WATER RESOURCES MANAGEMENT AND DEVELOPMENT IN NIGERIA - ISSUES AND CHALLENGES IN A NEW MILLENIUM

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TABLE OF CONTENTS

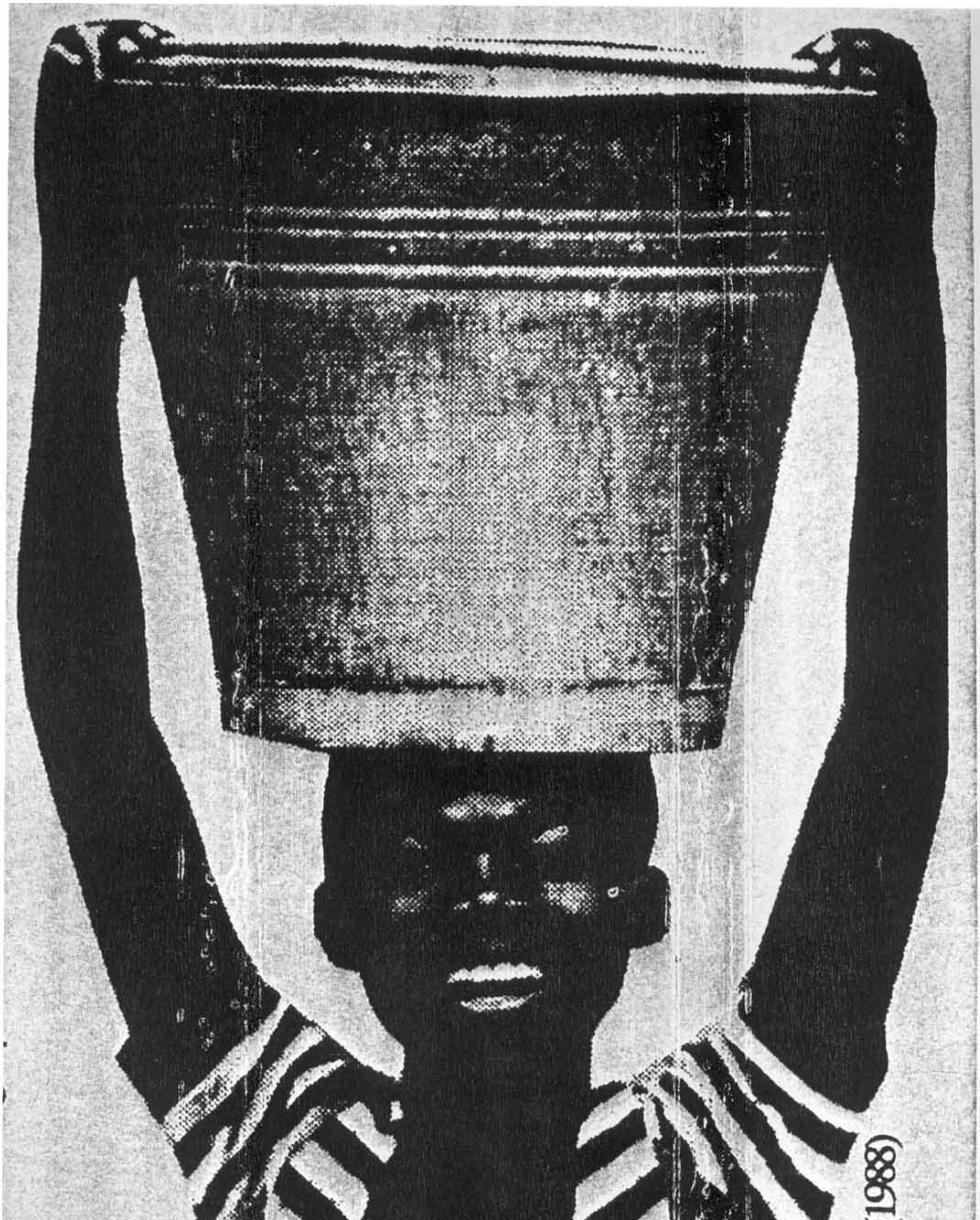

Figure 1 The Water Fetcher

PREAMBLE

Any Nigerian, older than 30 years, is familiar with this picture, **Fig. 1** – the portray of a young boy in search of water to cover the domestic needs of his family. It does not matter to him how far away the source of water is and he cares less about the quality of the water. All he is concerned with is to fetch water as directed. The special areas of water resources development and management seek to make water available at the time and place required, and in suitable quantity and quality. In fulfilling this task, hydrological, hydro-geological and hydrochemical tools are applied to solve a major socio-economic problem.

"ALL LIFE IS WATER", said Thales, the Greek philosopher, who lived between 640 and 540 BC.

Water resources development and management is as old as mankind. In Exodus 17: 1-6, God provided the children of Israel with water in a miraculous way on their flight through the Sinai desert to the promised land. In 2 Kings, chapter 2: 19-22, Elisha, the prophet of God cleaned the well of Jericho, which had become contaminated. And when a remnant of repentant Israelites returned from Babylon to their homeland, God led them to "water in the wilderness" - Isaiah 43: **14**, 19-22.

IAn .. adequate supply of "clean" water is one of the most basic human needs - and one that is not met for more than half of the world's population. According to various estimates, one-half to two-thirds of the world's population does not have access to adequate quantities of safe drinking water or sanitation. The United Nations declared the 1980s to be the "Water and Sanitation Decade" and directed the World Health Organization to carry out necessary actions to ensure that the world's people were provided with water and sewage facilities. The task was much larger than anticipated. At the end of the decade, large areas of the world and most the world's population still received inadequate water quantity and quality- in fact, an estimated 1.2 billion people were still without safe drinking water (UNESCO, 1992). Food supply and adequate nutrition also depend on adequate water, and associated costs in human lives, human potential, and economic costs mostly to African countries are incalculable.

Through the adoption of resolution AlRES/47/193 of22nd February, 1993, United Nations declared the 22nd March of each year as World Water Day, to be observed, starting from 1993. The aim is to create public awareness on the benefits of clean water, and problems of Later supplies.

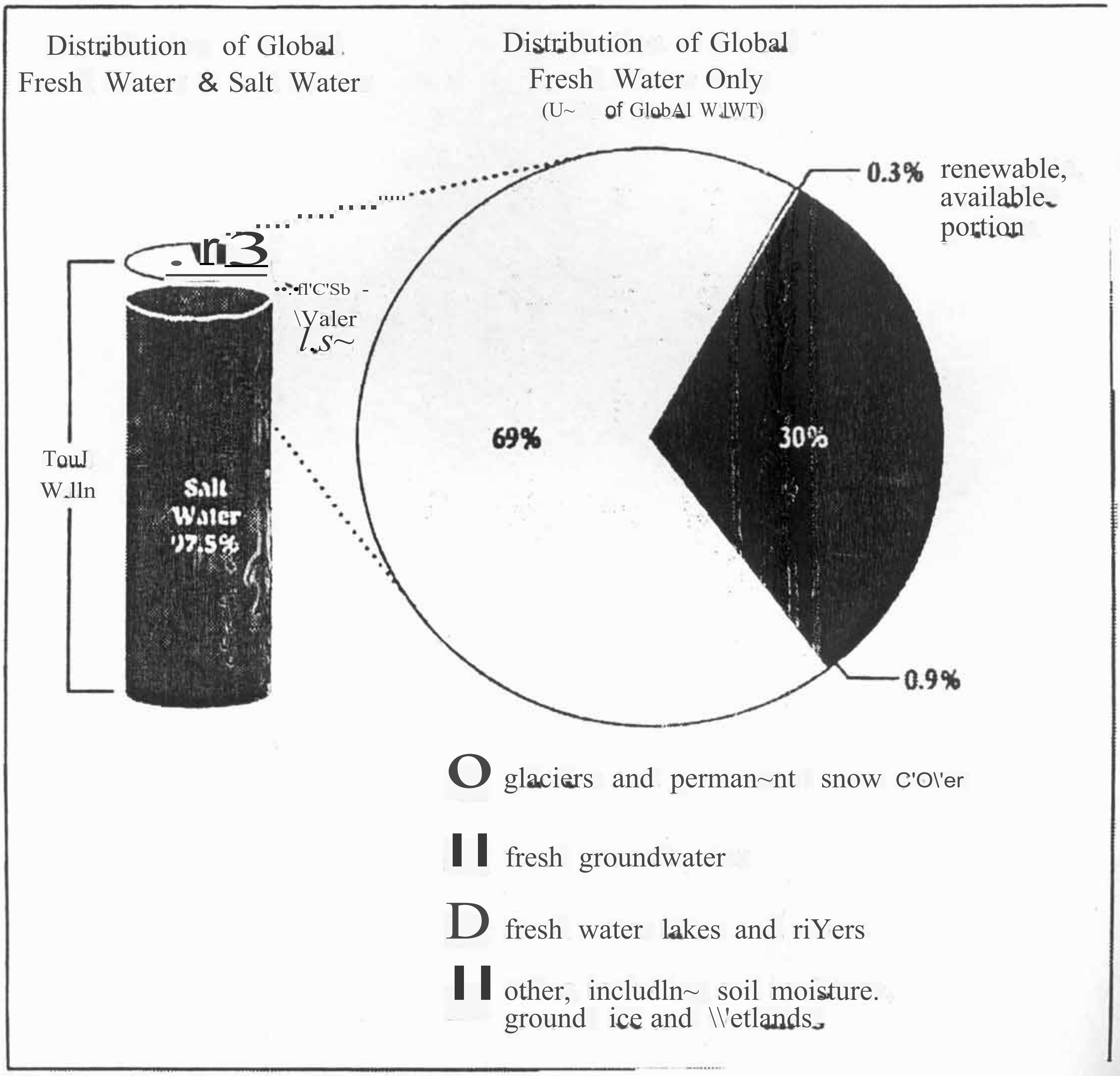

Fig.2: Distribution of Global Water Resources.

1. INTRODUCTION

Water is the most basic natural resource. More than 97% of the earth's water, for example, is saline ocean water (**Fig.** 2). Another largely unavailable reservoir of water is the 2% of the earth's water frozen in polar ice caps and glaciers. Of the remaining 1% of'the earth's water, more than half (0.6% of the total supply) is contained in groundwater (Shiklomanov, 1993).

Water's unique and vital role in nature stems from its wide range of unusual physical properties that define ways in which water can be used and treated. Some of the most important of these properties include the following:

[a] The wide range of temperatures at which water remains liquid

[b] Unusually high boiling and freezing points.

[c] Attainment of maximum density at 4°C, and a decrease of density as water cools between 4°C and O°C.

[d] An ability to hold a relatively constant temperature, thus buffering temperature changes (i.e. its high specific heat).

[e] Low viscosity that decreases with increasing pressure.

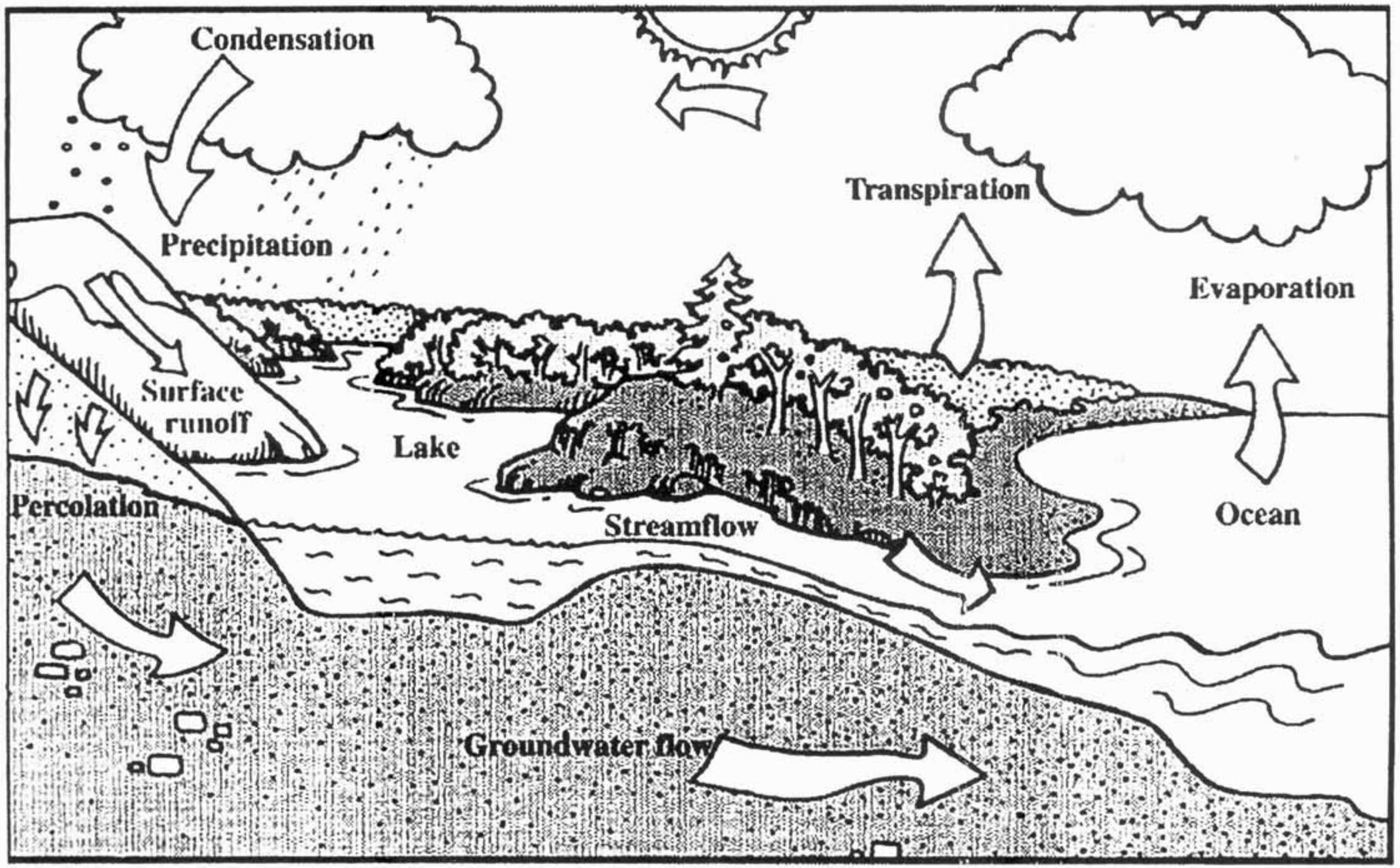

Fig.3: The Cyclic Path of Water

Other critical properties of water derive from its distinctive chemical structure and its unique, high density. The hydrogen bonds themselves make water molecules 'dipolar" (slightly positive at one end and slightly negative at the other), which enables water to dissolve more substances than any other liquid on earth.

These properties define possible human uses of water and explain why water can be found as a gas in the atmosphere, as a liquid both above and below ground, and as a solid wherever the temperature falls below 0^oC.

2.WATER CYCLE

An evidence of water's cyclic path can be found in the Bible – Ecclesiastes, chapter 1, verse 7, and I quote

" All rivers run into the sea, yet the sea is not full: unto the place from which the rivers cause, thither do they return again".

