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Spatial and Temporal Variations of Silica in a Disturbed Tropical River Basin

(Variasi Silika Mengikut Ruang dan Masa di Lembangan Sungai Tropika yang Terganggu)

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ABSTRACT

Spatial and temporal variations in silica concentration were determined at various rivers and tributaries in the Linggi River Basin, which has been highly polluted due to urban, industrial and agricultural wastes. The silica content measured as reactive silicate in the whole Linggi River Basin ranged from 1.4 to 26.3 mg/L. A clear seasonal variation in silica was noted especially in the major rivers with higher concentration during dry months and lower concentration during the wet months. The concentration was found to decrease as the water flooded downstream. The large drainage area with granite dominated lithology and high denudation especially in the upper catchment is attributed for high silica content in the water of Linggi River Basin.

Keywords: Diatoms; Linggi River; silica; tropical river; water quality

ABSTRAK

Kepelbagaian variasi kepekatan silika dalam dimensi ruang dan masa di beberapa sungai dan anak sungai di Lembangan Sungai Linggi telah dikesan tercemar disebabkan oleh pembangunan, aktiviti industri dan sisa pertanian. Silika teraktif yang diukur untuk menentukan kandungan silika di keseluruhan Lembangan Sungai Linggi mempunyai julat antara 1.4 hingga 26.3 mg/L. Variasi silika pada sesuatu musim adalah jelas terutamanya di sungai-sungai utama dan pada musim kering, kepekatan silika adalah tinggi dan kepekatan silika rendah pada musim lembap. Kepekatan silika berkurangan di bahagian hilir. Kawasan perparitan yang besar dengan batuan granit yang meliputi litologi dan penggondolan yang pesat terutamanya di bahagian atas takungan menyumbang kepada kandungan silika yang tinggi di dalam air di Lembangan Sungai Linggi.

Kata kunci: Diatom; kualiti air; silika; Sungai Linggi; sungai tropika

INTRODUCTION

The Linggi River Basin drains through densely populated area of the State of Negeri Sembilan in Malaysia and serves as the main source of raw water for about 60% of Seremban, the State capital and entire water need of the coastal tourist town of Port Dickson. The rapid urbanization and industrialization in and around the Linggi River Basin has resulted in increased water quality problems in the state. An intensive and extensive study on water pollution sources and a diagnostic water quality monitoring was carried out between 1982 and 1986, as part of Linggi River Basin Management Study commissioned by United Nations University (UNU), Tokyo to assess the suitability of the Linggi water resources for various purposes in different parts of the river basin. Since the study was initiated, a number of reports and research papers dealing with physical, chemical and biological aspects of the Linggi River Basin have been published (Nather Khan 1985, 1990a, 1990b, 1991a, 1991b, 1992a, 1992b; Nather Khan & Lim 1991; Wee Tee Tan et al. 1988).

Silica is one of the basic nutrients in water and is essential for the growth of certain phytoplankton and neoplankton species (Ferrante & Parker 1978). In natural waters, it occurs as silicic acid and its salts and one of the major nutrients for the growth of diatoms (Werner 1976). Diatoms take up silica in the form of orthosilicic acid (Si(OH)4) to build frustules around their cells. Once the silica is taken up by the diatoms, it is not available as a source of silica even during nutrient deficiency (Lewin 1961). Only after the death of diatom cells can silicic acid leach out (dissolution) and be added to the dissolved silica pool in the water. Shallow water columns and running water may inhibit complete dissolution of diatom frustules. Pearsall (1932) reported that silica can limit the development of diatoms at concentration below 0.5 mg/L. High silica concentration in water is also undesirable for a number of industrial uses. Studies on variation in silica concentration in riverine systems are scanty in literature. This paper summarises the spatial and temporal variation of silica concentration in the entire Linggi River Basin carried out more than an annual cycle in the region.

