BASELINE STUDY ON CHEMICAL COMPOSITION OF BRUNEI DARUSSALAM RIVERS

A thesis submitted for the degree of Doctor of Philosophy

by

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DEDICATED TO MY LOVING PARENTS, BELOVED WIFE AND MY SON,

MU'AZ ABDUL AZIZ

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بسم الله الرحمن الرحيم

IN THE NAME OF ALLAH, THE MOST BENEFICIENT AND MERCIFUL

ACKNOWLEGEMENT

Praise is only to Allah that I have been able to complete this research project successfully putting in a lot of hard work and obtain the necessary source materials. Initially, I was rather sceptical whether this field of research was relevant or viable at all. After extensive early exploration, investigation and urged by my local supervisor, I realised that the selected topic was not only relevant but also the research has not been done by any local researcher yet, as well as for the future and survival of Brunei Darussalam as an "Abode of Peace," the praise with which it is always associated.

Water pollution in Brunei, although not considered to be serious, needs to be addressed base on facts and figures and not on any generally held hypothesis. Based on this view only, I decided to launch on this line of research and I feel vindicated by the results of the research.

I wish to convey my profound sense of gratitude to my parents, (His Reverence, Pehin Dato Haji Abdul Aziz Juned and Datin Hajah Maznah Haji Muhammad), my parent's in-law and my wife, Hajah Rozana Haji Zainuddin, who have given me constant and untiring moral and material support to continue my education to the PhD research. Thanks are also due to my uncle - who has provided me with adequate information and source material, especially to my late brother, sisters and all of family in Brunei and Malaysia.

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My sincere thanks to all those who helped me in one-way or another to carry out the necessary research for this project.

My appreciation is also to the Ministry of Development - department under it, Ministry of Primary Resources and its various departments, Ministry of Health, Brunei Shell Company and other sources of relevance.

Lastly, thank to Allah, for bestowing me with the opportunity to undertake the course and courage and confidence to continue and complete my course of study. Without His divine guidance and blessings, my efforts would not have turned fruitful.

ABSTRACT

The research provides data of pH and conductivity, some anions (e.g. fluoride, chloride, bromide, nitrate, phosphate and sulphate), monovalent cations (e.g sodium, ammonium and potassium), divalent cations (e.g calcium and magnesium) heavy metals (e.g. iron, copper, zinc, nickel, cobalt, cadmium and manganese) and organic compounds – from water samples of rivers of Brunei Darussalam, namely, Brunei River, Belait River, Tutong River and Temburong River. The higher values of certain parameters with respect to the acceptable standard limits for river water indicate the pollution in river water samples of the study area, make the waters unsuitable for various applications and do pose a human health hazard.

The pH levels in Brunei Darussalam is quite reassuring and mostly safe. Although there are some stretches of rivers that show slightly lower levels of pH, there is no cause for any alarm as these waterways are not sources of drinking water. As for anions and cations, the only anion of significant levels detected in Brunei Rivers is chloride whereas only monovalent cation detected in significant levels, is sodium. The concentrations of chloride and sodium ions are below the standard concentrations. Brunei Rivers are still free from chloride and sodium pollution. For heavy metals, only iron is detected in Brunei Rivers.

Brunei being a oil based country experiments were done to identify levels of a numbers of significant toxic organic compounds, including, toluene and benzene which have been detected in the waters of the oil mining district of Belait District but are within normal limits.

The use of a photolytic cell system to achieve the photodegradation of benzene, toluene, ethylenediaminetetra-acetic acid (EDTA) and the surfactant – hexadecyltrimethyl-ammonium bromide ($C_{19}H_{42}NBr$) is reported. The system has been optimised by investigating the effects of the addition of hydrogen peroxide (H_2O_2) as an oxidant and

the addition of titanium dioxide (TiO_2) as a catalyst. The results show that the photolytic system can be used to achieve >99% degradation of organic contaminants.

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The research also includes a final chapter on management system which covers water protection, pollution control and solid waste management in Brunei. In addition to investigating various factors of the solid waste management in Brunei, the researcher has also exposed some of the weaknesses that need immediate addressing. Various measures have been suggested to make Brunei's water more efficient. Moreover, ways of preserving the high quality of Brunei's water figures in this chapter.

CHAPTER 1

THE IMPORTANCE OF WATER IN BRUNEI DARUSSALAM

1.1 INTRODUCTION

Water is an important resource for any country. It is used as potable water and for agricultural and industrial purposes. Maintenance of an adequate supply of water for these purposes involves both an understanding of the nature of the water resources in any country and the conservation of the resources. This is particularly true for a small country such as Brunei Darussalam. At the start of this research there was no reliable information on the chemical composition quality of the rivers and waters of Brunei Darussalam and no information on the extent of pollution of these waters [1].

The purpose of the research described in this thesis is to assess the quality of the waterways in Brunei, produce a water management plan for the country and to consider means of overcoming the most likely types of pollution arising from the major oil industry operation in the countries.

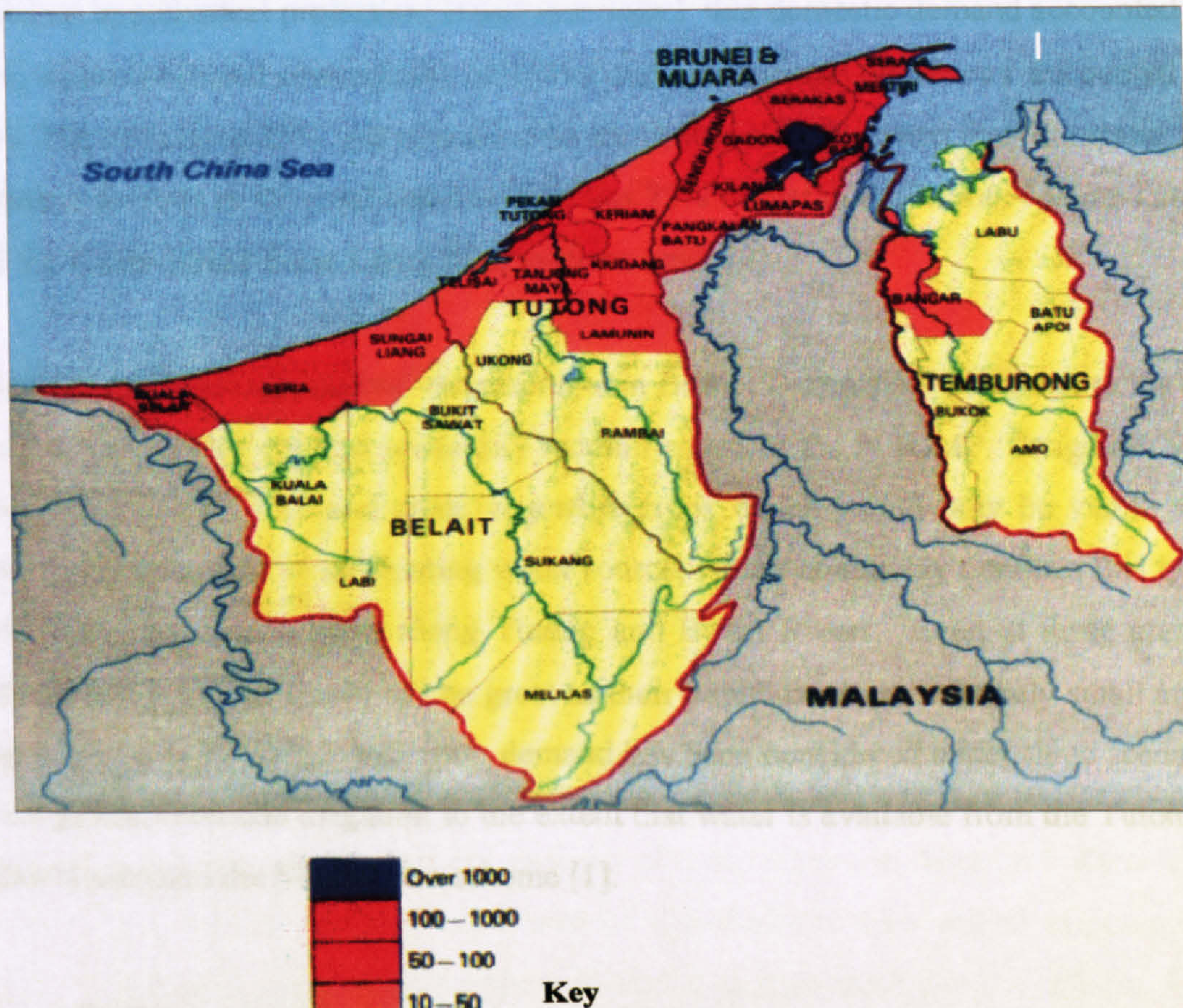
1.1.1 Importance of Rivers to Brunei Darussalam

Like most countries of the world, Brunei Darussalam Rivers are important for various purposes [1]. The rivers are the sources for:-

1. Transport to ferry the people of Kampung Air, the water village, to and from the town.
2. Main source of domestic and industrial water.
3. Moderate source for agricultural purposes.
4. A source for fishing.

1.1.2 Water Demand

The population projections used in this work were based on the growth rates derived from sectoral information compared with studies undertaken by the Negara Brunei Darussalam Master Plan (NBDMP) (Map 1.1). The NBDMP projections were based on the 1991 census data [2].



Map 1.1

The 1991 census showed that Brunei Darussalam had a population of 260 480 people. The Malays constitute 67%, Chinese 15.5% and others 11.5%. Infant mortality is amongst the lowest in the world.

These data indicated that the temporary population had increased at a greater rate than predicted, especially in the Brunei-Muara district. It was intended to obtain water consumption data from monthly meter summary reports, which would have given a sound database for analysis. Unfortunately they proved to be unavailable and it was necessary to obtain data direct from meter record books. The projected gross water demand for 1991 and 1992, when there was no restriction on supply, was very close to actual water consumption. Meter records from the other districts were examined to assess per capita consumption for comparison with the Brunei-Muara-Tutong system.

Based on hypothetical projection, it was concluded that domestic demand accounted for 50%, while combined commercial, industrial and institutional operations accounted for 25%. The remaining 25% was unaccounted for. It was also estimated that domestic that domestic demand in the rural communities was 75% of that in the Brunei-Maura-Tutong and the Kuala-Belait-Seria-Liang river systems areas [2].

It was assumed that agricultural development in Brunei Darussalam conforms to the types of agriculture based on land suitability recommended in the NBDMP. Irrigation would only be needed for rice and some vegetable crops which would only be viable where these are grown close to an existing water source, which effectively confines this type of agriculture to riverside areas along Tutong and Belait Rivers. Even in these areas the demand for irrigation would not be great as their populations are relatively small and the land is prone to flooding. Irrigation demand has been considered under three scenarios:- no irrigation, riverside irrigation to the extent that water is available from the Tutong and Belait Rivers and the Mulaut rice scheme [1].

1.1.3 Environmental Protection Agency (EPA)

The Environmental Protection Agency of the United States of America has published a compilation of its national recommended water quality criteria for 157 pollutants, developed pursuant to section 304(a) of the Clean Water Act (CWA) or the Act. These recommended criteria provide guidance for States and Tribes in adopting water quality standards under section 303(c) of the CWA [3]. Such standards are used in implementing a number of environmental programs, including setting discharge limits in National Pollutant Discharge Elimination System (NPDES) permits. These water quality criteria are not regulations and do not impose legally binding requirements on EPA, States, Tribes or the public.

Section 304(a) (1) of the Clean Water Act requires the EPA to develop and publish, and from time to time revise, criteria for water quality accurately reflecting the latest scientific knowledge [4]. Water quality criteria developed under section 304(a) are based solely on data and scientific judgments on the relationship between pollutant concentrations and environmental and human health effects. Section 304(a) criteria do not reflect consideration of economic impacts or the technological feasibility of meeting the chemical concentrations in ambient water. Section 304(a) criteria provide guidance to States and Tribes in adopting water quality standards that ultimately provide a basis for controlling discharges or releases of pollutants. The criteria also provide guidance to the EPA when promulgating federal regulations under section 303(c) when such action is necessary.

Table 1.1 below shows the EPA standards for some heavy metal ion, anions, cations and organics in water.

This introductory chapter is followed by a chapter describing the main water sources in Brunei (chapter 2), a chapter on the analysis of these waters to determine water quality (chapter 3), a chapter on the development of a method for the removal of potential oil industry pollutants from water (chapter 4) and a chapter describing a scheme for the management of the Brunei water resource (chapter 5).

TABLE 1.1

THE *EPA* STANDARDS FOR HEAVY METAL ION, ANIONS, MONOVALENT AND DIVALENT CATIONS AND ORGANICS IN WATER

	EPA Standards (mg/l)
pH	*6.5 – 8.5*
Heavy Metal Ion	
Iron (Fe^{2+})	*0.3*
Copper (Cu^{2+})	*1.3*
Nickel (Ni^{2+})	*0.04*
Zinc (Zn^{2+})	*5.0*
Cobalt (Co^{2+})	*0.02*
Cadmium (Cd^{2+})	*0.005*
Manganese (Mn^{2+})	*0.05*
Anions	
Fluoride (F^-)	*2.0-4.0*
Chloride (Cl^-)	*250*
Bromide (Br^-)	*NA*
Nitrate (NO_3^-)	*10*
Phosphate (PO_4^{3-})	*NA*
Sulphate (SO_4^{2-})	*250*
Mono&Divalent Cations	
Sodium (Na^+)	*28*
Ammonium (NH_4^+)	*0.01*
Potassium (K^+)	*NA*
Magnesium (Mg^{2+})	*NA*
Calcium (Ca^{2+})	*NA*
Organics	
Benzene (C_6H_6)	*0.005*
Toluene (C_7H_8)	*1*
Ethylenediaminetetra-acetic Acid (EDTA)	*NA*
Hexadecyltrimethyl-ammonium bromide ($C_{19}H_{42}NBr$)	*NA*

1.2 SAMPLING PROTOCOL (STANDARD)

The water quality sampling protocols and standards provides a resource for local community groups to develop water quality monitoring protocols that follow International, National and State standards. Protocols refer to procedural processes that should be followed for developing and undertaking a monitoring and reporting program. Standard refer to the International and National standards that should be applied when developing new protocols to ensure uniformity consistency of methodologies and values for water quality measurement [5].

Water quality monitoring may be carried out for a number of different reasons and the data collected will have different uses and different levels of data confidence associated with it [6]. The water quality guidelines provide additional practical and scientific information for applying national and regional guidelines to local site specific applications. The main objective of the water quality guidelines is to provide an over arching national resource to the current scientific advice for the development of site specific water quality monitoring and management at the local and regional scale [7].

The water quality guidelines also set national default trigger values for water quality relating to a range of environmental values that can be applied in the absence of verifiable local water quality data. The only way to develop representative guidelines for specific sites is undertake long term monitoring. There are many sites that do not fall strictly within these guidelines due to site specific variation and local conditions. This must be kept in mind when applying these general guidelines. The default trigger levels provide a broad scale, risk based assessment of environmental condition and is a starting point for water resource managers to refine these guidelines and develop more site specific guidelines at a local scale based on sound local knowledge and long term water resource data. Parameters that fall outside the guidelines indicate that there is a high risk of causing environmental harm if these levels are sustained and indicate that further site specific investigations should be conducted to determine the level of risk using more detailed site specific information [7].

1.2.1 Protocols for water sample collection, transport and storage

Where at all possible water quality measurements should be made *in situ* and in a site location that is representative of the conditions at the sampling site [5-8].

Equipment:-

- Sample bottles types – Sample bottles have colour coded labels for specific types of water quality analysis and testing.
- Extra bottles, syringes and filters should be carried in the field. In particular extra filters are often required for samples of elevated turbidity. Maintain a good supply of filters, syringes and bottles that can be used as spares or if there is a problem with availability.
- A sampling pole can be made from an aluminium pool net pole or wooden handle with a large clamp or bicycle water bottle holder attached to the end. The sample bottle can be secured on the end of the pole and will to allow greater reach to sample from the main flow of large creeks and rivers.

General rules:-

- Complete label details with waterproof pen before collecting sample.
- Wear disposable vinyl gloves if possible.
- Use laboratory supplied single use sample containers unless instructed by laboratory to do otherwise. Do not reuse or use previously opened bottles.
- Do not touch or contaminate any part of the bottle that will come into contact with the sample (i.e. inside of lids or mouth of sample bottle).
- Collect sample directly into sample container if possible. If not, collect in a sampling beaker (rinse out twice with water to be sampled) and transfer immediately to the sample container.
- If the bottle contains a preservative do not over fill the bottle as preservative may be diluted or lost.
- Collect sample in an open channel sample where the flow is greatest. Invert the bottle and lower until the mouth of the bottle is 10cm below the surface but

ensure that it does not pick up any settled solids from the base of the channel. Take sample by facing the mouth of the bottle upstream and turn the bottle upright until it fills.

- Keep your hand downstream and/or out of the flow as much as possible.
- Take spare bottles
- Document sampling site by GPS coordinates, detailed description, photo etc. Field notes must accurately describe where samples were collected, to allow cross-checking with the sampling locations.
- Fill in the field data sheets, describe the sample taken, their labels and all other variables measured prior to leaving a sampling site. It is particularly important to record comments on sampling conditions and recent weather and flow conditions as these will directly influence water quality.
- Bottles containing general ions, heavy metals and bacteriological samples should be filled completely.
- Do not fill nutrient bottles to the top allow room for expansion when frozen.
- Immediately after collection all samples are to be placed in an eski with an adequate supply of ice bricks for cooling.
- Do not smoke during operations
- Do not rinse sample bottle with waters to be sampled unless specified to do so by the laboratory.
- Do not risk loss of preservatives by overfilling containers.

1.2.2 Offshore Sampling

Carefully wade out into the river until the flowing portion of the water is comfortably within arm's reach. Do not enter the water above the waist, and do not enter the water if there is any concern for the safety. Be sure to have someone on shore that knows where you are.

Position yourself facing upstream and rinse the bucket in the river three times. Do not collect the water that is running over your legs/boots. With the bucket facing upstream and held along side your body, slowly dip the lip of the bucket into the flowing water and allow the bucket to fill.

Carefully return to shore with the bucket ½ - ¾ full and place it on the bank for immediate analysis. If collecting samples for laboratory analysis, wade out into the river and collect water in a sterilized E.coli bottle and transfer the water to shore in a labelled and prepared bottle. Preserve them properly (in a cooler on ice), and submit the samples to the laboratory within the sample holding time appropriate to each test.

1.2.3 Bridge Sampling

Lower the bucket from the upstream side of the bridge to the river and gather some water (doesn't have to be full). Pull the bucket up, swish the water around in the bucket to rinse and dump the water off the bridge. Repeat this process two more times. Return the bucket to the river on the upstream side of the bridge and fill as slowly as possible (you may wish to weight the bucket). Pull the bucket up and carry to a safe location (away from the road) for analyses.

1.2.4 pH Meters

If it is not analysing for turbidity, rinse the plastic container marked "sample" with deionised water. Rinse twice with a small amount of river water from the bucket. Pour sample water from the bucket into the plastic "sample" container slowly to avoid adding bubbles to the sample:-

- Make sure the probe is stored in the wetting cap and that there is a small amount of water in it. Do not use distilled water in the wetting cap. Use the manufacturers storage solution in the wetting cap for long term storage of the probe.
- Calibration should be conducted using a 2 point calibration procedure using two buffered standards in the pH range of normal field measurements.

1.2.5 Electrical Conductivity Meters

In the absence of a dedicated temperature probe or thermometer it is a national convention to record the field temperature from the conductivity meter.

1.3 REFERENCES

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CHAPTER 2

DESCRIPTION OF BRUNEI DARUSSALAM

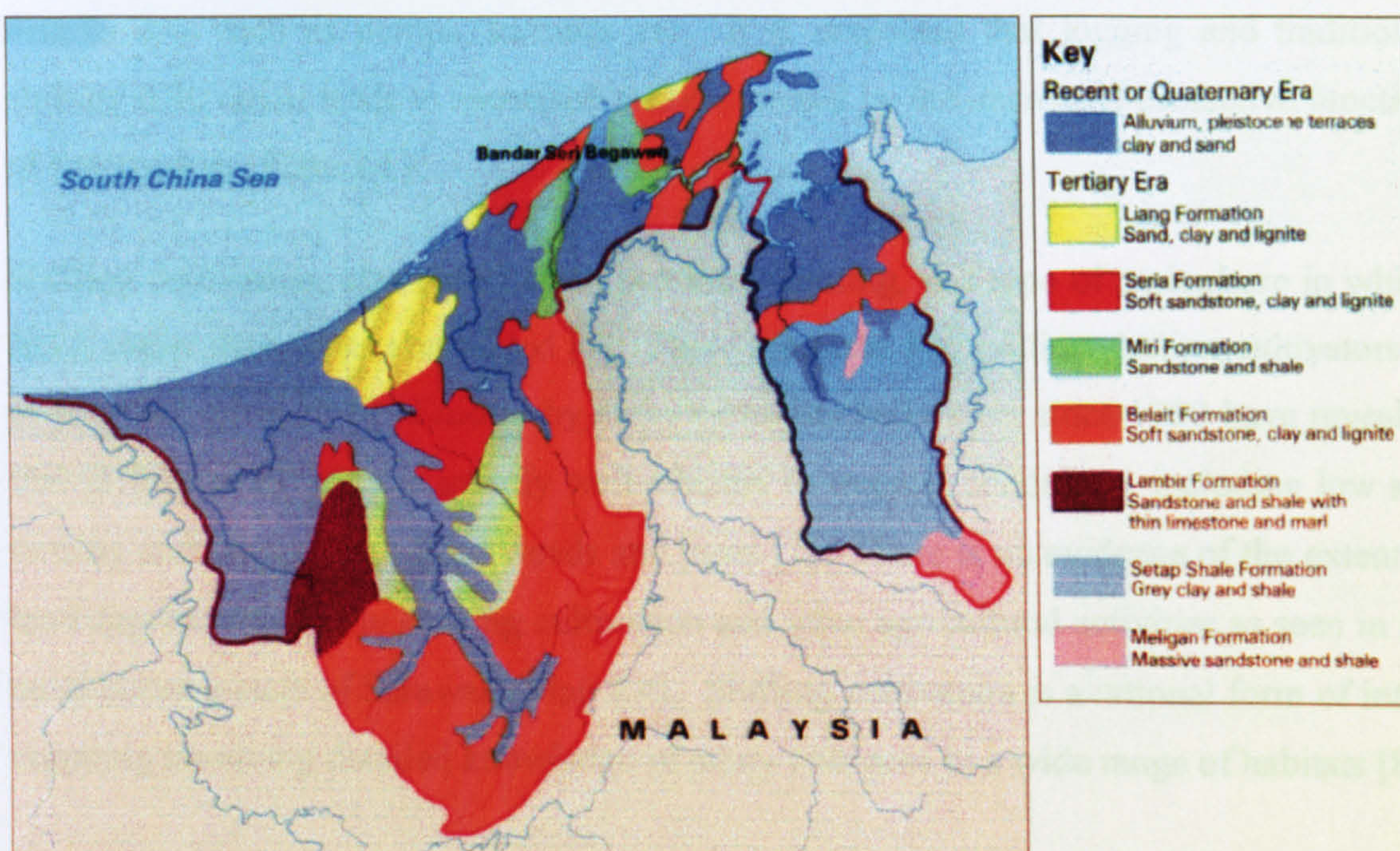
2.1 INTRODUCTION

Brunei Darussalam is relatively a small country situated in South-east Asia, bordering the South China Sea and Malaysia (Map 2.1). It is geologically young and dominated by sedimentary and igneous rocks [1]. Tertiary rocks and structures common to the Sarawak-Brunei Tertiary basin occur in the Crocker Range where, however, these rock formations move eastwards to become ultra basic ingenious rocks. The sedimentary rocks are of Tertiary age and consist mainly of thick layers of sandstone, siltstone, mudstone and shale. The age of the shale and mudstone in the Crocker Range is from Eocene to Lower Miocene, whereas the rocks date back to the Upper Eocene period. Igneous rocks are restricted to the Trusmadi Mountains. The Tambunan plain consists of clay, sand, coarse gravel and boulders, which appear to have been derived from the Crocker Range. The valleys draining from these mountains are thus partly filled with highly erosive alluvium. Weathering processes are still actively occurring and in areas where river channels cut through the alluvium, very high rates of dissolved sediments can be expected (Map 2.2).

2.1.1 Climate

The climate of Brunei Darussalam is equatorial, that is, relatively uniform temperatures in the range 23°C to 28°C with high humidity (80-85%) and abundant rainfall. Precipitation quantity and intensity varies greatly due to orographic effects of the mountain ranges on both sides of the flood plain from less than 2000mm per year in the flood plain to more than 4000mm per year in the mountain range and coastal belt [2]. Tropical rainforest occurs in the humid tropics. Even within the humid or so-called ever-wet tropics, however, there are periods of water stress of varying duration and now it is recognized that such conditions play an important role in plant and animal life and in distribution of forest types [3].