Water is cycled among the atmosphere, hydrosphere and lithosphere in a process called the hydrologic cycle: water is evaporated from surface waters or transpired from plant surfaces, released into the atmosphere, carried by wind, and returned to the earth as precipitation. The components of the hydrologic cycle are: precipitation, evaporation, transpiration, infiltration, percolation and run-off.

It should however be noted that the oceans are considered the sources of all water on earth **(Fig. 3)**. The continuous stream of energy originating in the sun and reaching the earth causes the evaporation of water from the oceans. Meteorological processes result in the precipitation of part of the atmospheric water vapor. Water then reaches the ground as liquid, and eventually finds its way back to the ocean, thus closing the hydrologic cycle. At smaller temporal and spatial scales, however, the movement of water in the hydrologic cycle is more complex, with water moving at different rates through the different water "reservoirs". How long water remains in each reservoir (i.e. its residence time) and the spatial extent of a given reservoir both have important implications for regional and local water quantity and quality.

Man has always tried to tap the hydrologic cycle at one or more points in order to utilize the water for a variety of purposes. The attempts to take advantage of certain aspects of the hydrologic cycle gave rise to water resources projects of a wide range of sophistication. Nigeria developed a number of programmes since the early sixties to provide water for people in general. The first National Development Plan Period of 1962-1968 contained the first attempt of the Federal Government at water resources development. Lake Chad and River Niger Basin Commissions were set up with neigbouring countries and within the country, the Sokoto Rima and the Chad basin Development Authorities were established in 1976. The number of River Basin Development Authorities, after several modifications, stands at 12 as at today. Their major assignments, expectedly, are to ensure the development of water resource potentials in their respective areas of operation. In recent times, other Agencies set up to enhance water resource development and management, include :National Water Resources Institute, Agricultural Development Projects (ADPs), National Council on

Water Resources, the defunct Directorate of Foods, Roads, and Rural Infrastructure (DFRRI) and the Petroleum Trust Fund (PTF). International organizations are involved in the race to develop Nigeria's water resources. Notable ones are: UNICEF, FAO, UNDP, WHO, and USAID. Between 1980 and 1990, several international loans were taken to address the issue of water scarcity, all yielding little dividend. For example in 1992, the Federal Government launched the National Water Rehabilitation Scheme with a USD 1.12 Billion foreign loan, taken on behalf of the 30 existing States. This was in addition to other loans of unspecified amounts taken from World Bank, African Development Bank, the Paris Club, etc. for water projects, that were mostly poorly executed. Yet, all hope is not lost as the Federal government in 2001 plans the construction of 23 000 boreholes in all the Local Government Areas of the country.

2.1 Hydrologic Reservoirs

Atmospheric water, surface water, and groundwater are all part of the hydrologic cycle, but each of these different reservoirs has a unique potential for water resource development and management. A large part of that potential relates to how quickly or slowly water is replenished or its quality degraded in the reservoir (i.e., residence time). The world's oceans represent the reservoirs with the largest residence time and hence, the smallest potential for degradation in the short run but the greatest risk for long-term degradation. Water may remain for hundreds of years in the ocean and travel for hundreds to thousands of kilometers before being recycled to atmospheric water and distributed elsewhere. The oceans' sheer volume makes them resistant to pollution impacts (they dilute inputs to a nondetectable level). Long residence time of oceanic waters means, however, that any pollutants and their effects persist for long periods.

In contrast, water in a lake has a shorter residence time and smaller spatial distribution. It is more susceptible to pollution because the diluting volume of water is lower.. At the same time, the lake will recover relatively quickly from any effects (once the source of the effect is removed) as the lake water is renewed. Similarly, atmospheric water is cycled back to the surface relatively quickly, so if a pollution source is removed, atmospheric water quality will recover quickly. Because it travels large distances, atmospheric water diffuses some pollutants and redistributes others.

2.1.1 Atmospheric Water

Distribution of atmospheric water in Nigeria is variable not only in time but in space, being highest in coastal areas, decreasing inland. Mean annual rainfall in the wettest areas ranges between 2500mm-4000mm while mean annual rainfall in the driest regions are between 100mm and 400mm. Major watersheds have a rainfall range of 1200mm and 1500mm. The mean number of rainy days therefore decrease from south to north:

- near the coast, 200 days
- north-west, north-east, 40 days
- south-west, 100 days

- south-east, 200 days
- 10s Plateau, 100 days

On the average, atmospheric water has a residence time of approximately 10 days. While that residence time is among the shortest of all hydrologic reservoirs, atmospheric water is also carried the farthest distance during that short time: air masses can be hundreds of kilometers wide and can carry water at speeds exceeding 100 km/sec.

An estimated generalised distribution of annual precipitation is such that 60-75% of rainfall is lost to evapo-transpiration, 10-15% recharge the groundwater reserve, while less than 15% is available as surface run-off The total run-off is therefore low relative to rainfall.

Nigeria receives an estimated 560 $x10^9$ m^3 of atmospheric water annually.

2.1.2 Hydrospheric Water

The hydrosphere encompasses all surface waters, from oceans to lakes and streams.

Nigeria is bounded in the south by the Atlantic Ocean, adjacent to a coastline of over 850 km long. The coastal zone, extending to about 40 km northwards, is characterised by enormous water resource potential, particularly the lagoons, creeks and estuaries.

Nigeria's land surface is well-drained by rivers and streams, the Niger river being the most prominent..

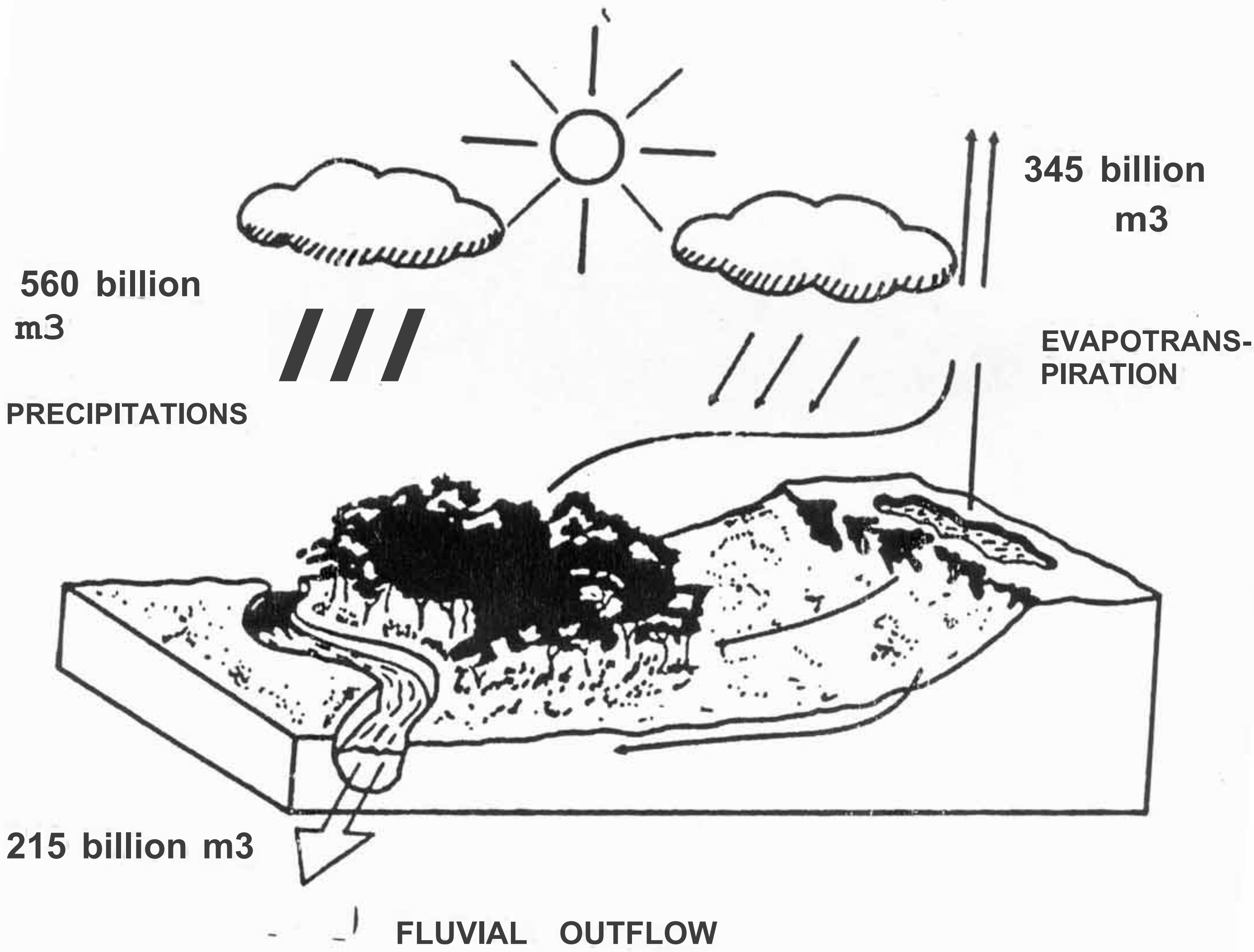

Fig.4: Nigeria's Surface Water BUdget

The surface water resource of the country can be assessed by defining the major drainage basins covering the area. Generally, five drainage systems are identified:

- Niger -Benue river System
- Chad lake system
- Cross river Basin
- Anambra river Basin
- Ogun- Oshun Basins.

These are further subdivided into hydrological areas, whose boundaries more or less coincide with the areas of operations of the River Basin Development Authorities (RBDAs) - Fig 5 .

From the annual total rainfall of 560 km^3, surface run-off is estimated at 215 km^3/yr, distributed among the major drainage systems as follows (Martins, 1995)- Fig. 4:

- Niger-Benue	: 127×10^9 m^3
- Chad	: 0.63×10^9 m^3
- South-east (Cross R., Anambra R., etc.)	: 66×10^9 m^3
- South-west (Ogun R., Oshun R., etc.):	22×10^9 m^3

The Niger-Benue system alone accounts for over 50% of the total annual run-off.

In spite of its transboundary nature (the Niger is shared by 11 countries), Nigeria derives the greatest benefit from the Niger river as 26% of its drainage basin is located within her boundary.

With an annual discharge of 127 km^3 (Martins & Olofin, 1991), the river's water resource potential is being grossly under-utilised, the most important hydraulic structures being the hydropower dams at Kainji, Jebba and Shiroro. To date, up to 70% of the total run-off from this major basin are derived locally from watersheds within Nigeria's political boundaries. However, the distribution of river waters varies both in time and space. Available discharge data for the Niger reveals that the river can be divided into an upper and lower course, with the line of demarcation located upstream of Kainji Lake. The upper course is characterised by a downstream increase in discharge, while the water volume increases down the river in the lower course (Martins, 1988a). Average annual water flow from the upper into the lower drainage basin is estimated at 1750 m^3/s; tributary inputs progressively increase the discharge downstream, reaching an average of 5500 m^3/s at Lokoja, and 6000 m^3/s at the delta.

Virtually all Nigerian rivers depict temporal variation of discharge. The hydro graph of the Niger at Onitsha (**Fig. 6**) demonstrates that the lower drainage basin is characterised by distinct high and low water periods, which occur from June to November and from December to May, respectively. The difference between the minimum and maximum discharge levels within a hydrological year is about 1: 13 (Martins, 1983; Martins and Probst, 1991). In addition to this rather simple configuration of river discharge variation, typical of sudano-sahelian area, rivers within the equatorial zone have bi- modal hydrograph and peak discharges occur in June/July and September/October - Martins and Awokola, 1996. **(Fig. 7)**.

Rit in Fig 7

2.1.3 Lithospheric Water

The lithosphere consists of water in soil and rocks under the soil. On a large scale, it is the largest reservoir of fresh water available for human consumption, although exact measurements of its volume are elusive. Estimates of groundwater volume (water in the saturated zone) range from 8 million km^3 to 10 million km^3 (Shiklomanov 1993). Long considered an inherently safe water source, groundwater is now recognized to be highly vulnerable. Groundwater moves extremely slowly, often on scales of tens of meters per year. Consequently, groundwater is renewed very slowly and is subject to build-up of contaminants. Residence times of groundwater discharges to the sea are approximately 4000 years; the potential for pollutants to accumulate in this water is, therefore, extremely high.

2.1.3.1 Groundwater Provinces

Nigeria's groundwater potential is estimated at 106×10^9 m^3 , distributed thus:

