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GROUNDWATER QUALITY INVESTIGATION AT NORTH KUDAT, SABAH, MALAYSIA

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ABSTRACT. *Chemical and physical compositions of groundwater samples collected from various stations throughout the study area were determined in order to describe the background of ion concentration and to identify the major hydrochemical processes that control the groundwater chemistry. The investigation results indicate that groundwater of North Kudat has evolved chemically through water - rock interaction. The geologic setting of the study area has a major impact on the physical and chemical characteristics of ground water. Groundwater quality of North Kudat depends upon the duration of contact with its geologic environment.*

INTRODUCTION

Historically, judging of water quality by man was basically by sense of smell, taste and sight. Today modern analytical facilities have been utilized to access water quality. Now quality status of water bodies can be determined and classified easily. In recent years Malaysia has undergone a very rapid development such as population growth, urbanization, agricultural, logging activities and industrialization. These changes cause complex environmental problems and the most effected natural resource is water (Abu Bakar, 1985).

This paper will discuss aspect of groundwater quality based mainly on chemical and physical parameters. Ground water chemistry of the study area is directly affected by the rock types present in surrounding drainage. This relationship can be quite complex. Many factors besides mineral composition of primary rock type could influence groundwater quality. Minor soluble constituents, such as salt or gypsum has disproportionate influences. Within the groundwater basin, redeposition of dissolved constituents, ion exchange reactions, and surface pollution sources are important considerations. The study of the geologic and hydrologic aspects of Northen Kudat provides a rational basis for the evaluation of various groundwater paramater including its quality. Before discussing the quality of groundwater can be made a knowledge of the above two basic sciences is necessary.

Objectives

The groundwater quality investigation in the study area was undertaken with the following objectives:

- to establish the quality of groundwater based on chemical and physical parameters,
- to determine the trace elements in groundwater,
- to define aerial geology and its effects on groundwater and
- to identify existing water quality problems.

Location

The study area is located in the northern tip of Kudat Peninsula (Figure. 1) comprises of about 120 km square. The longitudinal and latitudinal extends are from 116°41'E to 116°51' and 06°55'N to 07°03'N respectively. It is bounded on the west by the South China Sea and on the east by Marudu Bay.

Rainfall And Temperature

There are five climatic regions in Sabah based on dry and wet seasons which in turn are induced by minimum and maximum rain periods (Figure 2). Regionally the study area received between 200 - 250 cm rainfall. The recorded rainfall data at Kudat station for the period 1982 - 1993 indicate that the average annual rainfall is 1993.33 mm (Table 1) while the mean annual temperature for the area station for the same period is 26.8 - 27.7°C (Table 2).

Topography and Drainage

The morphology of the study area is a result of various geomorphologic processes acting under the climatic influences. The study area can be divided into two contrasting physiographic features, i.e. 1) the highlands with elevation ranging among 40 - 200 m and 2) lowlands with elevation ranges among 0 - 40 m. The study area is drained by numerous small streams (Figure 3). Most of the streams flow are not perennial. These streams turn turbulent during brief but heavy rainfall. The general flow direction is westward towards South China Sea or eastward towards Marudu Bay.

The gentle slopes within the highlands are usually covered by thick secondary forest and produce the main catchment area. The lowlands, especially coastal and alluvial plains form the populated and major agricultural area.

Stratigraphy

Rocks underlying the Kudat area vary in type and age starting from ophiolitic rocks of Jurassic age to young alluvium still being deposited. Five formations are present in the mapped area : the Ophiolitic rocks, Chert - Spilite Sequence, Kudat Formation, Melange and Quaternary Alluvium. Table 3 shows the composite stratigraphic column of the rock units exposed in the study area and their water bearing properties.

The structural map (Figure 4) based on aerial photograph interpretation and field observation of Kudat area reveals fault systems controlling the area. Movements along these structures in the geologic past had strongly influenced the geomorphology of the study area. Several secondary faults or fracture system can be observed traversing the fault zones and its vicinities. The rock formations within the fault zones and vicinities are controlled by joints and fractures generated by the Kudat Fault Zone. The joints are often unfilled by secondary materials. The presence of such discontinuities not only influences the mechanical behavior of the rock but also generates high porosities and secondary permeabilities, in the rocks thus increasing the water capacity of the Kudat Formation.