Materials and Methods

The Linggi River Basin is located within latitudes 2º 18'-2º 51' N and longitudes 101º 52'-102º 2' E at an altitude between 6.3 m and 1,174.5 m above sea level in the south western part of Negeri Sembilan, Peninsular Malaysia. It has four sub-basins: the Linggi (*sensus stricto*), Pedas, Rembau and Siput, with a total of 32 major tributaries (Figure 1). The Linggi (s.s.) is a relatively fast flowing shallow river with a mean water depth of less than one metre, excluding the estuarine area.

The Linggi River Basin is mainly composed of igneous and metasedimentary rocks. The north eastern part of the basin is dominated by granitic ridges and mountains that are predominantly plutonic and acidic with patches of hypabysal-vein quartz in the north-western regions. The igneous rocks of the area are mainly granitoids with rare occurences of serpentinite and late phase instrusions. The granites of the area are typically medium to coarse grained rocks, often porphyritic (Alexander 1968). However, various fine grained granites also occur and they often contain tourmaline together with muscovite and biotite. Granodiorites and adamellites are probably the most common types and biotite usually contain ferromagnesian silicate.

Soil type depends on the parent rock type of the basin, although variations may occur over small distance due to differences in local condition. The bed rock in the study area is overlain by alluvial deposits of red and yellow lateritic clay, sand and gravel. The alluvium is quite deep in certain areas especially along the hills due to aggregation and tin mining activities. The alluvial deposits, especially along the rivers are composed of gray clay and peat. More areas under laterite are found along the south-western coast of the state.

Land use in the Linggi River Basin is dominated by agricultural crops such as rubber and oil palm, followed by forest reserves, urban, industrial and institutional settlements, swamps and other miscellaneous development activities including small areas under padi fields. The water from the Linggi River Basin is extensively used for various purposes including domestic and industrial consumption, irrigation, fishery, aquaculture and navigation. Water for domestic use is tapped at three locations within the catchment area. The Drainage and Irrigation Department (DID) extracts water from various sources of the river for paddy irrigation.

Periodic samples of water were collected at 15 main stations located at four major rivers, the Linggi (s.s.), Rembau, Kundor and Simin during January 1983-January 1984 and measured for silica concentration. In addition, 27 supplementary stations (Stations A to W) which include 19 stations at major tributaries were sampled occasionally (Figure 1). Detailed description of each station, its morphology and pollutant input has earlier been described