Northern zone – 17%

Central zone - 43%

Southern zone – 40%

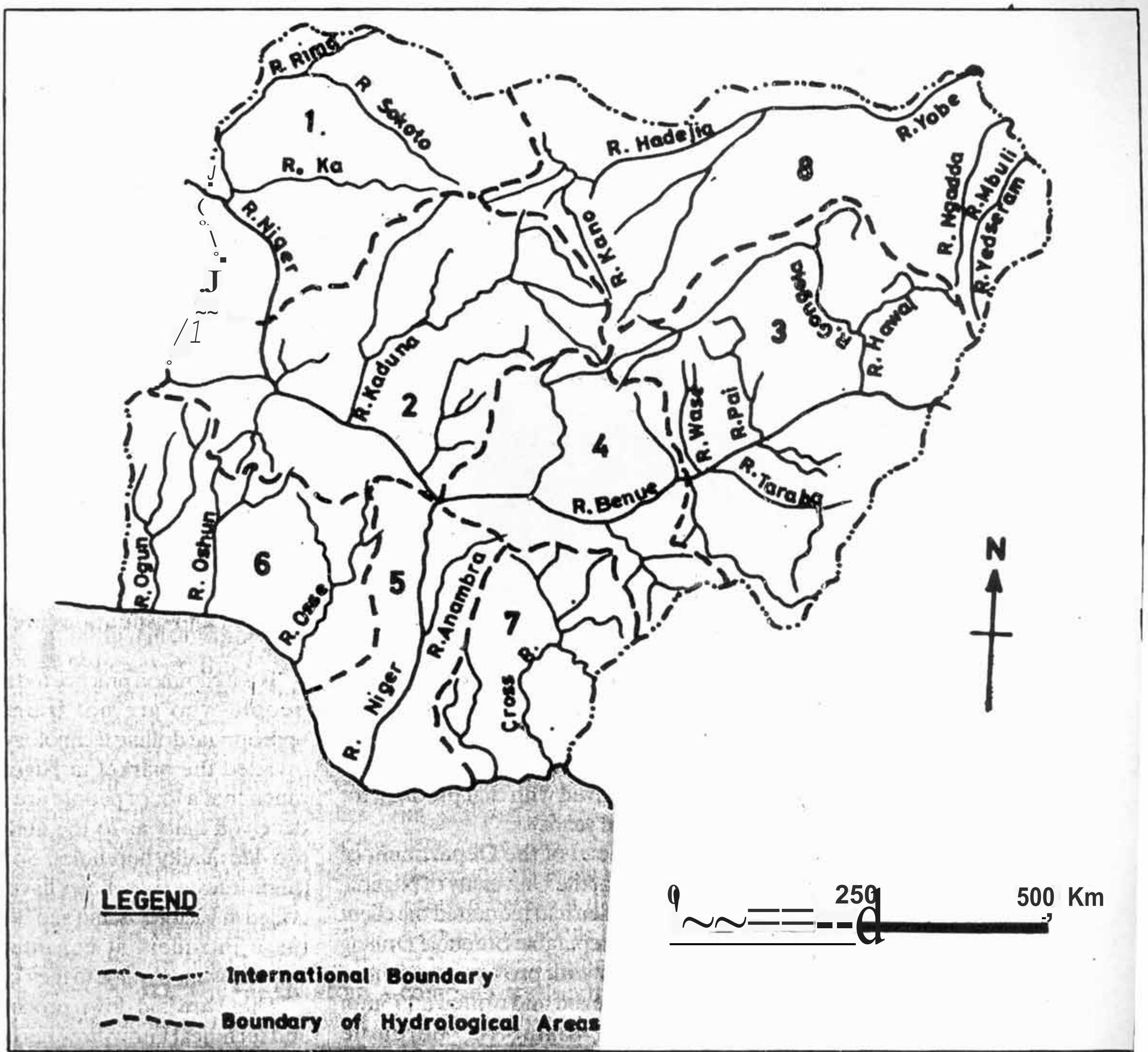

Fig.5: Major Hydrological Basins

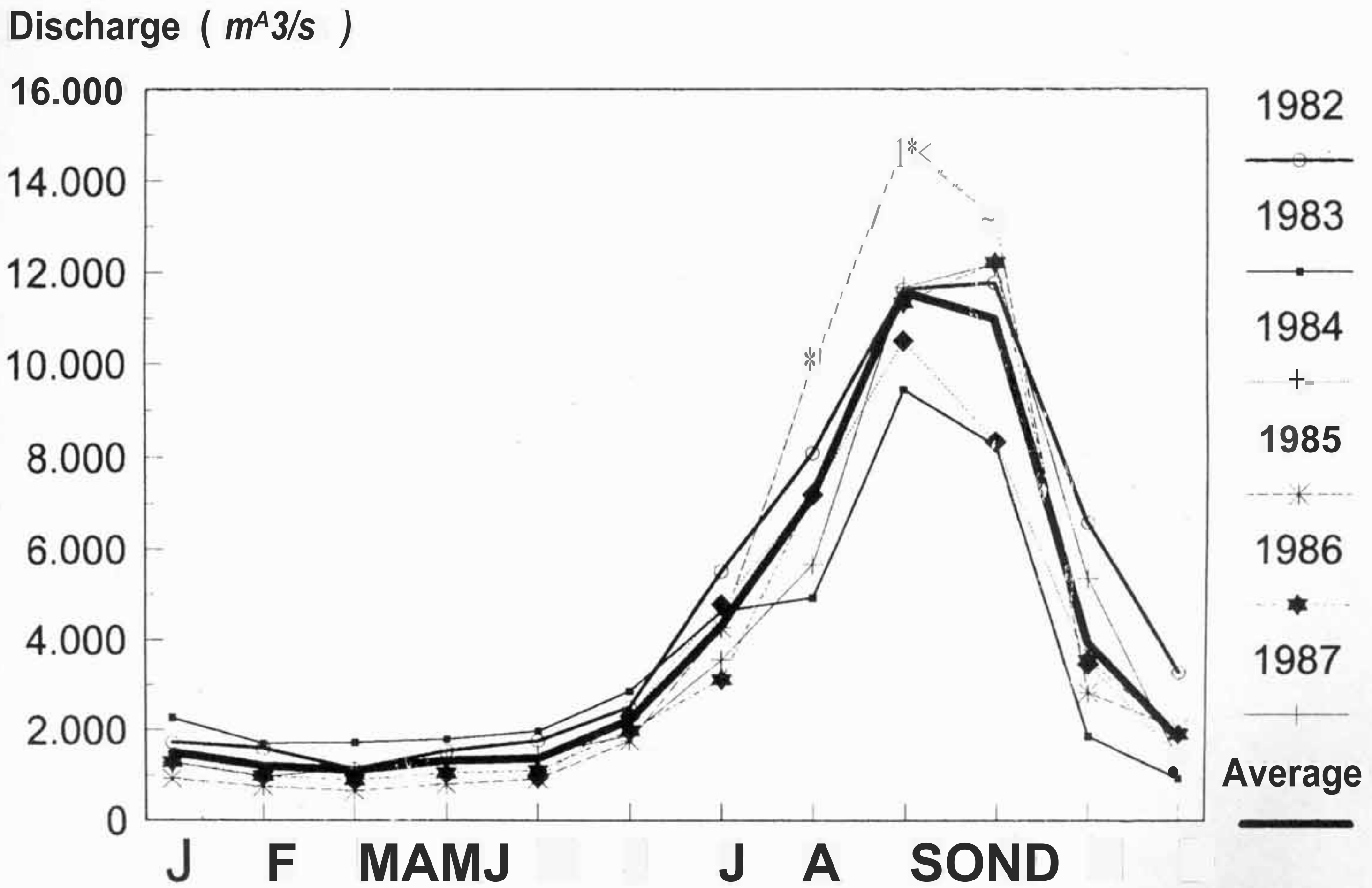

Fig.6: Monthly Hydrolograph of the Niger River at Onitsha-1982 to 1987,

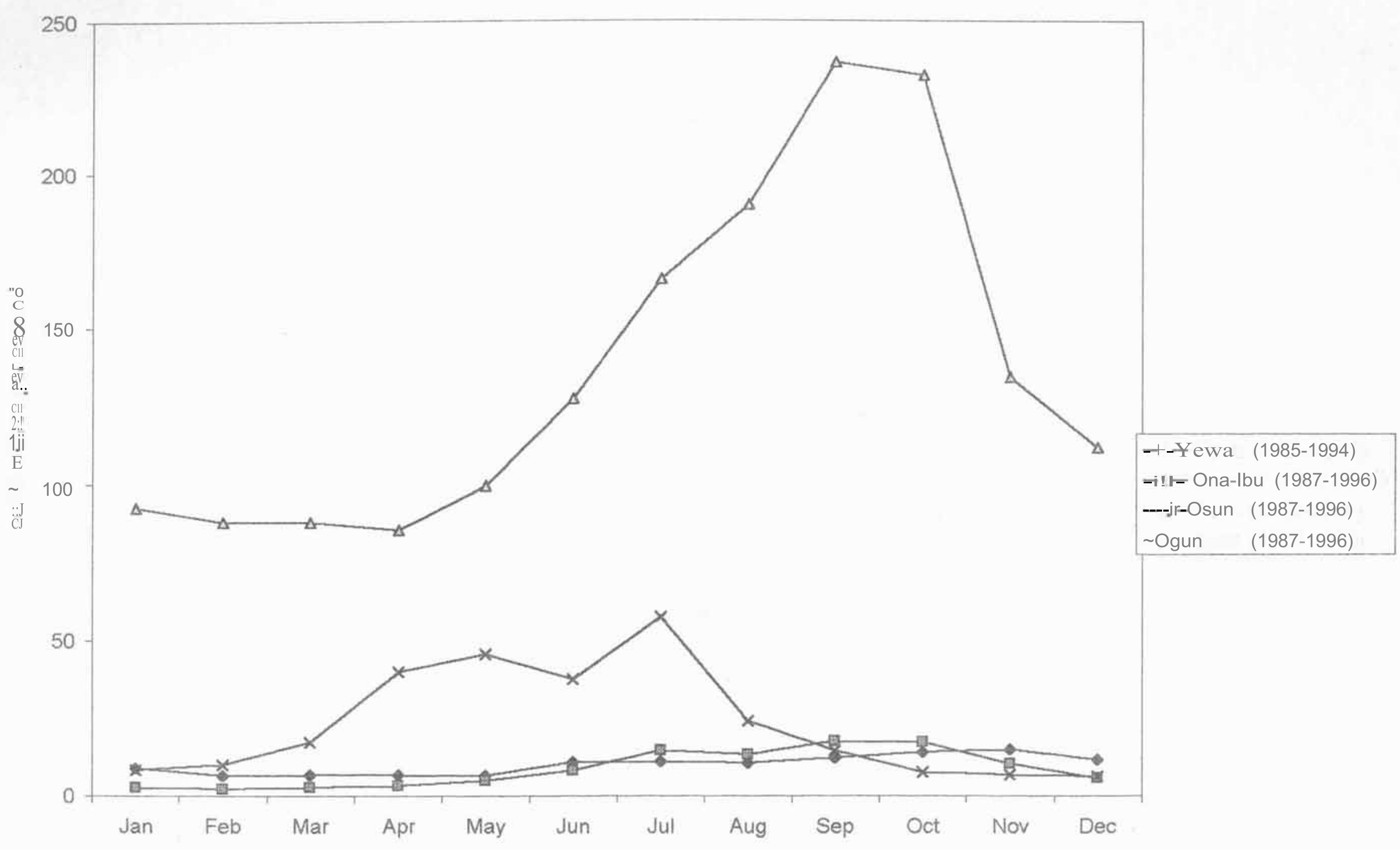

Fig. 7: Monthly discharge hydrographs of Yewa, Ona-Ibu, Osun and Ogun rivers.

ROCK TYPE	APPROX LAND AREA (Km2)	DOMI-NANT CLIMA-TIC TYPE	%DISTRIBUTION OF POPULATION
Crysta-lline	395 000	Semi arid	15
		Tropical humid	35
Sedi-mentary	590 000	Semi arid	20
		Tropical humid	30

Table 1 Distribution of Crystalline and Sedimentary Rocks, Main Climatic Types and Population

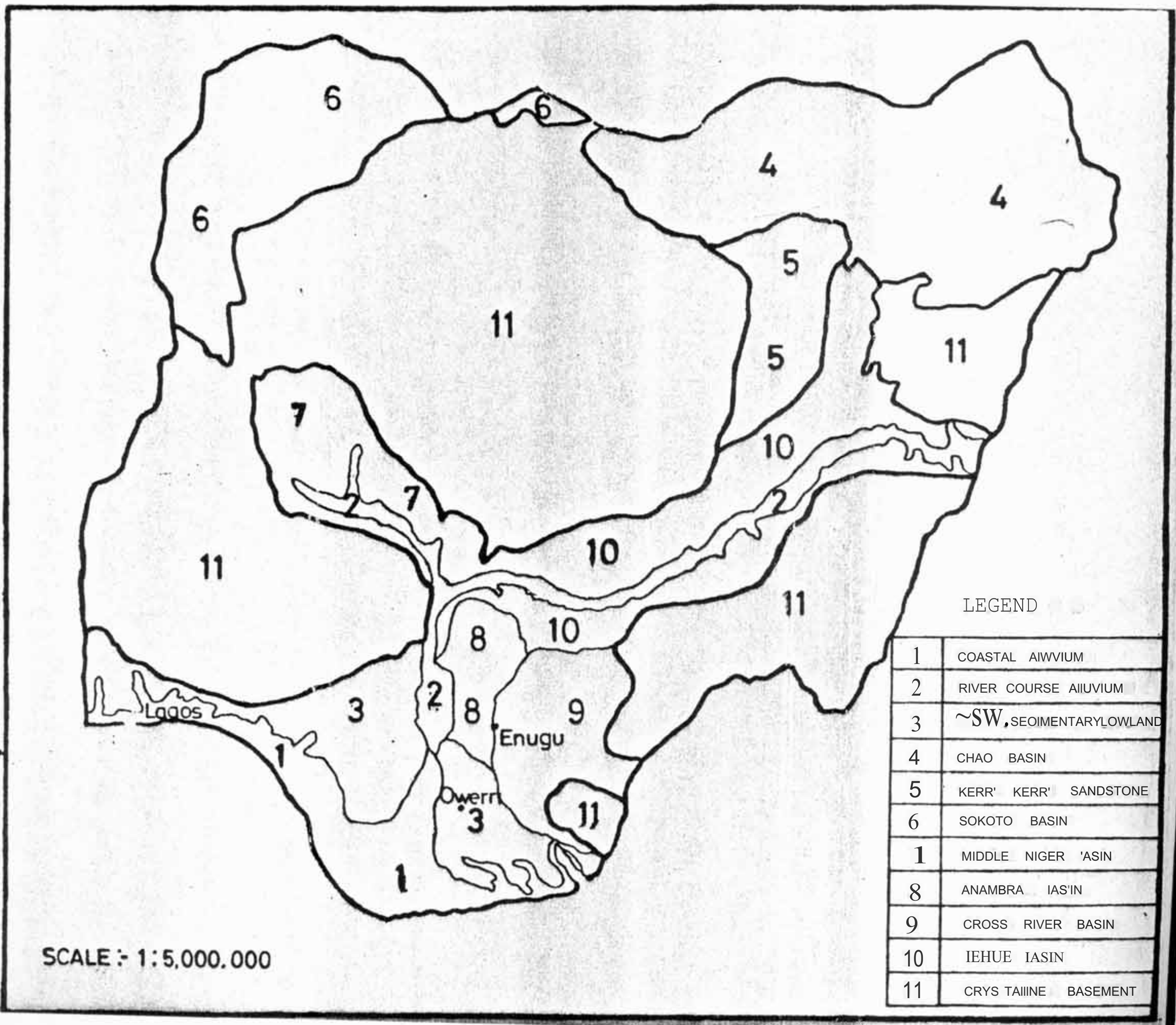

Fig.8: Groundwater Provinces in Nigeria

The widespread occurence of impermeable crystalline rocks limits groundwater availability in Nigeria. This a negative factor in the overall consideration of drainage basin water balance. **Table 1** shows the estimated distribution of permeable (sedimentary) and impermeable (crystalline) rocks in Nigeria, as well as the areal coverage, proportion of the population, and major climatic type within each area. Crystalline rocks cover 50% of the surface area where half the number of population live. 15% of the population are spread over semi-arid areas while the remaining 35% are within the tropical humid climatic zone.

(a) Sedimentary Aquifers

On the basis of nature of occurence and stratigraphy,there are 10 sedimentary groundwater provinces in Nigeria **(Fig. 8)**:

i Coastal alluvium

ii River valley alluvium

iii Dahomey Basin (Coastal sedimentary lowland)

iv Kerri-Kerri formation

v Chad basin

vi Sokoto basin

vii Middle Niger basin

viii Anambra basin

ix Cross river basin

x Benue basin

Each of them represents specific ground water province. In the sedimentary rocks, the water-bearing units occur as permeable horizons separated by impermeable horizons with ground water stored in the interstices and voids in the sediments.

Distribution of sedimentary aquifers in Ogun State

On the basis of groundwater potential and aquifer materials, 3 classes of sedimentary aquifers can be identified in Ogun State (Fig 9). The first class is usually made up of fine to medium grained sands and clayey sands.The aquifer typifies Abeokuta and Ilaro formation. In Abeokuta formation, the aquifer is constituted of coarse sands and gravelly horizons. The yields of the aquifer are usually greater than 10 m^3 hr^{-1}. The second class is constituted of sands and gravels and typifies the alluvial deposits and the Coastal Plain Sands. The aquifer has the highest potential in Ogun State and has yields of20 m^3 hr^{-1} and more. The third class of aquifers consists of limestone of Ewekoro formation. It is characterised by solution channels and subterranean drainages. The yields of the limestone aquifers range from 6.0-58.5 m^3 hr^{-1}.