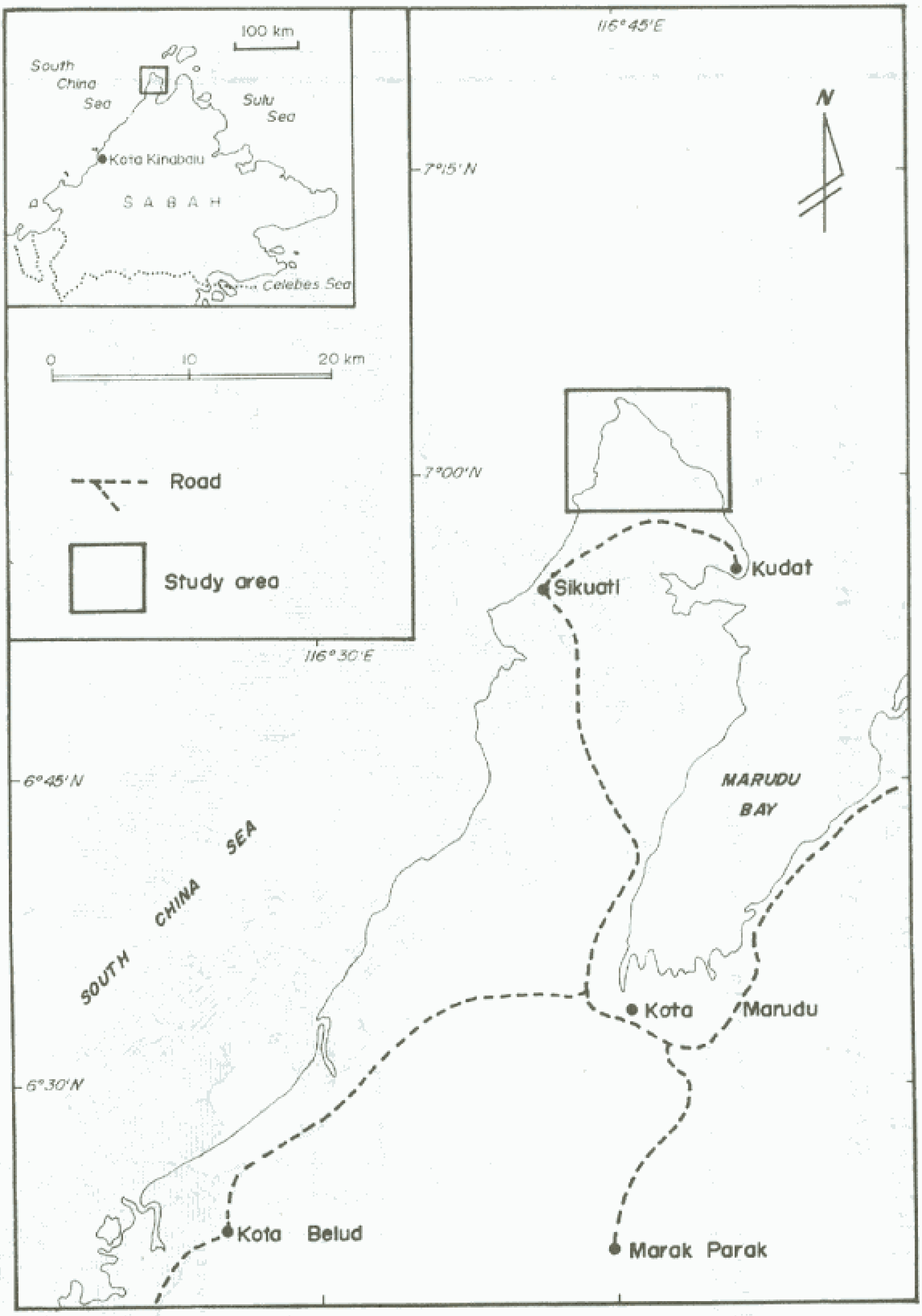

Figure 1: Map showing the location of the study area

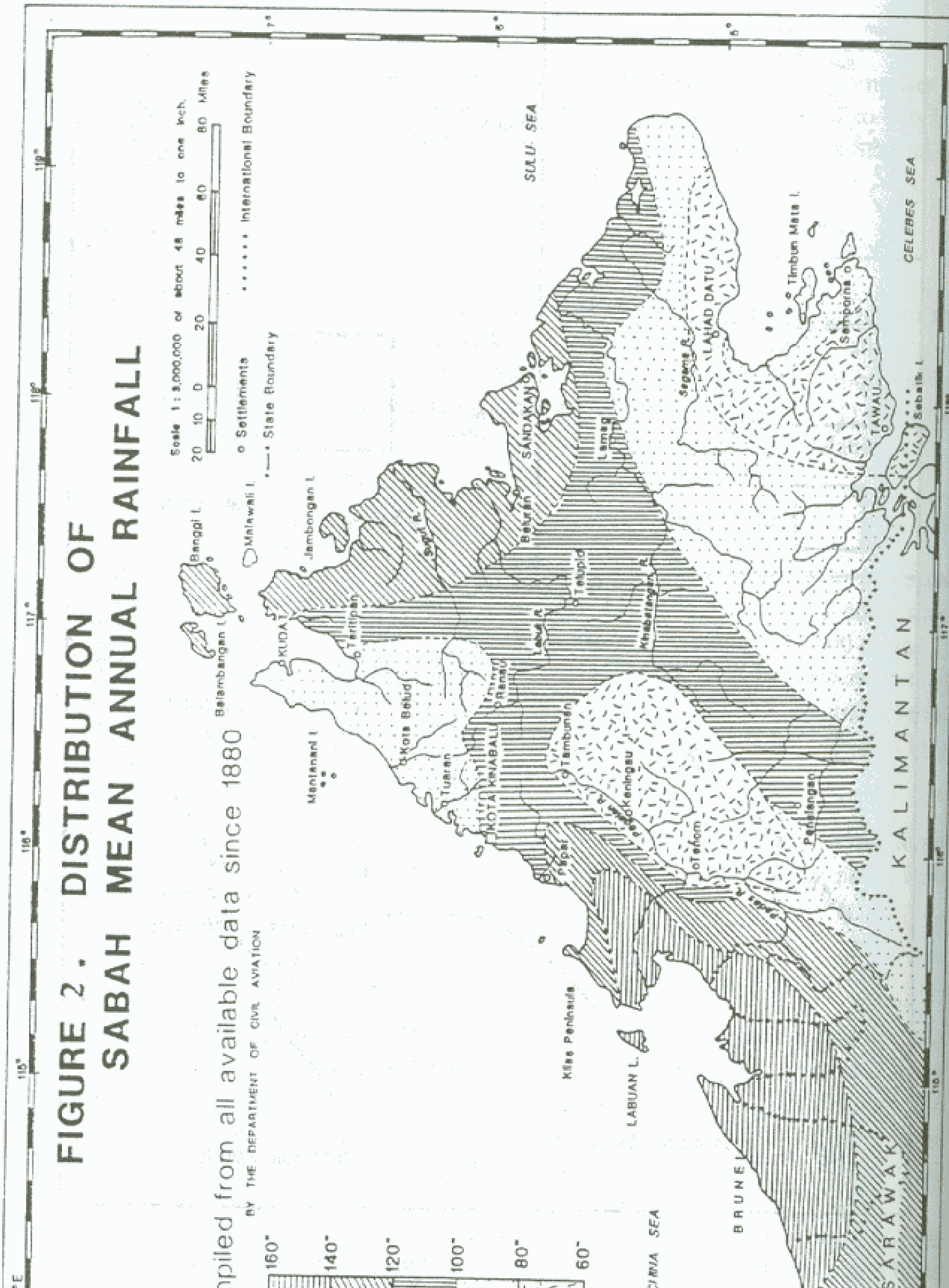
FIGURE 2. DISTRIBUTION OF
SABAH MEAN ANNUAL RAINFALL
Compiled from all available data since 1880
BY THE DEPARTMENT OF CIVIL AVIATION
160"
140"
120"
100"
80"
60"
SOUTH CHINA SEA
SULU SEA
CELEBES SEA
KALIMANTAN
SARAWAK
BRUNEI
LABUAN I.
Klias Peninsula
KUDAT
SANDAKAN
KOTA KINABALU
LAHAD DATU
TAWAU
Kota Belud
Tuaran
Papar
Keningau
Tenom
Tambunan
Ranau
Telupid
Beluran
Lamag
Pensiangan
Sempoma
Sebatik I.
Timbun Mata I.
Banggi I.
Malawali I.
Jambongan I.
Balambangan I.
Mantanani I.
Settlements
State Boundary
International Boundary