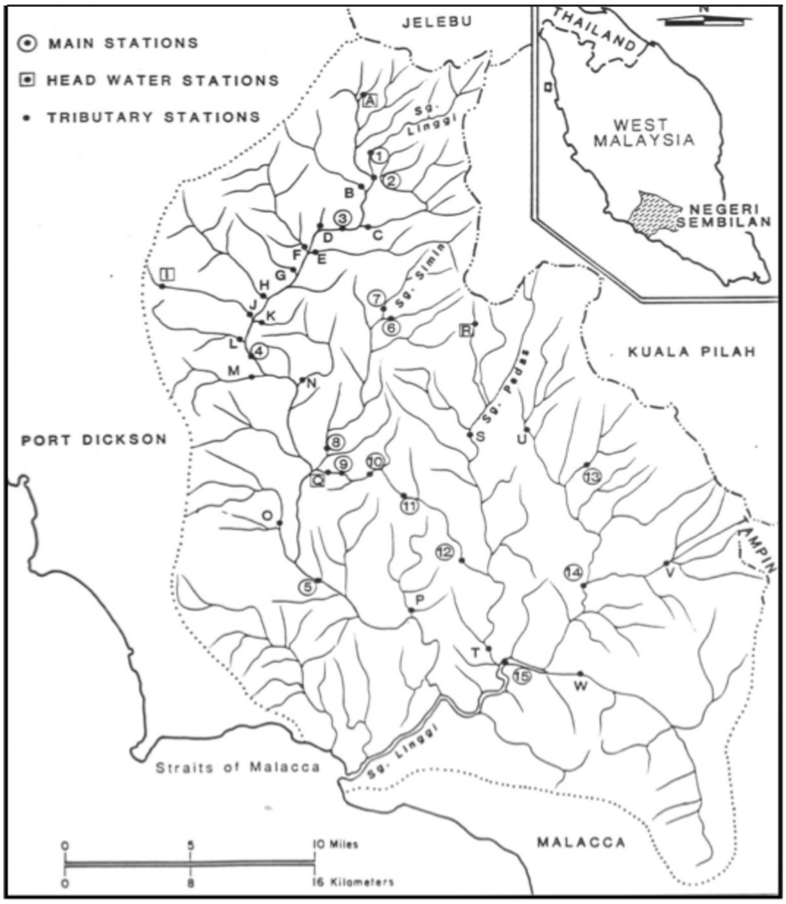


FIGURE 1. The Linggi River Basin showing the water sampling location

TABLE 1. Reactive Silicate (SiO 2) at 15 main stations in the Linggi River Basin (* indicates the beginning of Station 12)

Date	Sg. Linggi (s.s.)						Sg. Simin		Sg. Kundor			Sg. Rembau	
	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8	Station 9	Station 11&12	Station 13	Station 14	Station 15
24.01.83	21.2	22.5	21.6	16.2	12.4	-	-	-	-	-	-	-	-
02.03.83	15.8	14.9	14.5	13.2	12.8	-	-	-	7.7	7.7	16.6	9.9	9.4
22.03.83	20.8	20.4	20.4	18.1	19.1	-	-	-	10.1	11.8	20.8	13.6	14.7
26.04.83	18.7	18.7	17.9	15.3	14.5	16.2	15.3	15.3	7.7	12.8	26.3	21.7	16.2
29.05.83	18.7	17.9	15.3	13.2	11.0	11.1	9.0	8.6	6.9	10.3	-	13.6	10.7
26.06.83	17.4	17.4	14.5	8.2	11.1	10.7	8.2	4.8	6.9	11.1	16.6	11.1	10.7
30.07.83	18.7	18.7	16.6	12.0	7.3	3.1	1.4	7.7	5.6	6.7*	16.2	10.3	9.0
27.08.83	20.0	19.1	19.1	14.9	12.8	12.8	10.7	13.6	8.6	9.0	17.4	12.8	11.5
26.09.83	22.0	21.7	19.6	15.3	9.4	14.1	11.5	11.5	8.7	9.4	17.9	12.4	8.2
28.10.83	17.4	15.8	15.8	13.2	13.2	14.9	6.9	11.2	8.6	8.6	13.2	9.9	8.2
25.11.83	18.3	20.0	16.6	14.1	11.2	13.6	8.9	10.7	8.6	9.0	12.0	10.3	9.0
29.12.83	17.0	17.0	16.6	13.2	11.1	12.8	12.4	12.4	7.3	7.3	15.8	9.4	9.0
30.01.84	16.6	16.6	14.9	12.0	11.1	11.5	12.4	10.3	7.7	7.7	14.9	10.6	9.0

(-) – indicates no data available; s.s – senshu stricto

TABLE 2. pH values at 15 main stations in the Linggi River Basin (* indicates the beginning of Station 12)