The recent alluvial deposits and Coastal Plains Sands are in close proximity to surface waters and their high groundwater potential are probably due to the porous and permeable nature of the sands and gravels that constitute the aquifer materials and the likely hydraulic connection between the surface waters and the aquifers, such that, water percolates downwards through pervious beds under the influence of hydraulic gradient caused by pumping. The surface waters thus provide groundwater to the boreholes tapping the aquifers, ~e amount of which should increase as the cone of depression enlarges.

(b) Basement Complex in Ogun State

There are two major crystalline rock provinces - the north-central and the southwestern crystalline massifs. The latter covers close to 30% of Ogun State (Martins, 1998).

Mode of aquifer occurrence in crystalline rocks can be classified into 3:

- Occurrences in weathered portion of the rocks overlying the fresh basement..
- Occurrences in decomposed veins within the basement..
- Occurrences in fractured rocks

Wells tapping the crystalline basement complex have always been a traditional source of water supply in both urban and rural areas, where surface water network are sparse and seasonal.. By virtue of their formation, regolith aquifers are generally shallow in depth. Consequently, their groundwater is usually susceptible to pollution and their yielding capacity is subject to seasonal fluctuation. However, with optimal water resources planning, this means of water supply can be harnessed and exploited for domestic uses, even in the cities, where water supply from government water works is frequently epileptic.

Table 2: Well and hydraulic parameters

No.	Location	Total Depth (m)	Dia-meter (m)	SWL (m)	Hydraulic Head (m)	Transmissivity (m day"l) x 10-4		Specific Yield		Pumping regime		Recovery Regime	
						Pumping	Recovery	Pumping	Recovery	Time SPST	Total Drawdown (m)	Time SPSP (min)	Residual Drawdown (m)
I	Isabo	5,47	0.78	2.52	57,48	2.56	3.51	0,445	0.117	30	1,27	190	0.98
2	Nawair-Ud-Deen	3.54	0.79	I, II	68.39	4.73	1,62	0,471	0.306	30	1,08	180	0.84
3	Amolaso	6.96	0.74	3.80	55.70	2.16	1,21	0.335	0.375	9	0.58	76	0.28
4	Iyana Liberty	2.79	0.74	0.25	39.75	2.67	1,27	0.330	0.274	10	0.80	170	0.13
5	Igbore	3.37	0.91	1,12	48.88	2.24	1,58	0.219	0.26	16	0.84	ISO	0,47
6	Isale Igbein	0.91	1,67	0.01	53.49	2.20	1,69	0.070	0.071	6	0,40	II	0.025
7	Quarry Road	2.55	0.94	0.94	79.56	1,66	2.16	0.264	0.175	IS	0.75	24	0.11
8	Lantotro	1,76	0.82	0.59	81,31	3.07	2.32	0.309	0.154	12	0.77	16	0.06
9	Oke Ijeun	3.23	0.78	0.85	62.65	2.51	5.67	0.356	0.017	IS	1,03	180	0.80
10	Kuto	4.23	1,67	0.58	64,42	2.93	2.14	0.130	0.077	30	1,24	240	0.66
II	1toku I	1,97	1,85	0.57	51,43	7.03	1,87	0.200	0.112	5	0.14	180	0.36
12	lsale Igbein II	3.10	0.80	0.76	51.24	3.74	2,44	0.394	0.095	IS	1,36	70	0.02
I3	Onikoko	3.05	0.90	1,01	82.79	4.18	1,76	0.334	0.329	15	0.91	90	0.14
14	Alẹe	3.87	1,22	2.01	82,49	3.74	4.88	0.237	0,078	IS	0.69	20	0.19
15	Totoro	4.30	1,00	1,60	51.70	3.33	4.07	0.305	0.104	30	0.20	120	1,70

16	Kobiti	3.85	0.95	1.40	74.80	3.43	5.11	0.277	0.066	30	2.30	120	1.97
17	Ago-Oko	4.00	1.00	1.35	74.90	3.52	5.49	0.238	0.056	30	2.30	120	1.83
18	Iporo-Ake	2.95	0.85	1.00	60.00	3.92	6.64	0.34	0.074	25	1.90	120	1.60
19	Ikereku.	3.45	1.20	1.15	82.70	3.66	5.23	0.199	0.073	30	2.0	120	1.62
20	Itoku. II	4.50	0.08	2.00	55.20	4.29	3.49	0.258	0.260	30	2.0	120	1.52
21	Erunbe	4.40	0.90	1.00	82.80	2.76	3.77	0.274	0.106	30	2.70	120	2.0
22	Idi-Aba	5.50	1.10	1.55	74.70	3.50	6.66	0.172	0.015	30	2.30	120	1.93
23	Itori-Odo	3.85	0.90	0.70	85.00	2.55	5.49	-.96	0.014	30	2.90	120	2.54
24	Ita-Eko	3.45	1.20	1.00	82.80	3.43	4.14	0.309	0.0172	30	1.90	120	1.39
25	Ibara	3.95	1.1.35	1.80	82.00	3.54	3.38	0.168	0.253	40	1.95	120	1.30
26	Ijeun Titun.	5.60	1.40	0.15	53.20	2.50	4.39	0.138	0.002	90	4.65	120	3.84
27	Obantoko I	2.58	0.76	2.35	110.42	3.75	9.04	0.357	0.532	30	1.61	190	1.32
28	Obantokol I	4.40	0.97	0.63	110.60	1.49	12.25	0.303	0.647	30	1.66	180	1.16
29	Obantokol II	4.20	0.78	0.11	llO.50	2.26	4.84	0.961	0.407	30	0.72	20	0.11
30	Camp I	4.90	0.80	0.22	114.00	2.26	7.16	0.437	0.544	30	0.35	36	0.22
31	Camp II	7.00	1.10	1.60	115.00	1.42	3.80	0.092	0.099	32	0.65	40	0.07
32	Camp III	6.86	0.80	1.16	114.90	6.35	6.02	0.550	0.018	30	1.49	150	0.21

SPST: Since pumping started

SPSP:Since pumping stopped

Movement of water in crystalline rocks is strongly influenced by topography; recharge is mainly by percolating rainwater and in some places by seepage from adjacent surface water. Recharge areas consist of decomposed and fractured rocks in which pressure heads quickly spread through local water-bearing fissures and interconnected voids, thereby leading to abrupt rise in discharges in response to precipitation (Idowu, Martins, et al, 1998).

Geometry of Hand-dug wells

The parameters that describe any given well include location, total depth, diameter and static water level. **Table** 2 lists some wells within Abeokuta. The total depth of the wells range from 0.91 m to 7.10 m with an average of 3.96 m, while the diameter ranges from 0.74m to 1.85m at with an average of 0.99m. The static water levels ranges between 0.01m at Isale Igbein and 3.80 at Amolaso with an average of 1.18m.

An overburden thickness of between 6.1m and 115.8m with an average of 43.2m has been reported for the Basement complex areas of Ogun State (Martins et al., 2000).

Hydraulic Parameters

The hydraulic parameters are listed in **Table 2.** Transmissivity values are generally low. They range between 1.42×10^{-4} m/s to 7.03×10^{-4} m/s for the pumping phase and between 1.21×10^{-4} m/s to 12.25×10^{-4} m/s for the recovery phase. Except for Obantoko III where the transmissivity is 12.25×10^{-4} m/s, all the transmissivity values fall within the expected range of 10^{-4} - 10^{-5} m/s for weathered crystalline rocks (Bernard and Mouton, 1981). The specific yields of the phreatic aquifers for the pumping and recovery regimes range from 0.092 to 0.61 and 0.02 to 0.647, respectively. The typical specific yields for an unconfmed aquifer may be on the order of 0.01 to 0.3 (Watson and Burnett, 1995). The high values obtained for Abeokuta reflects the potential for a high storage impact on the holding capacity of the aquifers. This is understandable in view of the constitution of the aquifers of clayey materials (which has high capacity for storing water but low capacity for transmitting it.) derived from the weathering of the basement rocks (Idowu, Martins et aL., 1998). The high variation of the transmissivities and specific yields may indicate varying degree of weathering and/or composition of the aquifer materials by varying amounts of clayey materials. Transmissivities in the range of 0.6 m^2.day-1 and 7.4 m^2.dai^{1} have been reported by Martins et aL., (2000) for the aquifers in the basement areas of Ogun State on the basis of borehole data. Rates of recovery generally appear slow with an average recovery of 47% for average recovery duration of 114 minutes, and pumping duration of 26 minutes. The recovery rate ranges from 12% to 100% for a recovery duration of 11 minutes to 240 minutes and pumping duration of 6 minutes to 90 minutes.