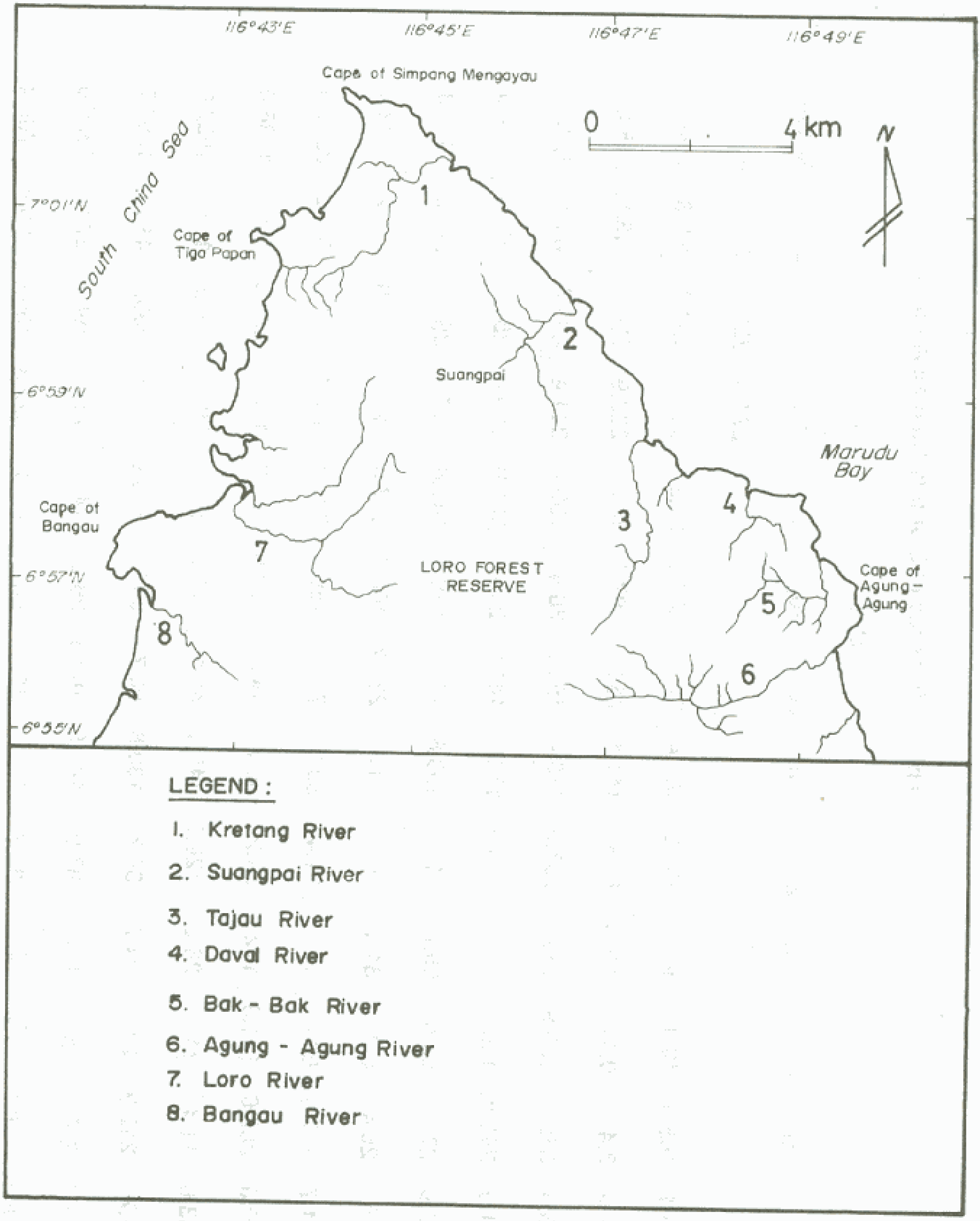

Figure 3: Drainage map of the study area.

Table 1 - Records of Monthly Rainfall Amount

Unit : mm

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1981										274.5	222.5	263.6	N.A.
1982	333.4	105.3	40.3	36.4	104.2	164.4	51.1	268.1	86.2	90.7	157.8	202.8	1640.7
1983	144.9	3.4	0.4	0.0	19.8	141.1	75.3	197.6	180.1	230.9	357.6	1132.3	2483.7
1984	866.8	385.2	125.9	160.4	337.0	173.4	150.7	36.4	155.2	311.4	209.7	427.6	3339.7
1985	211.9	242.8	126.2	57.5	259.6	17.3	141.1	26.4	161.9	160.0	259.1	200.8	1864.6
1986	605.9	37.7	53.5	59.7	41.6	160.8	132.9	119.1	142.6	117.1	391.9	111.5	1974.3
1987	53.6	25.4	0.2	31.4	38.0	73.3	237.7	108.5	137.0	121.5	121.6	454.2	1402.4
1988	371.7	163.8	67.6	11.3	61.4	80.0	74.0	186.9	205.7	304.1	711.6	700.2	2938.3
1989	190.0	258.6	101.3	122.7	59.2	36.7	44.0	172.5	168.2	162.4	273.6	145.9	1736.0
1990	453.6	11.4	24.9	36.2	126.7	145.4	45.1	123.8	100.5	79.7	266.6	153.7	1567.6
1991	84.7	212.9	8.4	34.7	39.7	180.8	96.7	89.7	178.9	145.5	393.0	415.7	1880.7
1992	158.3	2.7	18.7	0.4	87.9	142.5	108.5	26.2	14.8	148.8	398.6	279.2	1386.6
1993	158.4	128.7	11.2	68.6	31.7	84.2	130.7	56.0	62.0	322.3	190.8	460.8	1705.4