Date	Sg. Linggi (s.s.)					Sg. Simin			Sg. Kundor		Sg. Rembau		
	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8	Station 9	Station 11&12	Station 13	Station 14	Station 15
24.01.83	6.56	5.56	5.16	5.46	5.02	-	-	-	-	-	-	-	-
02.03.83	5.88	5.70	5.71	6.08	5.44	-	-	-	5.87	6.07	5.29	4.89	4.88
22.03.83	5.26	5.06	5.12	5.41	5.21	-	-	-	5.6	5.78	5.6	5.63	5.79
26.04.83	6.7	6.65	5.95	5.7	5.55	5.75	6.1	5.6	5.7	5.75	5.6	5.4	5.35
29.05.83	6.55	6.50	5.7	5.6	5.65	5.80	5.85	5.5	5.45	6.5	-	5.25	5.15
26.06.83	5.81	5.57	5.52	5.42	5.69	5.95	5.50	5.36	5.47	6.17	5.82	5.77	5.72
30.07.83	6.04	5.80	5.52	5.54	5.29	5.23	4.95	5.15	4.84	5.44	5.54	5.41	5.21
27.08.83	6.20	5.76	5.72	5.74	5.6	5.48	6.07	5.63	5.53	5.88	5.65	5.89	5.67
26.09.83	5.82	5.49	5.17	5.10	4.77	5.47	4.70	4.99	5.5	6.0	4.99	4.78	4.44
28.10.83	6.05	5.20	5.1	5.02	4.75	4.43	4.64	4.66	5.11	5.11	4.33	4.5	4.32
25.11.83	5.38	4.64	4.59	5.4	4.6	4.26	40.4	4.97	6.14	4.87	4.19	4.11	4.1
29.12.83	6.50	5.04	4.81	5.24	5.13	5.89	5.44	4.99	4.45	4.65	4.05	4.47	4.3
30.01.84	6.75	5.86	5.38	5.2	5.07	4.87	5.70	4.81	4.75	6.38	5.65	5.4	5.37

(-) – indicates no data available; s.s – senshu stricto

TABLE 3. Total Dissolved Solids (TDS) at 15 main stations in the Linggi River Basin (* indicates the beginning of Station 12)

Date	Sg. Linggi (s.s.)						Sg. Simin		Sg. Kundor			Sg. Rembau	
	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8	Station 9	Station 11&12	Station 13	Station 14	Station 15
24.01.83	52.4	54.2	55.6	83.2	72.8	-	-	-	-	-	-	-	-
02.03.83	49.0	56.0	68.0	105.4	94.7	-	-	-	190.0	80.0	67.0	35.0	81.4
22.03.83	38.7	67.3	66.6	93.9	83.9	-	-	-	143.9	155.3	91.0	86.6	75.9
26.04.83	56.0	67.0	75.0	108.0	116.0	55.0	407.0	149.0	187.0	179.0	141.0	126.0	123.0
29.05.83	60.0	68.0	73.0	102.0	108.0	48.0	142.0	83.0	157.0	297.0	-	79.0	63.0
26.06.83	63.0	71.0	74.0	96.0	100.0	52.0	122.0	41.0	89.0	182.0	77.0	81.0	77.0
30.07.83	55.0	62.0	73.0	89.0	81.0	51.0	112.0	72.0	58.0	67.0	73.0	70.0	60.0
27.08.83	52.0	70.0	82.0	111.0	77.0	49.0	380.0	90.0	110.0	581.0	60.0	60.0	80.0
26.09.83	77.0	66.0	66.0	100.0	78.0	54.0	261.0	69.0	102.0	107.0	73.0	115.0	83.0
28.10.83	35.0	59.0	62.0	77.0	92.0	51.0	182.0	86.0	46.0	61.0	61.0	53.0	56.0
25.11.83	43.0	60.0	64.0	97.0	89.0	47.0	758.0	69.0	72.0	66.0	68.0	59.0	54.0
29.12.83	54.0	54.0	62.0	100.0	100.0	55.0	655.0	80.0	73.0	66.0	77.0	55.0	65.0
30.01.84	50.0	66.0	86.0	111.0	107.0	62.0	502.0	88.0	103.0	85.0	82.0	61.0	57.0