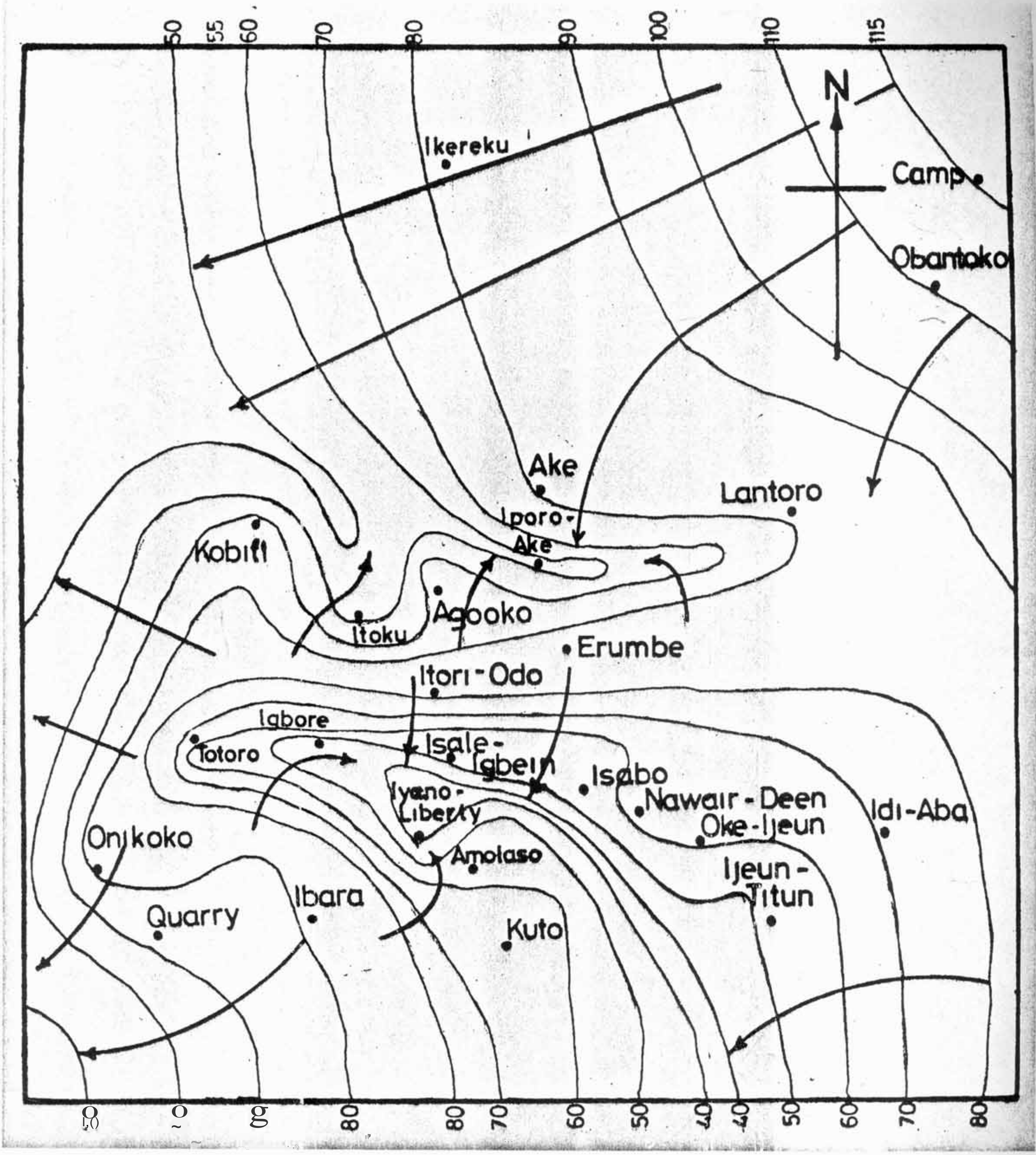

Fig. 10: Configuration of Water Levels in Basement Complex Aquifers

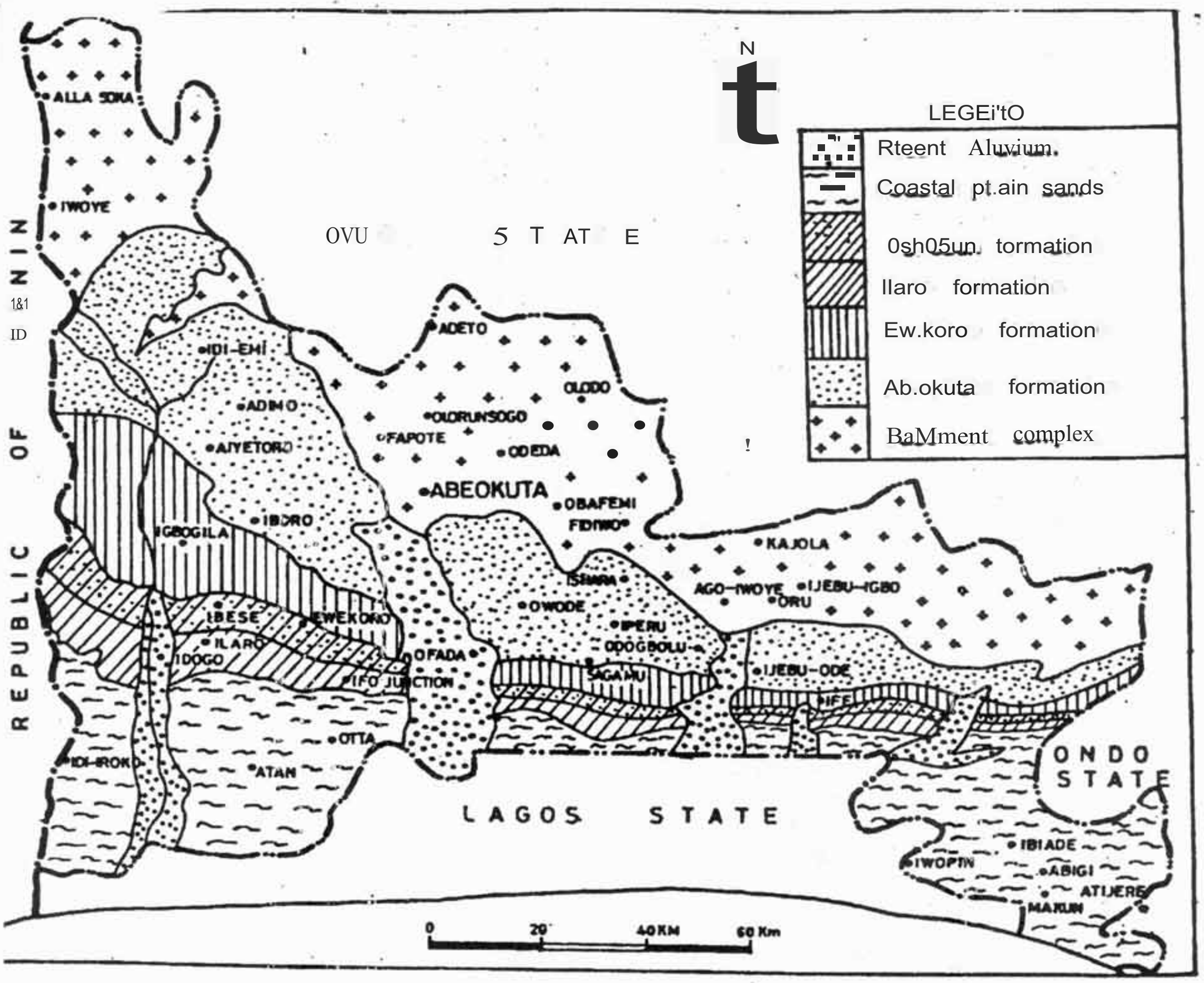

Figure 9. Major Aquifer Units in Ogun State

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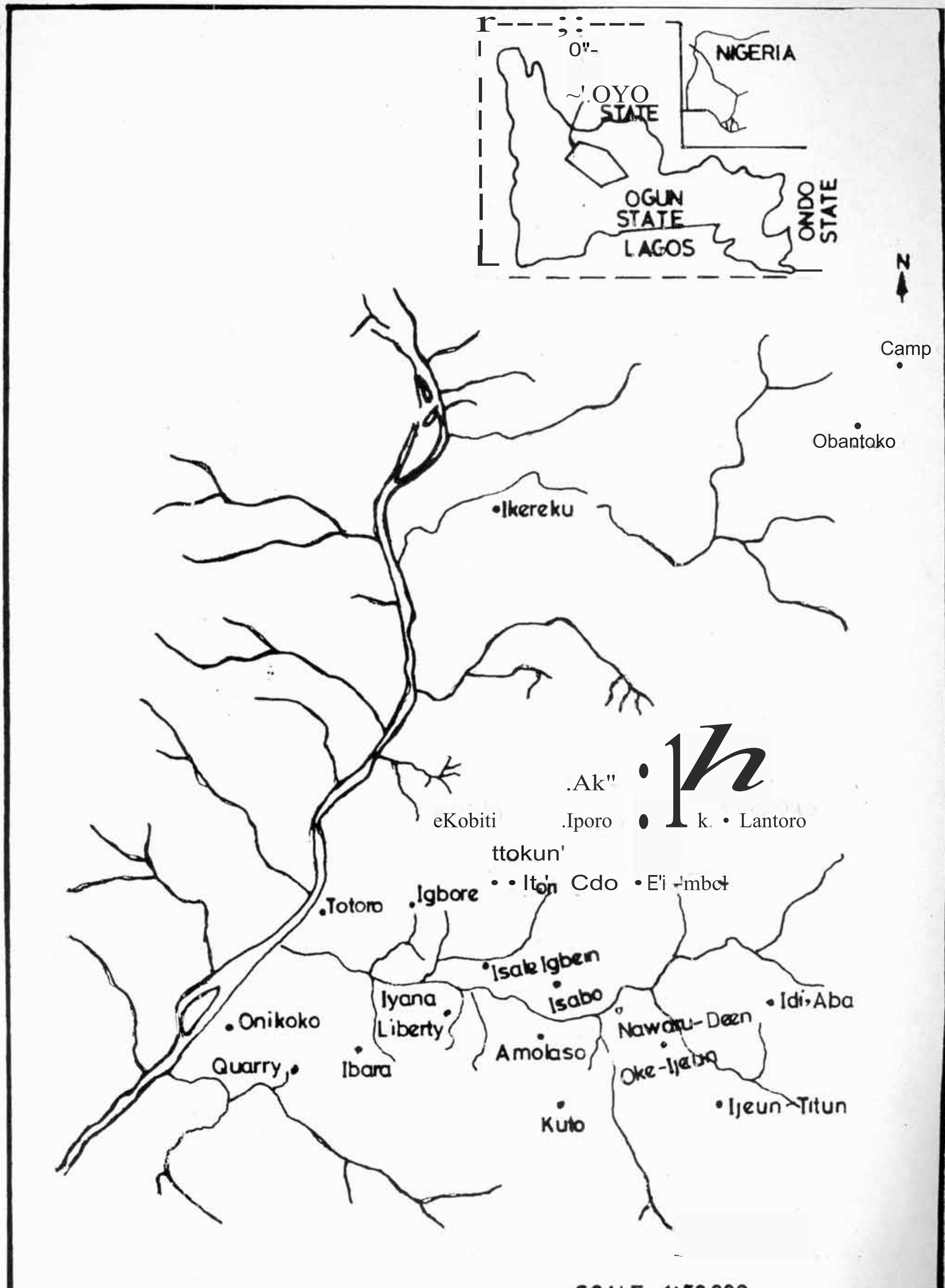

Figure 11. Drainage pattern (rainy season) in parts of Abeokuta

Groundwater Flow Direction

Figure 10 shows the configuration of the water levels. Flow directions are dictated by surface topography. This may be a reflection of varying degrees of weathering at different groundwater fronts and the occurrence of the fresh basement at different depths at different locations. The water table map enables identification of two major areas of recharge. One occurs on a water divide that runs along Itori Odo, Totoro, Ita Eko, Ibara and Kuto in the South and the other occurs on the Northeastern part of the city. Groundwater flows on the opposite sides of the water divide towards River Ogun in the west and converges around Isale Igbein, Isabo, Nawair-ud-deen, Iyana Liberty and Amolaso in the central part. This is evidenced by the occurrence of many streams and springs (especially in the rainy season) in the central area (Fig. 11). In the eastern half , flow is generally towards the southwest to Olobi, Sokori and Olokuta streams around Camp, Obantoko, Ijeun Titun, Idi-Aba and Oke Ijeun areas and eventually towards the west around Ikereku, Ake, Iporo Ake and Lantoro areas. The average hydraulic gradient from both recharge areas are comparable, being 1.7×10^{-2} in the northeast and 1.5×10^{-2} in the central part of the area.

Both the sedimentary and crystalline rock types have different hydraulic properties which are also reflected in their water-bearing capabilities **(Table 3)**.

Properties	Basement Aquifers			Sedimentary Aquifers		
	Ranfle	Mean	Well Nos	Ranle	Mean.	Well
Yield (mlh(l)	0.24-65.00	7,33	72	2.34-181.61	31.47	130
Trasmissivity (m^2 day·l)	0.61-5.32	2.30	6	0.43-958.96	89.27	17
Specific capacity at 0.5 h~ (m^2 day")	0.01·2.24	0.83	6	0.52-52.90	9.33	22
Aquifer depth (m)	3.05-73:15	23.14	24	3.00·166.00	35.95	48.
Aguifer thickness (m)	11.00-92.97	49.92	24	4.57.109.73	33.82	46
Overburden thickness (m)	6.10-136.40	45.17	47			

Table 3 Hydraulic Properties of Basement and Sedimentary Aquifers

Yield, transmissivity and specific capacity are generally higher for the sedimentary aquifers than for the basement. The values reflect the differences in the rock materials which constitute both aquifer types: yields of the basement aquifers seem to be highest in areas where aquifer thickness is greatest, although no definite pattern is discernible. When aquifer thickness and borehole yields are compared for both basement and sedimentary aquifers, correlation coefficients of 0.10 and 0.29, respectively, are obtained. Yields of the sedimentary aquifers are controlled by thickness, degree of sorting and coarseness of rock materials - well sorted, coarser and thicker aquifer materials are expected to yield more water than poorly sorted, fme grained and thin aquifers. On the other hand, yields of basement aquifers are controlled by the extent and depth of weathering and fracturing.

Put in Fig 12

2.1.3.3 Age of Groundwater

The sustainable use of groundwater reserves constitutes an important problem, mostly in the drier areas of Nigeria, where hardly any water is renewed and old or fossil groundwater often forms the only reliable water resource. Areas under the threat of groundwater depletion include the north-western and north-eastern parts of the country.

Use of environmental isotopes have proved an important tool in the determination of age of water. Stable isotopes of hydrogen (H-2= deuterium) and oxygen (0-18) as well as radioactive isotopes of hydrogen (H-3= tritium) and carbon (C=14), occuring in natural waters can be used to determine the inter-relationships of water from various sources within the hydrologic cycle (Matheis, 1973; Loehnert,1980).

Available evidence from isotope data (IAEA, 1979), shows that only near-surface aquifers in the Sokoto and Chad basins are currently being recharged by rainfall; the deeper aquifers (Tertiary and Cretaceous), on the other hand, are fossil waters that were last recharged some 20 000 to 30000 years ago. Intensive exploitation of such aquifers is not sustainable as they face the threat of being depleted. Waters from the middle zone of the Chad basin aquifer system are equally old, and no recharge is taking place (Fig. 12).

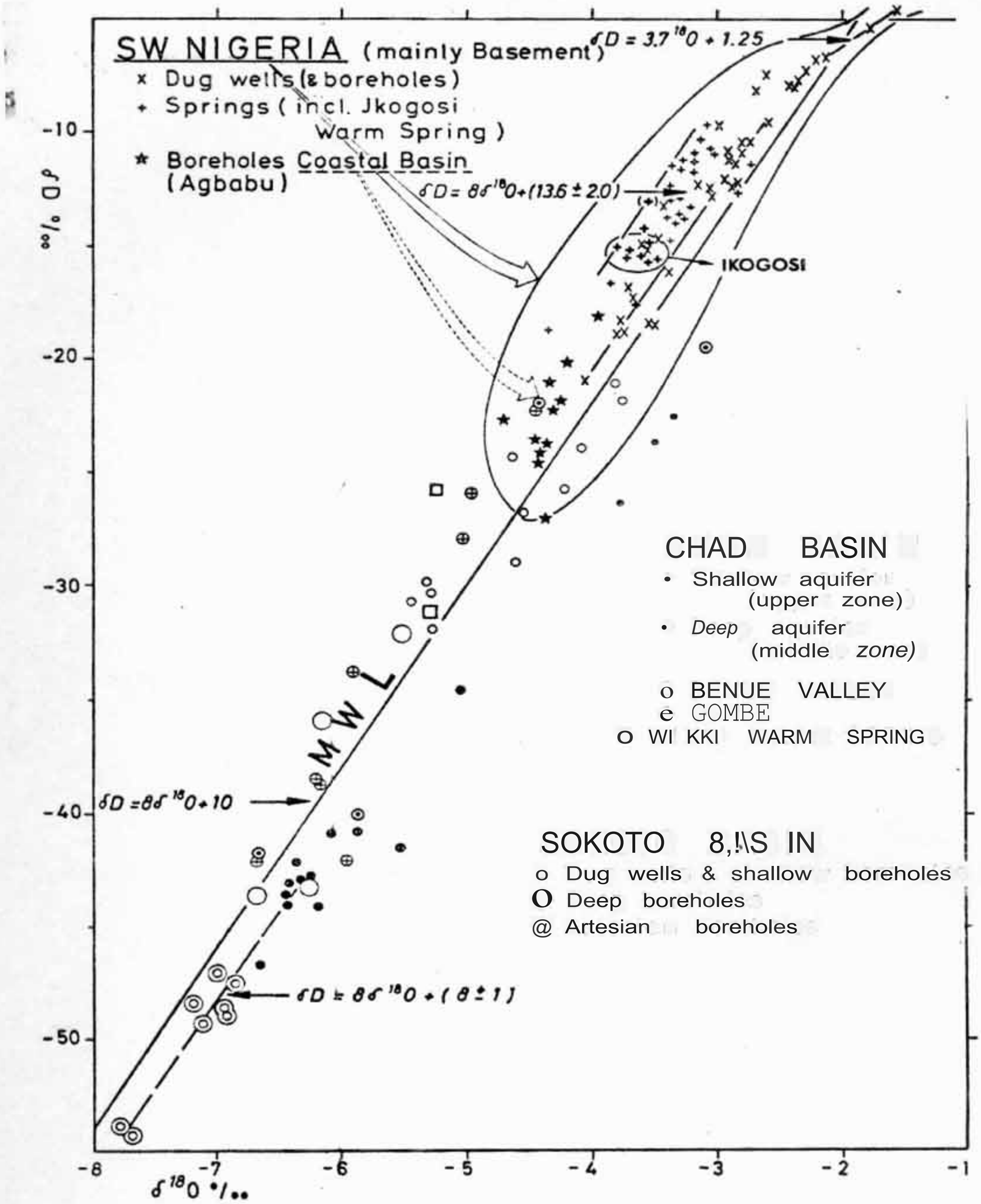

Figure 12. Isotopic Dating of Goundwater Recharge

While most of the shallow aquifers in southwestern Nigeria are being currently recharged, their water potential is limited. The deeper aquifers, however, have greater water potential.

3.0 WATER QUALITY

Water quality management serves largely as an intermediary or interpreter between any water body and its users, balancing the biophysical capabilities of the water resource against the multitude of uses that may affect it. Notably, different societies, cultures, and regions all have different priorities based on their water-related needs so the water quality manager in each situation must balance a different set of considerations.

3.1 Natural threshold

Natural water contains naturally occurring compounds, such as major ions (e.g., Ca^{2+}, HCO_3^-), plant nutrients (SiO_2, NO_3^-, NH_4^+ orthophosphates), organic compounds (e.g., humic acids and hydrocarbons), and xenobiotic substances (synthesized by humans). In these latter substances,thousands of products or by-products can be found at very low concentrations but possessing toxic properties. They are, therefore, termed organicmicropollutants (e.g., pesticides, polyaromatic hydrocarbons [PAH], polychlorobiphenyls [PCBs], solvents). When they are very stable in the aquatic environment or in soils, they may not degrade for years and can eventually accumulate in either sediments, soils, or even higher organisms. These specific compounds are now termed persistent organic pollutants (P0Ps). Metals, particularly the heavier metals, such as lead (Pb), cadmium (Cd), mercury (Hg), zinc (Zn), chromium (Cr), copper (Cu) , arsenic (As), antimony (Sb), and tin (Sn), are naturally found in rock-forning minerals. Variability in weathering and erosion processes causes large natural variations in the background concentration of these elements. When concentrations of these elements are elevated by human activities to toxic levels (for biota and humans), they are termed inorganic micropollutants, often simplified as heavy metals. Major ions, metals, nutrients, and carbon species that reach harmful levels from the human perspective by natural processes (variability) cannot be considered pollutants.

3.1.1. Rock-Water Interaction

Predominant drainage basin lithology is the principal factor determining the type of dissolved substances found in natural waters (Meybeck, 1980; Martins, 1991). Other factors that play a modifying role are climate, vegetation, relief, chemical reactions and atmospheric input. The influence of the latter depends on the proximity of the drainage basin to the ocean, as well as the prevalent wind direction.

Rain water contribution to total dissolved solids concentrations

Several authors have considered the contribution of rainfall to the total dissolved loads of rivers (e.g. Douglas, 1968; Gibbs, 1970; Mathieu, 1976; Stallard, 1980). Douglas (1968) estimates that cyclic salts or rain water input contributes between 25 per cent to 66 per cent of the total dissolved solids loads of rivers in various parts of the world.

