles were wrapped with aluminium foil and kept at room temperature for 3 days before analysis. Suspended solids were determined after filtration through 0.45-μm filters. Surface-sediment samples were obtained by using the Ekman grabber and were kept in clean polythene bags inside the freezer until analysis. Heavy metals in water and sediment samples were determined using flame atomic-absorption spectrophotometry. However, the sediment samples were first extracted into different reagents sequentially according to techniques suggested by Tessier *et al.* (1979). Before extraction the sediment sample was placed in a crucible and dried at 105°C to constant weight (48 h). The dried sediment sample was then ground with a mortar and pestle, and sieved through a 63-μm mesh. The fine sediment (<63 μm) was kept in clean polythene bags before further analysis. The analyses of total metal in the sediment samples were compared to the contents of metals in Standard

Reference Sediment BCSS-1 and NBS 1646, which were put through a similar regime for quality assurance. One gram of sample was digested in a 50-ml aqua-regia solution heated to 50 to 60°C until near dryness, cooled to room temperature, filtered through 0.45-μm filters, diluted with distilled water to the 250-ml mark in a volumetric flask, and analyzed using flame AAS (Perkin Elmer model 2380). Another subsample was put through a sequential-extraction analysis using the methods of Tessier *et al.* (1979) to determine the amount of metal associated with different fractions in the sediment, i.e. (a) exchangeable, (b) bound to carbonates, (c) bound to oxides and hydroxides of iron and manganese, (d) bound to organics, and (e) residual fraction bound to lithogenous matrix of the sediment.

RESULTS

A number of hydrological parameters of the Klagan River show wide variation. The data reveal considerable degree of erosion of river banks. Erosion is particularly great during torrential rain in an area where annual precipitation averages 305 cm. River-bank erosion is mainly responsible for increasing the concentration of suspended solids to a level as high as 328 mg l^{-1}.

Because the region is covered with rainforest that is a big reservoir of plant and animal life, the surface runoff brings plant residue and animal wastes in substantial quantity. This accounts for large amounts of organic matter in the Klagan River and high values of BOD. The BOD increases from upper to lower reaches. Variations in nitrate concentration were related to rainfall, agricultural activity on adjoining land, and mixing of seawater (in deltaic range). The influx of rainwater has a diluting effect on nitrate content. High nitrate values in upper reaches, especially at stations KL2, KL3, KL4, occur where palm farming is carried out, inorganic fertilizers are used, and nitrate entering runoff contributes to high values of this inorganic substance. However, the nitrate level in water remains below the maximum value recommended for drinking and survival of aquatic organisms.

Phosphate content appears to be linked to release of this chemical from sediment under certain conditions of temperature, anaerobic activity, and pH. Desorption of phosphate from ferric hydroxide at high pH is a distinct possibility. Water content of sulfate varies with salinity. Obviously, it is high in the lower reaches (delta).

Regarding the heavy metals in the water, Cd, Mn, and Zn are detectable, whereas Cr, Cu, and Pb are not. Co and Ni occurred in the first sampling at station KL7. Cd may represent the sediment-water exchangeable fraction.

Concentrations of heavy metals in the sediment follow the order: Mn $>$ Ni $>$ Cr $>$ Zn $>$ Cu $>$ Co $>$ Pb $>$ Cd. Excepting Cd, Cu, and Zn, which are relatively constant, the remaining metals decrease in concentration from upper to lower reaches of the Klagan River. Cd occurs dominantly as a water-exchangeable fraction and also appears to originate from carbonate compounds. Co, Cr, Mn, Ni, Pb, and Zn are mainly in the lithogenous fraction and have low solubility. The non-lithogenous fraction accounts for less than 20% of the detectable Cu, which is mainly cleavably linked to the organic fraction. Pb is dominant in the lithogenous fraction. High Co content is attributed to ultrabasic rocks in the region. Mn is chiefly found in exchangeable and iron-manganese oxide/hydroxide fractions. Relatively larger quantities of Ni in the sediment are from basaltic rocks.

These data are useful in determining the effect on the water quality by proposed industrial mining in the river valley. The findings leave no doubt that besides altering the water quality in the short-run, the proposed mining could lead to long-term consequences. Some of the metals are linked to sediment, and depending on residual time and physicochemical factors, they gradually enter the flowing water. In addition to being a risk factor for society, the disruption of chemical equilibria of the river beyond its self-purification capacity can seriously threaten its biogenic potential and sustainability. The river studied supports large populations of fishery crustaceans and other aquatic organisms, and also contributes to an estuary, which is a favorite breeding and feeding ground of many marine fish and shrimp. Tropical waters are a good source of germplasm. Preserving natural biodiversity is becoming increasingly important, which calls for careful planning of developmental strategies to be implemented with the industrialization.

Acknowledgement The authors thank Y. Bhg. Datuk Wilfred Lingham, Mr Mohd. Harun Abdullah, Mr Amirul Aripin (Ministry of Tourism and Environmental Development, Sabah), Dr Wan Mazlan Hj. Mohd. Woojdy, and Mr Pitong Sulaiman (Department of Medical and Health Services in Beluran) for their assistance.

REFERENCES

American Public Health Association (APHA) (1985) *Standard Methods for the Examination of Water and Wastewater*, 17th edn. APHA, New York.

Tessier, A., Campbell, P. G. C. & Bisson, M. (1979) Sequential extraction procedure for the speciation of particulate trace metals. *Anal. Chem.* **51**, 844-850.