(-) – indicates no data available; s.s – senshu stricto

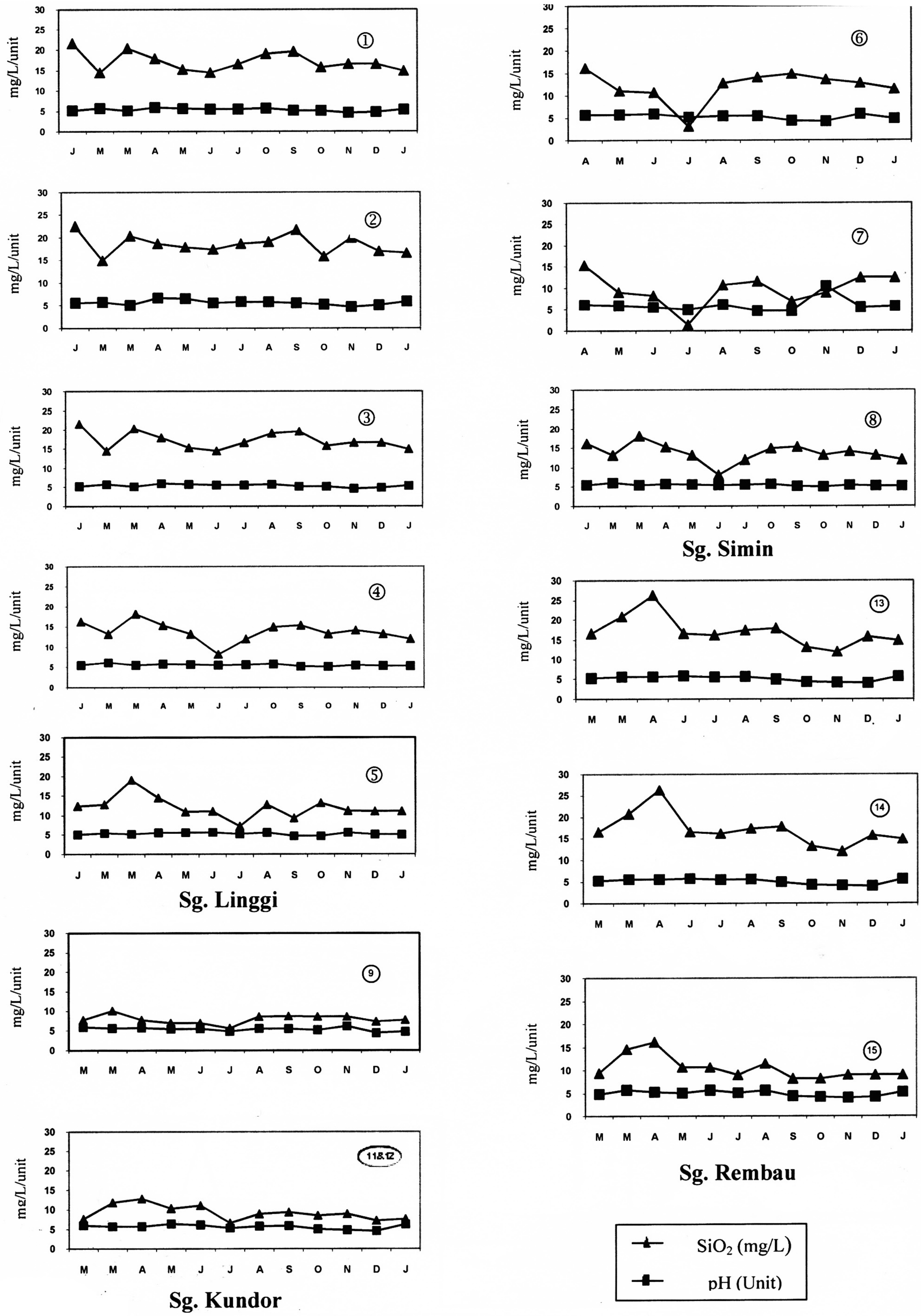


FIGURE 2. Monthly variation in silica (SiO_2) and pH at 15 main station in the Linggi River Basin