Note: N.A. - Not Available

Table 2. Record of 24 hour mean Temperature

Station : Kudat
Lat. : 6° 55' N
Long. : 116° 50'E
Ht. above M, S, L. : 3.5 m

Unit : °C

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1981	----------	----------	----------	Not Available		----------	----------	----------	----------	26.6	26.4	26.8	-
1982	26.4	26.4	27.4	28.2	28.2	27.2	27.0	26.7	27.3	27.0	27.6	27.2	27.2
1983	27.4	27.5	28.5	28.8	29.0	28.3	27.5	27.4	27.1	27.0	26.5	25.6	27.5
1984	25.4	26.5	27.2	27.7	27.3	26.8	26.9	27.3	26.5	26.4	26.9	26.3	26.8
1985	26.0	27.2	27.7	27.3	27.5	27.8	26.5	26.9	26.3	26.4	27.0	26.6	26.9
1986	26.1	26.4	27.1	28.5	28.1	27.4	26.9	26.9	26.9	26.8	26.5	27.2	27.1
1987	27.0	26.5	27.9	28.8	28.9	28.5	27.2	27.3	28.0	27.4	27.4	27.2	27.7
1988	27.6	27.0	28.4	28.8	28.5	27.6	27.3	27.5	27.2	26.7	26.2	25.7	27.4
1989	26.9	26.4	26.6	27.0	27.6	27.2	27.5	27.4	27.6	26.9	27.1	27.0	27.1
1990	26.7	27.7	27.8	28.6	28.3	27.6	27.1	27.6	27.5	27.7	26.9	27.3	27.6
1991	27.0	26.6	27.5	28.3	28.9	28.1	27.6	27.4	27.3	27.0	26.4	27.1	27.4
1992	26.7	27.5	28.1	28.8	28.5	27.8	27.1	27.8	28.0	27.2	26.3	26.9	27.5
1993	26.6	26.3	27.1	27.8	28.7	28.1	27.3	27.4	26.9	26.7	26.9	26.7	27.2

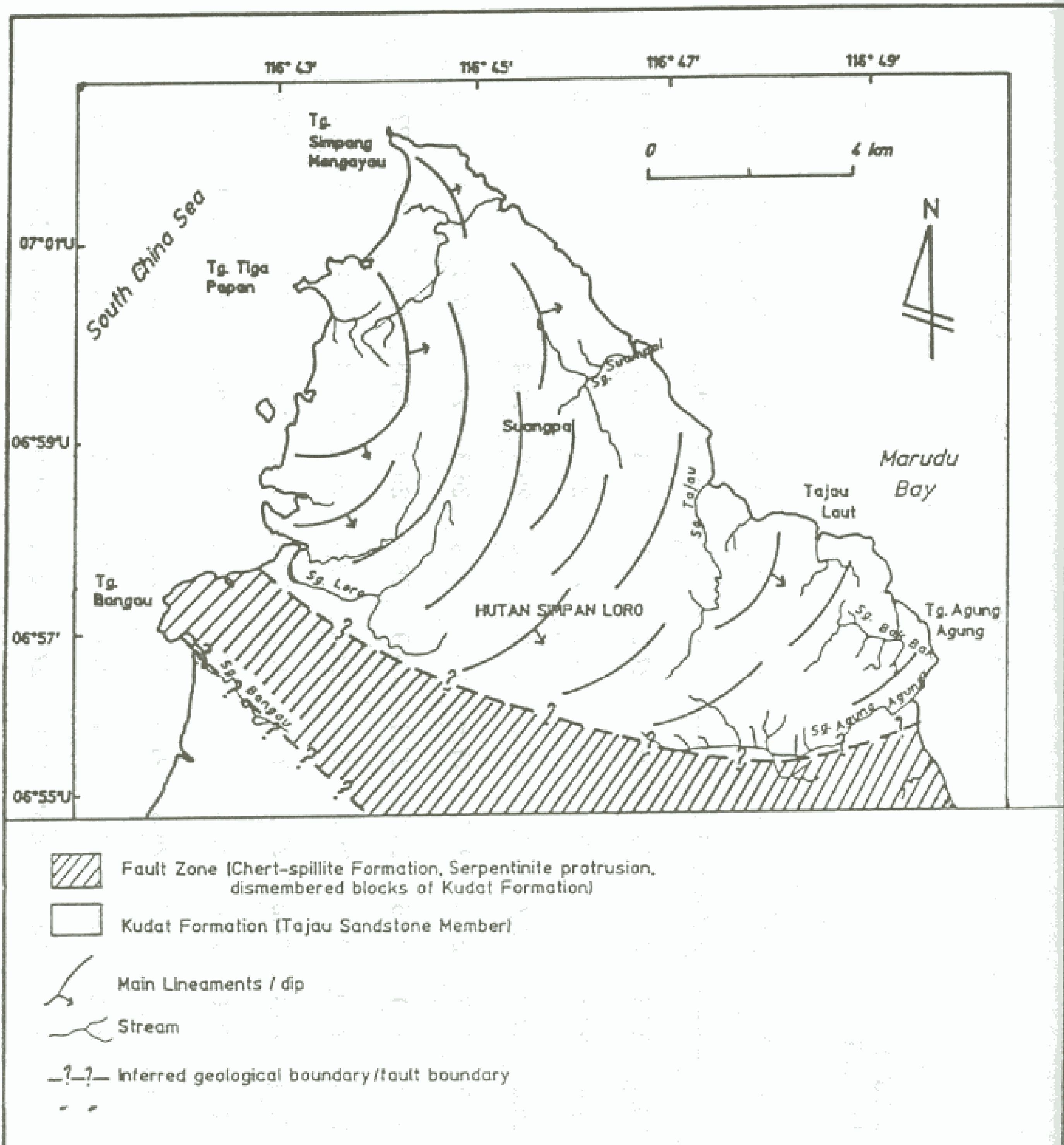

Fig. 4 : *Structural Map of the Northern part of the Kudat Peninsular, Sabah, M'sia.*