Map 2.1
Location Map of Brunei Darussalam



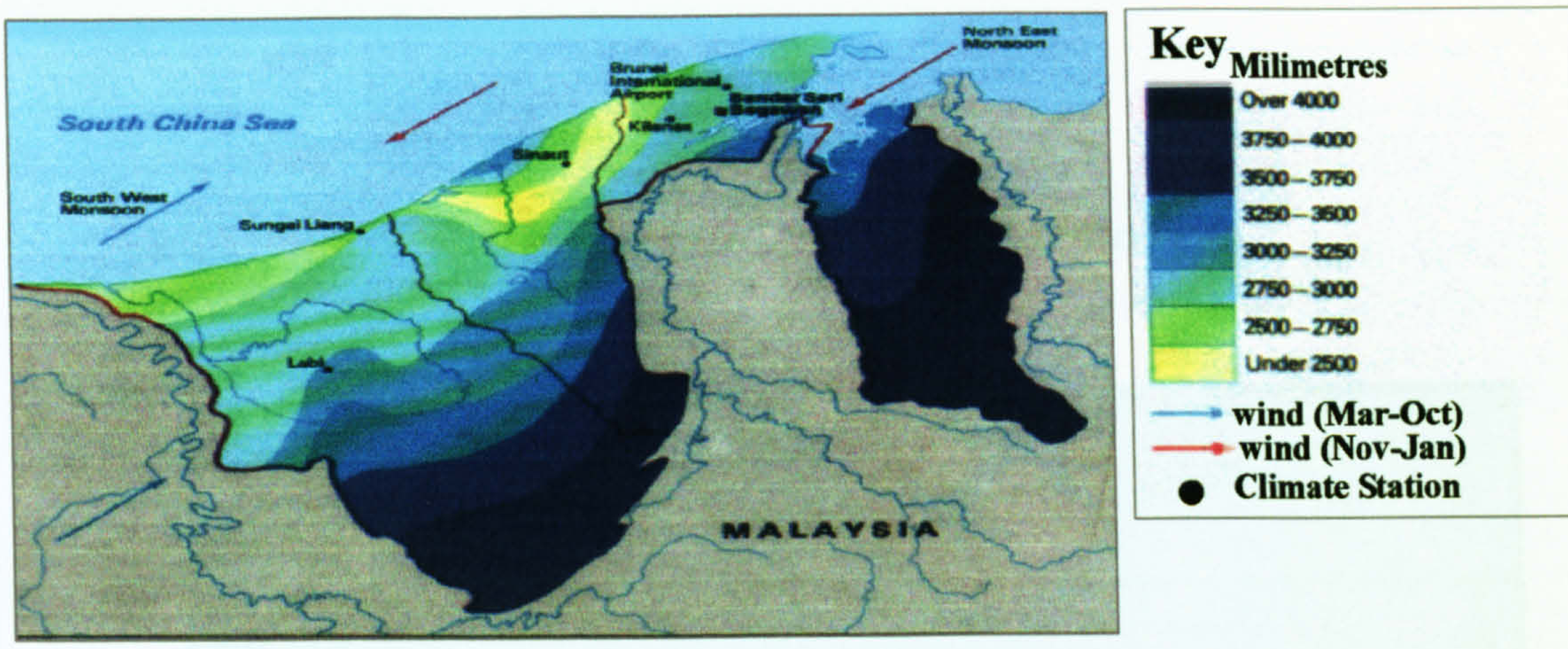
Map 2.2
Brunei Darussalams' oldest rocks occur in the Temburong Highlands, whilst the youngest are found along the coast and river valleys.

Rainfall is mainly caused by convection, which causes air masses to rise along the mountain range until water vapour is condensed into water droplets. No continuously collected data on spatial variability of rainfall is available for the Crocker Range area. The dominant influences on the climate are the northeast monsoon from November to March and the southwest monsoon between May and September. (Map 2.3)

High rainfall in the Crocker Range is drained into the flood plain. Sediments eroded from the geologically young catchments originate from riverbank erosion. Erosion can be substantial at high discharge rates during the wet seasons (Table 2.1 and Figure 2.1), and depends on the land use type within the catchments. Suspended matter in rivers poses a severe problem for organic life (eg. coral reefs in the coastal zone near the river outlet) and in aquatic environments by reducing the solar radiation needed for photosynthesis. Sediments may also damage fishery operations. Finally, the stream capacity of the rivers can be reduced due to sedimentation and this may cause mechanical damage to installations such as pumps, turbines etc. It is suspected that logging and traditional shifting cultivation leads to increased erosion caused by the decreased protective function of forest cover (Plate 2.1).

Shifting cultivation, also called slash and burn farming, is a type of agriculture in which fields rather than crops are rotated [4]. There are some 140 million shifting cultivators in tropical countries [5-6]. Studies by anthropologists and others since 1950 have revealed that shifting cultivation is usually well adapted to tropical conditions, including low soil fertility and competition from weeds and pests [7]. There is no evidence of the extent of land degradation due to shifting cultivation and other agricultural activities as seen in the neighbouring state of Sarawak (Map 2.4). Shifting cultivation is a rational form of inter-cropping involving detailed knowledge of many cultigens in a wide range of habitats [8].

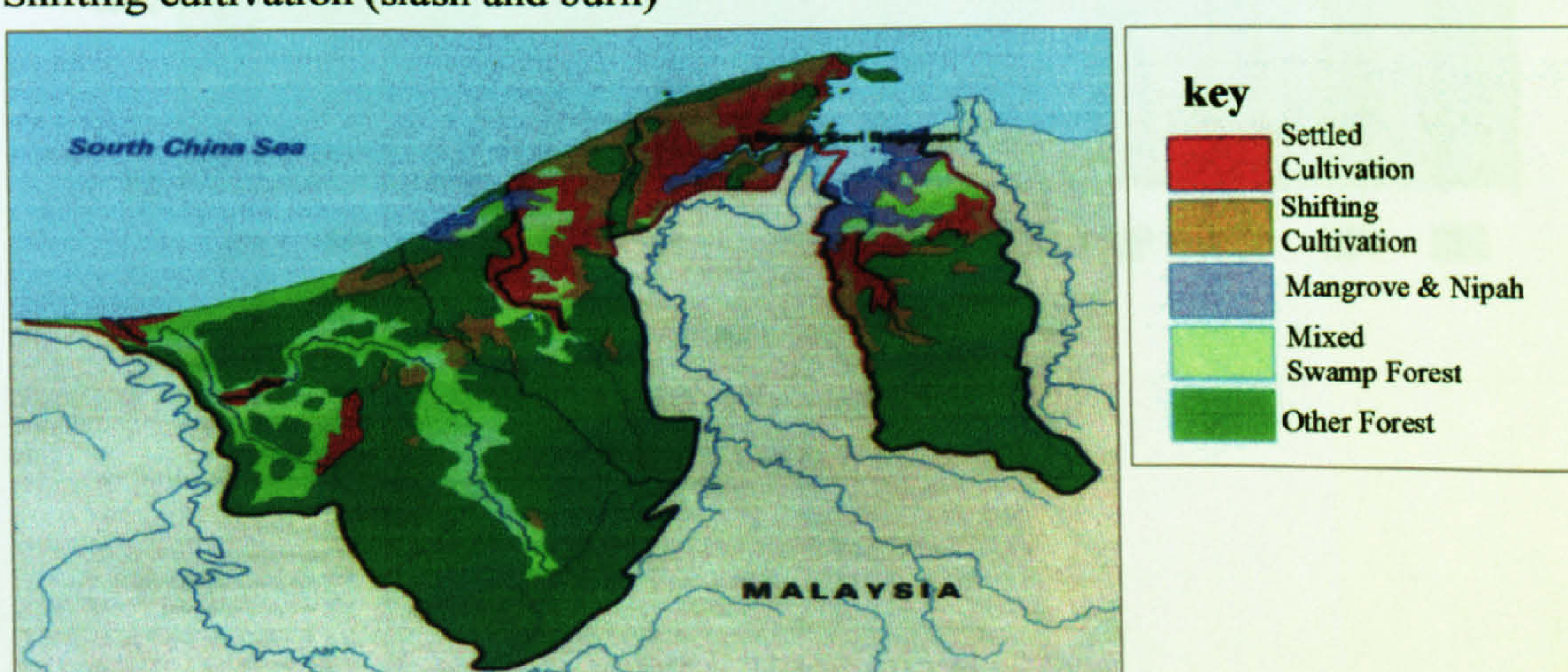
Roughly 12% of Sabah (0.98 million ha) and 18% of Sarawak (2.24 million ha) were being utilized for shifting cultivation in the mid 1960s [9]. The trend is increasing with 19% of Sabah and 26% of Sarawak coming under shifting cultivation [10]. Such a vast area of shifting cultivation may not be true of Brunei but it is very much a continuing practice.



Map 2.3 - Climate

Brunei Darussalam has a equatorial climate with warm temperatures, high humidity and high rainfall. Rainfall varies between 2200mm on the coast to more than 4000mm over the Temburong Highlands. The main wet season is from November to January when the North East Monsoon wind blows.

Plate 2.1
Shifting cultivation (slash and burn)



Map 2.4 - Vegetation

Tropical evergreen rain forest covers approximately 81% of the total land area. Man's influence in the form of fire, timber extraction and the introduction of grazing animals has greatly influenced Brunei Darussalam's.

Figure 2.1
Monthly Rainfall for 2001
Station: Brunei International Airport

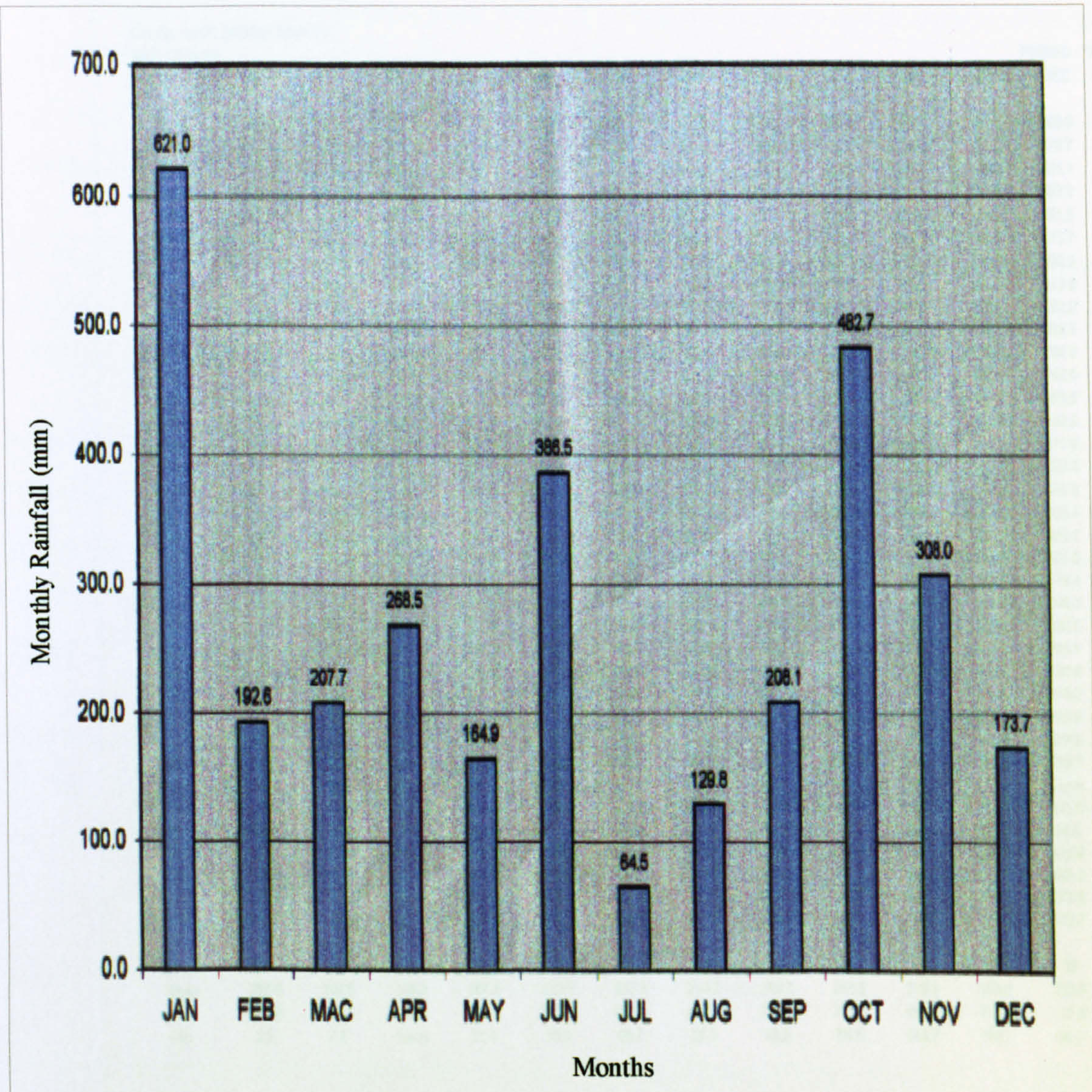


Table 2.1
Monthly and Annual Precipitation Totals

STN. No. 96315 BRUNEI AIRPORT
UNIT: millimetre

PERIOD : 1966 - 2001

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
1966	109.4	77.4	215.5	222.3	229.9	227.2	172.8	328.4	326.9	429.2	253.1	308.9	2901.0
1967	326.9	144.2	308.1	207.6	182.7	324.6	102.5	116.6	235.5	316.8	303.3	378.7	2947.5
1968	264.0	54.6	55.1	99.8	350.0	244.4	265.2	140.1	184.5	241.4	146.2	405.1	2450.4
1969	107.9	21.3	120.1	121.3	189.3	175.1	200.3	256.1	98.7	224.1	387.6	393.6	2295.4
1970	295.4	7.6	163.7	51.0	471.8	95.4	131.2	87.3	333.2	432.7	314.2	281.5	2665.0
1971	161.4	345.9	246.9	110.4	198.5	123.1	164.7	358.4	159.1	315.5	341.1	415.7	2940.7
1972	476.2	201.5	102.3	160.2	142.4	122.3	47.2	108.4	200.0	275.8	394.2	200.3	2452.8
1973	2.0	49.0	89.1	337.1	271.3	269.5	187.8	420.6	386.3	369.3	438.6	313.9	3134.5
1974	479.2	270.6	251.5	172.1	180.5	175.1	262.4	301.0	339.3	187.8	242.1	263.5	3125.1
1975	291.9	63.5	136.3	52.5	173.1	214.5	207.1	298.0	479.9	144.7	402.8	389.3	2853.6
1976	626.9	246.0	37.6	105.8	169.0	124.6	100.0	123.6	84.5	379.2	278.2	228.9	2506.3
1977	559.6	241.1	336.0	121.1	95.2	280.7	279.9	150.3	104.1	328.2	490.6	240.6	3227.4
1978	74.6	34.5	111.7	117.3	304.3	128.9	245.6	81.2	327.1	198.0	260.6	363.5	2247.3
1979	72.3	78.4	77.9	107.4	203.5	627.9	355.8	157.4	353.5	408.1	391.0	290.9	3124.1
1980	304.0	58.8	56.0	250.7	163.6	312.0	303.3	381.9	174.3	411.0	197.6	715.6	3328.8
1981	575.2	443.1	153.9	97.2	256.3	178.6	314.0	34.0	469.4	336.9	515.1	320.4	3694.1
1982	363.0	91.7	114.2	445.8	263.3	146.8	135.2	157.4	114.5	308.2	224.0	695.0	3059.1
1983	249.8	12.8	10.7	81.5	172.1	115.7	453.5	176.6	721.9	272.7	382.0	528.4	3177.5
1984	487.9	259.4	68.2	300.9	522.2	126.7	417.9	88.4	289.9	353.2	360.3	355.1	3630.1
1985	305.5	137.8	72.7	263.5	285.8	87.6	172.3	18.0	244.1	381.4	284.0	521.2	2773.9
1986	305.2	113.3	120.6	180.1	68.3	279.0	72.6	265.2	172.3	372.1	398.8	174.4	2521.9
1987	24.8	131.3	33.5	59.8	273.4	288.2	199.1	360.9	142.0	250.7	388.2	249.3	2401.2
1988	277.1	220.1	220.0	203.5	219.6	165.5	301.1	468.0	356.4	201.3	486.2	280.5	3399.3
1989	151.4	300.9	186.4	193.9	201.6	168.7	78.8	80.2	344.4	272.1	462.7	245.1	2686.2
1990	387.8	0.6	112.1	293.9	197.8	183.6	161.0	46.3	186.8	185.8	276.3	120.8	2153.0
1991	71.7	53.2	46.1	302.5	287.4	215.9	69.2	110.3	233.3	391.7	177.1	279.0	2237.4
1992	201.8	20.6	3.1	119.8	387.8	269.9	247.3	85.4	116.3	311.5	305.6	250.9	2320.0
1993	28.8	52.0	20.3	191.8	329.7	190.4	472.0	71.2	177.8	287.5	410.0	320.6	2552.1
1994	358.2	67.3	121.5	257.4	158.9	178.5	94.8	397.3	136.0	279.0	288.5	316.1	2653.5
1995	179.1	90.0	184.6	83.5	209.6	204.6	364.7	451.0	212.1	257.2	313.5	513.0	3062.9
1996	503.5	200.6	112.8	288.2	274.4	170.4	252.9	295.0	168.1	396.0	317.5	315.5	3294.9
1997	241.2	248.0	7.0	141.7	523.6	189.6	294.7	63.5	273.9	351.3	486.1	94.5	2917.1
1998	8.0	21.0	Trace	114.8	59.0	235.2	373.2	711.9	307.7	252.1	230.7	531.4	2845.0
1999	469.8	348.3	169.2	191.8	323.1	68.7	126.3	196.3	307.7	580.7	197.3	380.3	3359.5
2000	209.8	303.8	149.6	316.0	132.6	461.5	21.3	339.1	348.3	309.9	252.8	273.6	3118.3
2001	621.0	192.6	207.7	268.5	164.9	386.5	64.5	129.8	208.1	482.7	308	173.7	3208.0
Months	36	36	35	36	36	36	36	36	36	36	36	36	36
Mean	282.6	144.6	126.3	184.8	239.9	215.5	214.2	218.2	258.8	319.3	330.8	336.9	2868.5
Max	626.9	443.1	336.0	445.8	523.6	627.9	472.0	711.9	721.9	580.7	515.1	715.6	3694.1
Min	2.0	0.6	Trace	51.0	59.0	68.7	21.3	18.0	84.5	144.7	146.2	94.5	2153.0

Some parts of Brunei have long shown signs of abuse by shifting cultivators [9] in terms of the extensive tracts of "belukar" (secondary forest) in Brunei and the grasshopper-infested hillsides of Sabah and Sarawak [11,12]. Heavy rainfall in the devegetated areas would cause severe rain splash erosion; the high runoffs can cause severe gully erosion and sedimentation combined with deep chemical weathering occurs because of alternating rain and sunshine.

Some argue on the basis of local field experience, however, that vegetation recovers within a very short period of time after the cultivators move, thereby effectively offsetting part of this process [1].

Brunei's climate is characterized by high rainfall and temperature throughout the year. The total rainfall was 2654mm in 1994. There are two rainy seasons; from September to January and May to July. The average precipitation in the nearby city of Kota Kinabalu (Sabah, Malaysia) is 2691mm and this could be considered as a reasonable estimate for the average precipitation in Brunei.

The temperature is relatively uniform throughout the year, with an annual average of 27.9°C, ranging from 23.8 to 32.1°C. The drought months of March and April are the warmest. Due to high temperature and rainfall, humidity is high throughout the year with an average of 82%. (Map 2.3).

2.1.2 Activities and Sources that pollute the Brunei Rivers

Some of the potential environmental problems in Brunei Darussalam are minor, on which there are very little data. For this reason, this section deals with the more serious issues. Much of the Primary Forest lands are still intact and there is no serious contribution from forest fires causing any potential damage to the chemical composition of the rivers (Plate 2.2). Industrialization, improvements in transportation and the steeply rising demands for products like tropical hardwoods and palm oil in the metropolitan or core regions have all contributed to the widespread tropical deforestation since the nineteenth century [13,14].

The potential and major source of sea pollution is from the offshore and on-shore oil exploration and production (Plates 2.3.1 and 2.3.2). Under normal conditions, oil seepage out of the ocean floor may take place but the ocean system is capable of absorbing and cleaning it. However, the potential of pollution is real in cases of accidents (Plates 2.4.1 and 2.4.2). Two such accidents happened as oil blow-outs in 1981 and 1984 resulting in the contamination of shoreline and some rivers of Brunei [1].

Another major environmental problem is a manifestation since 1971, along Brunei coast and rivers of the red tide phenomenon brought about by the *dinoflagellate pyrodinium bahamense var. sompressum* species. This species produces a highly poisonous toxin that is not dangerous to shellfish but to humans if the shellfish are later consumed. There were two major outbreaks in 1980 and 1989 and from the 90's it has become an annual event (Plates 2.5.1, 2.5.2 and 2.5.3) of varying intensity [1].

A more serious water pollution problem is that which is found in Brunei River which is home to nearly 100,000 people. These people live in houses on the water called '*Kampung Air*' (the **Water Village**). The garbage, kitchen toilet and bathroom refuse are dumped straight into the river water. Organic waste discharged into the Brunei River per household per day amounts to 2.83 kg or 2.85 million kg for the whole settlement per year. (Plates 2.6.1, 2.6.2 and 2.6.3)

2.1.3 Location and Hydrology of River Systems in Brunei Darussalam

There are four main river basins in Brunei: **Belait, Temburong, Tutong and Brunei Rivers**. The drainage basins of these rivers cover a catchment area of 5765km^2, approximately 75% of the country's land area (Map 2.5). The four rivers affect the quality of coastal waters. The Belait and the Tutong Rivers discharge into the South China Sea while the Brunei and the Temburong Rivers drain into the Brunei estuary leading to Brunei Bay.

The **Belait** is the longest river and has a catchment area of about 2700km^2. The lower catchment comprises an extensive area of peat swamp forest. The river narrows at the town of Kuala Belait and a sandbar restricts the discharge of water to the South China Sea. Some areas in the upper catchment have been cleared for agriculture.

The drainage basin of **Temburong**, cover a catchment area of about 1000km^2.

The **Tutong** basin, which has a catchment area of about 1300km^2, has a complex estuary system formed between two sandspits. It is subject to fairly high tidal influence and its lower catchment is mainly floodplain. The upper catchment is jungle with patches of agriculture.

The **Brunei** is the smallest river has a catchments area of about 765km^2. The upper reaches of the river are a major freshwater source, particularly for the western part of the country.

By analogy with the rest of the island of Borneo, the runoff coefficient is estimated at 1.5 m/year corresponding to a surface flow of 8.5 m/year. Limited reserves of ground water have been identified in the Liang River and Seria areas of the Belait District and in Berakas area of the Brunei-Muara District. The estimated safe yield is 17.3million m^3/year. Also by analogy with the rest of the island of Borneo, the total groundwater resources are estimated at 0.1 km^3/year, all being drained by the rivers. Not all the rainfall over the forest reaches the ground, some is intercepted by foliage and subsequently evaporated [15]. Rain that does reach the ground percolates or flows laterally through the soil horizons. Dense evergreen forests intercept a surprising quantity of rain. Estimates and measurements of interception loss for lowland green rainforest of Peninsular Malaysia and Sarawak range from 21.8% to 36.0% [16-18].

The same can be said for the forests of Brunei Darussalam, as its forests are simply an extension of Sarawak itself, only divided by political boundaries. Leaf litter also intercepts rainfall but no statistics are available on this. These interceptions do not allow much of the water to reach the river system thereby there is no substantial contribution of sediments or nutrients from the rapid runoff from land after rainfall in Brunei Darussalam. Volumes of surface wash collected were found to be closely related to the thickness and completeness of the litter cover [19,20].

Plate 2.2
More than 80 percent of Brunei is covered by forest, a higher percentage than any other nation. Vegetation ranges from mangrove along the edge of coastal waterways to thick champs of rainforest than shroud inland mountains.

Plate 2.3.1
Brunei Shell Oil Platform - Offshore

Plate 2.3.2
Brunei Shell - Onshore

Plate 2.4.1
Fire in Rasau.

Plate 2.4.2
A view of fire accident in Rasau

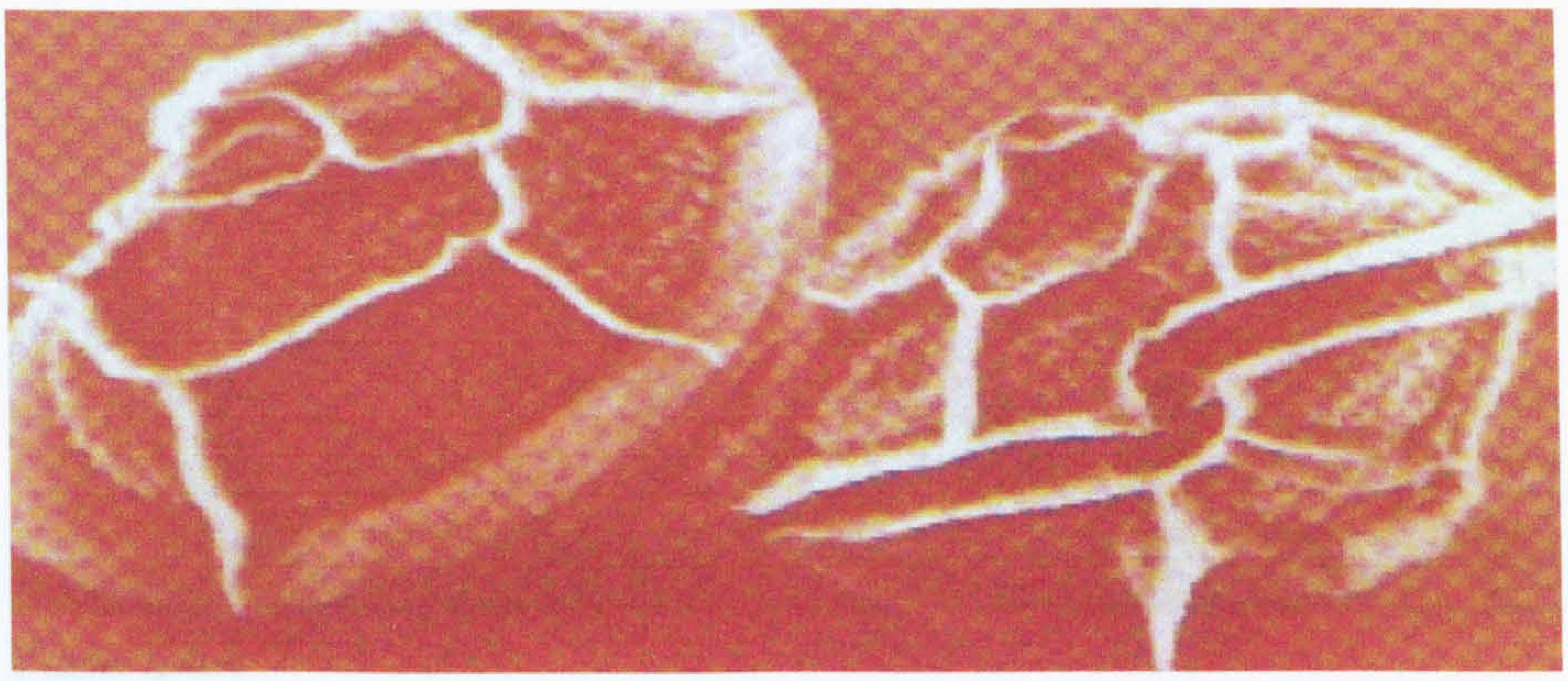


Plate 2.5.1
Red Tide Algae Cells - pyrodinium Bahamense var. compressum.