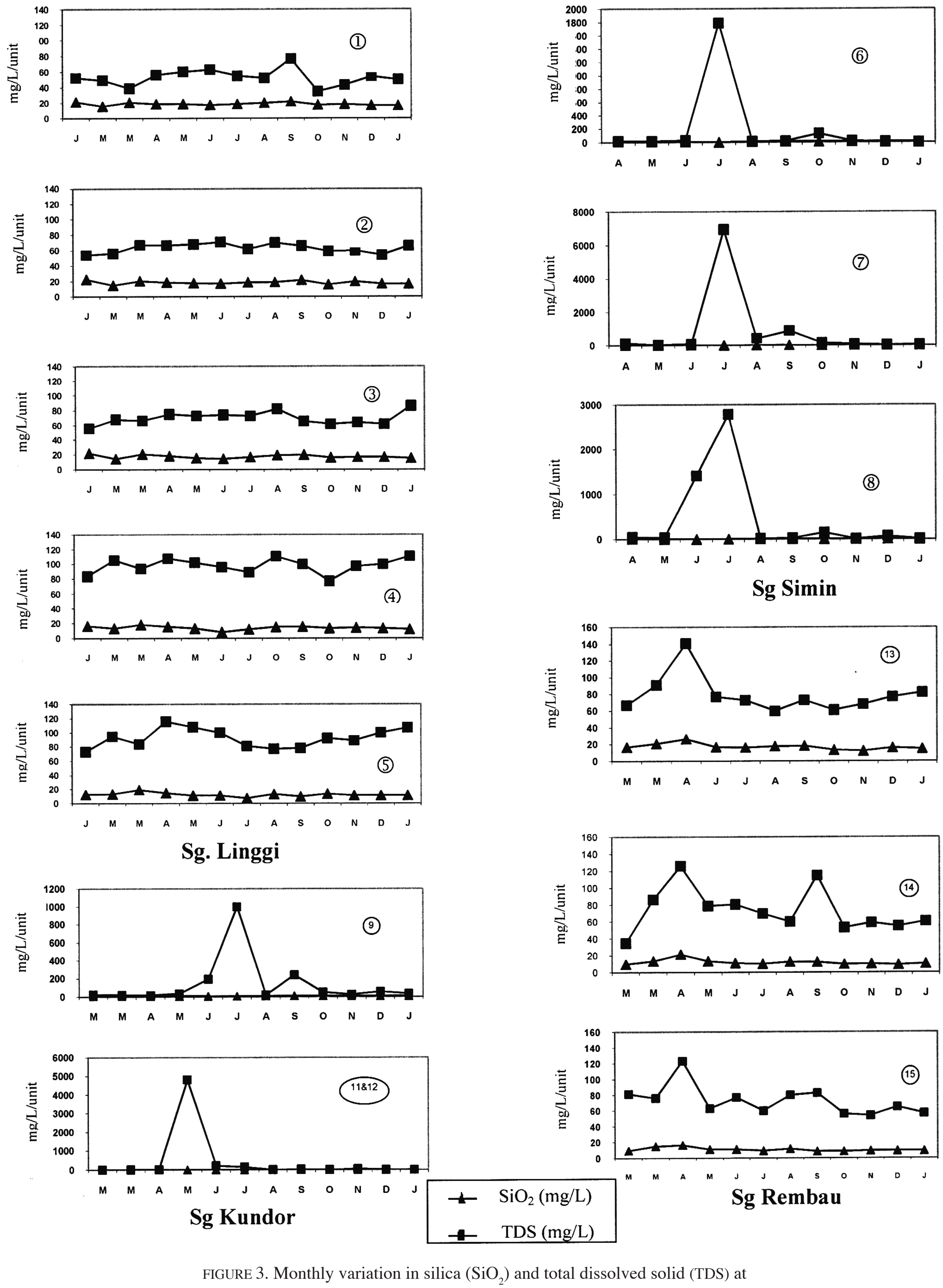


FIGURE 3. Monthly variation in silica (SiO_2) and total dissolved solid (TDS) at 15 main station in the Linggi River Basin

in other publications (Nather Khan 1985, 1990a, 1990b, 1991a, 1991b, 1992a, 1992b). Silica, as soluble reactive silicate, was determined colorimetrically (365 mm) by the acid molybdate-stannous chloride method. Phosphate interference was prevented by adding oxalic acid. This method was described by Kobayashi (1960) and employed by Golterman and Clymo (1969) for waters with high silica content. A stable potassium chromate solution prepared according to method described by Macleretj (1963) was used as a standard.