To quantify the contribution of cyclic salts to river solutes, Gibbs (1970) plotted the ratio $Na^+/Na^+ + Ca^{2+}$

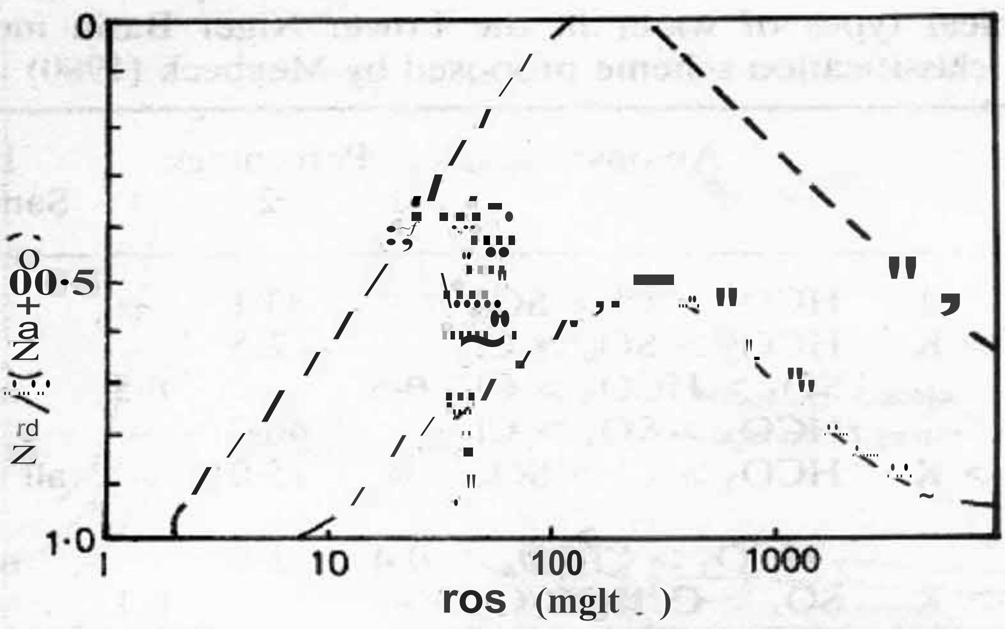

Figure 13. Plot of $Na^+/Na^+ + Ca^{2+}$ for Niger River Samples

against TDS values for various world rivers, and defined a zone of atmospheric precipitation dominance. This relationship is examined in Figure 13.

Seventy- five per cent of the samples fall into the field of precipitation dominance as defined by GIBBS. However, if a cyclic salt correction is performed on the samples, points within this field should shift towards the low TDS-low $Na^+/Na^+ + Ca^{2+}$ area of the diagram. This correction was made by assuming a charge balance between Cl^- and Na^+ ions, and deducting the concentration of Cl -associated Na^+. No appreciable change in the position of points was evident when this cyclic salt correction was made. This seems to suggest that the influence of rain water on the composition of dissolved load in most of the rivers is minimal. In the Niger river, Martins (1983) estimated that only 5% of the total dissolved solids could be attributed to rain water input.

		Ca	Mg	Na	K	$HC0_3$	CI	S04	SiO_Z
	Average Lower Niger River water (mvall-I)	0·305	0·18	0·12	0·Q4	0·059	0·025	0·03	0·27
	After deducting likely rainwater input	0·28	0·18	0·095	0·0395	0·56	–	–	0·269
	New average (mmole I-I x 10)	1-4	0·9	0·95	0·395	5·6	–	–	2·69
A.	1·4 CaAh Si_Z Of! + 4·2 HzO anorthite + 2·8 CO_Z = 1·4 ALz Si_Z Os {OH)4 Kaolinite + 1·4 Ca^{Z+} + 2·8 $HC0_{3-}$	0·0	0·9	0·95	0·395	2·8	–	–	2·69
B.	0·3 KMg Al Si_3 0_{10} {OHh + biotite 1·75 CO_Z + 0·9 HzO = 0·15 Ah Siz Os {OH)4 + 0·3K+ + 0·9 MgZ+ + 1·75 $HC0_3$ + 0·6 SiO_Z	0·0	0·0	0·95	0·095	1·05	–	–	2·09
C.	0·95 Na $AISi_3$ Of! + 0·95 CO_Z + 1·42 albite H_20 = 0·475 AI_2 Si_2 Os {OH)4 + 0·95 Na+ + 0·95 $HC0_3$ - - 1·9 $Si0_2$	0·0	0·0	0-0	0·095	0·1	–	–	0·19
D.	O·lK $AISi_3$ Of! + 0·1 CO_2 + 0·14 potassium-feldspar H_20 = 0·05 Ah SizOs {OH)4 + 0·1 K+ + 0·1 $HC0_3$ + 0-19 $Si0_2$	0-0	0·0	0-0	0·0	0-0	–	–	0·0

Table 4: Evaluation of source minerals using average Niger River Water Composition

Table 4

The weathering balance

Some of the methods used in evaluating the genesis of dissolved materials in natural environments have been described by Garrels (1967) and Holland (1978). Provided the chemical weathering product as well as the approximate mineral composition of the source rock are known, weathering reaction equations can be applied to reproduce the likely source minerals responsible for the dissolved species in the river water.

In Table 4, possible chemical weathering processes leading to the chemical composition of the average Niger river water, are assessed (Martins, 1983; Martins 1988a; Martins & Probst, 1991; Martins & Bammeke, 1998; Martins, et aL, 2001) . The basic assumptions made are that:

- Silicate rocks predominate in the drainage basin
- All chemical reactions are restricted to anorthite, biotite, albite, and potassium-feldspar, in that order.
- Kaolinite is the major weathering product.

Correction for precipitation input is made by deducting the rain water chemistry (in mval/l) proposed for the average Nigerian river water chemistry.

In all the weathering reactions, the respective silicate minerals react with carbon dioxide and water to produce kaolinite. For reaction A, the chemically balanced weathering equation shows that the 1.4 mmole/l of calcium in the river water can. be accounted for, while only half (2.8 mmole/l) of the bicarbonate is produced by this reaction. The mole ratios in the equation are then deducted from those for the relevant elements in the river water.

In reaction B, all the magnesium (0.9 mmole/l) in solution is assumed to be produced by the weathering of biotite. Also given as products of the reaction are: 0.3mmole/1 of

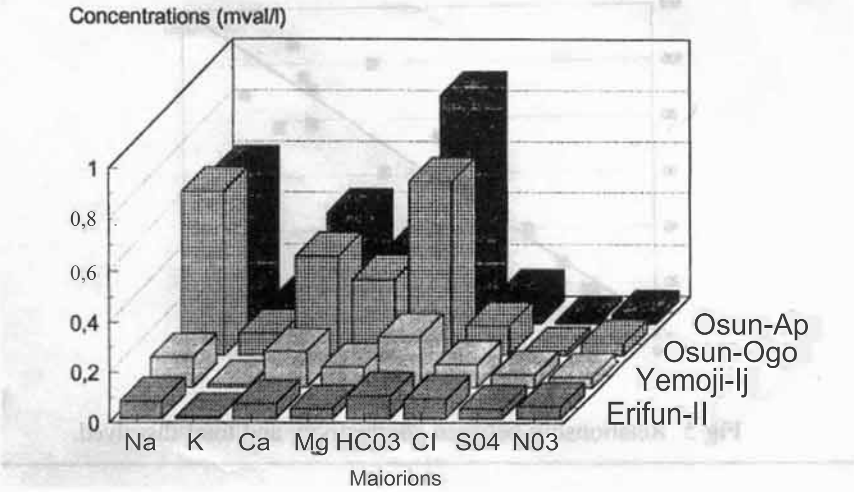

Figure 14a Comparative ionic composition in Oshun, Yemoji, and Erifun Rivers

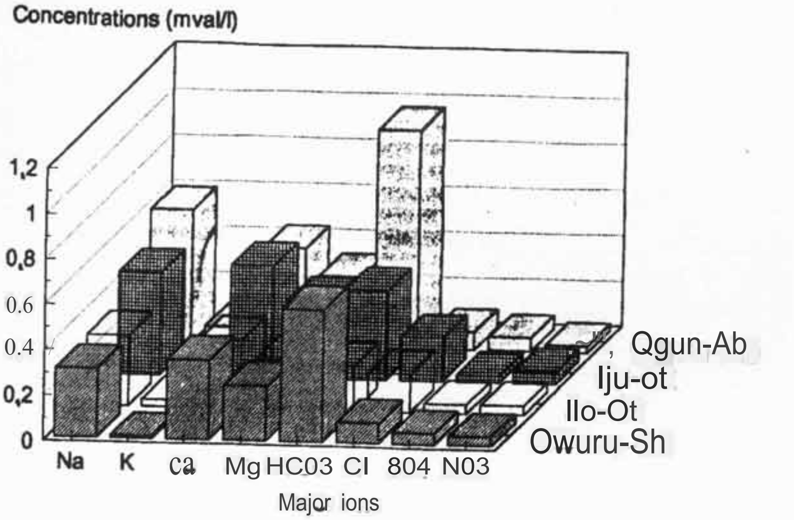

Figure 14b Comparative ionic composition in Ogun, Iju, Ilo, and Owuru Rivers

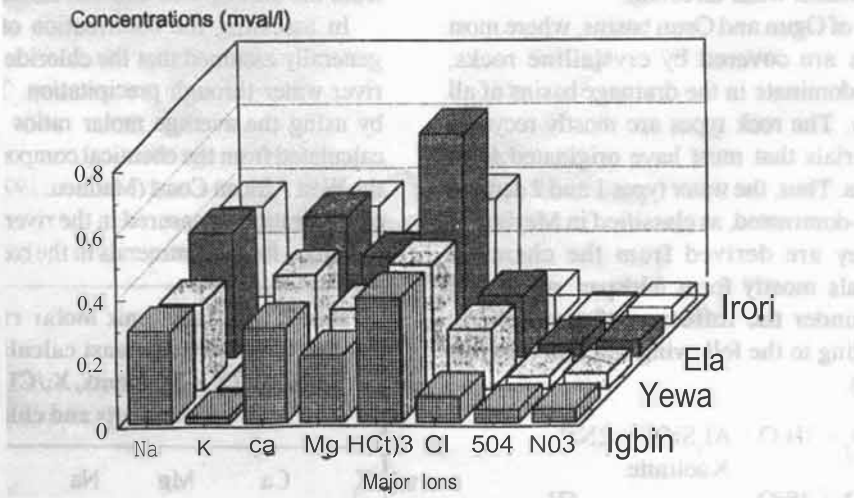

Figure 14c Comparative ionic composition in Irori, Ela, Yewa, and Igbin Rivers

potassium (representing 75 per cent of potassium in river water), 1.75mmole/l (31 per cent) of bicarbonate, and 0.6mmole/l (22 per cent) of dissolved silica.

Reaction C follows the same procedure for sodium, leaving 0.095 mmole/l of potassium, 0.1 mmole/1 of bicarbonate and 0. 19 mmole/1 of dissolved silica. These are produced by the last weathering reaction (0.095mmole/1 potassium is approximated to 0.1 to ease the calculations). It is, therefore, obvious form these reactions that the bicarbonate, which forms a major part of the TDS, is derived from the atmosphere and soil carbon dioxide.

Main Water Types in Ogun-Oshun drainage basins

Generally, river waters in south-west Nigeria are low in dissolved mineral contents delivered by crystalline rocks in their upper reaches; sedimentary rocks, which cover the lower 15 to 20% of the drainage basins, consist mostly of reworked sand and clayey particles that originated from decomposed and eroded crystalline rocks. Thus, alkalinity and dissolved silica dominate the bulk of the dissolved elements, accompanied by sodium, calcium and magnesium. Generally, the waters are low in chloride and sulphate ions (Martins & Awokola, 1996) - Figure 14 (a-c).

Principal waters identified are

(1) Na, Ca – HCO_3: This is found in Ogun, Osun, and Ela rivers . The water is characterised by a high bicarbonate ion participation of over 50% TDS range between 60 and 117 ppm.

(2) Ca, Na - HCO_3: This is found in Ibu , Yewa, lgbin, Yemoji,. Owuru and lju rivers: the concentration covers a long range ofTDS values (30- 136 ppm). However, the bicarbonate participation is relatively lower, being between 42% and 44%.

(3) Na, Ca - Cl< HCO_3: This is observed in the creek *rivers* (Sowore, Ifara, Agbure, Erifun); their basins are located at about 20 km to the ocean and they have the lowest TDS values.

Specific characteristics of all the rivers are the low sulphate and nitrate ions as well as the high alkalinity and chloride values. Owing to the proximity of their drainage basins to the coast, the bulk ofthe dissolved solids in these rivers may have been derived from atmospheric input.

3.2 Water Quality Standards

One of the most common legislative tools in water management is establishment of quality standards (i.e. attributes of the type of water that we wish to retain). Quality standards are, in effect, a regulatory tool that lists specific qualities associated with specific desired uses. To establish such standards, uses or values of the water resource are determined and then specific quality attributes are assigned to those uses. For example, a water body for use as a public water supply will have an associated list of attributes such as low turbidity or levels of heavy metals below some certain threshold. Consequently, quality standards are specific to a given use and represent the maximum allowable level of pollution.

Quality standards are based on assimilative capacity of a water body (i.e., the ability of the resource to receive wastes or impacts and maintain its structure and function within the bounds of set standards). An ecosystem can assimilate or diffuse some impacts without exhibiting unacceptable characteristics. Logically, larger bodies of water can assimilate more than smaller streams; fast-moving streams can assimilate more than slow-moving ones. Because water treatment facilities are extremely expensive, an enormous emphasis has been placed on the natural assimilative capacity of waters throughout history (i.e. "dilution is the solution to pollution"). This concept is still the primary "treatment" philosophy in many developing countries. Identifying the uses for which a water resource will be managed is the first, and most important, step in managing water quality.

In Nigeria, as in most developing countries, water quality is generally deteriorating, especially around urban areas. Population growth, and industrial expansion are generally not managed by appropriate standards, enforcement of infrastructures such as sewer systems and water treatment plants is not done. Meybeck et al. (1989) noted that only 10 out of 60 rapidly developing countries have established effective water quality laws, regulations, or enforcement of relevant infrastructures. In addition, the fast pace of development and pollution creates nearly impossible situations: the pollution that grew over a 100-year period in developed countries now occurs in barely a generation in developing countries (Meybeck et al. 1989). Consequently, few major cities in the developing world have adequate sewage treatment facilities, and municipal potable water supplies are often not disinfected. Nigeria is not an exception.