Plate 2.5.2
In South African Coastal Town of Elands Bay, 1 000 tonnes of Cape Rock Lobster stranded on the shore after a "red tide". (Singapore Straits Times - 05.03.2002).

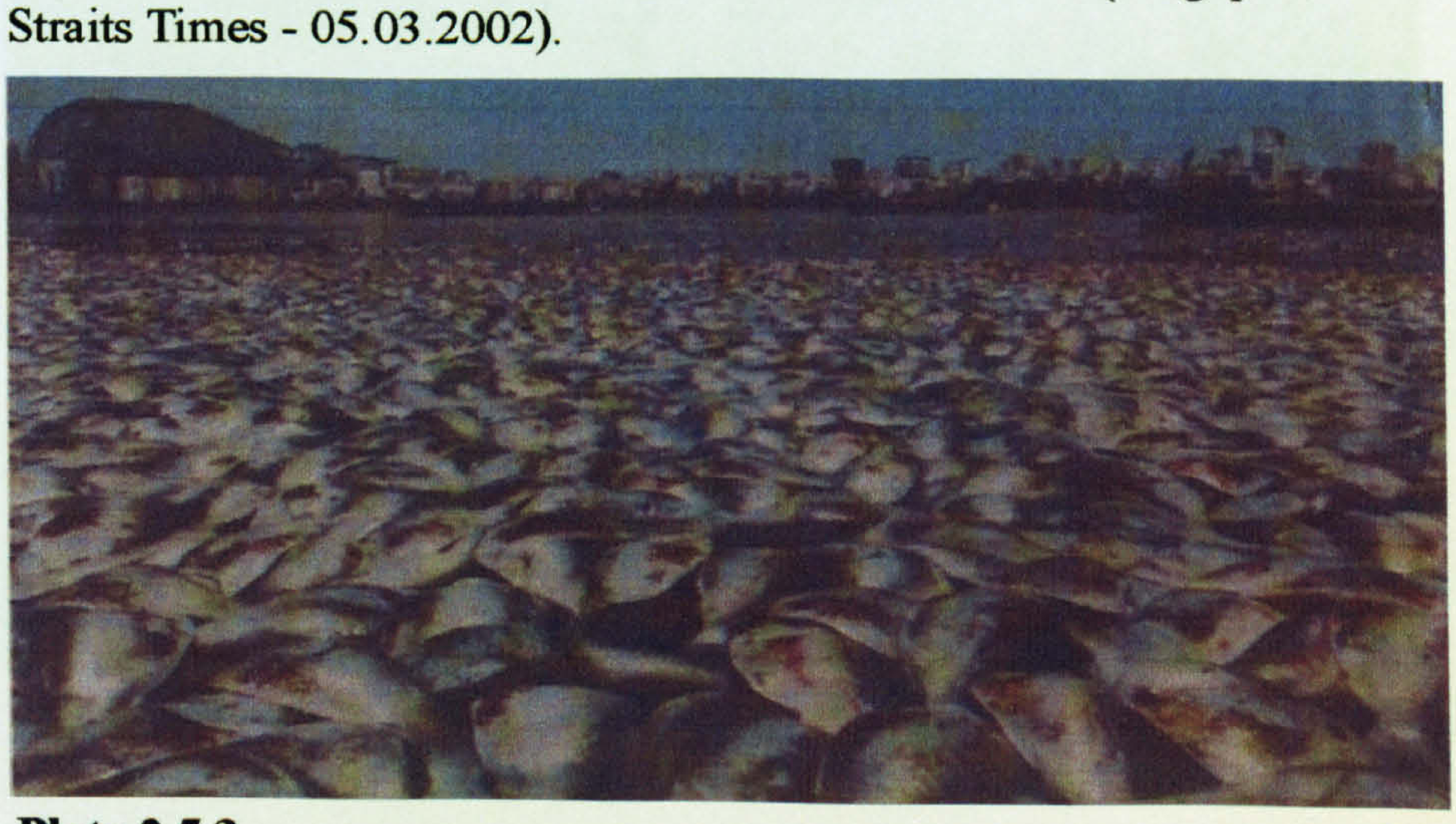


Plate 2.5.3
Dead fish covering the shore of the Rodrigo de Freitas lagoon in Rio de Janeiro, caused by leaking sewer. (The Straits Times - 08.03.2002)

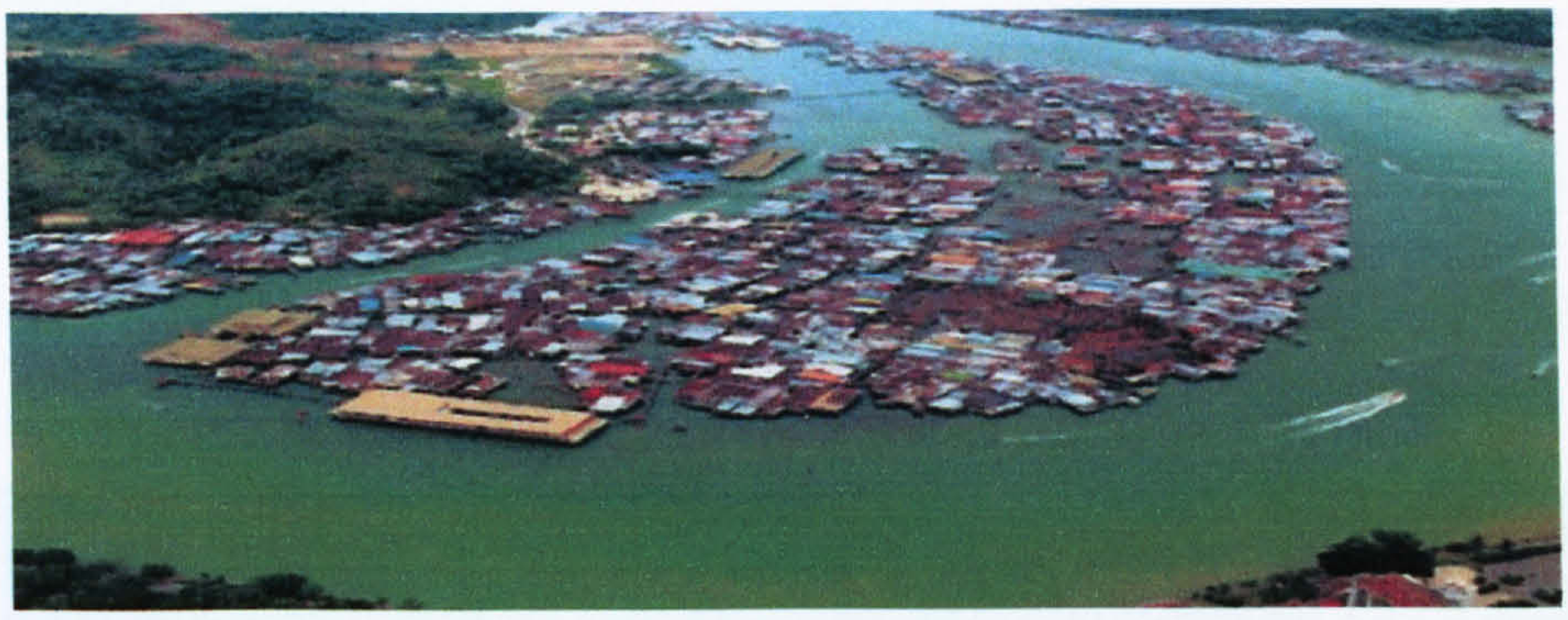


Plate 2.6.1
A general view of Kampung Air - Water Village.

Plate 2.6.2
The roof tops from the wooden houses in water village which is made from zinc and the stilt made from concrete or iron bars.

Plate 2.6.3
A closer view of stilt concrete.

Map 2.5
The districts of Brunei are Brunei-Muara, Temburong, Tutong and Belait

The full details of the hydrology of the four main rivers in Brunei Darussalam are shown in Table 2.2 below:

TABLE 2.2

RIVER	AREA (km^2)	LENGTH (km)
Belait	2,700	209
Tutong	1,300	137
Temburong	1,000	98
Brunei	765	41

2.1.4 Lakes and Dams

Brunei has two dams with a total storage capacity of 45 million m^3. The Tasik reservoir is used for water supply. It has a total capacity of 13 thousand m^3 and a catchments area of 2.8km^2. The Benutan dam, an impounded reservoir, is used to regulate the Tutong river and has a total storage capacity of 45 million m^3 and a catchment area of 28.6km^2.

At present there is no hydropower dam though one suitable site has been located within the National Forest Reserve of Temburong.

2.1.5 Water withdrawal

In 1994, the total water abstraction was estimated at 92 million m^3. The urban water supply is entirely derived from surface water. The major use of water in industrial processes is for the liquefied natural gas industry, which abstracts and treats its own water from the Belait River. Other industrial uses are on a smaller scale for example the sawmill industry, dairy farming, soft-drink manufacture and workshops, which account for an estimated 25% of the overall water demand.

Initially, groundwater abstraction was undertaken in the 1950s for use by the oil and gas industries. This has been replaced by surface water sources. Groundwater abstraction, which accounts for 0.5% of the total water supply, is currently limited to the local bottled water industry.

2.1.6 Irrigation and Drainage Development

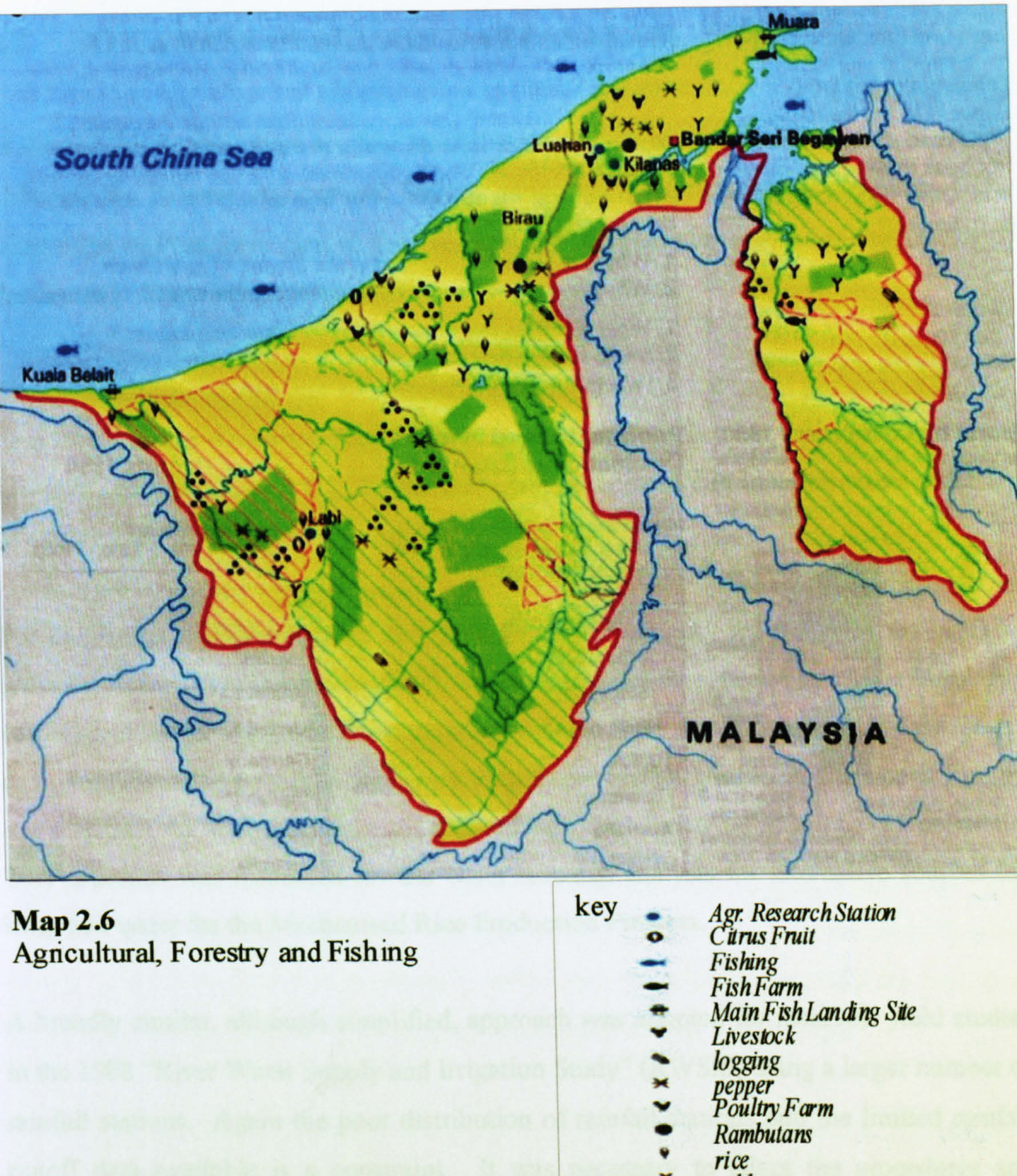
All irrigation facilities were equipped in 1980. There are only minor irrigation schemes (up to 0.9 ha). Irrigated agriculture represents 1000 ha, and all irrigation is surface irrigation. The existing infrastructure and facilities are being upgraded in rural areas, but the irrigated area has remained unchanged since 1980.

The major irrigated crops are rice, vegetables and fruits. The figures for rice show that the country is able to meet only 3.6% of the total demand of 27,500 ton per year. Lack of labour is the main constraint on agricultural development in the country. (Map 2.6)

2.1.7 Trends in Water Resources Management

The water demand for 2002 was estimated at 105million m^3 and basically depends on the growth of the population (Map 1.1, chapter 1) and expected increase in per capita consumption as a result of increased urbanization [1].

Efforts are being made to diversify the economy away from a heavy dependence on oil and gas towards a more independent agriculture sector. The first of the government's major objectives in agriculture was to enhance domestic production of vegetables, poultry and livestock. The government is trying to stimulate greater interest in agriculture through the establishment of model farms and by providing training, advice and support.



Map 2.6
Agricultural, Forestry and Fishing

2.2 SITUATION IN BRUNEI DARUSSALAM

In Brunei Darussalam there are few rainfall stations with records for more than 30 years, although the Kilanas Agricultural Station gauge has a continuous record since 1936. Most other stations have gaps in their records and there are few stations in the interior of the country. There are no long-term records of stream flows.

The paucity of good data has influenced the approach to hydrological analysis in Brunei. The 1979 "Water Resources Study" (WRS) was largely based on statistical analysis of low flows at Kuala Ungar [1]. It was considered that there was insufficient rainfall data to establish a rainfall-runoff relationship.

For the design of Benutan reservoir, flow duration frequency relationships for medium and long return periods were required. It was necessary to generate synthetic long term rainfall and runoff data using computer techniques from the Kilanas and Kuala Ungar data, supplemented by about ten years data from rainfall gauges in the upper Tutong catchments. As a consequence yield estimation was based on statistical calculations. This approach was continued for the water resource analysis for alternative sources for irrigation water for the Mechanised Rice Production Projects.

A broadly similar, although simplified, approach was adopted for reservoir yield studies in the 1988 "River Water Supply and Irrigation Study" (RWSIS) using a larger number of rainfall stations. Again the poor distribution of rainfall stations and the limited rainfall runoff data available is a constraint. It was necessary to adapt the procedures and relationships presented in various Malaysian Hydrological Procedures to the Brunei conditions to estimate low river and flood flows for use in the study. While these can be justified, there is little actual stream flow measurement to verify these estimates [1].

It can be seen that the hydrological studies carried out to date in Brunei have been heavily reliant on rainfall data for Kilanas and stream flow data from Kuala Ungar [1]. While useful work has been accomplished using this very narrow database, it is essential to broaden it, especially with respect to rainfall in the upper catchments and stream flow measurement, as a matter of urgency to meet the minimum requirements presented above for the effective analysis of future water resources in Brunei Darussalam.

2.2.1 Characteristics of Brunei Rivers

There are currently no river discharge gauging stations operational in the country and only three small river water level monitoring sites are operational. Consequently, the characterisation of rivers has to rely heavily on reconnaissance and physical information on the catchments.

In general terms, the higher rainfall of Temburong district will sustain higher rates of runoff and give the potential for significant water supply sources to be developed. The mean annual runoff will generally decline from the forested interior towards the coast, and the available data would suggest that runoff drops from 1900mm for the Ulu Tutong and Ulu Belait areas to 1500mm in the lower Tutong and coastal catchments. Even lower values from 550 to 750mm have been calculated for the data from the Imang and Tasek Rivers, but the credibility of such low annual runoff estimates is open to question. The accuracy of the data have not been assessed in detail during the present study, but the quality of the river flow data is generally worse than the rainfall data, with the exception of the two closed stations on Tutong and Merimbun Rivers at Kuala Ungar.

The Department of Public Works retains in their archives a fair number of red spot flow gauging books for small streams mainly in the coastal belt of Brunei-Muara district, but without a long-term water level record to go with them, the records are of little use for water resource purposes [1].

2.2.2 International Hydrological Programme

The lack of water catchments management data is by no means confined to Brunei. In recognition of this, UNESCO has set up the International Hydrological Programme with the general objective of developing the scientific and technological basis needed to achieve total catchment management. In its recent publication "A Programme for the Humid Tropics" (UNESCO, International Hydrological Programme) it stresses the need to continue long term monitoring of rainfall, climate and stream flow and extend it as far as the capacity of the countries involved allow. It also stresses the importance of data validation, archiving and publication.

2.2.3 Existing Data

Some five years ago the hydrological network of stations in Brunei was rationalised and a number of stations were discontinued. It is fair to describe the records as patchy and of uncertain quality. Despite an effort to collect all hydrological data, it is apparent that there needs to be a much more detailed inventory of assets within the existing hydrological section in Department of Public Works [1].

2.2.4 Water Level

The main historic record of water level has been obtained from chart recorders. There were two types: Negretti and Zambra circular charts and monthly strip charts. The latter are particularly valuable, but are prone to errors due to losing time. Again a computer programme could be written to correct the pairs of level and time data read off the charts, using the actual times and water levels noted on the charts when they were changed. An alternative and probably more reliable approach would be to redigitise the original charts using modem hardware.

2.2.5 Basins

Watersheds of the four main rivers in Brunei Darussalam: Brunei River, Tutong River, Belait River and Temburong River generally coincide with Brunei's international and inter-district boundaries. The exception to this is that the boundary between Temburong district and the Limbang district of Sarawak is the Pandaruan River. Only the right (east) bank catchment of this river is in Brunei Darussalam. The remainder of Brunei Darussalam is comprised of coastal areas with numbers of short streams discharging directly to the sea or to Brunei Bay. The three main areas are:-

1. The area adjacent to the Brunei catchments from Binturan (east of Tutong) to Pintu Malim on the Brunei estuary including a small area on its east bank. This includes the Muara Peninsula.
2. The area on the other side of Brunei Bay in Temburong, comprising coastal swamp.
3. The area adjacent to the Tutong and Belait catchments from Kampung Telisai to Kuala Belait in which the largest individual catchments is that of Lumut River.

The main river basins are described briefly below:-

Tutong and Belait River

The Tutong and Belait Rivers have several similarities although the Belait River catchment is approximately three times as large as that of Tutong River. They share the area enclosed by an arc of hills between the Ladan Hills on the east and the Ubi Hills on the west. Their common watershed is a range of low hills extending north westerly from the southern end of the Ladan Hills to the Andulau Hills near the coast between Telisai and Lumut (Map 2.7.1). Both rivers have their headwaters in the higher ground at the southern end of the Udan Hills. The Tutong River flows generally north-westerly in an extremely sinuous channel to an elaborate estuarial system which it shares with Telisai River extending parallel to the coast for over 10km and in places only separated from the sea by a distance of less than 100m (Map 2.7.2). The Belait River initially flows in a south-westerly direction before turning northwards to flow parallel to the Tutong River in an equally sinuous channel before passing through the gap between the Labi and Andulau Hills at Bukit Puan into its lower catchment comprising an extensive peat swamp forest. Beyond Badas it flows in a southerly direction, turning northwards again at Kuala Balai.

Brunei River

The Brunei River catchments are separated from that of Tutong River by low hills lying between the ends of the Ladan Hills ridge and the coast. The northern watershed extends along the Bukit Siudam ridge and then to a ridge near the coastline before curving southward near Berakas, around the international airport, to the Subok ridge.

The Brunei River was until geologically recent times (about 5000 years ago) the estuary of the Limbang River in Sarawak, which has changed course to enter Brunei Bay further south. The watershed between the two rivers is through low-lying swamp and is indistinct but approximates to the international boundary between the Lumapas and Bukit Ladan.

In relation to the size of its estuary, the Brunei River has a small catchments area - about 330km^2 upstream of Bandar Seri Begawan. Its headwaters are the Sungai Imang and Tajau Rivers in the Bukit Siudam. Damuan River, a major left bank tributary, has a mainly rural catchment extending into the coastal hills. (Map 2.7.3)

Temburong River

The Temburong River flows into the head of Brunei Bay and has a catchment area of about 840km^2 most of which is mountainous. On its eastern and southern sides the catchment boundary is the international boundary with Sarawak while on the west it is the watershed with the Pandaruan River comprising a ridge running between 1 and 3km from Temburong River and its main upper tributary the Belalong River. (Map 2.7.4)

Map 2.7.1
Map of Tutong River

Map 2.7.2
Map of Belait River

Map 2.7.3
Map of Brunei River

Map 2.7.4
Map of Temburong River

The upper catchment south of Kampung Batang Duri comprise deep, steep-sided jungle covered valleys, and rises to 1850 m in the vicinity of Bukit Pagar. Downstream of Kg Batang Duri, the river flows through a wide flat valley containing gravel deposits before flowing through a steep-sided gap in the Biang ridge immediately upstream of Bangar town. North of Bangar it meanders through low-lying swamp to Brunei Bay.

Two tributaries, the Batu Apoi and Labu Rivers, flow across the coastal swamp from upper catchment in the mountainous area along the eastern boundary of Temburong district. The Batu Apoi River has a widened valley upstream of the Biang ridge. All the rivers are tidal with the risk of saline intrusion to points upstream of the rivers.

2.3 MANGROVE SWAMPS OF BRUNEI DARUSSALAM AND THE TIDAL TREE

Rapid population growth in Third World countries is both a contributor to and a consequence of under-development [21-22]. Third World government policies have resulted in excessive forest depletion [23]. Forest clearance may result in altered rainfall patterns and intensities [24-25]. Whether extensive deforestation will result in regional climatic change is unclear as models predict contradictory results [26-27]. Studies suggest that removal of the rainforest results in reduced rainfall interception, increased runoff, river sedimentation and down stream flooding [24, 28-30].

Mangrove ecosystems form conspicuous and important features of sheltered coastlines and riverbanks in Brunei Darussalam. A lot of such swamps are being denuded by human economic activities. For example, in Thailand, in the last 30 years nearly 46% of the total mangrove swamps have disappeared giving way to shrimp ponds. Unlike Thailand, the Brunei swamps are in outstanding preservation. In South-east Asia, the mangrove swamps of Brunei Darussalam rank among the best preserved in the region (Plate 2.7). About 3% of the total land areas or 18,814 hectares are relatively unexploited and among the best preserved mangroves in the region.

A short term survey showed the following results about the water quality of Brunei River. The salinity value averaged 24.1% compared to the mean of 35% in the South China Sea. Temperature differences between the surface and the rest of the vertical column did not exceed 0.2°C pH value in the river at Kedayan River and upper parts of the catchments estuary range from 6.4 to 6.9°C. This relatively acidic characteristic is due to the mangroves swamps that contribute both the acidic and anoxic.

Plate 2.7

Mangrove swamps of Brunei Darussalam

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CHAPTER 3

ANALYSIS OF BRUNEI WATERS

3.1 INTRODUCTION

As part of the work of this thesis, water samples were taken from a large number of sites in Brunei and analysed to assess their quality. The samples were analysed for the following:-

Anions	: *fluoride, chloride, bromide, nitrate, phosphate and sulphate*
Monovalent Cations	: *sodium, ammonium and potassium*
Divalent Cations	: *calcium and magnesium*
Heavy Metals	: *lead, iron, cadmium, manganese, zinc, nickel and copper*

3.1.1 pH and Conductivity Analysis

pH is an important measurement to assess how acidic or basic the water is. The range of pH is from 0 to14, with 7 being neutral [1]. A pH less than 7 indicates acidity, whereas a pH greater than 7 indicates basicity. pH is really a measure of the relative amount of free hydrogen and hydroxide ions in the water. Water that has more free hydrogen ions is acidic, whereas water that has more free hydroxide ions is basic. Since pH can be affected by chemicals in the water, pH is an important indicator of water that is changing chemically [2]. pH is reported in "logarithmic units," like the Richter scale, which measures earthquakes. Each number represents a ten-fold change in the acidity/basicity of the water. Water with a pH of 5 is ten times more acidic than water having a pH of 6 [3]. An unbalanced pH system, though it may go unnoticed and undetected for years, can actually lead to the progression of most, if not all, degenerative diseases including cardiovascular disease, cancer and diabetes, as well as the never ending frustration of excessive systemic weight gain [4].