RESULTS AND DISCUSSION

The silica content measured as reactive silicate in the whole Linggi River Basin ranged from 1.4 to 26.3 mg/L (Table 1). Variation in the silica concentration was observed at different stations studied. The values ranged from 7.3 to 22.5 mg/L at Sungai Linggi (sensus stricto); 1.4 to 16.2 mg/L at Sungai Simin; 5.6 to 12.8 mg/L at Sungai Kundor; 8.2 to 26.3 mg/L at Sungai Rembau and 4.4 to 20.2 mg/L among the tributaries (Table 2). It was not possible to determine the silica level at Station 10 of Sungai Kundor as the palm oil effluent masked colour development during the colorimetric analysis.

Seasonal variation in silica content was noted especially at Sungai Linggi (sensus stricto) and Sungai Rembau, with high concentrations during the dry months of March, April, August and September and low concentrations during the wet months of June, July, December and January (Figure 2). The variability in concentration between the months could be related largely to precipitation. The very low silica concentration recorded at Stations 6 and 7 in July could be attributed due to heavy rain storms while sampling where there is possibility of silica being carried off owing to the lotic condition.

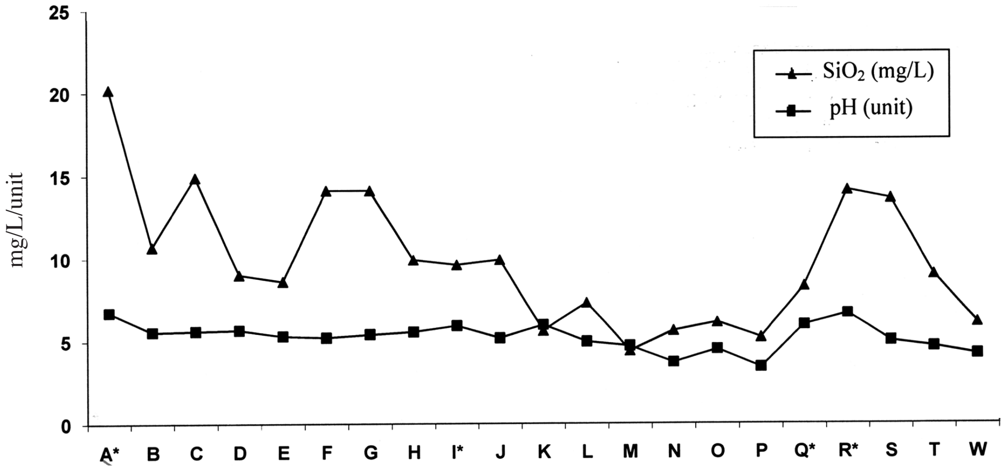
Among the rivers, very high concentration of silica (>20 mg/L) was recorded at the upstream tributaries of Sungai Linggi (s.s.) and Sungai Rembau. Both these rivers originate from steep central mountain range of Peninsular Malaysia. The concentration decreased as the water flowed downstream. This could probably be attributed to various processes that take place during the flow of the river which included dilution, lack of silica enrichment at the low-lying tributaries run-off granite, utilization of silica by diatoms and other aquatic and marginal plants. It seems that most silica occurs in the main channel at downstream stations originating from the upstream, as the concentration of silica at low land tributaries were very low.