3.3 Water Degradation

3.3.1. Surface Water Pollution

Quality of river water is modified through the direct discharge of domestic and agricultural wastes (organic matter, carbon, nitrogen and phosphrous compounds) and dumping of industrial wastes (trace metals, complex organic compounds). However, unless sampling of pollution point sources are carried out, dilution of the toxic wastes

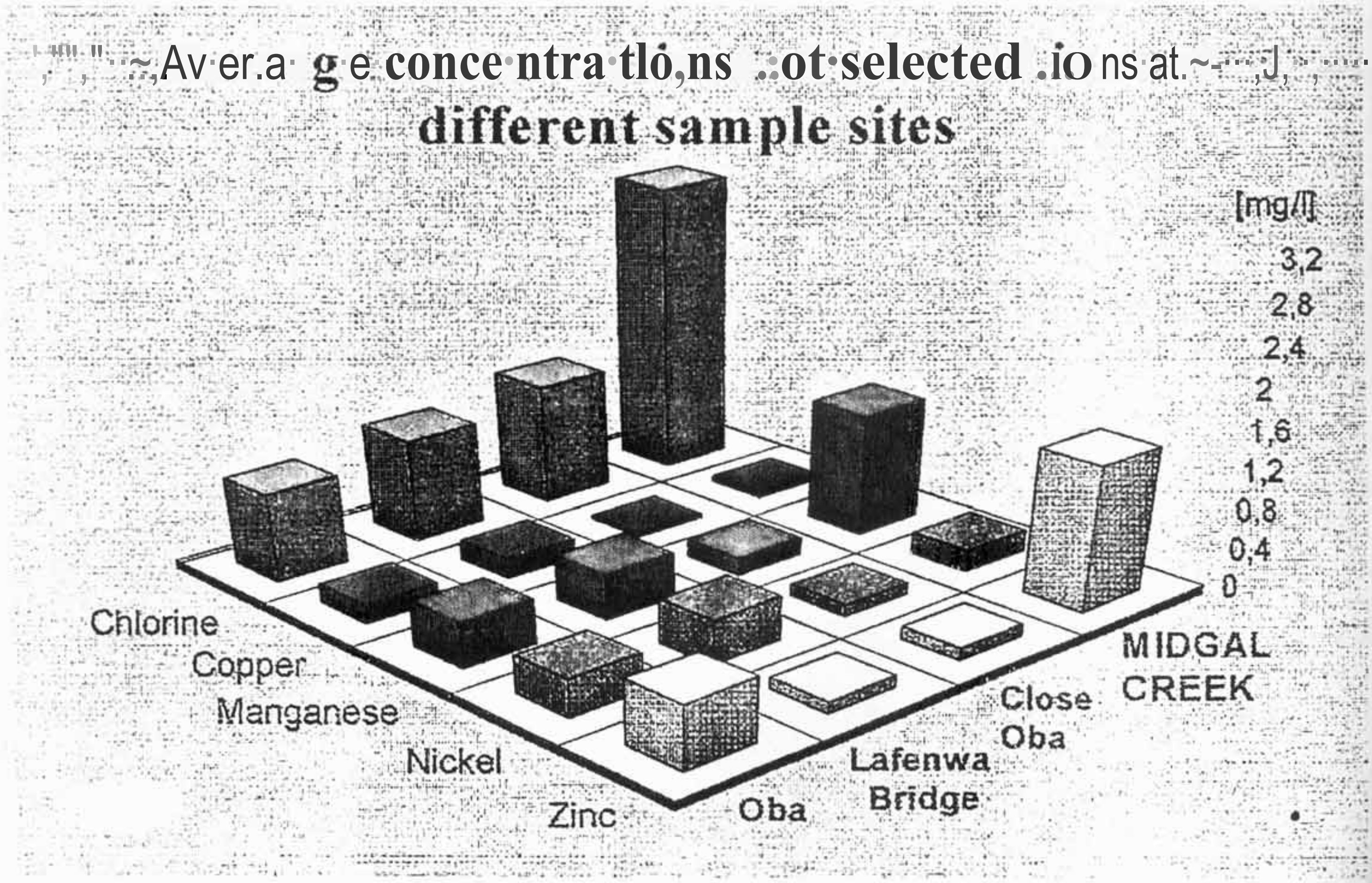

Fig. 15: Heavy Metal Content of Ogun River Basin

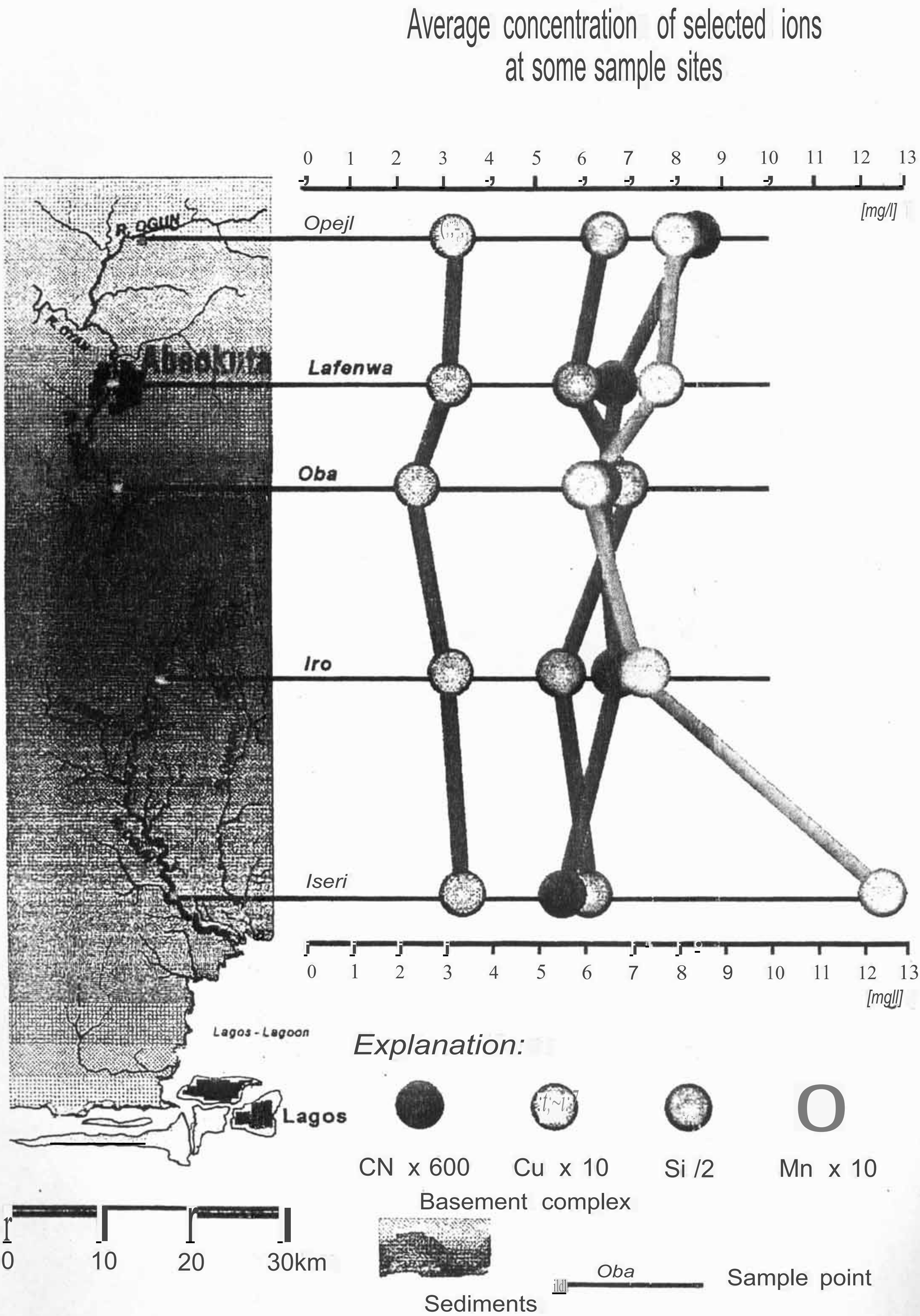

Fig. 16: Longitudinal Variation of Cyanide, Copper, silica and manganese in Ogun River sediments.

do not allow their immediate detection at the river catchment level, given the low precision potentials of most analytical equipment in the developing countries. The toxic nature of these wastes are recognized in most cases, as heavy concentrates in the coastal zone, after a lot of damage might have been done.

Recently, high concentrations of Zinc was observed in one of the tributary streams of the Ogun adjacent the Midgal industry (Fig. 15). Zinc concentration rose from 0.3 mg/1 in May, increasing gradually, it reached a maximum of 7.4 mg/1 in August and 5.2 mg/1 in September. Increased Zinc contamination could still be noticed 10 km downstream (at Oba) of the Ogun river, where the concentration was still 0.27 mg/1 - 3 times higher than the permissible level in drinking water . Other rivers around Abeokuta are also polluted as concentration levels of heavy metals such as copper and chromium are **high** (Fig. 16).

Polluted river water reaches the groundwater since there is hydraulic connectivity between surface and groundwater particularly during the dry season when river baseflows recharge sub-surface aquifers. For instance, recent pollution study carried out in Abeokuta has shown that infiltrating precipitation and seepage water from streams appear to have impact on the aquifer water leading to the observed conductivity values, which are mostly in the excess 500 uS/cm (Martins and others, 2000).

In a well –functioning ecosystem, water is used and re-used many times. Natural ecosystems must be recognized as legitimate users of water that deserve a fair allocation of the total available supply. As more and more is extracted for people's needs, natural water reserves are being stretched to capacity. Bacteria that are naturally abundant in water decompose organic matter and help to recycle nutrients in the environment. These micro-organisms break down organic wastes and cleanse it to a certain level so that it can be used again. This self-cleansing ability of water is being constantly exploited in the rural areas, where the same river used for waste disposal by a village upstream, is being used as a source of drinking water further downstream. The balance is very easily disrupted by chemical changes in the water, such as heavy metal pollution - toxic metals can kill the organisms that cleanse water, so that it is no longer suitable for domestic use. Such dangers abound in rivers that flow through industrial areas, receiving toxic effluents from industries before flowing through villages that use the stream as their natural source of domestic water supply.

3.3.2 Groundwater Pollution

The geology of the subsurface is the major controlling factor of groundwater sentivity to pollution. Soil type, aquifer characteristics, recharge, groundwater flow and drainage area all play a role in determining the destination and pathway of a pollutant. Sensitivity ratings combine these physical characteristics to estimate susceptibility of groundwater to contamination. Typically, sensitivity estimates are based solely on geophysical features, although recent evidence indicates that incorporating land use practices into these ratings would improve their utility (Geier et aL, 1993). The most common water-bearing lithologic units are represented in Ogun State.

Limestone or Karst Formations

Karst formations are carbonate rocks in which carbonic acid in groundwater has dissolved the substrate. Karst areas are characterized by large fissures such as sinkholes, caves, allogenic streams, and springs. Each of these structures increases the interaction between the land surface and underlying aquifers, making these areas extremely sensitive to contamination. In agricultural areas, surface run-off often feeds directly into aquifers via these sinkholes, resulting in high nitrate and pesticide concentrations in groundwater. Examples of this type of formation are found in

Ewekoro Formation, underlying parts of Yewa (north and south), and in the the northwestern part of Nigeria (Sokoto and Yobe States).

Basement Complex Formation

These aquifers lie close to the surface, although they can be overlain by a variety of lithology which may result in a range of sensitivities but, in general, the shallowness of the aquifers results in high sensitivity to pollution. Deeper aquifers are usually better protected from contamination because of the filtering effect of the many layers of rock. Shallow aquifers often experience little, if any significant, filtering.

Table 5 shows the chemistry of the well waters. Concentrations of the analyzed ions are very variable, an indication of varying degrees of extraneous material input. The high nitrate values are clear proofs of the input from domestic and agricultural wastes. Matheis (1973) explained one of the processes of agricultural pollution when he observed that oxidation of nitrogen content of fertilizers by atmospheric oxygen leads to the formation of amino acids, ammonium ions, nitrites and finally nitrates, which is capable of producing soluble salts with metal ions.

Location	pH	Conductivity (J.lS/cm)	Ca^{2+} (ppm)	Mi+ (ppm)	Ie (ppm)	$HC0_3$- (ppm)	$N0_3$- (ppm)	Diss. Si02 (ppm)	Cd2+ (ppm)
lsale-Igbein	7.8	850	65	139	70	71	60	15	0.005
!tori-Odo	7.4	1313	65	90	70	191	60	30	0.012
Amolasol	7.3	827	60	103	22	118	200	15	0.01
Nawair-Ud-Deen	6.7	770	25	52	35	113	80	15	0.014
ljeun-Titun	6.5	980	36	55	11	90	120	7	0.014
lkereku	7.0	887	50	92	75	264	105	30	0.012
Erunbe	7.0	600	42	67	19	240	32	7	0.008
lata-Eko	7.3	745	55	80	13	324	50	15	0.014
Kobiti	7.2	709	40	61	8	192	32	30	0.006
lbara	6.4	1738	14	130	16	383	46	7	0.012
Omida	7.3	1900	42	115	180	216	320	30	0.01
Kuto	6.4	753	40	72	29	108	140	15	0.024
Amolaso2	6.0	684	24	49	13	69	140	15	0.012
CampI	7.2	798	16	33	5	283	55	30	0.005
Camp2	6.2	788	20	45	11	274	25	20	0.017
Camp3	5.6	1000	45	35	21	314	16	15	0.05
Obantokol	6.2	870	18	50	15	285	12	25	0.018

Table 5: Physico-chemical analyses of well water

Element	No of samples	Equation (meqll) Y=A+BX	Corelation Coefficient
Magnesium	17	Y = 0.952 + 0.0025 xMg++	0.82**
Calcium	17	Y = 0.35 + 0.00074 X cart	0.70**
Potassium	17	Y = 0.0019 X K+ - 0,472	0.91 ***
Nitrate	17	Y= 0.0025 X N03- - 0.126	0.87***
Bicarbonate	17	Y=1.294 + 0.002 X HCUj-	0.51 *