Pollution can change the pH of the water which in turn can harm animals and plants living in the water. For instance, water coming out of an abandoned coal mine can have a pH of 2. Not only does the pH of a stream affect organisms living in the water, a changing pH in a stream can be an indicator of increasing pollution and other environmental factors.

Conductivity is defined as the ability to produce electric currents. Ionic materials are inorganic salts. Seawater has a high and freshwater has a low conductivity. Conductivity in water is influenced by the conductivity of rainwater, by road salt application, fertilizer application and evaporation. Rainwater has variable conductivity depending on whether the rain clouds formed over the ocean (which tends to have higher conductivity due to salts in ocean spray) or land.

3.1.2 Anions, Cations and Heavy Metals Analysis

The analysis for **anions** can involve the determination of many negatively charged ions. In the present work only six ions: *Sulphate, Phosphate, Fluoride, Chloride, Bromide and Nitrate* were determined. The method of determination used was ion chromatography (IC). Chromatographic separation utilising ion exchange techniques requires the use of aqueous eluents which contain a mixture of ionic species. The eluent may or may not contain other constituents such as organic solvents.

The most extensively used eluents in dual-column IC of anions are dilute solutions of salts of weak acids. These eluents are employed in the determination of anions of strong acids with pK_a values less than 5. In the suppression system the eluent is converted into a slightly dissociated acid with low conductivity and the analyte anion is converted into a strong acid with high conductivity. The eluents used in the determination of anions of weak acids with pK_a higher than 6 are dilute solutions of salts of strong acids [5]. In such cases the anion to be determined is converted in the suppression system into a slightly dissociated acid and the eluent into a strong acid with high conductivity. The anion is detected by the reduction of the conductometric signal. Solutions of organic acids or solutions of their salts are the usual choice for eluents in the determination of anions.

Gjerde suggested that the anions of these acids possess high affinity for the separating sorbent and therefore rapid and selective separation is achieved at low concentrations of the eluting ion [6]. Solutions of salts and solutions of weak acids can be used for elution. Small suggested that in anion determination, the suppressor column is packed with a high capacity cation exchanger in the H^+ form [7]. In most cases the eluent is converted in the suppression column into a slightly dissociated acid and the analyte anions are converted into strong acids.

In most cases anions in the dual-column method are determined with carbonates as the eluent. The anions are usually separated on a Dionex Anion column using a 3mM $NaHCO_3$/2.4mM Na_2CO_3 solution as the eluent with the flow rate being kept at 2.3ml min^{-1}, which is referred to as the standard eluent. It has been reported by Williams that the retention time of inorganic anions does not exceed 30min when the standard eluent is used [8]. Anions that are retained strongly are eluted with a 6mM Na_2CO_3 solution in less than 20 minutes. For the determination of anions in very pure water, containing less than 1μg ml^{-1}, the sample must be concentrated prior to analysis. The time required for the analysis including the process of concentration, is 5 to 10 minutes longer and the reproducibility of results is not so good. Analysis of samples with a high anion concentration, greater than 500 μg m^{-1}, should be preceded by the dilution of the sample. Preliminary preparation of the sample involves filtration through a porous filter. Roberts stated that the detector limits for the anions lie in the range 100-300 μg l^{-1} [9]. Jackson also stated that there are 10 to 50 times greater than the detection limits of anions determined by the dual-column method [10]. Okada stated that to improve sensitivity, prior concentration is used or a special back-flush method is used [11].

For the analysis of anions present in the water samples, Dionex chromatography was used. The Dionex DX500 IC was set-up to run anion analysis with a conductivity detector. Up to four different buffers or any combination can be set using the GP40 gradient pump system. A dual head pump moves the mobile phase solution from the proportioning valve, where buffers are combined through the injection valve to the anion exchange column.

The ion-chromatographic method is used mainly for the determination of metals in the form of their **cations** rather than their anions complexes. In dual-column ion chromatographic analysis of alkali metals and ammonia strongly acidic eluents such as solutions of hydrochloric acid and nitric acid are often used. The eluents are converted into water in a suppressor, which is packed with an anion-exchange resin in OH^- form. Lash suggested that the cations are detected conductometrically in the form of the corresponding hydroxides and the possibility of analysing lithium, sodium, potassium and ammonia in geothermal waters has been considered [12].

Fulmer also suggested that to increase the sensitivity of determining sodium and potassium compounds present in especially pure water the sample is concentrated before analysis [13]. This makes it possible to determine these cations at a concentration level of 1 $\mu g\ l^{-1}$, with a sample volume of 10ml. A 7.5mM solution of HCl served as the eluent. Apart from conductometric detection, other detectors can be used. It has been proposed by Tanaka that the coulometric detector be used for determining alkali metal cations and ammonia in waters following biological purification [14].

Dokija suggested that a 3mM nitric acid solution was used as the eluent to determine ammonia in atmospheric precipitation. Also, sodium and potassium ions in drinking water have been determined with a nitric acid solution (pH 2.5) as the eluent [15]. Mizobuchi made a comparison of the results of ion chromatographic determination of sodium, potassium and ammonia in wastewaters with analytical results obtained by the atomic-absorption and atomic-emission methods [16]. According to Smith, alkali metal cations (Na^+, K^+, Rb^+ and Cs^+) have been separated on a silica gel column [17]. Since silica gel exhibits cation-exchange properties only in neutral media, the eluent was 2.5mM lithium chloride solution.

Nordmeyer, however, suggested that magnesium and calcium in natural water are eluted as cations with a solution of barium or lead salts followed by a reduction of the background signal on a high-capacity sulphate form anion exchanger [18]. Lamb also suggested that calcium, strontium, barium and magnesium in natural waters could be determined using a 1mM $Pb(NO_3)_2$/0.1mM HNO_3 solution (pH 4) as the eluent, followed by suppression of the conductometric background signal on a high-capacity iodate form anion exchanger [19].

Choporova suggested that, in the dual-column method, ethylenediamine tartrate or ethylenediamine chloride be used as the eluent with conductometric detection for the determination of calcium, strontium and barium [20]. The background signal was suppressed by using a column packed with an nitrate form anion exchanger. At a concentration of 20μg l^{-1} of the cation the relative standard deviation for the determination was 1.5 to 5.0%, with the detection limit being at the μg l^{-1} level. Wimberley shows that a solution of m-phenylenediamine and nitric acid can be also used as the eluent [21]. Moreover, Ishihara suggested that dual-column IC with a coulometric detector could be utilized in determining calcium in purified waters [22]. A 2.5mM solution of m-phenylenediamine and 2.5mM nitric acid served as the eluent.

All **heavy metals** exist in surface waters in colloidal, particulate and dissolved phases, although dissolved concentrations are generally low. Anthropogenic sources of metals can have severe and obvious impacts on the local environment but signs of environmental change across a larger region and on a broader scale are subtle and difficult to interpret. Connecting dead trees and bare ground to a nearby smelter complex is not hard.

Metals occur naturally in the environment and are present in rocks, soil, plants and animals. Metals occur in different forms: as ions dissolved in water, as vapours or as salts or minerals in rock, sand and soil. The colloidal and particulate metal may be found in hydroxides, oxides, silicates or sulphides; or adsorbed to clay, silica or organic matter. The soluble forms are generally ions or unionised organo-metallic chelates or complexes. The solubility of trace metals in surface waters is predominantly controlled by the water pH, the type and concentration of ligands on which the metal could adsorb the oxidation state of the mineral components and the redox environment of the system. The behaviour of metals in natural waters is a function of the substrate sediment composition, the suspended sediment composition and the water chemistry. Sediment composed of fine sand and silt will generally have higher levels of adsorbed metal than will quartz, feldspar and detrital carbonate-rich sediment. Metals also have a high affinity for humic acids, organo-clays and oxides coated with organic matter. The water chemistry of the system controls the rate of adsorption and desorbtion of metals to and from sediment. Adsorption removes the metal from the water column and stores the metal in the substrate. Desorbtion returns the metal to the water column, where recirculation and bioassimilation may take place. Metals may be desorbed from the sediment if the water experiences increases in salinity, decreases in redox potential or in pH.

Heavy metals in surface water systems can be from natural or anthropogenic sources. Excess metal levels in surface water may pose a health risk to humans and to the environment. Plants and animals depend on some metals as micronutrients. Living organisms require trace amounts of some heavy metals, including cobalt, copper, iron, manganese, molybdenum, vanadium, strontium and zinc. Excessive levels of essential metals, however, can be detrimental to the organism. Non-essential heavy metals of particular concern to surface water systems are cadmium, chromium, mercury, lead, arsenic and antimony. Certain forms of some metals, however, can also be toxic, even in relatively small amounts and therefore pose a risk to the health of animals and people. While the effects of chronic exposure to trace amounts of some metals is not well understood, a legacy of incidents tell us about the seriousness of high levels of exposure to some metals, especially cadmium and methyl mercury.

Heavy metals are elements which occur near the bottom of the periodic table, having atomic number between 21 and 110 and a specific gravity greater than 4.0. Their densities are high compared to those of other common materials. A heavy metal is any metallic mineral with a specific gravity of five or more times that of water. All of the heavy metals, when given in large enough concentrations, produce symptoms and signs of poisoning in animals and humans. But some of them in just trace quantities are necessary to sustain good health. The heavy metals are, for example: *Antimony, Arsenic, Bismuth, Cadmium, Cerium, Chromium, Cobalt, Copper, Gallium, Gold, Iron, Lead, Manganese, Mercury, Nickel, Platinum, Silver, Tellurium, Thallium, Tin, Uranium,* *Vanadium* and *Zinc.* None of these metallic elements is biodegradable, but rather accumulate until they leach from the soil and enter the sea. Unless precautions are taken, the legacy of exploiting metal-containing natural resources is thus likely to stay with us for a long time.

Heavy metals are among the most problematic causes of water pollution; a number of industries emit them. Since household waste also contains heavy metals, the added danger exists that heavy metals will enter the groundwater and surface water through seepage from household waste. The heavy metals that reach the water are relatively quickly diluted: either they react to form carbonates, sulphates and sulphides, or mineral and organic sediment adsorbs them. For that reason the heavy metal content of water sediment is always increasing.

Heavy metals found in the water body are mainly derived from effluents discharged from metal processing and finishing plants either to the sewer or directly to the waterway. Metals are present in trace quantities, in foodstuffs and are essential requirements of the human body. Metals can exist in a variety of forms in the water environment: as free ions (*eg.* Cd^{2+}, Cu^{2+}); inorganic complexes [*eg.* $Cd(H_2O)_6^{2+}$, $Cu(H_2O)_4^{2+}$)]; organic complexes and compounds (*eg. Zn-fulvic acid and methyl mercury*); and may be associated with particulate matter, usually absorbed onto the surface [23-26].

The availability of metals to fauna and flora is dependent upon their form, which can be altered by such factors as changes in pH levels and redox potentials and the presence of other materials. While the composition of groundwater is determined primarily by its contact with soil, minerals and rocks, non-point surface pollution is often the primary source of groundwater contamination, which occurs mainly as a result of municipal or industrial landfills, disposal of liquid mining wastes or mining tailings, or excessive use of agricultural chemicals. Increased usage of groundwater resources and an increase of inputs of non-point surface pollutants into groundwater zones may cause contamination and general deterioration of groundwater quality.

The analysis of heavy and transition metals, especially mercury, in environmental and biological samples has received attention in recent years [27]. From the ecotoxicology point of view, Hg^{2+}, Pb^{2+} and Cd^{2+} etc are the most toxic metals. They can accumulate in various organisms. So it is an important task to establish a rapid and convenient method for the simultaneous determination of these metals.

The major analytical methods used in this work are ion chromatography (IC), high performance liquid chromatography (HPLC), ultra-violet spectroscopy (UV)and infrared spectroscopy (IR). Numerous analytical techniques have been employed in the determination of heavy and transition metals. But ion chromatography (IC) seems to be one of the most effective and simple techniques to determine both anionic and cationic species owing to its high sensitivity, rapidity, selectivity and simplicity coupled with the possible advantage of simultaneous determination [28].

Ion Chromatography (IC) is a modern term and its use implies a separation technology that is more or less high performance. Logically, IC refers to the chromatography of ions. It can be stated that IC developed, by Small, has become a routine tool for the sensitive determination of ion content in many sample matrices in industry, analytical laboratories, the clinical environment etc [35]. The scope of IC was considerably enlarged by newly designed electrochemical and spectrophotometric detectors. A growing number of applications, using post-column derivatization in combination with photometric detection, opened the field of heavy and transition metal analysis by IC, thus providing a powerful extension to conventional atomic spectroscopy methods. These developments make IC an integral part of both modern inorganic and organic analysis [36-38].

Common applications of IC include the determination of simple anions, such as chloride and sulphate, simple cations, such as sodium and calcium, transition metals, lanthanide and actinide metals, organic acids, amines, amino acids and carbohydrates. IC is most often applied to aqueous samples or to solid samples that will dissolve in or can be extracted into aqueous solutions [39,41]. An IC system consists of an eluent reservoir, an analytical pump to deliver the eluent to the analytical column, an injection valve or other means of introducing the sample, an analytical chromatographic column, a detector and a data processing device (Figure 3.1).

The dual-column method is a classic version of this technique (Figure 3.2) and has been described by Small [35]. This technique is characterized by the presence of a suppression system and a conductometric detector. The eluent is pumped under pressure through the injection system into the separating column. The sample to be analysed is injected by means of a system consisting of a six-port valve containing a metering loop.

One of the most important applications of IC is the analysis of water. IC is an ideal method for the determination of the ionic composition of water, in particular the anionic composition. The conditions for the determination of ionic components in water depend on the concentration of ions, their proportion, the presence of interfering compounds and a number of other factors. IC has been used to determine the components of waters such as surface freshwater, atmospheric precipitation, seawater, subterranean water and wastewater [42-47]. The IC system used in the present work is the DIONEX Ion Chromatograph (Plates 3.1.1 and 3.1.2). The *DX 500* is an integrated, high-speed liquid chromatography system that simplifies system configuration for any IC or HPLC application. DX 500 pumps, detectors and chromatography modules are engineered to function as a fully integrated system.

The widely used cationic IC methods involve a cation-exchange (or a mixed cation/anion-exchange) separation followed by post-column complexation with 4-(2-pyridylazo) resorcinol (PAR), to form chelates, which can be sensitively monitored by spectrophotometric detection [29]. The anion-exchange approach does offer some advantages with respect to selectivity and for the analysis of complex samples. At present, the bifunctional ion-exchange column is the most effective analytical column for separating heavy and transition metals [30]. The most commonly used eluents are oxalic acid or pyridine 2, 6-dicarboxylic acid (PDCA) [31]. When oxalic acid was used, cadmium and manganese coeluted [32] and, furthermore, iron and aluminium could not be eluted from the analytical column. PDCA was found to be of particular interest because it is such a strong complexing agent that heavy and transition metals could be well separated as their anionic chelates M $(PDCA)_2^{2-}$ on the mixed-bed resin of the analytical column. Ruth could separate Pb^{2+}, Fe^{2+}, Cu^{2+}, Ni^{2+}, Zn^{2+}, Co^{2+}, Cd^{2+} and Mn^{2+}, using 3mM l^{-1} PDCA/ 4.3mM l^{-1} LiOH/ 2mMl^{-1} Na_2SO_4/ 25mMl^{-1} NH_4OH (adjusted to pH 11 with acetic acid) as the post-column derivatization reagent [33]. Moreover, Yan has used the IC method to analyse Zn^{2+}, Cd^{2+} and Hg^{2+} simultaneously by post-column derivatization with a water-soluble porphyrin giving the detection limits for Zn^{2+}, Cd^{2+} and Hg^{2+} were 1, 0.05 and 5μg l^{-1}, respectively (Table 3.1) [34].

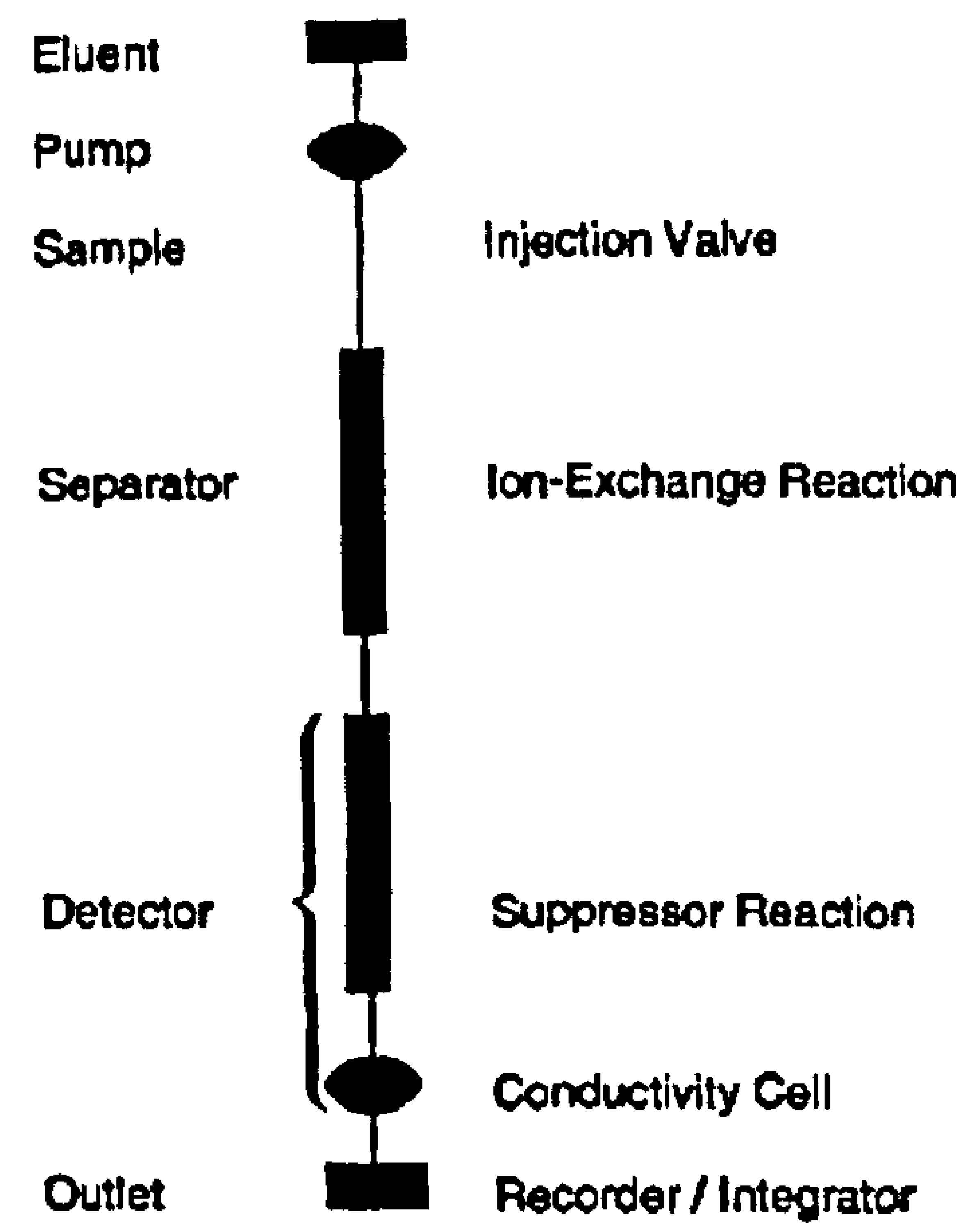


Figure 3.1
Basic components of an ion chromatograph

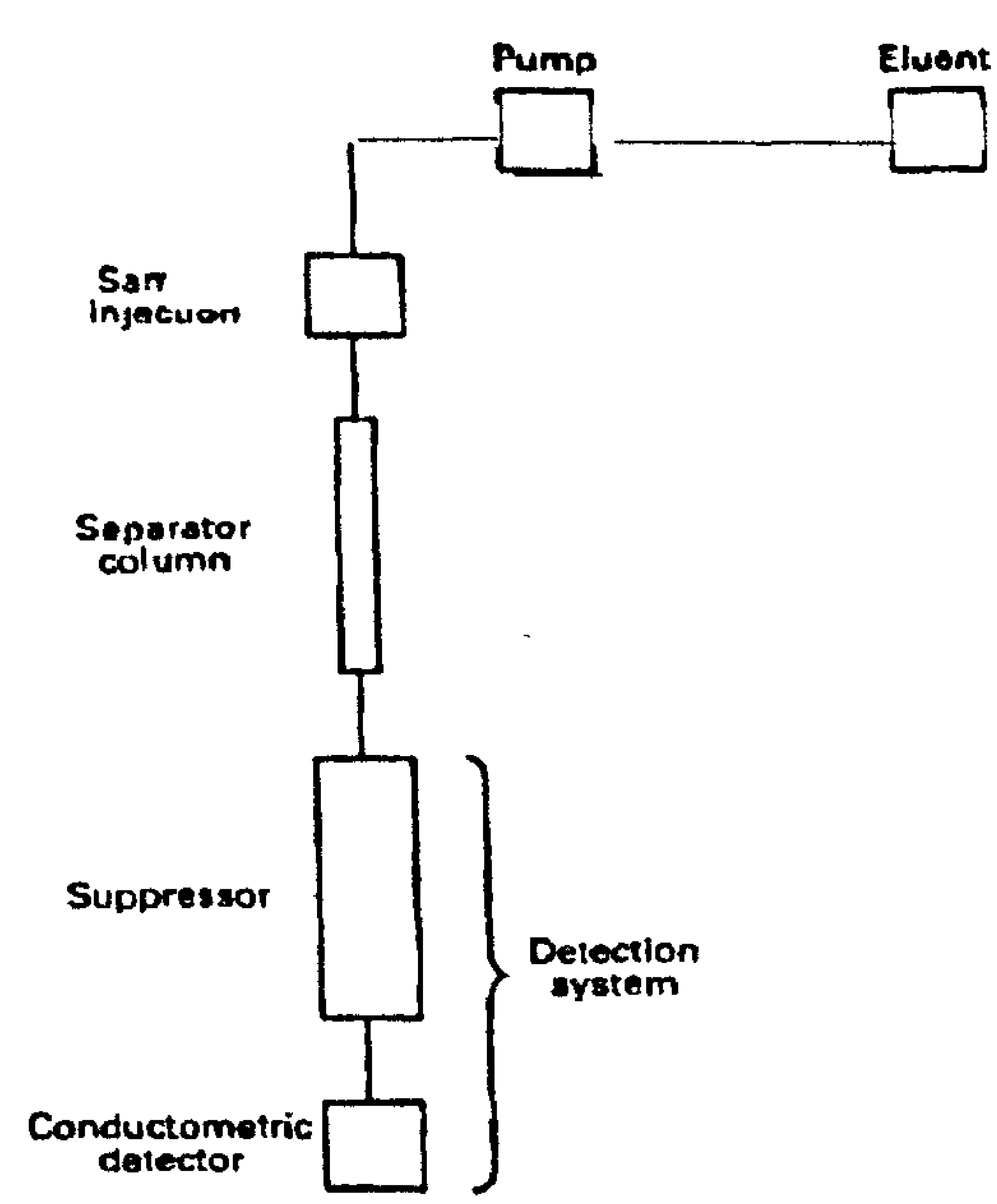


Figure 3.2 - Dual-column method
Scheme of a dual-column
ion chromatographic system.