Table 3 - LOCAL STRATIGRAPHIC COLUMN

AGE	ROCK FORMATION	MEMBER	FACIES	SYMBOL	GENERAL CHARACTER	WATER-BEARING PROPERTIES
Quaternary	Alluvium	-	-	Qal	Unconsolidated gravel, sand and silt with minor amounts of clay deposited along the rivers or streams and their tributaries. Includes natural levee and flood plain deposit.	Gravelly and sandly, portions are highly permeable and yield large quantities of water. Important to groundwater recharge.
Early Middle Mocene (N9)	Kudat Melange	-	-		Low density, water saturated materials distorted by the chaotic structure of fault imbrication and plastic folding. Mixture of sandstone, greenstone, breccia, chert and other rocks in sheared, shaly matrix.	Not reliable source of ground water.
Early Miocene	Kudat Formation	Tajau	Clastic		Medium to coarse thick sandstone interbedded with thin layers of shale, highly faulted, fractured and jointed.	A major water-bearing formation
			Carbonate		Mainly fossiliferous limestone present as lenses in study area occasionally interbedded with thin layers of shale, highly faulted, highly fractured.	Moderately permeable. May be good source of ground water.
		Sikuati	-		Inter layering sand stone and shale with various thickness	of little importance to ground water provides some water. Ground water various from unconfined to confined.
Early-cretaceous	Chert-spilite				Interbedded chert and shale (Red) and spilite. Highly folded and fractured.	Largely non water bearing.
Jurassic or older	Ophiolitic Rock				Fractured and faulted unit of ophiolitic rocks includes basalt, plagiogranite and dolerite dyke.	No importance to ground water.

Evapotranspitation

Evapotranspiration (Et) is the combined process of evaporation and transpiration wherein evaporation is a purely physical process whereby water is returned to the earth's atmosphere through media. Transpiration on the other hand, is a biological process by which water is returned to the atmosphere through the medium of plant growth.

The values for potential evapotranspiration were computed using Thornwaite's method. This method required temperature and precipitation data.

Water Balance

The term water balance was introduced by meteorologist C. Thornewaite in 1944 to refer to the balance between "income" of water from precipitation. In investigations conducted on the hydrologic balance of any catchment area, the balance must exist between the incoming and outgoing water, and water stored within the basin. The equation of hydrologic equilibrium, simplified below, expresses the quantitative nature of this balance, as stated below:

$$Inflow = outflow \pm storage$$

Analysis of Table 4 and Figure 5 shows that during February to September, potential evapotranspiration is higher than rainfall. Theoretically, therefore all the precipitation occurring during this month will be lost through evapotranspiration leaving no or little excess water for surface runoff and deep percolation. Practically it is only during January, October, November and December that excess rainfall will become available for runoff and deep percolation.

Occurrence of Groundwater

The geology of the study area indicates that only the sedimentary rocks of Early Miocene Kudat Formation and Quaternary alluvium can be considered important groundwater reservoirs. The older rocks are either highly compacted and yield insignificant quantities of water or are buried at depths at which groundwater development is not economically feasible. Sand and gravel layers with variable thickness define the major aquifer within the alluvium. Shallow clay beds occasionally act as aquicludes resulting in semi - confined conditions in some alluvial areas.

The other groundwater reservoir is the sedimentary unit of Kudat Formation. The permeable bed occurs as irregular masses of sandstones intercalated with impervious bed of shale, clay and silt. Shale beds or lenses locally occurring within the sandstone might be extensive enough to separate water bearing layers into several aquifers. Most the aquifers within Kudat Formation are under confined conditions. The most significant aquifers within the Tajau Member of Kudat Formation are the sandstones and carbonates. The large pore spaces with the coarse-grained sandstones would increase the permeability and offer good sources of groundwater in the area. Diagenetic changes in the sandstones may have locally reduced their porosity and permeability. However, fracturing related to the Kudat fault zones may have enhanced secondary porosity and permeability.

Table 4 Computation of Water Balance

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Temperature C°	26.80	26.80	27.60	28.30	28.40	27.90	27.30	27.40	27.40	27.10	26.70	26.90	-
Monthly heat index	12.72	12.71	13.26	13.80	13.90	13.42	12.91	13.15	13.16	12.88	12.77	12.77	157.45
Standard potential Evapotrans: mm	138.95	139.39	141.66	144.47	144.86	142.47	140.54	141.14	125.62	139.79	139.79	139.17	1676.60
Correction Factor	1.00	0.91	1.03	1.08	1.08	1.06	1.08	1.07	1.02	1.02	0.98	0.99	-
Assessed potential Evapotrans: mm	138.95	126.84	145.81	148.81	156.44	151.79	161.01	161.01	142.56	142.56	135.43	137.77	1730.55
Precipitation mm	259.60	105.20	35.70	45.60	60.80	113.00	108.70	110.30	126.20	175.20	343.50	340.50	1824.30
Difference	-	21.64	110.21	103.21	95.64	38.03	43.09	40.71	17.81	-	-	-	470.34
	120.95	-	-	-	-	-	-	-	-	32.64	208.07	202.73	564.09
Uncorrectedactual Evapotrans mm	138.95	105.20	35.70	45.60	60.80	113.00	108.70	110.30	126.20	142.56	135.43	137.77	1260.21

Annual soil moisture deficiency = 470.34 - 100 ** = 370.34 mm
Actual annual evapotranspiration = 1260.21 + 100 ** = 1360.21 mm
Run-off + deep percolation = 1824 - 1360.21 = 464.09 mm