Relatively high silica content has been recorded in tropical and sub-tropical waters (Bishop 1973; Douglas 1967; Dudgeon 1982; Kobayashi 1960). This is due partly to the high mobility of the element in tropical soils (Nather

TABLE 4. Reactive silicate (SiO_2) and pH at major tributaries in the Linggi River Basin (sampled on 15th February, 1984 at basal flow)

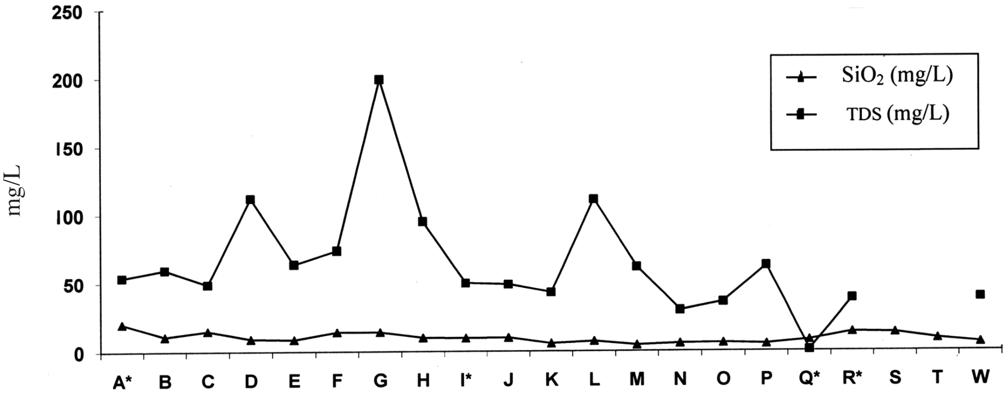
Station	Tributary	SiO_2 (mg/L)	pH	TDS (mg/L)
A	Sg. Jeralang	20.2	6.73	54.1*
B	Sg. Sikamat	10.7	5.55	60.00
C	Sg. Terip	14.9	5.60	49.00
D	Sg. Simpo	9.0	5.66	112.0
E	Sg. Paroi	8.6	5.3	64.00
F	Sg. Temiang Diversion	14.1	5.21	74.00
G	Sg. Temiang	14.1	5.40	199.00
H	Sg. Kapayang	9.9	5.54	95.00
I	Sg. Mantau	9.6	5.9	50.00*
J	Sg. Mantau	9.9	5.17	49.00
K	Sg. Anak Ayer Garam	5.6	5.95	43.00
L	Sg. Kayu Ara	7.3	4.95	111.00
M	Sg.Bemban	4.4	4.70	62.00
N	Sg. Nyotah	5.6	3.70	30.00
O	Sg. Siliau	6.1	4.5	36.00
P	Sg. Solok	5.2	3.4	63.00
Q	Sg. Kundor Besar	8.3	5.95	41.00*
R	Sg. Beringin	14.1	6.65	38.50*
S	Sg. Pedas (s.s)	13.6	5.0	-
T	Sg. Pedas	9.0	4.65	-
W	Sg. Siput	6.1	4.2	39.00

(*) Mean values of the samples collected on two occasions (18th and 26th November 1983)
(-) – no data available



(*) Mean values of the samples collected on two occasions (18th and 26th November 1983)

FIGURE 4. Silicate (SiO_2) and pH at various tributaries in the Linggi River Basin



(*) Mean values of the samples collected on two occasions (18th and 26th November 1983)

FIGURE 5. Silicate (SiO_2) and total dissolved solid (TDS) at various tributaries in the Linggi River Basin

Khan 1985) and partly to prevailing high denudation activities in the greater part of the upper catchment. Ho (1973) recorded mean values ranging between 6.80 and 7.69 ppm SiO2 at various stations of small river of Sungai Renggam. Douglas (1969) gave a mean value of 11.7 mg/L for Asian waters and estimated a mean value of 15 mg/L at the mouth of Sungai Gombak, Malaysia. Bishop (1973) obtained high silica concentrations for tributaries which had their sources in coarse grained granite areas, slightly lower concentrations from tributaries that drained fine grained granite areas and very low concentrations from those found in quartzite, shale and chert areas.

In the Linggi River Basin, the mean values of silica recorded at both upstream and downstream stations are higher than the values reported for other Malaysian rivers. The large drainage area with granite dominated lithology, steep gradients and high denudation, especially in the upper catchments, are the probable cause for high silica content in the waters of the Linggi River Basin.

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