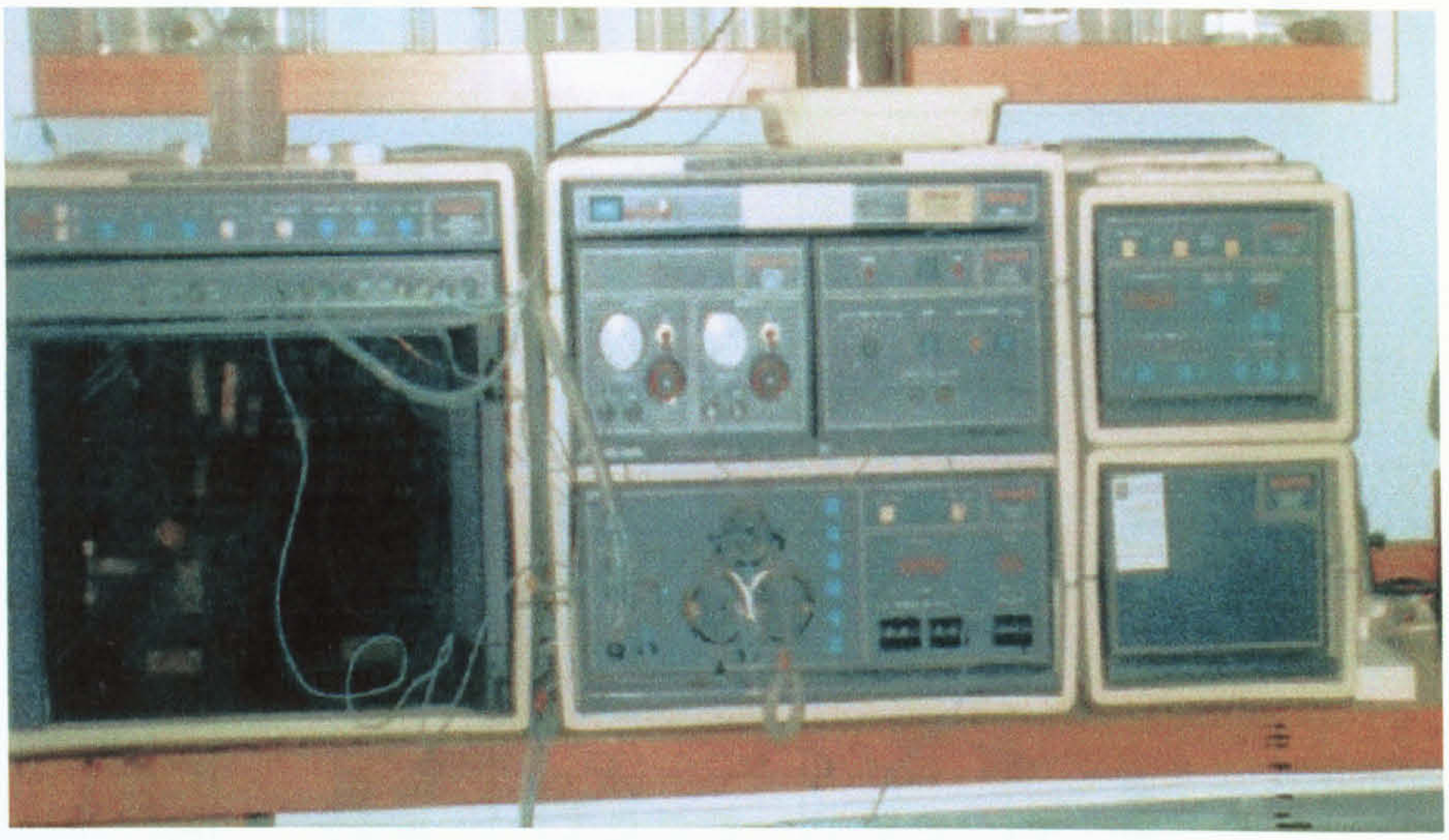


Plate 3.1.1
Ion Chromatography (old) Instrument - Anions and Cations Analysis

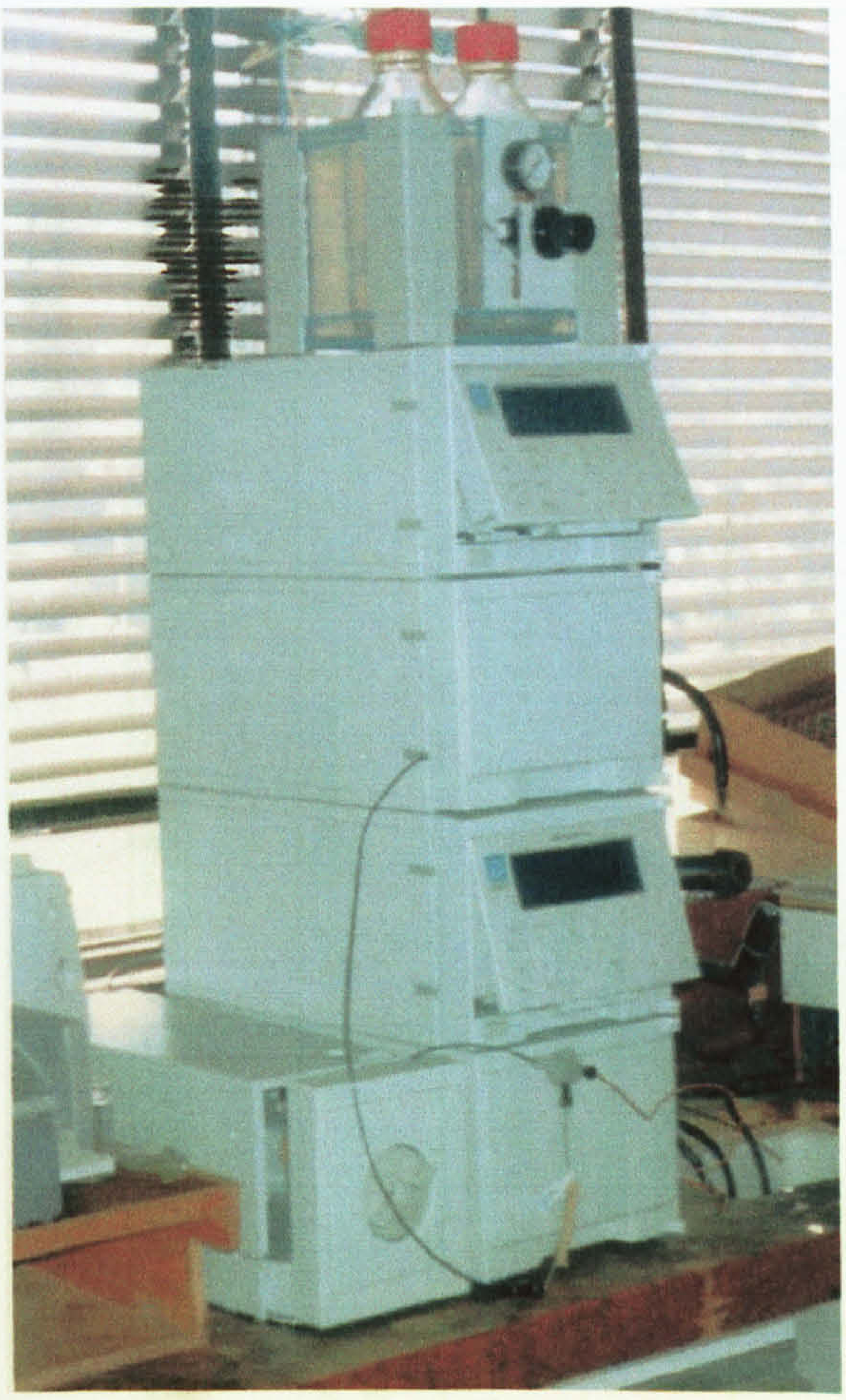


Plate 3.1.2
Ion Chromatography for Heavy Metal Analysis.

TABLE 3.1

CHEMICALS REQUIRED FOR THE SEPARATION AND ANALYSIS OF HEAVY METALS USING ION-CHROMATOGRAPHIC TECHNIQUE

Reagents for Eluent / post column	Chemicals	Quantity	Catalogue No. (Aldrich)	Formula Weight (FW)	Conc. Required	Weight / Volume / L
PDCA Eluent	*1. 2,6-Pyridine dicarboxylic acid (PDCA)*	*25g*	*P6, 380-8*	*167.12*	*7.0mM*	*1.17g*
	2. Potassium hydroxide	*500g*	*22,147-3*	*56.11*	*66mM*	*3.70g*
	3. Potassium sulphate	*500g*	*22,132-5*	*174.27*	*5.6mM*	*0.98g*
	4. Formic acid	*500g*	*25,136-4*	*46*	*74mM*	*3.40g*
Oxalic acid Eluent	1. Oxalic acid	500g	24,753-7	126.07	80mM	10.1g
	2. Tetramethylammonium hydroxide	1L	42,631-8	91.15	100mM	8.97ml
	3. Potassium hydroxide	500g	22,147-3	56.11	50mM	2.81g
PAR Reagent	*1. 4-(2-pyridylazo) resorcinol monosodium salt monohydrate*	*5g*	*17,826-8*	*255.21*		*0.12g/l*
	2. 2-Dimethylaminoethanol (N, N-Dimethylethanolamine)					
	3. Ammonium hydroxide	*500ml*	*D15, 740-6*	*89.14*	*1.0M*	*100ml*
	4. Sodium hydrogen carbonate					
		1L	*22,122-8*	*35.05*	*0.50M*	*19.5ml*
		500g	*23,652-7*	*84.01*	*0.30M*	*25.2g/l*

High Performance Liquid Chromatography (HPLC) was developed in the late 1960s and 1970s. HPLC is an analytical separation technique used to detect and quantify analytes of interest in more or less complex mixtures and matrices [48-50]. In HPLC used for preparative separation, the following components have to be adapted to the preparative specifications of large columns such as reservoir, pump, sample introduction, detector and outlet device (Plates 3.2.1 and 3.2.2).

HPLC is also used to isolate and purify compounds. It is also the most powerful of all the chromatographic techniques. It can easily achieve separations and analyses that would be difficult or impossible by other forms of chromatography.

The mobile phase in HPLC is the solvent being continuously applied to the column which is the stationary phase. The mobile phase acts as a carrier for the sample solution. A sample solution is injected into the mobile phase through the injector port. As the sample solution flows through a column with the mobile phase, the components of that solution migrate according to the non-covalent interactions of the compound with the column. The chemical interactions of the mobile phase and sample with the column determine the degree of migration and separation of components contained in the sample [51-53]. The injection port of an HPLC commonly consists of an injection valve with a sample loop. The sample is typically dissolved in the mobile phase before injection into the sample loop by being drawn into a syringe and injected into the loop via the injection valve which has two working positions, "load and inject". Rotation to the "inject" position closes the valve and opens the loop in order to inject the sample into the stream of the mobile phase. Loop volumes can range between 10μl to over 500μl. In modern HPLC systems, the sample injection is typically automated [54-56].

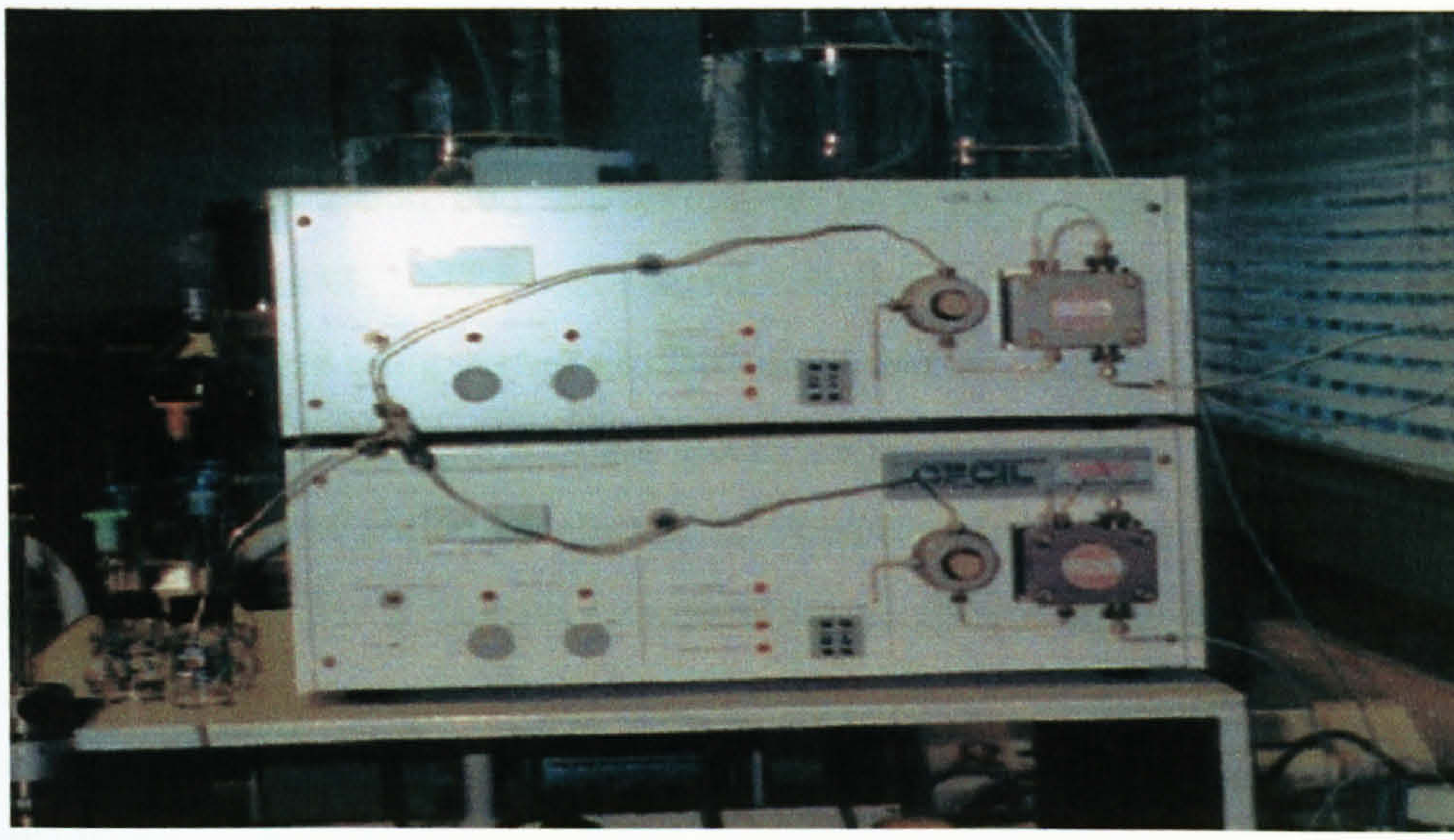


Plate 3.2.1
CE 1100 Liquid Chromatography Pump

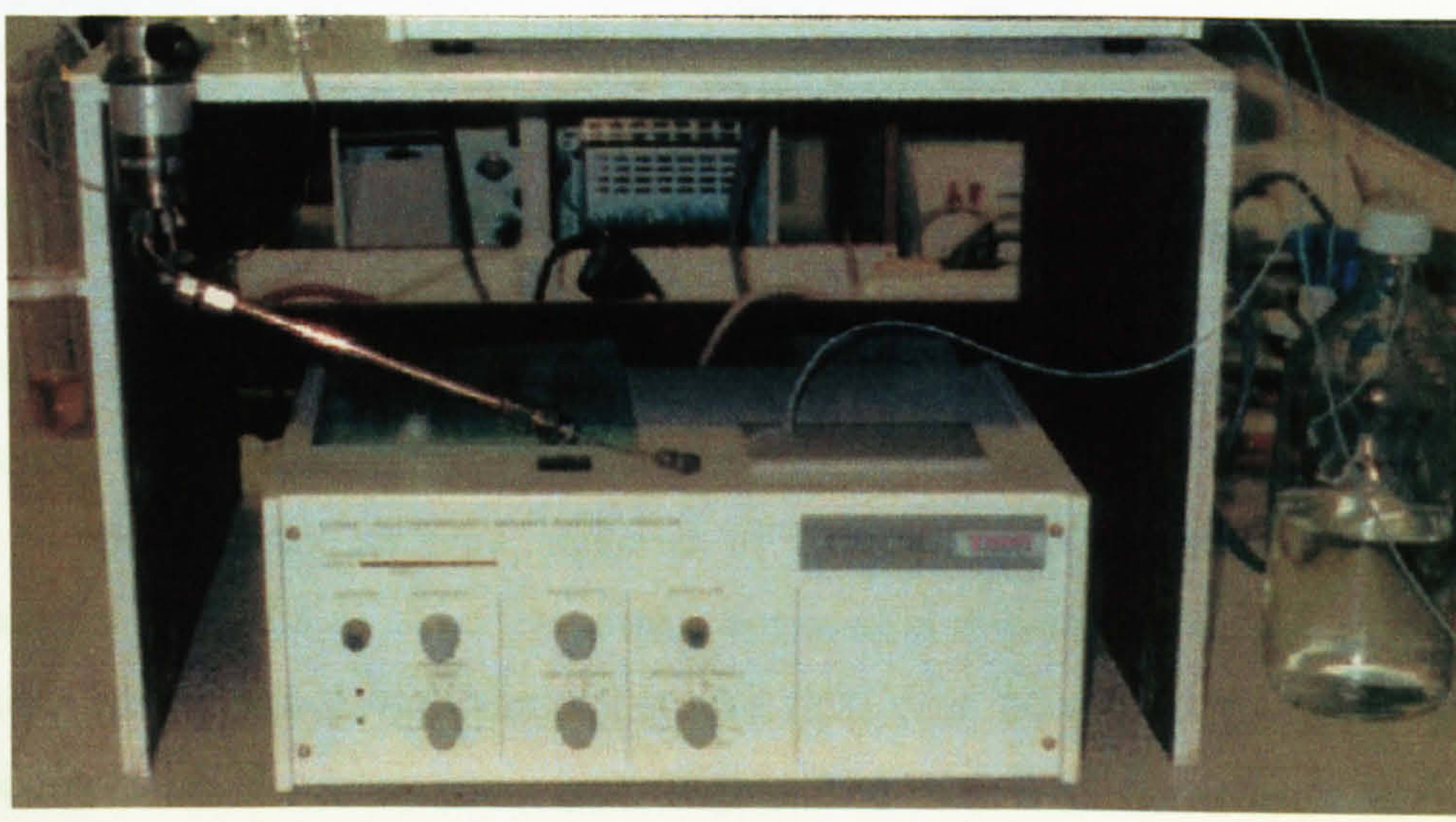


Plate 3.2.2
CE 1200 High Performance Variable Wavelength Monitor

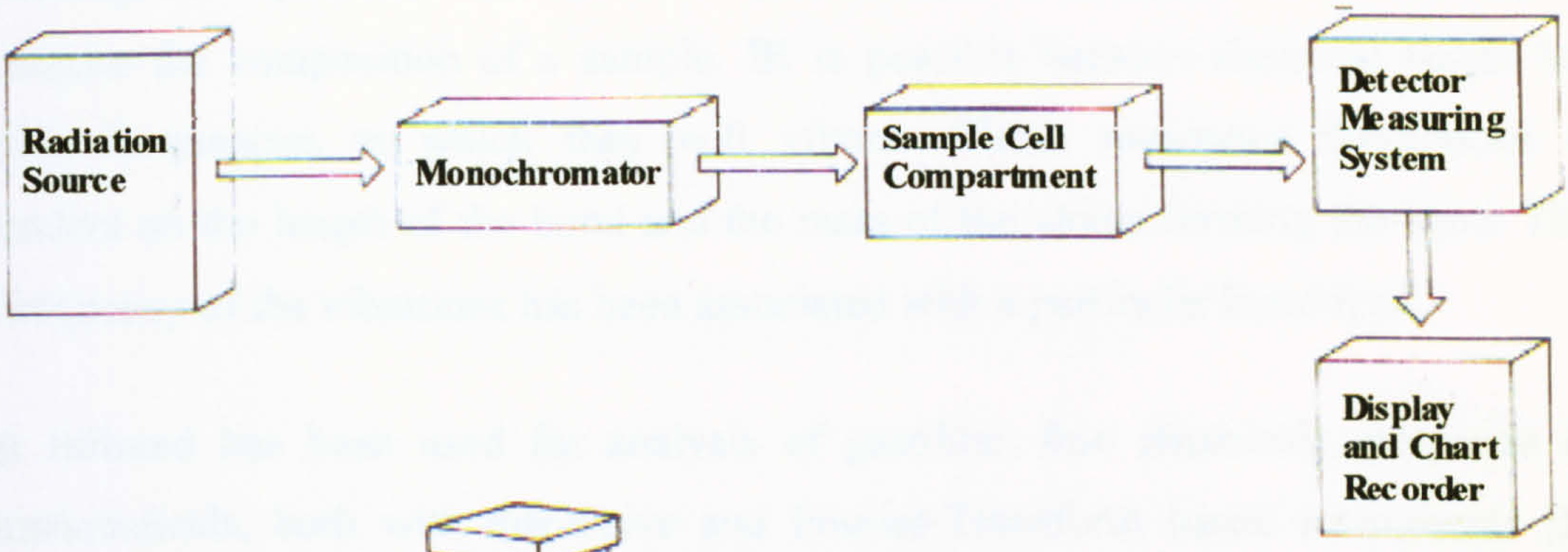
Ultraviolet/visible Spectroscopy (UV/vis) has been applied to very many determinations which have been developed over the years. In all of these areas UV/vis is an essential tool in the identification and quantification of a very broad range of chemical and biological substances. The equipment required ranges from very simple colour comparators to large computer-controlled automatic scanning instruments that cover the whole of the UV/visible region of the electromagnetic spectrum. There are five essential components required for most absorption spectrometers. The general arrangement of these components for a simple spectrometer is shown in Figure 3.3. There are as follows:-

1. A source or sources of radiation covering the required wavelength range.
2. A means for selecting a narrow wavelength band.
3. Facilities for holding the cells containing the sample solution and the blank in the radiation beam.
4. A device or devices capable of measuring the intensity of the radiation beam transmitted through the cells.
5. A display or output device to record the measured quantity in a suitable form.

Cells for the UV region are 330nm quartz or fused silica cells, whereas for visible region they may be made of glass (or transparent plastic if aqueous solutions are being used). A cell is specified by its type, material of construction, path length and dimensional tolerances (Figure 3.4). The UV instrument used in this work is shown in Plate 3.3. The system has a wavelength range between 200 and 800nm. The cells used in the experiment are the rectangular type (Figure 3.4) with the eluents and reagents used in Table 3.1.

Spectroscopy is the study of the interaction of electromagnetic radiation with a chemical substance. The nature of the interaction depends upon the properties of the substance. When radiation passes through a sample (solid, liquid or gas), certain frequencies of the radiation are absorbed by the molecules of the substance leading to the molecular vibrations. The frequencies of absorbed radiation are unique for each molecule which provides the characteristics of a substance.

Figure 3.3
Basic construction of a spectrometer



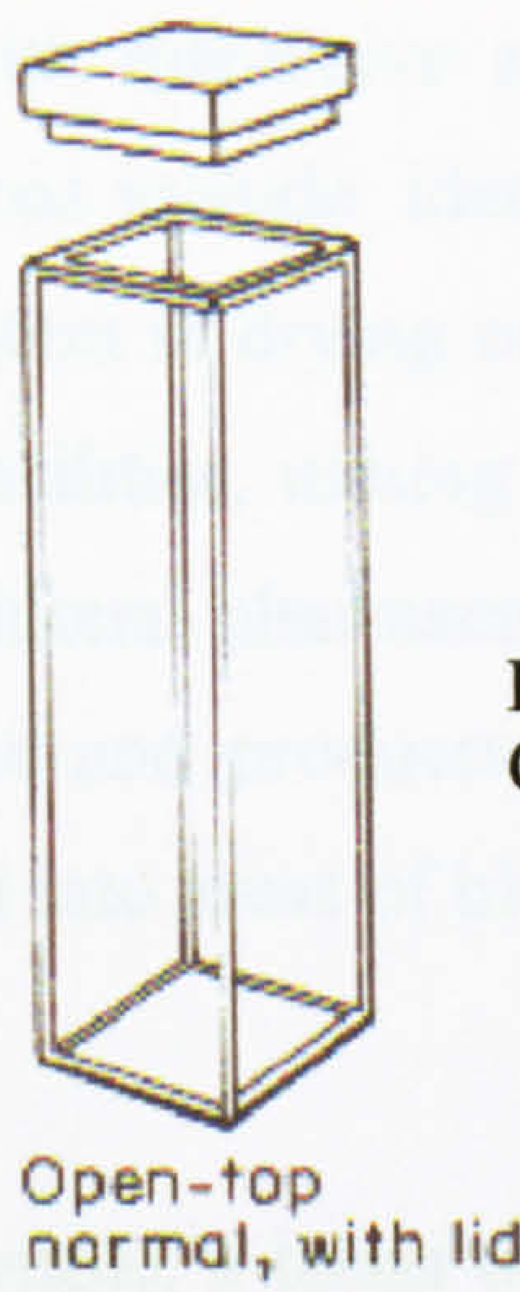


Figure 3.4
Cuvette open top normal with lid

Plate 3.3
Ultraviolet (UV) Spectroscopy Instrument

Infrared spectroscopy (IR) is a type of spectroscopy that uses the infrared portion of the electromagnetic spectrum. As with all spectroscopic techniques it can be used to investigate the composition of a sample. IR is possible because chemical bonds have specific frequencies at which they will vibrate. These resonance frequencies are dependent on the length of the bond and the mass of the atoms forming the band. Thus, the frequency of the vibrations has been associated with a particular bond type.

Near infrared has been used for analysis of gasoline, fine chemicals, polymers and pharmaceuticals, both with dispersive and Fourier-Transform based instruments [57]. Pharmaceutical applications include: identification of raw materials and product quality, moisture and solvent content in drying or solvent removal processes, residual drug carry over in manufacturing facilities, mixing quality evaluation, and imaging of tablets and packaging systems. Additional pharmaceutical applications include real-time monitoring of fermentation processes and products. More recently, medical applications for near-infrared have proliferated into areas of blood analyte monitoring and imaging of materials including tissue [58].

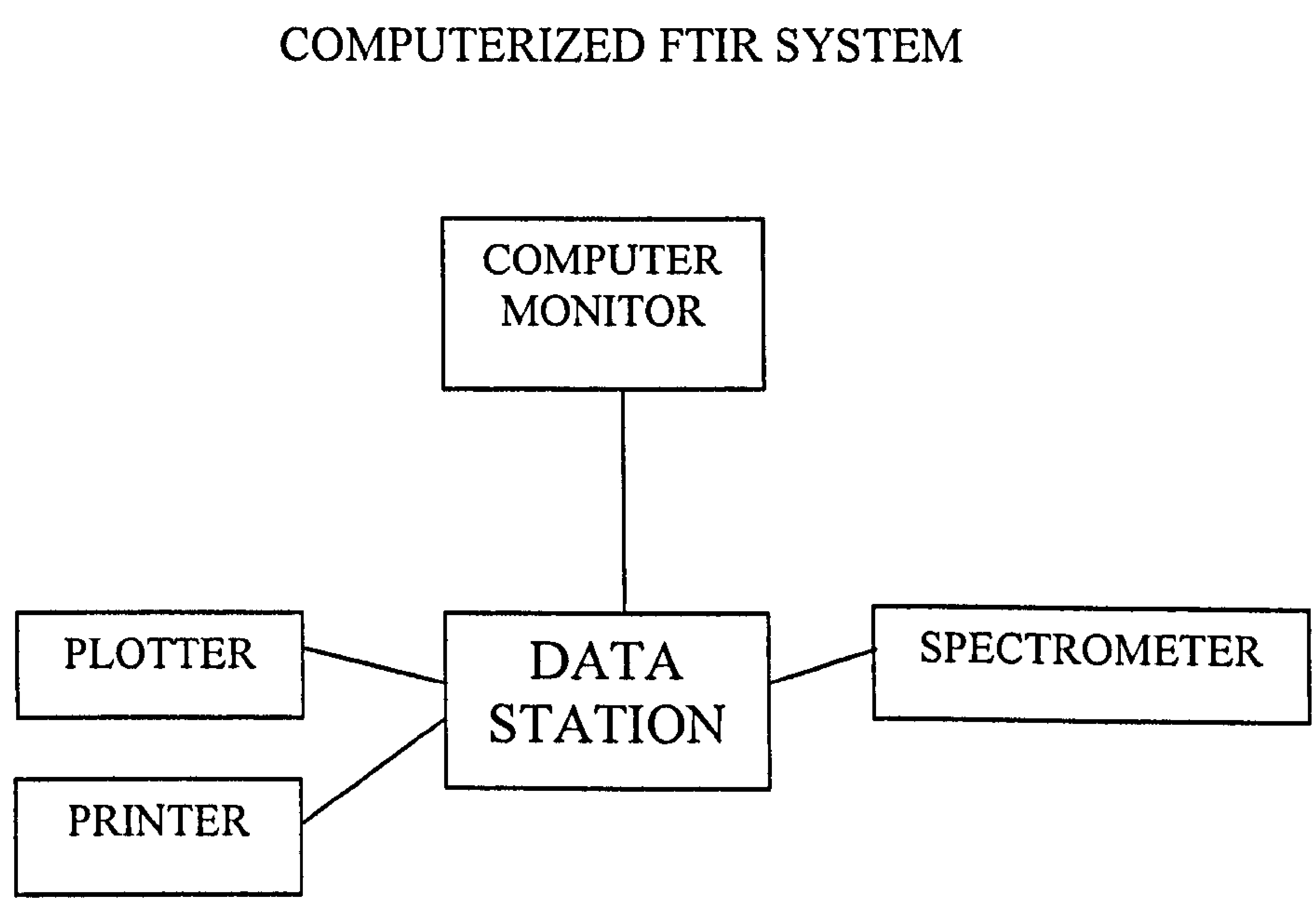
In order to measure a sample, a beam of infrared light at a specific frequency is passed through the sample, and the amount of energy absorbed is recorded. By repeating this operation across the range of interest (usually no more than 4000-500cm^{-1}), a chart can be built up. When looking at a chart for a substance, an experienced user can identify the substance from the information on the chart.