** 100 mm = assumed soil moisture utilization

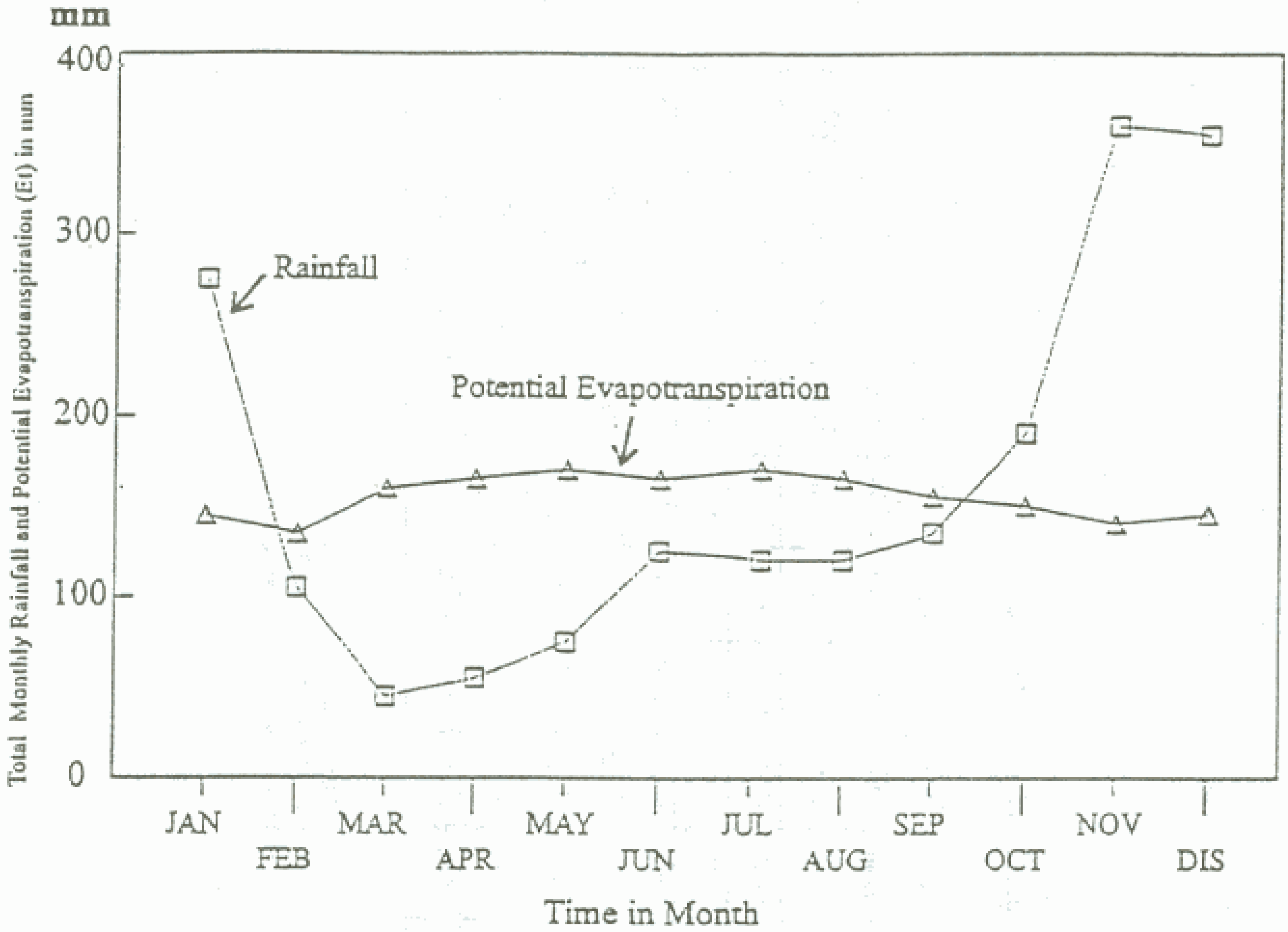

Figure 5 Relationship between average monthly rainfall and average monthly evapotranspiration (1986 - 1993)

METHODOLOGY

Field Methods

The collection of water samples for analysis involves not only the taking of samples but also the measurement of the physical properties of water such as, pH values.

Recalibration of the pH meter was done after every five measurement to correct any instrument drift for pH values. Other properties like clarity, odor, color, and taste (optional) were also noted.

For each sampling site, three samples were collected : 1) one-liter representative sample, 2) sample for nitrate analysis, and 3) sample for metal analysis. The representative samples were not treated with any chemical and were placed in one-liter polyethylene bottles filled up to the top to avoid oxidation by contact with air. The samples for nitrate analysis were collected in 50-ml polyethylene bottles. Since nitrate is unstable, addition of 3 drops of chloroform to each sample was done to stabilize the nitrate content. On the other hand, the samples for the metal analysis were also collected in 100-ml polyethylene containers filtered through a 0.45 membrane using the syringe. Filtering is necessary to eliminate particulate matters while allowing metal colloids to pass through. Addition of 3 drops of suprapure $HNC0_3$ to each sample was also done to prevent the precipitation of metal hydroxides or oxides.

A total of 39 samples as shown in Tables 5 & 6 (Figure 6) were collected from the study area and analyzed for cations and anions. During sampling, several physical properties such as pH, temperature, and salinity were measured *in situ*.

Laboratory Method

The atomic absorption spectrophotometer was used mainly for this analysis.

RESULTS AND DISCUSSION

Generally the pH values represent natural type of water with value (< pH 6.5) and this may be due to release of proton during nitrification, dissolution of $C0_2$ in water and oxidation of organic materials. Seven samples have relatively high pH - values representing an alkaline type of water. The salinity values of groundwater samples are normal in most of the localities. However, sample No W_{13}/W_{15} showed relatively high value and this might be due to seepage of saltwater during high tide while W_{12} might be due to the use of pesticide in adjacent agriculture land. Discrepancy in the meq/L values of cations and anions is due to the very low values of $N0_3$ and $C0_3$ (<1%).