This technique works almost exclusively on covalent bonds, and as such is of most use in organic chemistry. The clearest charts (or spectra) are single compound samples of high purity. The technique, however, has been used for the characterization of very complex mixtures.

The basic components of an infrared spectrometer are shown in block diagram form in Figure 3.5. The system consists of an interferometer, a computer, a data station and a printer and/or plotter for data output.

Figure 3.5

Basic components of a computerized spectrometer system



With an infrared data station, the computer acquires, processes, stores and retrieves spectral data. Many commercial software packages including spectral enhancement, quantitation and searching are available for infrared spectroscopy.

3.2 SAMPLING SITES AND METHODS

The research on Brunei water samples involved direct field study so as to get a correct a geomorphological picture. Brief sketches of the course of the four main rivers in Brunei showing the sampling points are in Figures 3.6.1 to 3.6.4. Travelling to the points of collection was mostly by powerboat (Plates 3.4.1, 3.4.2 and 3.4.3*)*. The instrument used in the sampling is shown in Plate 3.4.4. A total of *22 sampling stations* were identified along the four main rivers in Brunei Darussalam.

BRUNEI RIVER

In this section the five main tributaries of the Brunei River are described. They are ***Salar, Batu Marang*** **,** ***Pandan*** **,** ***Kedayan*** and ***Damuan Rivers.***

Salar River

The Salar River sampling point is approximately 1.5km SSW of Jalan Muara and Jalan Kota Batu road junction. The area is about 1.53km^2. Geologically, the river flows through interbedded sandstones and mudstones of the Belait Formation, striking N25°E, and dipping 50-65° west. The alluvium is thin and sandy. The height of the river is approximately 12.7m founded on stripped bedrock. The volume of the river is 0.73Mm^3 and the maximum depth of water is 10.5m. The area is surrounded by mangrove and nipah swamps. (Plate 3.5.1).

Batu Marang River

Geologically, this river flows through interbedded sandstones and mudstones of the Belait Formation. The level of alluvium is thin and sandy. The volume of the river is somewhat less than that of the Salar River and the maximum depth of the water is about 4m. Physically, the bank is entirely covered with mangrove and nipah swamps (Plate 3.5.2).

Pandan River

This river flows through interbedded sandstones of the Belait Formation and the alluvium is thin and sandy. The volume of the sampling area of the river is somewhat less than 500m^3 and the maximum depth of water is about 3m. Wooden houses, wooden walkways and jetties, a mosque, schools and police station built by the government for the residents are situated on the banks of the river (Plate 3.5.3).

Kedayan River

As with the Pandan River, wooden houses, walkways and jetties along with schools, fire station and a mosque surround the area. The volume of the sampling area is also approximately 500m^3 and the maximum depth of water is about 3m. Geologically, the area is also interbedded with sandstones and mudstones of the Belait Formation and the alluvium is thin and sandy (Plate 3.5.4).

Damuan River

The sampling point on the Damuan River is situated about 100m upstream (west) of the Road Bridge on the coastal road. The area is about 9.5km^2. Again, geologically, the river flows through interbedded sandstones and mudstones of the Belait Formation, striking N25°E, and dipping 30° west. The Belait Formation is grading into the Miri Formation southwards. Soft alluvium is deposited in the flood plain of river. Oil seepage is reported locally and a fault may underlie this site. The height of the river is approximately 6.0m founded on soft to very soft alluvium. The volume of the river is 3.86Mm^3 and the maximum depth of water is 3.0m. Like the Salar River, the river is surrounded by mangrove and nipah swamps (Plate 3.5.5).

BELAIT RIVER

The sampling area of this river area has a volume of approximately 500m^3 and the maximum depth is about 4m. Geologically, the area is alluvium, clay and sand. The sampling area of the sampling is from the Belait district centre, which is comprised of modern facilities like schools, hospitals, mosques, police and fire stations along with a Marine Construction Yard and a Light Industrial area, to the area of an old and new sewerage treatment plant at Kampung Mumong, which is far from the city centre. The approach to the Kampung Mumong is entirely covered with mixed swamp forest. The sampling locations can be seen in Plates 3.6.1 to 3.6.5.

TUTONG RIVER

Geologically, this river is also situated on alluvium, clay and sand. The sampling area has a volume of approximately 500m^3 with a maximum depth of about 3m. The sampling points started from the Kelakas River tributary, which is surrounded by mangrove and nipah swamps, straight into the Tutong District centre, along the market and wood-cutting industry areas. The sampling ended at the beach area, very close to the sea. The sampling locations can be seen in Plates 3.7.1 to 3.7.6.

TEMBURONG RIVER

As with the Belait and Tutong rivers, the Temburong River has its geology alluvium, clay and sand. The volume of the sampling area is approximately 500m^3 and the maximum depth is about 3m. The area of sampling started from Batang Duri River, which is surrounded by mangrove and nipah swamps and stone-industry sites, to the Bangar town centre. The sampling locations went on further up to Getahan River, which is entirely covered with mangrove and nipah swamps. The sampling locations can be seen in Plates 3.8.1 to 3.8.6.

River stations were selected using the following criteria:

- Unpolluted area – eg. forest/jungle

- Area of industrial effluent (eg. gravel industry, logging industry) and sewage discharge
- Town centre, market and village area
- Area very close to petroleum station
- Area of confluence of main river and important tributary

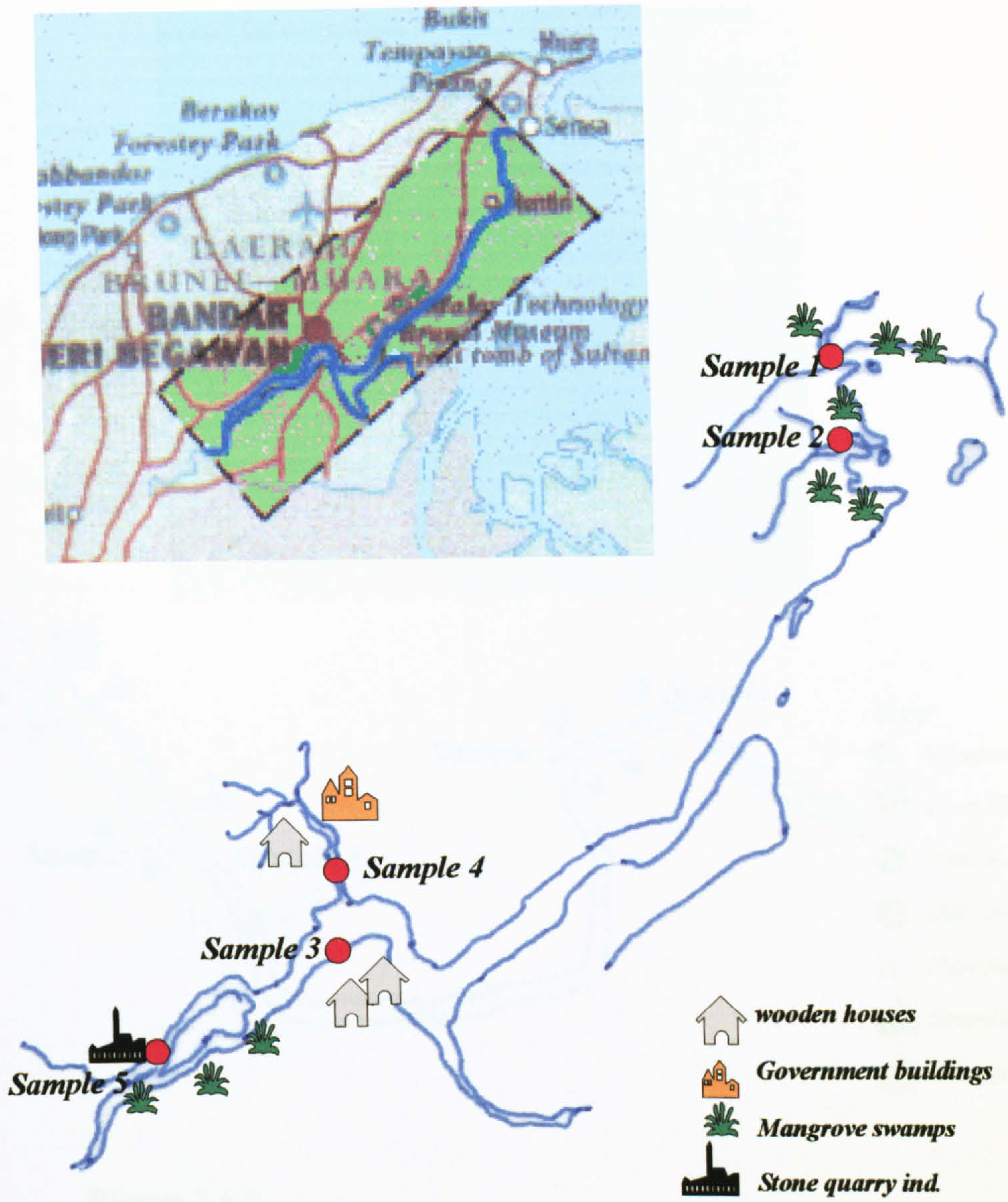


Figure 3.6.1
Map showing the course of the Brunei River and sampling stations

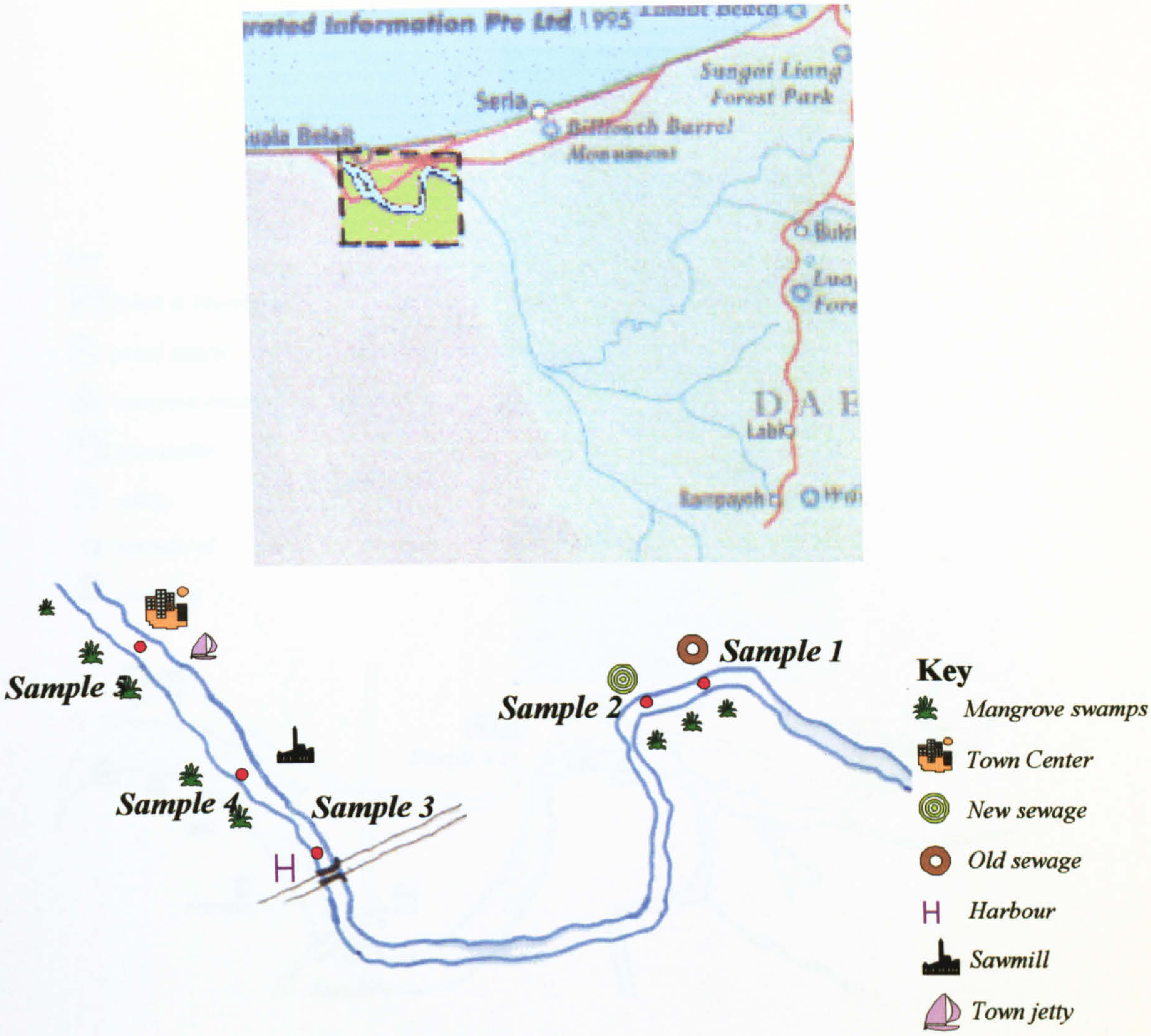


Figure 3.6.2
Map showing the course of the Belait River and sampling stations

Figure 3.6.3
Map showing the course of the Tutong River and sampling stations

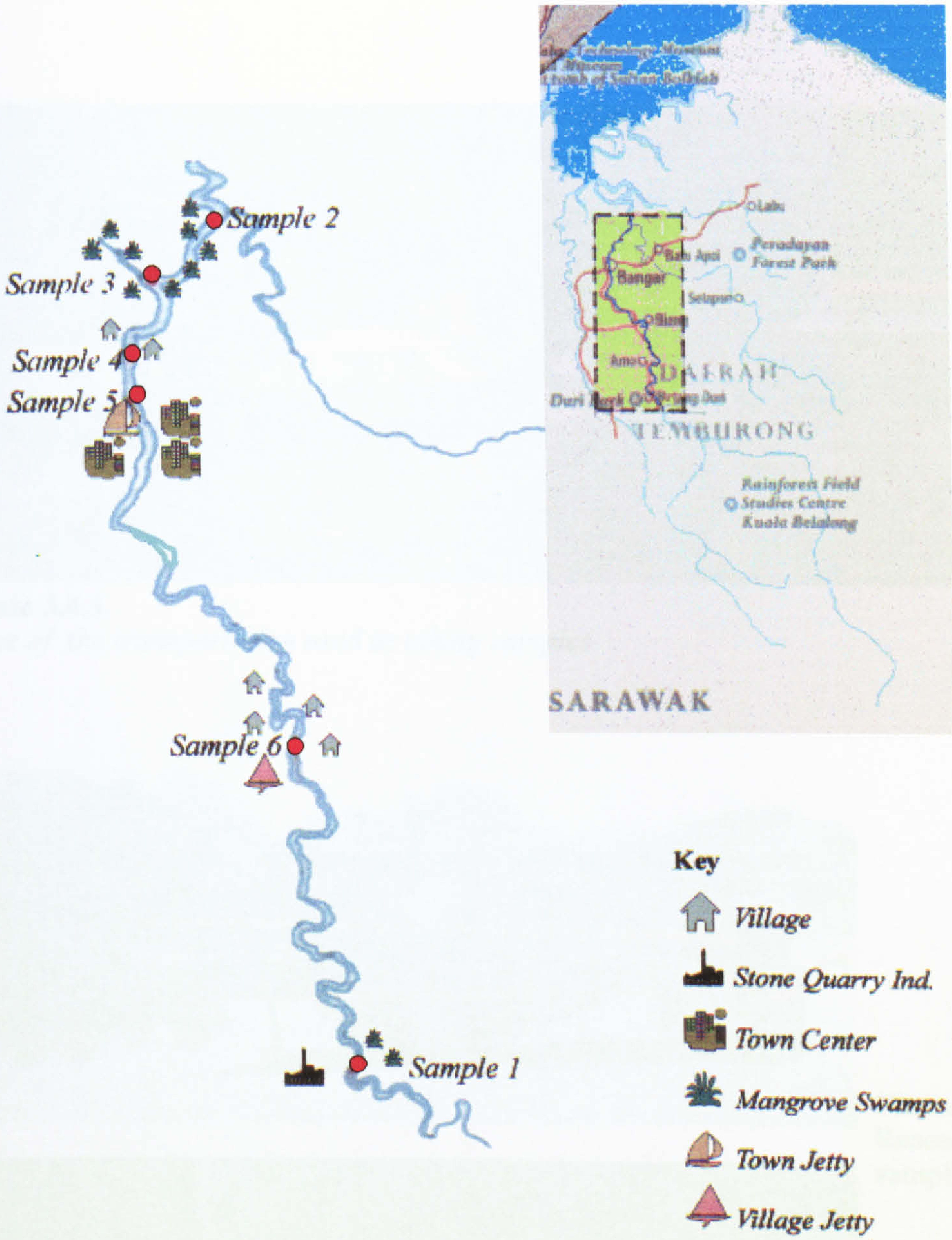


Figure 3.6.4
Map showing the course of the Temburong River and sampling stations

Plate 3.4.1
One of the transportation used in taking samples

Plates 3.4.2 and 3.4.3
Researcher on sampling expedition

Plate 3.4.4
Sampling Instrument - to collect water sample from the rivers.

Plate 3.5.1
Salar River - Surrounded by mangrove swamps.

Plate 3.5.2
Batu Marang River - Covered with mangrove and nipah swamps.

Plate 3.5.3
Pandan River - A view of the river surronding by a wooden houses, probably another source of pollution from the domestic activity.

Plate 3.5.4
Kedayan River - Probably moderate source of pollution from the domestic activity.

Plate 3.5.5
Damuan River - Stone quarry industry area which is probably a source of pollution. This area is a part of the quarry industry which some of the metal flow into the river.

Plate 3.6.1
Belait River - Old sewage treatment area

Plate 3.6.2
Belait River - New sewage treatment area

Plate 3.6.3
Belait River - Probably source of pollution

Plate 3.6.4
Sawmill industry area - Another source of pollution

Plate 3.6.5
Belait River - A view of town jetty, probably moderate source of pollution from transportation

Plate 3.7.1
Kelakas River - Thick Mangrove Undergrowth Swamp - Probably no source of pollution.

Plate 3.7.2
Tutong River beach area - Probably no source of pollution.

Plate 3.7.3
Probably a source of pollution from the sawmill industry.

Plate 3.7.4
Village area - Source of pollution from the domestic activity

Plate 3.7.5
Tutong River - Petrol Station, probably source of petroleum pollution.

Plate 3.7.6
Tutong River - A town jetty, probably moderate source of pollution.

Plate 3.8.1.1

Plate 3.8.1.2

Plate 3.8.2

Plate 3.8.3

Plate 3.8.4

Plate 3.8.1.1
Batang Duri River - Stone quarry industry area which is probably a source of pollution.
Plate 3.8.1.2
This area is a part of a quarry industry which some of the metal flow into the river.
Plate 3.8.2
Getahan River - Area is surrounded by thick mangrove undergrowth swamps.
Plate 3.8.3
Sulok River - Non mangrove river bank, pristine forest. Probably less source of pollution.
Plate 3.8.4
The main Temburong River - About 40% is a village area.

Plate 3.8.5
Temburong River - Town Center and Jetty areas, probably moderate source of pollution.

Plate 3.8.6
Temburong River - Village jetty, mild source of pollution from transport.

3.3 ANALYTICAL METHODS

3.3.1 Experimental Methods for Anions

0.01M of concentrated sulphuric acid (H_2SO_4) was prepared by mixing 2.8ml of concentrated sulphuric acid with deionised water making up the volume of 5 litres in a standard volumetric flask. The eluent was prepared by dissolving 0.25g of sodium hydrogen carbonate ($NaHCO_3$) and 0.933g of sodium carbonate (Na_2CO_3) making up the volume to 5 litres in standard volumetric flask with deionised water. Before injecting the water specimens into the Dionex instrument (Plate 3.1.1), separate standard solutions of bromide, chloride, fluoride, nitrate, phosphate and sulphate were made. After each sample of water was injected, the chromatography time was 15 minutes and the results were recorded according and shown in the chromatogram. To make sure that the results are reproducible and to avoid any probable experimental errors, each sample of river water was injected twice.

3.3.2 Experimental Methods for Monovalent Cations Analysis

5mM of concentrated hydrochloric acid solution was prepared by mixing 2.1ml of concentrated hydrochloric acid and make up the volume to 5 litres in a standard volumetric flask with deionised water. The suppressor reagent was prepared by diluting 65ml of a 25% aqueous tetramethylammonium hydroxide ($(CH_3)_4NOH$) solution to 5 litres in a 5 litres standard flask with deionised water. As in the anion experiments, before injecting the water specimens into the Dionex instrument for monovalent cations (Plate 3.1.1), separate standard solutions of sodium, potassium and ammonium were prepared. After each sample of water was injected, the chromatography time was 15 minutes and the results were recorded. The results are shown in the chromatogram. In order to make sure that the experiment is more accurate and to avoid any probable experimental errors, each sample of river was injected twice.

3.3.3 Experimental Methods for Divalent Cations Analysis

1.1g of meta-phenyldiamine (M-PDA) was weighed and diluted to 5 litres in a standard flask with deionised water. The second eluent and the suppressor solution were the same as described in the conditions for the analysis of monovalent cations. As in monovalent cation experiments, the separate standard solutions of calcium and magnesium were made before injecting the specimens into the Dionex instrument (Plate 3.1.1). Then the same procedure was applied.

3.3.4 Experimental Methods for Heavy Metals Analysis

500ml of water samples were concentrated into 50ml by heating between 60°C to 70°C. After cooling, the sample was injected in duplicate into the Dionex ion chromatography and allowed to run for 15 minutes and the results recorded. Before injecting the samples, the standard solutions of heavy metals (*copper, iron, cobalt, zinc, nickel, manganese* and *cadmium*) were injected (Plate 3.1.2).

3.4 ANALYTICAL RESULTS

3.4.1 Analytical Results for pH and Conductivity Analysis

Table 3.2 shows the results of pH and conductivity determinations for the four major rivers of Brunei Darussalam. The pH values for the 22 samples collected vary with the lowest being on the acidic side (pH 3.2) and the highest being neutral (pH 7.2).

TABLE 3.2

Sample	Date	Colour/ Weather	Characteristics	Av. pH	SD	Av. Conductivity (mS)	SD	Temp. (^0C)
Brunei River								
Sample 1	26/09/00	Clear, dry hot cloudy	*Salar River*. Surrounded by mangrove swamps.	6.1	±0.3	26.2	±0.3	23
Sample 2	26/09/00	Clear, dry hot cloudy	*Batu Marang River*. Covered with mangrove swamps.	6.2	±0.3	25.9	±0.3	23
Sample 3	26/09/00	Clear, dry hot cloudy	*Pandan River*. Surrounded by wooden-made houses.	5.2	±0.3	9.9	±0.3	23
Sample 4	26/09/00	Clear, dry hot cloudy	*Kedayan River*. Covered with wooden-made houses and other governments' buildings.	3.5	±0.3	2.92	±0.3	23
Sample 5	26/09/00	Clear, dry hot cloudy	*Damuan River*. Stone Quarry site.	3.6	±0.3	1.92	±0.3	23
Belait River								
Sample 1	11/08/00	Dull and Hot	*Mumong River*. Near the old sewage treatment.	4.0	±0.3	3.48	±0.3	23
Sample 2	11/08/00	Dull and Hot	*Mumong River*. Near the new sewage treatment.	3.8	±0.3	5.42	±0.3	23

Sample 3	11/08/00	Dull and Hot	Near shipyard area.	5.0	±0.3	15.9	±0.3	23
Sample 4	11/08/00	Dull and Hot	Near sawmill area.	5.0	±0.3	3.0	±0.3	23
Sample 5	11/08/00	Dull and Hot	Near the town and jetty area.	5.3	±0.3	3.7	±0.3	23
Tutong River								
Sample 1	10/09/00	Clear and hot	*Kelakas River*. Covered with mangrove swamps.	6.0	±0.3	4.81	±0.3	24
Sample 2	10/09/00	Clear and hot	Near playground and beach areas.	7.2	±0.3	3.16	±0.3	24
Sample 3	10/09/00	Clear and hot	Sawmill activity area.	6.9	±0.3	2.52	±0.3	24
Sample 4	10/09/00	Clear and hot	Near village area.	6.4	±0.3	1.11	±0.3	24
Sample 5	10/09/00	Clear and hot	Near petrol station site.	6.4	±0.3	1.35	±0.3	24
Sample 6	10/09/00	Clear and hot	Near town centre and jetty areas.	6.0	±0.3	5.81	±0.3	24
Temburong River								
Sample 1	20/08/00	Dull and hot	*Batang Duri River*. Stone Quarry area.	3.2	±0.3	3.22	±0.3	26

Sample 2	20/08/00	Dull and hot	*Getahan River.* Covered with mangrove swamps.	5.8	±0.3	3.42	±0.3	26
Sample 3	20/08/00	Dull and hot	*Sulok River.* Covered with mangrove swamps.	5.7	±0.3	7.45	±0.3	26
Sample 4	20/08/00	Dull and hot	Near village area.	5.8	±0.3	3.10	±0.3	26
Sample 5	20/08/00	Dull and hot	Near town and jetty areas	5.9	±0.3	3.06	±0.3	26
Sample 6	20/08/00	Dull and hot	Near village jetty areas.	5.4	±0.3	4.83	±0.3	26

It is universally agreed that a pH range of 5 to 8 is within normal levels, pH 5 being lower and pH 8 the upper normal limit. In any case, allowance must also be given to experimental error. Based on this assumption, it can be deduced that except for four rivers, all rivers of Brunei Darussalam have recorded pH levels of internationally acceptable limits of human tolerance of consumption. Four rivers showed marginal and/or significant difference in the pH reading.

Table 3.2 shows the results of pH and conductivity for Brunei Rivers. The lowest pH reading is recorded by Batang Duri River of Temburong District with a reading of 3.2. The highest pH reading level is recorded by Tutong River of Tutong District with a figure of 7.2, which is near the playground and beach areas.

Of some concern but not immediately to the research will be five stretches of rivers such as *Kedayan River* and *Damuan River* of Brunei River (pH 3.5 and 3.6), *old* and *new Mumong River* sewage treatment of Belait River (pH 4.0 and 3.8) and *Batang Duri River* of Temburong River (pH 3.2). Among these rivers, Batang Duri River shows a very low reading of 3.2 and Mumong River (*old and new sewage treatments*) shows a range of 3.8 to 4.0 pH values. However, all these rivers are well below normal levels and showed significant difference in the pH reading.

In table 3.2 data for Belait River, the pH values for sample 3 and 4 are similar (*pH 5.0*). The comparison between these two samples is in sample 3 where the location is near the shipyard area and in sample 4 the location is near the sawmill industry site. In table 4 for Tutong River, the pH values for sample 4 and 5 are similar (*pH 6.4*). One sample is in the village areas (sample 4) and the other one is very close to petrol station (sample 5). In Temburong River data (Table 4) for sample 2 and 4, the pH values are also similar (*pH 5.8*). For sample 2, the area is entirely covered with mangroves swamps whereas for sample 4, the area is in the village areas. The rivers in Tutong District have quite normal pH values in the normal range being between 6.0 and 7.2.

The results show that most pH measurements in the 4 major rivers in Brunei are in the range of normal situations except locations which are very close to the industrial sites. Table 3.2 shows that most of the sample with low pH values have high conductivities and associated with industrial activities.

Factors Affecting pH levels are:-

1. *Bacterial activity*
2. *Salinity levels.* pH levels fluctuate over time in an estuary (An estuary is a naturally occurring mixing of salt water with freshwater). Estuarine pH levels generally average from 7.0 to 7.5 in the fresher sections to between 8.0 and 8.6 in the more saline areas. The slightly alkaline pH of seawater is due to the natural buffering from the carbonate and bicarbonate dissolved in the water.
3. *Rate of photosynthesis.* pH levels are related to dissolved oxygen (DOC) levels. As DOC levels rise and carbon dioxide levels decrease with photosynthesis, pH will increase.

4. *Water turbulence.* The more the precipitation runoff is mixed with lake and stream water, the more the acid levels are diluted and the water's natural buffering capability can be implemented.
5. *Chemical constituents in runoff flowing into the water body.* Chemical toxins released into the water by poorly sealed sewage lines, chemical spills or dumping of harmful cleaners or other substances into storm drains can have dramatic effects on pH levels.
6. *Human activities* (in and outside the drainage basin) such as acid drainage from coal mines and acid precipitation. Human activities that cause large, short-term swings in pH or long-term acidification of a water body are exceedingly harmful. For instance, algal blooms, which are often initiated by an overload of nutrients, can cause pH to fluctuate dramatically over several hours, greatly stressing local organisms. Acid precipitation in the upper, freshwater reaches of an estuary can diminish the survival rate of eggs deposited there by spawning fish.

3.4.2 Analytical Results for Anions Analysis

The results for anions analysis in Brunei are shown in Table 3.3 and Figures 3.7.1 & 3.7.2 below. The results show that only chloride ions are detected in each sample for all four main rivers. This can be seen by comparing the chromatogram with the standard solutions in Figure 3.7.1.

In the Brunei River (Table 3.3), the greatest peak of chloride ion comes from Salar River (21.2mg/l) and Batu Marang Rivers (11.9mg/l) and the lowest comes from Kedayan River (0.02mg/l). This shows that both Salar and Batu Marang rivers have high levels of chloride ions in their water.

For the Belait River (Table 3.3), the highest level of chloride concentration comes from the shipyard area (29.1mg/l) and the lowest comes from sawmill site (4.18mg/l). For the Mumong Rivers (old and new sewage treatments), there is no chloride concentration in the rivers.

In the Tutong River (Table 3.3), the highest level of chloride concentration comes from the beach and playground areas (44.2mg l^{-1}) and the lowest comes from Kelakas River (6.2mg l^{-1}). In table 3.3 of Temburong River, the highest level of chloride concentration comes from Getahan River, which is considered to be near the sea area (4.28mg l^{-1}) and the lowest comes from the town centre of Temburong District and jetty area (0.68mg l^{-1}).

Figure 3.7.1
Anions: Standard Solutions

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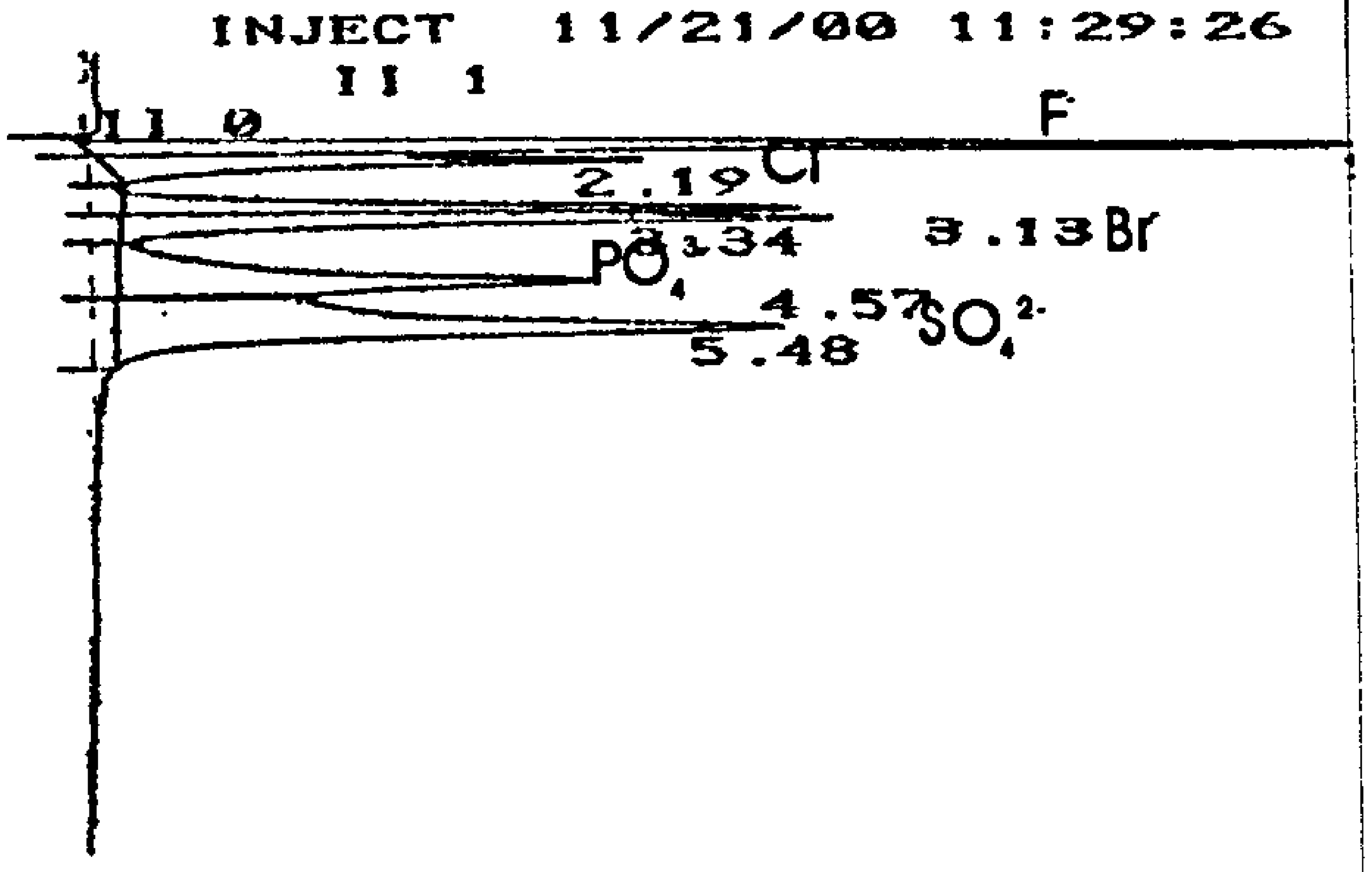


DATA SAVED TO BIN # 5

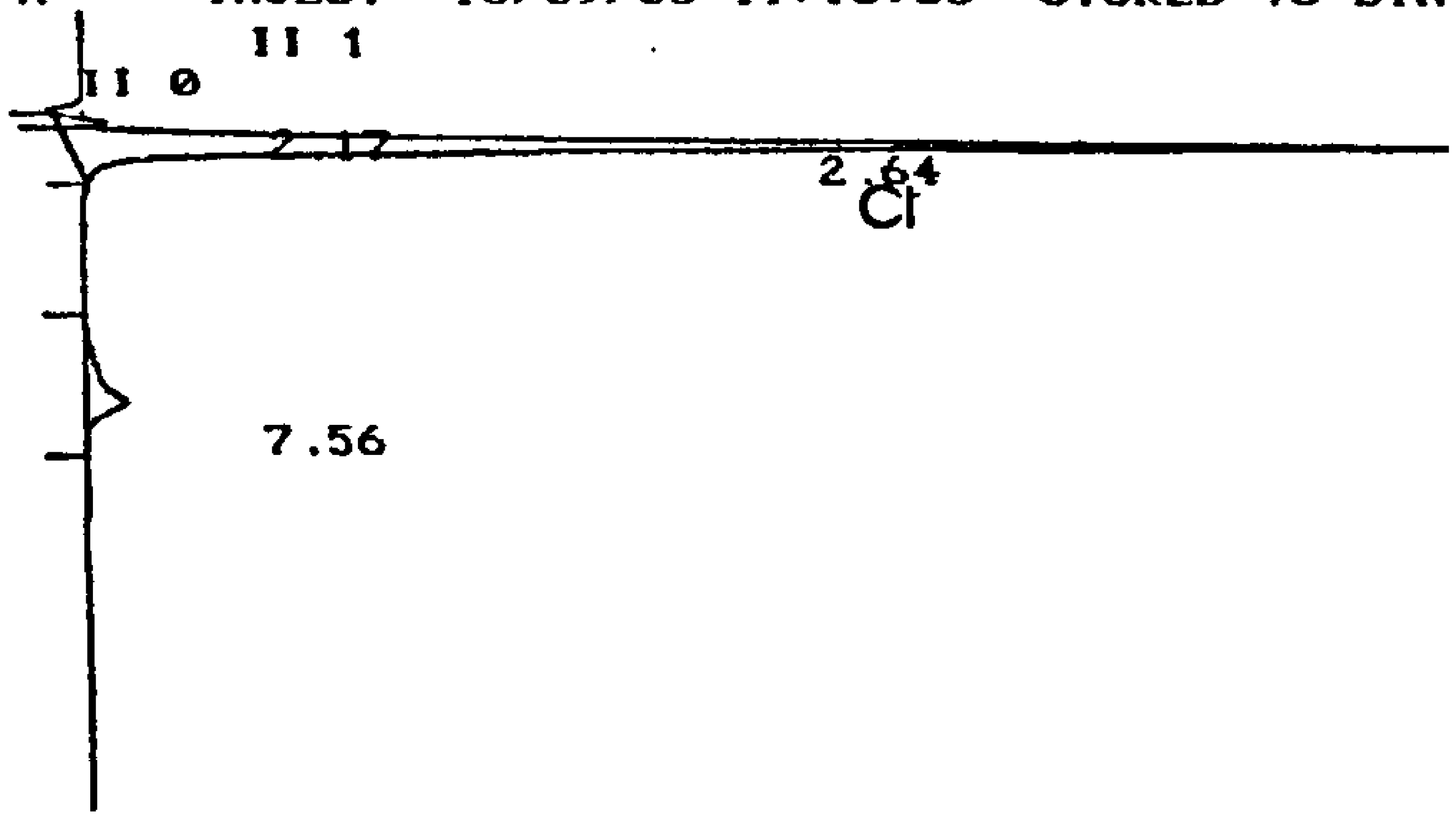
11/21/00 1

FILE 1. METHOD 0. RUN 5

PEAK#	AREA%	RT	AREA	BC
1	20.75	1.89	9134248	02
2	8.883	2.19	3910467	03
3	13.515	3.13	5949589	02
4	12.923	3.34	5688578	02
5	17.048	4.57	7504808	02
6	26.88	5.48	11832867	03
TOTAL	100.		44020557	

Figure 3.7.2
Anions: Salar River

CHANNEL A INJECT 10/09/00 11:13:55 STORED TO BIN



DATA SAVED TO BIN # 5

10/09/00 11:13:55 CH=

FILE 1. METHOD 0. RUN 5 INDEX 5

PEAK#	AREA%	RT	AREA	BC
1	2.416	2.17	421355	02
2	88.909	2.64	15506156	03
3	8.676	7.56	1513066	01
TOTAL	100.		17440577	

Table 3.3
(Chloride ions)

Sample	Characteristics	Average Concentrations (ppm)	Standard Deviation (SD)
Brunei River			
Sample 1	*Salar River*. This area is situated near the sea and it is entirely covered with mangrove swamps.	21.2	±0.8
Sample 2	*Batu Marang River*. The area is quite near to the sea and it is also covered with mangrove swamps.	11.9	±0.9
Sample 3	*Pandan River*. The area is entirely surrounded with wooden-made houses.	0.38	±0.01
Sample 4	*Kedayan River*. The area is very close to the mainland. It is also surrounded with wooden-made houses and other governments' buildings.	0.02	±0.01
Sample 5	*Damuan River*. The area is situated near the stone quarry industry site.	1.71	±0.1

Belait Rivers			
Sample 1	*Mumong River*. It is near the old sewage treatment.	0.00	±0.0
Sample 2	*Mumong River*. It is near the new sewage treatment.	0.00	±0.0
Sample 3	The area is situated near the shipyard site.	29.1	±0.9
Sample 4	The area is situated near the sawmill site.	4.18	±0.2
Sample 5	It is in town centre of Belait District and jetty areas.	6.08	±0.3
Tutong River			
Sample 1	*Kelakas River*. The area is covered with mangrove swamps.	6.17	±0.3
Sample 2	The area is situated near the beach and playground areas and mangrove swamps on one side of the area.	44.2	±0.9
Sample 3	It is at the sawmill industry site.	31.3	±0.9
Sample 4	It is at the village area.	15.8	±0.5
Sample 5	It is situated near the petroleum station.	20.3	±0.7

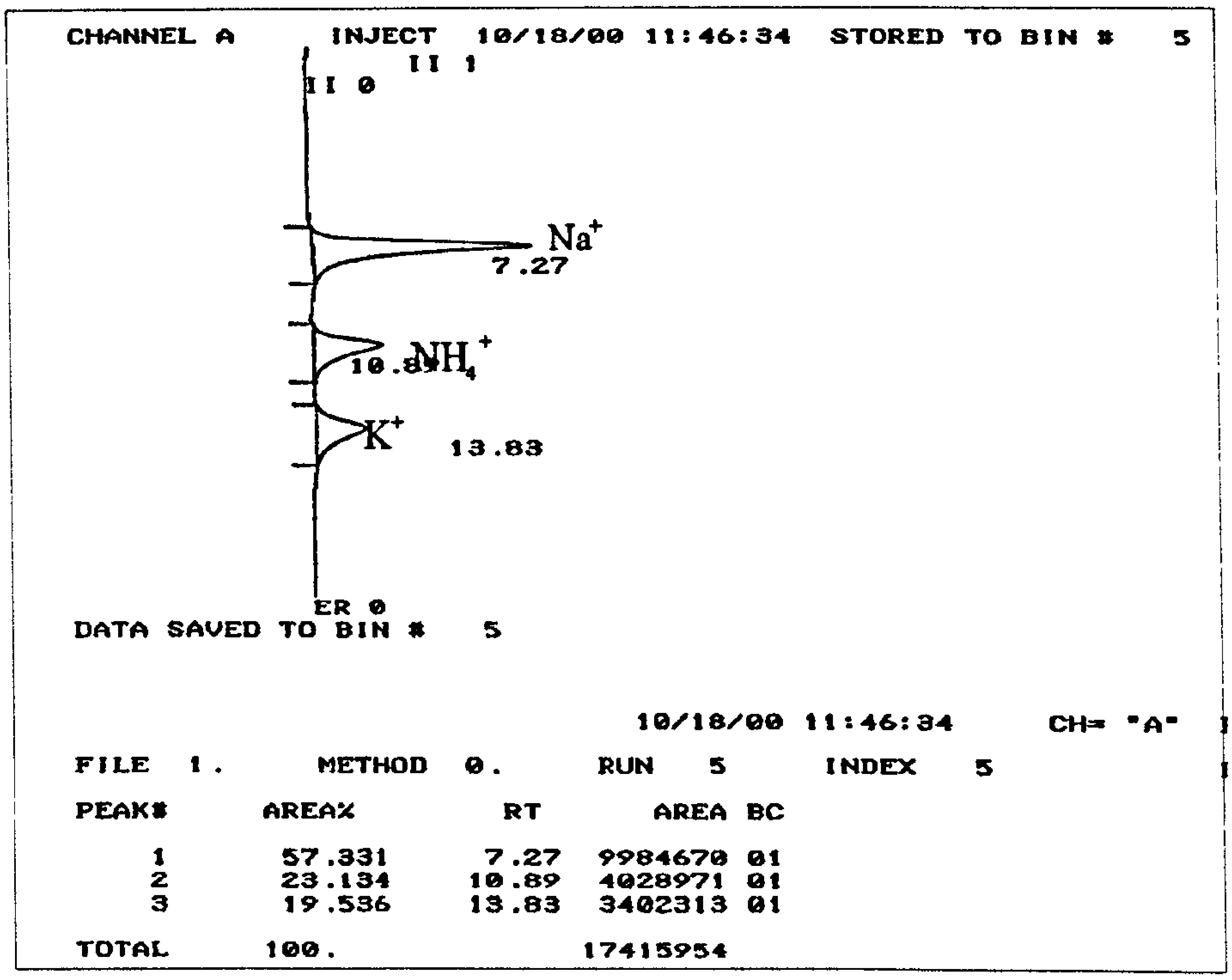
Sample 6	It is situated in the town of Tutong District and jetty areas.	9.18	±0.4
Temburong River			
Sample 1	*Batang Duri River*. The area is situated near the stone quarry industry site.	2.58	±0.1
Sample 2	*Getahan River*. The area is entirely covered with mangrove swamps.	4.28	±0.2
Sample 3	*Sulok River*. The site is covered with mangrove swamps.	3.07	±0.2
Sample 4	It is near the village area.	3.18	±0.2
Sample 5	It is in town of Temburong District and town jetty.	0.68	±0.02
Sample 6	It is near the village jetty	0.78	±0.02

The increase level of chloride ions in certain rivers mentioned above is due to its nearness to the seashore. For the rest of the rivers, the concentration of chloride ions in water is not as high as the other rivers which have high concentration of chloride ions. This could be due to the locations which are quite further up, away from the sea.

3.4.3 Analytical Results for Monovalent Cations Analysis

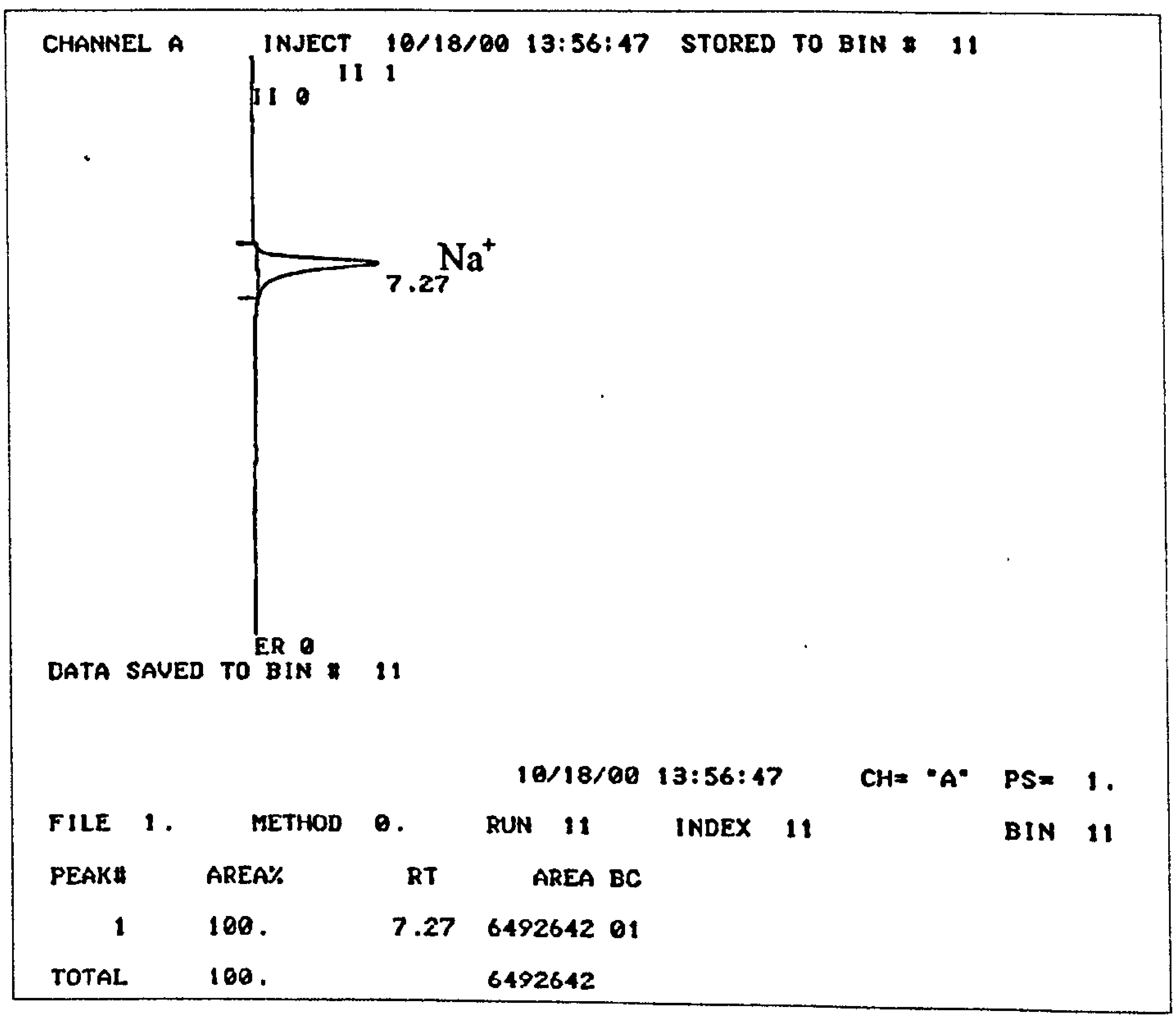
The results of the monovalent cations analysis can be seen in Table 3.4 and Figures 3.8.1 & 3.8.2. The results show that only sodium ions are detected in each sample for all main rivers in Brunei. This can be shown by comparing with the standard solutions for monovalent cations in Figure 3.8.1.