The values for $N0_3$ are extremely low and are beyond the detection limit of the instrument. The $C0_3$ on other hand is unstable in nature and converts to $C0_2$.

Twenty percent of the total samples (Table 4) show high concentration of calcium. The source of calcium most probably came from calcite found in the carbonate bed within in the Kudat formation. The concentrations of mangesium in most of the samples are normal except sample No W_8 that is located within the magnesium rich rock, viz. serpentinite.

The potassium concentration is low in most of the samples (< 10 ppm) except two samples that showed high concentration of potassium. The high potassium concentration is explained by presence of feldspars mica, and clay minerals that are present in the Kudat Formation.

Table 5. Results of analysis of ground Water Samples collected from the study area.

Sample No.	Temperature (°C)	pH	Salinity (ppt)	Ca (ppm)	K (ppm)	Mg (ppm)	Na (ppm)	Fe (ppm)
W1	27.5	5.90	–	–	–	–	–	–
W2	8.0	5.80	–	–	–	–	–	–
W3	29.0	4.65	–	–	–	–	–	–
W4	27.0	5.45	–	–	–	–	–	–
W5	28.0	6.12	0	–	–	–	–	–
W6	27.5	6.13	0	26.84	0.72	1.14	34.40	1.725
W7	28.0	5.90	0	16.49	1.38	0.92	30.60	1.274
W8	30.5	7.20	0	6.41	0.08	77.80	6.41	–
W9	32.0	6.98	0	625.60	2.45	20.40	50.20	0.003
W10	31.0	6.37	0	46.30	0.53	3.57	16.10	0.017
W11	28.0	6.99	0	111.80	1.19	14.40	30.00	–
W12	28.0	7.17	0.2	577.80	19.56	3.54	59.20	0.028
W13	28.0	7.30	0.01	577.40	0.85	3.82	31.40	0.028
W14	28.0	6.11	0	9.08	1.93	2.59	22.90	0.158
W15	28.0	6.85	0.1	80.40	5.61	11.00	204.00	0.010
W16	27.5	6.54	0	246.10	0.86	4.22	86.60	0.010
W17	28.0	6.30	0	37.17	1.16	1.90	18.00	0.777
W18	27.5	6.25	0	26.51	0.82	2.48	14.10	0.410
W19	27.5	5.95	0	25.41	1.73	1.46	20.60	4.083
W20	27.0	6.93	0	66.90	3.39	4.86	9.58	0.035
W21	28.0	6.17	0	21.97	1.23	1.90	15.80	0.926
W22	27.5	6.50	0	551.80	1.61	8.80	62.80	0.849
W23	28.5	6.90	0	294.80	1.23	21.70	95.10	0.005
W24	29.2	6.56	0	68.50	3.17	6.60	24.20	0.010
W25	28.0	6.35	0	26.28	1.90	3.29	8.94	2.761
W26	27.0	5.75	0	14.29	1.83	1.57	8.56	1.105
W27	28.0	5.95	0	18.67	2.73	34.00	183.60	7.440
W28	28.0	5.78	0	18.30	2.09	2.38	29.80	0.734
W29	30.0	7.15	0	71.00	0.54	1.48	5.15	0.026
W30	27.5	6.35	0	20.73	1.15	3.53	83.00	0.202
W31	29.5	6.55	0	42.08	1.12	3.06	44.40	0.263
W32	28.0	6.22	0	36.65	0.60	4.52	89.70	0.028
W33	28.5	7.25	0	44.60	13.59	1.11	17.80	0.045
W34	28.5	7.53	0.001	103.30	0.95	5.39	5.50	0.007
W35	28.0	7.35	0	85.50	0.95	2.84	2.62	0.005
W36	28.0	5.44	0	16.23	0.63	2.44	9.85	0.025
W37	27.0	6.62	0	18.02	0.40	22.80	32.20	0.030
W38	28.0	5.65	0	16.82	0.63	2.71	15.60	0.021
W39	28.0	7.15	0	–	–	–	–	–

– Not deducted

Table 6. Result of analysis of Water Samples for heavy metals in groundwater.

Sample No.	Cd (ppb)	Cr (ppm)	Cu (ppm)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)
W1	0.006	0.003	0.010	–	–	–	0.003
W2	–	0	0.003	–	–	–	0.002
W3	0.005	–	0.003	–	–	–	0.024
W4	0.005	–	–	–	–	–	0.023
W5	0.003	0.001	0.008	–	–	–	0.005
W6	0.003	0.002	0.002	0.030	–	–	0.024
W7	–	0.001	0.004	0.037	–	–	0.028
W8	0.003	0.003	0	0.005	–	–	0.006
W9	0.003	0.004	0.006	0.029	–	–	0.017
W10	0.001	0.002	0.001	0.071	–	–	0.323
W11	0.007	0.001	0.007	0.229	–	–	0.002
W12	0.006	0.002	0.005	0.316	0.007	–	0.164
W13	0.003	–	0.005	0.009	–	–	0.014
W14	0.005	–	0.003	0.014	–	–	0.043
W15	0.013	–	0.004	0.023	–	–	0.010
W16	0.005	–	0.002	0.160	–	–	0.017
W17	0.006	–	–	0.554	–	–	0.018
W18	0.004	–	–	0.217	–	–	0.007
W19	–	0.001	–	0.167	–	–	0.006
W20	–	–	–	0.005	–	–	0.005
W21	0.002	0.003	0.003	0.048	–	–	0.055
W22	0.002	–	0.001	0.363	–	–	0.001
W23	0.002	0.005	0.004	0.001	–	–	0.011
W24	–	–	0.003	0.070	–	–	0.025
W25	0.004	–	0.005	0.407	–	–	0.044
W26	0	–	0.005	0.147	–	–	0.017
W27	0.002	0.005	0.008	0.376	–	–	0.016
W28	–	–	0	0.039	–	–	0.021
W29	0.001	–	0.03	0.003	–	–	0.002
W30	–	0.003	–	0.149	–	–	0.392
W31	–	–	0.001	0.160	–	–	0.001
W32	0.006	–	0.002	0.407	–	–	0.013
W33	–	–	0	0.002	–	–	0.011
W34	–	0.005	0	0.011	–	–	0.011
W35	0.005	–	0.002	0.009	–	–	0.006
W36	0.003	–	–	0.011	–	–	0.014
W37	–	0.002	–	0.347	–	–	0.002
W38	0.001	–	0.004	0.009	–	–	0.004
W39	0.005	–	0.006	–	–	0.100	0.012