Figure 3.8.1
Monovalent Cations: Standard Solutions



PEAK#	AREA%	RT	AREA BC
1	57.331	7.27	9984670 01
2	23.134	10.89	4028971 01
3	19.536	13.83	3402313 01
TOTAL	100.		17415954

Figure 3.8.2
Monovalent Cations: Salar River



PEAK#	AREA%	RT	AREA BC
1	100.	7.27	6492642 01
TOTAL	100.		6492642

Table 3.4
(Sodium ions)

Sample	Characteristics	Average Concentrations (ppm)	Standard Deviation (SD)
Brunei River			
Sample 1	*Salar River*. This area is situated near the sea and it is entirely covered with mangrove swamps.	3.29	±0.4
Sample 2	*Batu Marang River*. The area is quite near to the sea and it is also covered with mangrove swamps.	2.49	±0.3
Sample 3	*Pandan River*. The area is entirely surrounded with wooden-made houses.	1.18	±0.2
Sample 4	*Kedayan River*. The area is very close to the mainland. It is also surrounded with wooden-made houses and other governments' buildings.	0.38	±0.1
Sample 5	*Damuan River*. The area is situated near the stone quarry industry site.	0.58	±0.1

Belait River			
Sample 1	*Mumong River*. It is near the old sewage treatment.	0.00	±0.0
Sample 2	*Mumong River*. It is near the new sewage treatment.	0.00	±0.0
Sample 3	The area is situated near the shipyard site.	7.38	±0.8
Sample 4	The area is situated near the sawmill site.	3.08	±0.4
Sample 5	It is in town centre of Belait District and jetty areas.	3.48	±0.4
Tutong River			
Sample 1	*Kelakas River*. The area is covered with mangrove swamps.	2.68	±0.3
Sample 2	The area is situated near the beach and playground areas and mangrove swamps on one side of the area.	9.80	±0.7
Sample 3	It is at the sawmill industry site.	12.0	±0.7
Sample 4	It is at the village area.	4.98	±0.6
Sample 5	It is situated near the petroleum station.	5.58	±0.6

Sample 6	It is situated in the town of Tutong District and jetty areas.	4.28	±0.5
Temburong River			
Sample 1	*Batang Duri River*. The area is situated near the stone quarry industry site.	2.48	±0.3
Sample 2	*Getahan River*. The area is entirely covered with mangrove swamps.	2.18	±0.3
Sample 3	*Sulok River*. The site is covered with mangrove swamps.	1.47	±0.2
Sample 4	It is near the village area.	1.48	±0.2
Sample 5	It is in town of Temburong District and town jetty.	1.14	±0.2
Sample 6	It is near the village jetty	1.75	±0.2

In the Brunei District, the highest sodium ion concentration comes from Salar River, which is 3.29mg l^{-1}. The lowest comes from Kedayan River (0.38mg l^{-1}). In the Belait District, the highest reading of sodium ion comes from Belait River near the shipyard area (7.38mgl^{-1}) and the lowest comes from sawmill site (3.08mg l^{-1}). Like chloride ions, for Mumong River of old and new sewage treatments, there is no sodium concentration in the rivers. The difference between the highest and lowest sodium concentrations is almost triple.

As for Tutong river, the highest sodium ion concentration comes from the river stretch near the sawmill. It shows a reading of 12.0mg l^{-1} (Table 3.4). On the other hand, the lowest sodium ion reading comes from Kelakas River (2.68mg l^{-1}).

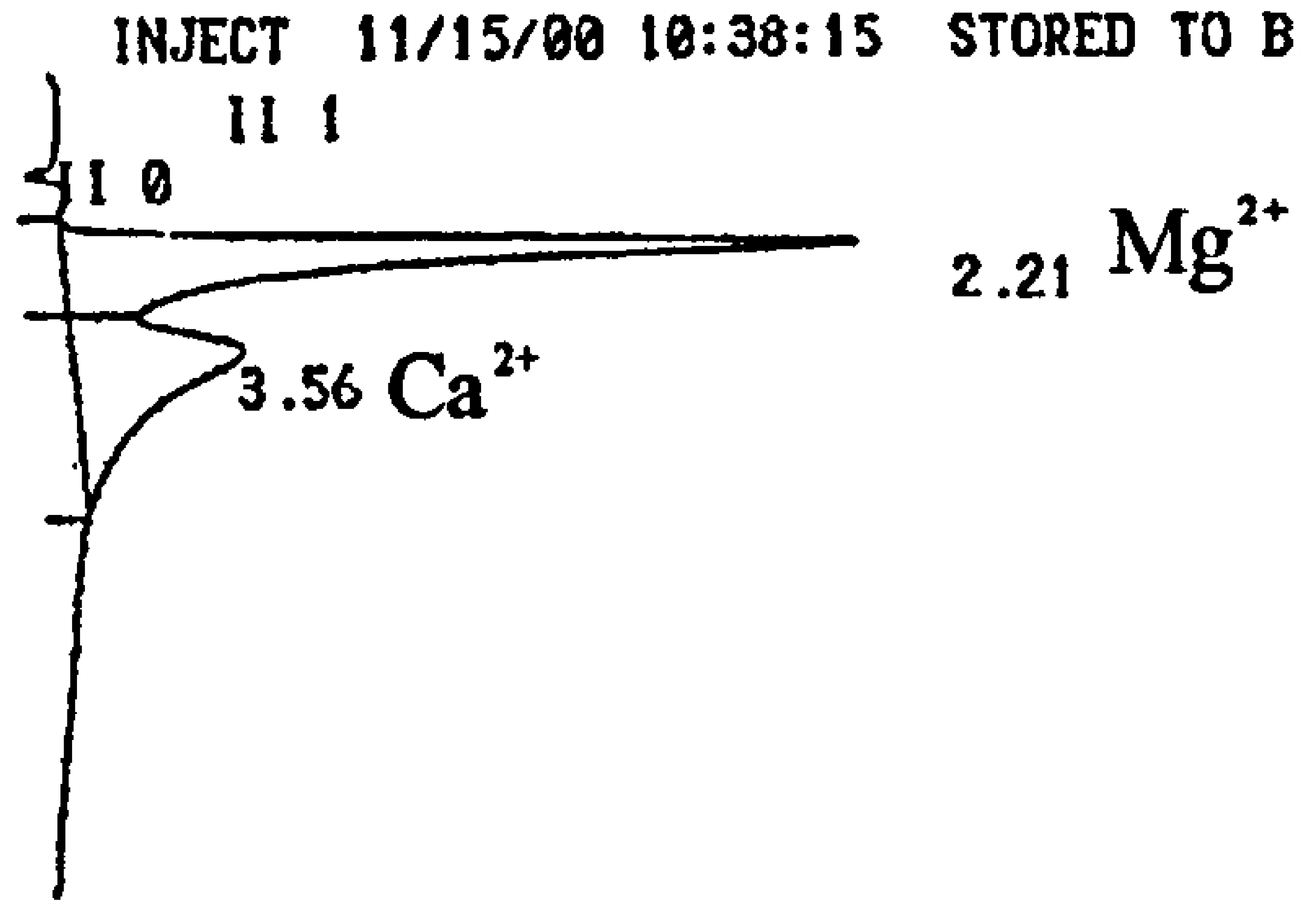
In the Temburong District, the highest sodium ion reading comes from Batang Duri River of Temburong Rivers (2.48mg l^{-1}), which is near the industrial site and the lowest comes from the areas near town and jetty (1.14mg l^{-1}). The difference between these two rivers is almost double but Batang Duri River has the lowest sodium concentrations.

The reason for the high level of sodium concentration in certain rivers mentioned above is due to their closeness to the seashore, where the water from the sea seep in and mix with the river water.

As for divalent cations (magnesium and calcium), both cations are absent or not detected in four major rivers in Brunei (Figures 3.8.3 and 3.8.4). Therefore, for all the 4 major rivers in Brunei Rivers, there are no divalent cations detected in the river waters.

Figure 3.8.3
Divalent Cations: Standard Solutions

CHANNEL A INJECT 11/15/00 10:38:15 STORED TO BIN # 3



DATA SAVED TO BIN # 3

11/15/00 10:38:15 CH= "A" PS= 1.

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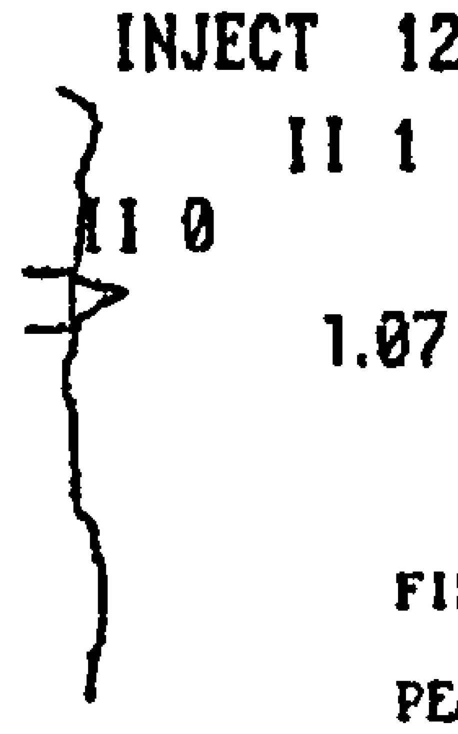
PEAK#	AREA%	RT	AREA BC
1	63.157	2.21	16349150 02
2	36.843	3.56	9537479 03
TOTAL	100.		25886629

Figure 3.8.4
Divalent Cations: Old Sewage Treatment

CHANNEL A INJECT 12/11/00 14:23:54 STORED TO BIN # 23



12/11/00 14:23:54

FILE 1. METHOD 0. RUN 23 INDEX 23

PEAK#	AREA%	RT	AREA BC
1	100.	1.07	471997 01
TOTAL	100.		471997

3.4.4 Analytical Results for Heavy Metals Analysis

The results for heavy metals are shown in Figures 3.9.1 to 3.9.2 and Table 3.5 below. The following discussion will be based on:-

- **Results obtained from the investigation undertaken in the present work.**
- **Comparison of the data for the Brunei Rivers Maximum Contamination Levels (MCLs) stipulated by the Environmental Protection Agency (EPA) of the United States of America.**

The long-term temporal trends of heavy metal pollution can be compared by looking at their concentrations for each sample of the rivers and the EPA standards for each metal, including comparison of various rivers from other countries. An overview of the heavy metal concentrations in the four main rivers of Brunei Darussalam is shown in Table 3.5.

TABLE 3.5

Sample	*Characteristic*	*Iron (mg/l)*	*Copper (mg/l)*	*Nickel (mg/l)*	*Zinc (mg/l)*	*Cobalt (mg/l)*	*Cadmium (mg/l)*	*Manganese (mg/l)*
Brunei River								
Sample 3	Pandan River. Surrounded by wooden-made houses	2.75	-	-	0.21	-	-	-
Sample 5	Damuan River. Stone quarry industry area	0.70	0.14	0.03	2.36	0.005	-	0.02

Temburong River								
Sample 1	Batang Duri River. Stone quarry industry area	0.05	0.07	-	1.60	0.001	-	0.01
Sample 5	Near the town and jetty areas	0.30	-	-	-	-	-	-
Belait River								
Sample 1	Near the old sewage treatment area	0.25	-	-	-	-	-	-
Sample 2	Near the new sewage treatment area	0.25	0.07	-	-	-	-	-
Sample 3	Near shipyard area	0.20	-	-	0.11	-	-	-
Sample 4	Near sawmill industry	-	-	-	-	-	-	-
Sample 5	Near town and jetty areas	-	-	-	0.64	-	-	-
Tutong River								
Sample 1	Covered with mangrove swamps	-	-	-	-	-	-	-

Sample 2	Near beach and playground areas	-	-	-	-	-	-	-
Sample 3	Sawmill activity areas	-	-	-	-	-	-	-
Sample 4	Near village area	0.05	-	-	0.32	-	-	-
Sample 5	Near the petrol station	-	-	-	-	0.01	-	-
Sample 6	Near town and jetty areas	0.50	0.07	-	-	-	-	-

Figure 3.9.1
Heavy Metals: Standard Solutions

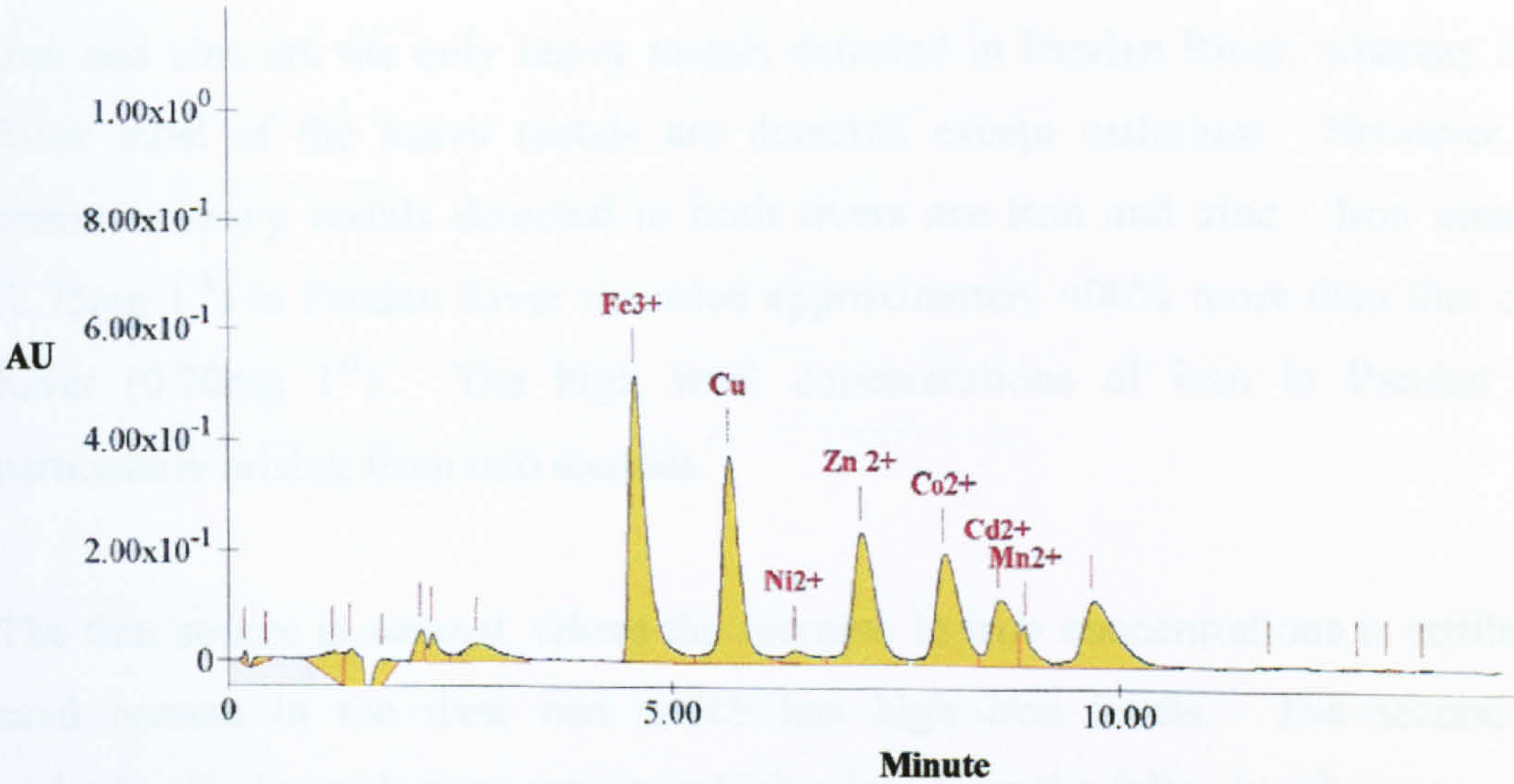
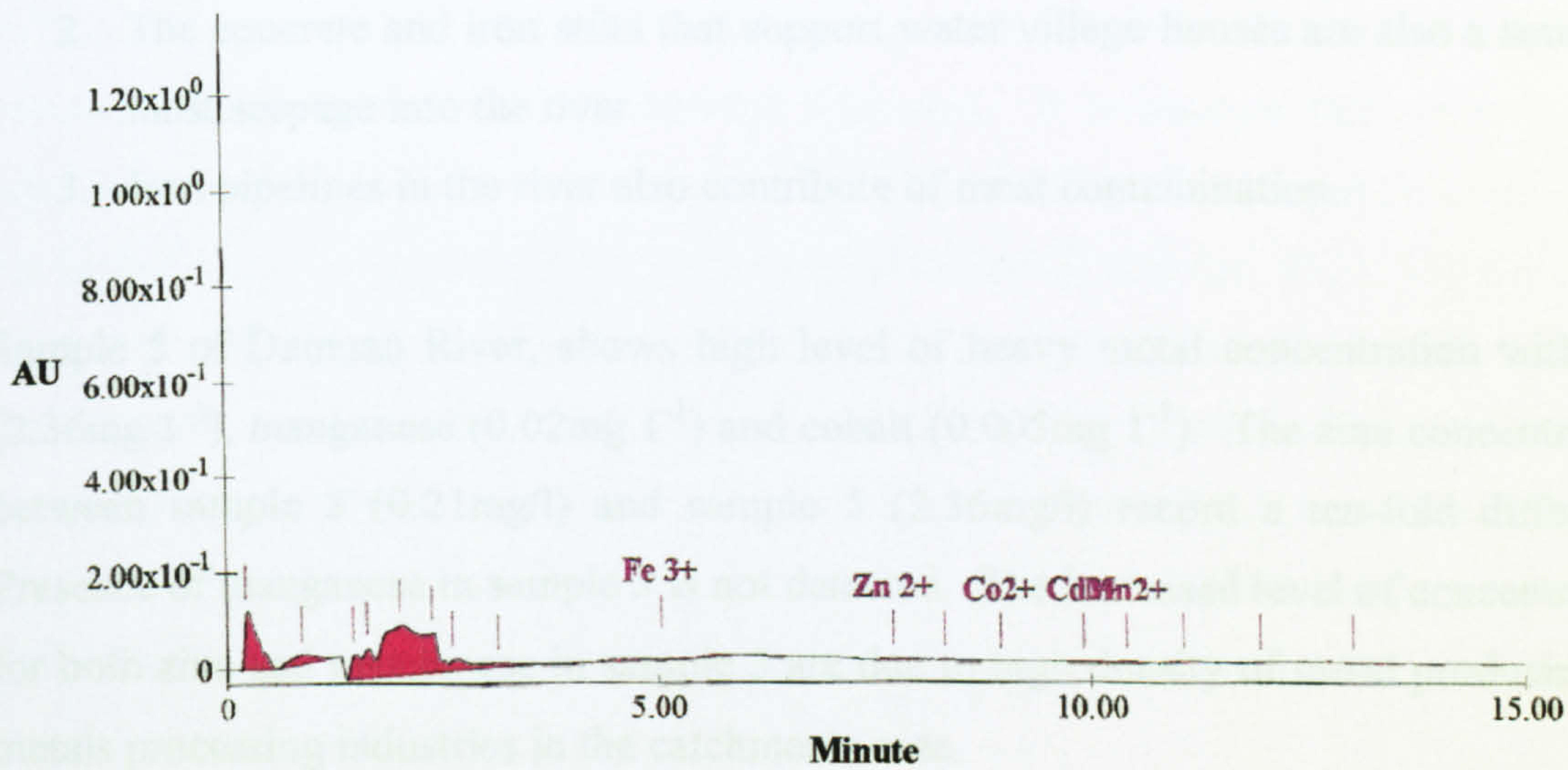


Figure 3.9.2
Tutong River (Near Beach and Playground Area)



Brunei River

Iron and zinc are the only heavy metals detected in Pandan River, whereas in Damuan River most of the heavy metals are detected except cadmium. However, the most common heavy metals detected in both rivers are iron and zinc. Iron concentrations (2.75mg l^{-1}) in Pandan River recorded approximately 400% more than that of Damuan River (0.70mg l^{-1}). The high level concentrations of iron in Pandan River are particularly arising from two sources.

The first source is *natural*, where the increase in iron concentrations is attributed to the sand present in the river bed which has high iron levels. The second source is undoubtedly due to *human activity*, which arises from the following factors:-

1. The rooftops from the wooden-made houses in Pandan River area have low quality of zinc plates, which eventually release iron from rusting.
2. The concrete and iron stilts that support water village houses are also a source of most seepage into the river.
3. Iron pipelines in the river also contribute of most contamination.

Sample 5 of Damuan River, shows high level of heavy metal concentration with zinc (2.36mg l^{-1}), manganese (0.02mg l^{-1}) and cobalt (0.005mg l^{-1}). The zinc concentrations between sample 3 (0.21mg/l) and sample 5 (2.36mg/l) record a ten-fold difference. Presence of manganese in sample 3 is not detected. The increased level of concentrations for both zinc and manganese in sample 5 are due to high density of metal producing and metals processing industries in the catchments area.

Temburong River

Table 3.5, shows that nickel and cadmium are the only heavy metals absent in Batang Duri River, whereas in sample 5 of Temburong River (near the town and jetty areas), only iron is detected. In Batang Duri River of the Temburong District, zinc (1.60mg l^{-1}) is the only heavy metals detected with increased concentrations in the water. There is a higher concentration of iron in the Damuan River (Brunei District with the reading 0.70mg l^{-1}) than in the Batang Duri River (Temburong District with a reading of 0.05mg l^{-}). The Damuan River has nearly 14 times more iron than the Batang Duri River. This is because of the frequency of the barges that carry stone back and forth. Damuan River stone quarry is visited everyday by many barges but Batang Duri River stone quarry is visited by occasional barges only. This is also because Damuan River is in the main District of the country whereas Batang Duri River stone quarry is situated in the least populated and isolated District of Temburong.

Belait River

In Belait River (Table 3.5), the result shows that the most common heavy metal detected is iron. No heavy metals are detected in sample 4. The only iron contamination is detected in samples 1 and sample 2 (0.25mg l^{-1}) which are from the old and new sewage treatment plants, and sample 3 (0.20mg l^{-1}) which is near the shipyard area. The difference between the old and new sewage treatment is that only copper ion concentration is detected in new sewage treatment. It is because that waste water is usually treated in sewage treatment plant and the resulting sludge contain considerable amount of copper originating from domestic and industrial sources. Most of the domestic copper comes from the piping used in household water systems. The remainder comes from faeces, because all the food we eat contain natural amount of copper. The old sewage plant area does not show any copper detected because it has been already closed. Table 3.5 shows no cadmium and manganese in Belait Rivers. Hence there is no serious pollution due do to cadmium and manganese. Other metals that do not exist in Belait River are cobalt and nickel.

Tutong River

Again only iron is detected in the Tutong river water samples with varying concentrations (Table 3.5). Table 3.5 shows the highest level of iron concentration comes from sample 6 of Tutong River, (0.50mg l^{-1}) and the lowest comes from sample 4, which is very close to a village area (0.05mg l^{-1}).

The difference between the area near the town and jetty of sample 6 (Tutong District), sample 5 (Belait District and Temburong District) is that in Tutong District, roads are not well connected but in Belait District, the roads are well connected because it is an oil mining District. This means more boats are used in Tutong District than in Belait District. In Temburong District roads are not well connected and people use boats but the population is just about 6,000 people. This is why the concentration in Temburong is less than that of Tutong.

Only in samples 1, 2 and 3, iron is absent. Other heavy metals detected in Tutong Rivers are copper, nickel, zinc and cobalt. But copper is detected only in sample 6 of Tutong River (Table 3.5). Zinc and cobalt, are detected only in sample 4 and sample 5 (Table 3.5). So none of these rivers discussed show any potential health hazard or serious contamination level in terms of copper and other heavy metals. Table 3.6 below shows the comparison data between Brunei Rivers and EPA maximum contamination levels.

Table 3.6

Comparison data between Brunei Rivers and EPA maximum contamination levels.

Metals	Brunei Rivers max. /min. (mg l^{-1})	Tutong Rivers max. /min. (mg l^{-1})	Belait Rivers max. /min. (mg l^{-1})	Temburong Rivers max. /min. (mg l^{-1})	EPA – Maximum Contamination Levels (mg l^{-1})
Iron (Fe)	2.75 (max.) 0.70 (min.)	0.50 (max.) 0.05 (min.)	0.25 (max.) 0.20 (min.)	0.30 (max.) 0.05 (min.)	0.3
Zinc (Zn)	2.36 (max.) 0.21 (min.)	0.32 (max.) -	0.64 (max.) 0.11 (min.)	1.60 (max.) -	5.0
Manganese (Mn)	0.02 (max.) -	- -	- -	0.01 (max.) -	0.05
Cobalt (Co)	0.005(max.) -	0.01 (max.) -	- -	0.001 (max.) -	0.02
Copper (Cu)	0.14 (max.) -	0.07 (max.) -	0.07 (max.) -	0.07 (max.) -	1.0
Nickel (Ni)	0.03 (max.) -	- -	- -	- -	0.04
Cadmium (Cd)	- -	- -	- -	- -	0.005

3.5 CONCLUSION

It can be concluded that only chloride ions are detected in the Brunei Rivers. Most of the highest level of concentration of chloride ion comes from the areas, which are very close to the sea and some come from industrial site. Most of the chloride ions in four major rivers in Brunei are below the standard guidelines and even the highest chloride concentration is 44.2mg l^{-1}. The chloride ions range from 44.2mg l^{-1} from Tutong River and 0.02mg l^{-1} from Kedayan Rivers of Brunei District. In fact, the EPA standard for normal chloride ion is around 250mg l^{-1}. This shows that all the four major rivers in Brunei are still free from chloride pollution.

The above results can conclude that only sodium ion, which is a monovalent cation is detected in 4 major rivers of Brunei. Calcium and magnesium are not detected in all 4 major rivers of Brunei. Most of the highest level of sodium concentration comes from the area near the sea and a few of them from industrial site. The overall sodium concentration in 4 major rivers of Brunei is below the EPA standards.

It can be concluded that most common of the heavy metal detected in four major Brunei Rivers is iron. The highest concentration of iron comes from Pandan River, a tributary of Brunei River and the lowest comes from Batang Duri of Temburong River and Tutong River, which is near the village area. Manganese concentration is detected only in Batang Duri River of Temburong River and Damuan River of Brunei River.

It should be also concluded that Damuan River of Brunei River and Batang Duri River of Temburong River have most of the metals detected. The difference between the stone quarry areas (*Damuan and Batang Duri Rivers*) is that only cadmium is not detected in Damuan River, whereas nickel and cadmium are not detected in Batang Duri River.

The sawmill areas of Tutong and Belait Rivers are similar in terms of the heavy metals content in the water. Both do not have any iron detected in the water. In the town and jetty areas, experiment shows that Tutong River records the highest reading (0.50mg l^{-1})

of iron concentration whereas Temburong has moderate detection (0.30mg l^{-1}). Surprisingly, Belait does not show any detection of iron.

Iron iscted tede in both old and new sewage treatment areas in Mumong River of Belait Rivers. The area near the new sewage treatment shows copper detected but not in the area near the old sewage treatment. The results show that only iron concentrations are beyond the EPA standards (0.30 to 2.75mg l^{-1}: EPA – 0.3mg l^{-1}).

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