\- Not deducted

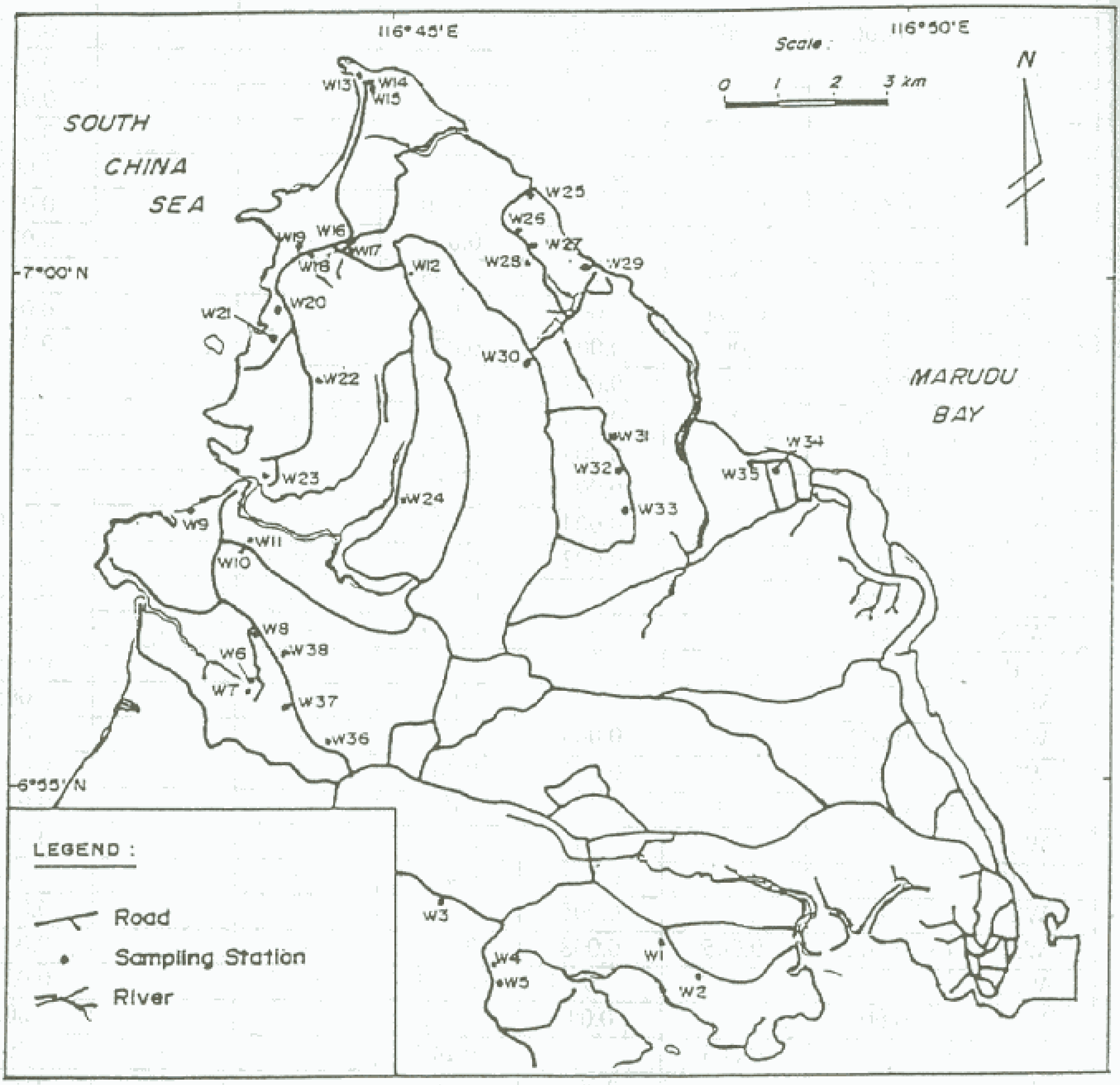

Figure 6 Ground Water Samples location Map

For sodium majority of the samples in the study area have normal values. Only six samples show higher values and they are represented by samples No W_{15}, W_{16}, W_{23}, W_{27}, W_{32}. The high concentration of Na (> 71 mg/L) might be due to the presence of albite, clay mineral, and halite that are common in the study area. Sea water intrusion or connate water could also account for high Na concentration.

About 25% of the total groundwater samples contain high Fe concentration ranging from 0.7—7.44 mg/L. This is explained by the presence of Fe - bearing pyroxene, magnetite or pyrite that are accessory components of the Kudat Formation. The source might be come from Fe-bearing oxides, carbonates and sulfide or sulfate minerals.

About 35% of the total samples have high concentration of manganese (Mn). This might be related original of the Kudat Formation which is a deep marine deposit.

About 15% of total samples (Table 6) show high values of Cd. This may be explain due to the effect of human activities rather the geologic since sedimentary rocks generally contain low values of Cd. Cu, Cr and Zn has low concentration (Table 5) whilst that of nickel (Ni) and lead (Pb) can not be detected in most of the samples. Relatively high concentration of Pb in sample No W_{39} might be due to water pollution from lead-bearing utensils from the neighbouring housing areas.

CONCLUSION

The result shows that the geologic setting of the study area has a major impact on the physical and chemical characteristic of groundwater and also indicate that the groundwater of North Kudat has evolved chemically through water - rock interaction. Low levels of environmental pollution were detected in the coastal aquifer and no saltwater intrusion is present within the study area.

In general groundwater quality in the study area depends upon the duration of contact with and the physical and chemical characteristics of its geologic environment.

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