***, **, * Significant at 0.1, 1, 5 %levels respective I

Table 6: Relationship between some major elements and specific conductivity

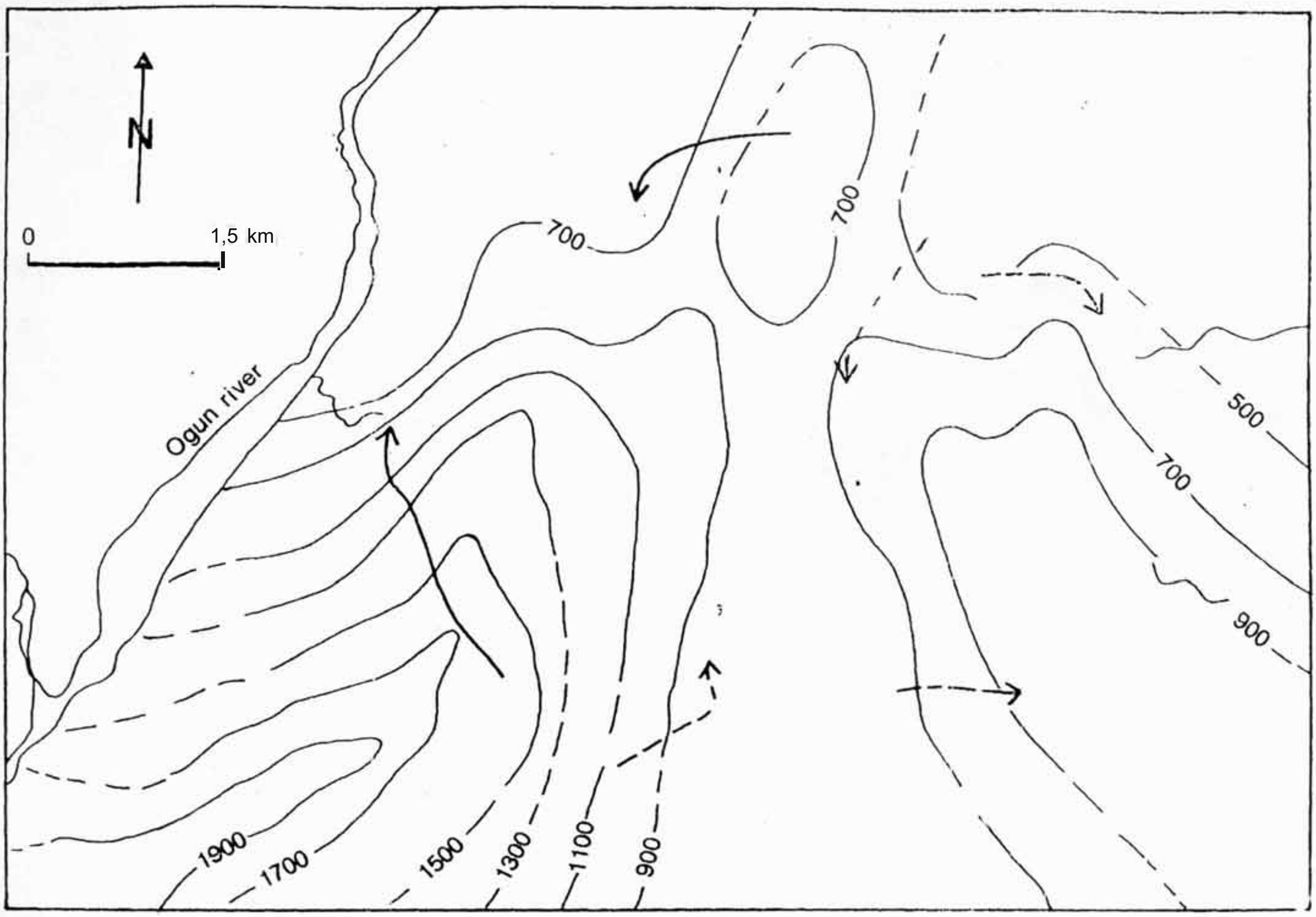

Fig. 17: Groundwater flow lines super-imposed on the configuration of conductivity in shallow aquifers

In Table 6, the relationship of nitrate and cations (Ca, Mg and K) with conductivity suggests that the dynamics of the cations are closely linked with that of the nitrate ion. The enhanced mobility of ions down the soil profile reduces soil fertility, which may result in poor vegetation cover, low organic matter content and a breakdown of soil structure. There is occurrence of high concentration of nitrate (> 45 ppm ,which is the recommended maximum value for drinking water by WHO) indicating that health hazard, is probable in the area.

Almost 70% of sampled shallow hand-dug wells in and around Abeokuta show cadmium metal concentrations. (a toxic metal that is known to be an important component of dyes that are used in textile industries. It is also used in the manufacture of paints and tyre tubes. For example, high cadmium concentration (> 0.005 ppm) was reported in shallow wells that serve as alternate source of drinking water (Martins, 1995; Idowu, Martins et al., 2000).

Put in fig 17

Spatial variation in the groundwater chemistry in the area is expressed by the occurrence of two types of water whose sources seem to coincide with the identified recharge areas. The groundwater from the northern recharge area tends to be relatively less mineralized while that from the south is highly mineralized. A mixing of the two water types occurs in the southwestern part around Itoku, Iporo Ake and Ago-Oko (Fig. 17).

Put in Table 7

Table 7 depicts the nitrate and cadmium values for both recharge areas. The southern recharge area seems to be a major source of nitrate ions, while cadmium ions are washed in from both directions. Cadmium is known to be an important component of battery cells, polyproducts, motor engine oil and dyes (Patterson, 1977). Possible sources are the numerous intra-city motor mechanic garages and sewage dumps located in and around the city. Traditional textile factories also discard high concentrates of dyes into surface drains, which may eventually find their way to the groundwater level.

Recharge Area	Well Location	Nitrate (ppm)	Cadmium (ppm)
NORTH	CampI	55	0.005
	Camp2	25	0.017
	Camp3	16	0.05
	Obantoko	12	0.018
SOUTH	Omida	320	0.01
	Kuto	140	0.024
	Amolaso	140	0.012

Table 7: Value of nitrate and cadmium ions from both recharge areas

4.WATER DEMAND AND USE

Water use falls into several major classes, each of which is associated with certain quantity and quality requirements. These classes include water for drinking and cooking, waste disposal, crop production, aquaculture, livestock, industrial use, recreational use, navigational uses, and ecological values such as survival of natural lake, riverine or wetland communities. The quantity of water required for activities within each of these classes is influenced mainly by variables such as climate and precipitation.

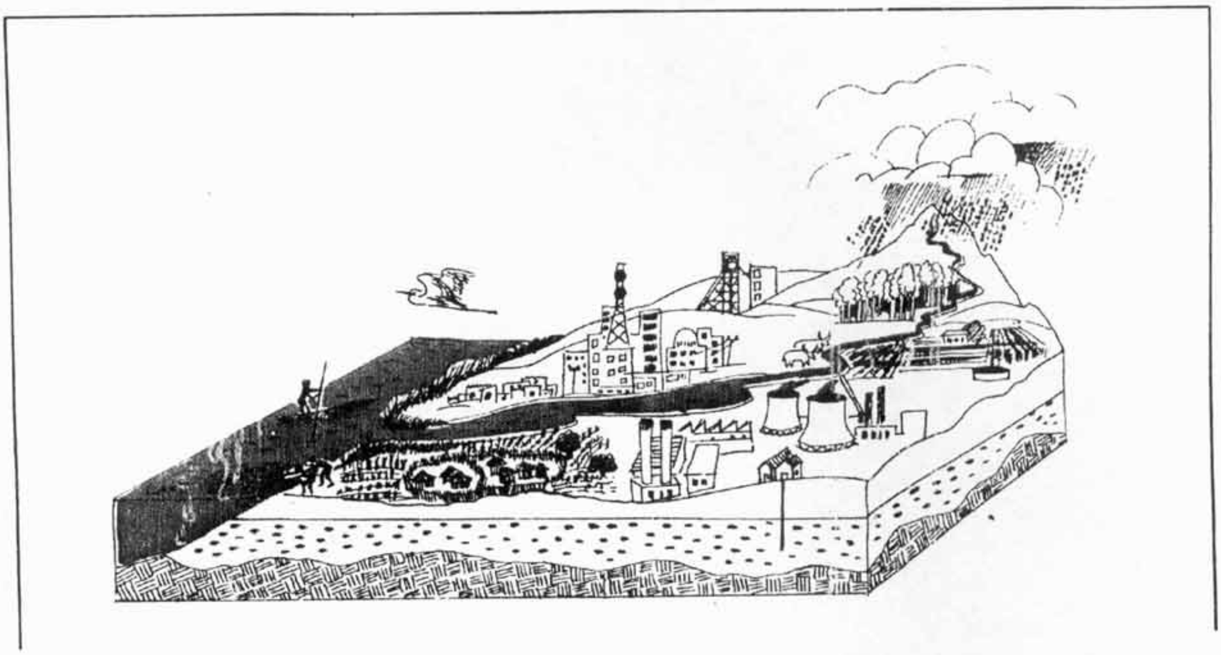

Fig. 18 Schematic representation of possible uses of a river.

Table 8 gives a breakdown of minimum water requirement for an average Nigerian; a total water volume of 80 litres per head per day is required to sustain a moderate living standard.

UAle Items	Water Volume Required (litreslhead/day)
Cloths washing	10
Drinking and Cooking	5
Utensils	5
Bathing	20
Body washing	5
House cll'!anins	5
Water Closet (WC)	20
Miscellaneous	10
TOTAL	60

Table 8: Minimum Domestic Water Requirement (Martins, Idowu et al.,1998).

The proportion of total water used for any specific purpose is controlled by socio-economic conditions, tradition, culture and water availability (Fig. 18). Agriculture-based economies, such as Nigeria's, shall require up to 80% of available water for agriculture, and 10% each for industrial and domestic purposes.

Table 9 compares water availability and use in Nigeria with what obtains in selected countries representing different economies. **In** spite of Nigeria's huge water reserve, level of exploitation is still very low and skewed - most inhabitants are still without adequate acess to water supply, while rainfed agriculture is the predominant mode of farming.

In an urban setting, the water used to generate electricity may be used for irrigation down a river. The same water might be used yet again as it is withdrawn for a public water supply or an industry . Only a few uses actually consume water (i.e. remove it from the system so that it is no longer available to down-stream users). Irrigated agriculture, for example, consumes 55% of the water it uses. The consumptive nature of irrigation, therefore, limits many simultaneous users of the same resource. Municipal facilities such as cities consume 21% of water they withdraw. In contrast, industry, which withdraws very large quantities of water, consumes only about 3% of that water, although the quality of the water returned to the system may change. Unless unacceptable changes in quality occur, many industrial users could benefit from the same water resource.

Country	Available water (km^3/yr)	Per Capita With-drawal (m^3/yr)	Fraction of available water withdrawn per year	Domestic (%)	Agriculture (%)
France	185	728	22	16	15
United States	2478	2162	19	12	42
Libya	0.7	623	40	15	75
Iraq	100	4575	43	3	92
Nigeria	560	21	<3	<1	17

Table 9. Water availability and use in selected countries

4.1 Water Availability

One approach to defme water availabilty is to take the total run-off in a river basin as a measure of water availability in that basin, on the basis that freshwater is a renewable resource and the renewal rate in therefore a measure of water availability (Martins, 1995; World Resources Institute, 1996). However, the total runoff in a river basin is the upper limit to water availability and could be regarded as the potential water availability for a given basin.

The total runoff from Nigeria's river basins is 215 km^3 *la,* which translates to 600 million m^3 per day or 5 700 litres per capita per day- this is a huge water potential.

Domestic water use

The human needs about 2-10 litres of water per day for normal physiological functions, depending on climate and workload. About 1 litre of water is provided by daily food consumption. The total water consumption per capita per day is determined by a number of factors, such as availability, quality, cost, income, size of family, cultural habits, standard of living, ways and means of water distribution and climate (World Bank Water Research Team, 1993).

Tha development and provision of domestic water supply in Nigeria in the pre-independence period was largely through individual and community efforts. The regional governments later got involved with creation of Water Boards or Corporations. The drought of early seventies prompted the Federal government to take a number of actions which resulted, for example in the establishment of the Federal Ministry of Water Resources (1976), National Water Resources Institute (1977) and River Basin Development Authorities (RBDAs)- 1978.

The tempo of water supply was raised in 1980 with the support of the Federal government for the United Nations International Drinking Water Supply and Sanitation Decade (1981-1990). The goal was to provide water for all by the year 1990 with the target that every individual would have access to 120 liters per day, according to WHO standards. That was the dream, but what has been the reality ? Only about 22% of the rural and 55% of the urban population enjoy potable water and the national per capita water supplies of 63 liters per day for urban and 25 litres per day for rural communities indicate how inadequate the water supply situation in the country is. In actual fact, the average per capita water use can be as low as 18 litres per day for urban areas and 2-5 liters per day for rural areas (Oyebande, 1990).

At the current withdrawal rate less than 1% of Nigeria's water resources is being made available to the average Nigerian.

Coming nearer home, recent estimates (Martins, Idowu et al. ,1998) reveal that Ogun State receives 2.6 x 10^9 m^3 of precipitation water annually. Recharge of crystalline rock aquifers is at a rate of 1.02 x 10^9 m^3/yr while the value in sedimentary aquifers is 1.54 x 10^9 m^3/yr. Given the total population of 2.50 million for Ogun State, available ground water alone is capable of providing up to 104 m^3/capita/yr or 285 litres/capita/day. This is a realistic target, given the current effort of the State government to improve water supply to urban and rural areas. Care should however be taken to make sure that the rate of ground water exploitation does not exceed the recharge rate in order to avoid mining of the aquifer, which could have grave environmental consequences.

4.2 Industrial Water Uses

Most industrial water is used for cooling, although many industries consume large quantities of water in their manufacturing practices. Industrial production requires enormous amounts of water. Countries that prioritize industrial production, therefore, face numerous trade-offs in areas where industrial requirements compete with other supply needs.

In most developed countries, industrial water uses are closely monitored and regulated by government and are usually operated to have minimal impact. However, in cases where industrial effluents are not managed, water quality impacts are of three general classes: heat, algicides, and metals. As noted, many industries use water for cooling, discharging very large quantities back to the surface water. The heat loads of those waters can be significant, raising in-stream temperatures by several degrees centigrade in isolated cases. Industries must expose water used for cooling to the atmosphere so that evaporation can remove the waste heat. Industries consume much smaller quantities of water in their manufacturing processes than they use in cooling. These process waters are the ones most closely regulated and most likely to cause a downstream impact. The contaminants commonly found in industrial wastewater include heavy metals and other toxic compounds.

Industries in Nigeria rely almost entirely on independent sources of water supply for their operations due to inadequacies of government supplies. This is done through abstraction of groundwater by the construction of boreholes. This portends threats and danger to the environment especially in our cities where concentated abstraction of groundwater is taking place without any monitoring or regulation by the government. The threats are in terms of lowered water levels, land subsidence, and attendant problems such as destruction to public works, flooding and collapse of structures. The grim picture is that these are already happening in Nigeria. In Lagos, there are more than 500 boreholes abstracting groundwater in Ikeja alone. A resultant water level depression of 2 meters /year has been reported for Ikeja, and similarly water level has been found to be declinig at a steady rate of nearly 2 meters/ year since 1967 in Agege and 1.6 meters /year in Iganmu area (Onwuka and Adekile, 1986).

Although, groundwater recharge currently takes place is near-surface aquifers in Lagos, the rate of water removal is quite high. Most of Lagos is situated on geologically recent sand banks that are still undergoing consolidation. Intensive removal of water from the sub-surface, sets the land in a downward motion, leading to subsidence, flooding and saline intrusion into groundwater aquifers.

4.3 Agricultural Water Uses

Agriculture is by far the largest water user in the world today. Vast areas of the world are already irrigated, and irrigation development continues to increase in an attempt to meet the world's growing food demands. Much of the water applied to agricultural crops is consumed through either evaporation or plant growth. Because irrigated agriculture occupies such a large land area, the quantity of water consumed is dramatic: irrigated agriculture in China, for example, consumes a quantity of water each year equivalent to one and a half times the mean daily flow of the River Niger. Water consumption rates range between 5-10,000 m^3/ha/yr depending on the crop, temperature and length of the growing season.

Agricultural waters are primarily taken from surface waters. Excess waters are released back into many streams and rivers. Beyond the sheer volume of use, agricultural uses of water are critical because of the often significant changes in downstream water quality due to fertilizers, herbicides, erosion, and stream diversions (which may affect water volume). Thus, the source of agricultural water is as important a consideration as is the ~urn water. Agriculture has the largest water quality impact of any water use.

In Nigeria, level of irrigation is still low: irrigated land consttitutes only 3% of total land area, as against 9.6% and 12.7% in South Africa and Morroco, respectively (World Resources Insttitute, 1997). Correspondingly, fertilizer use in Nigeria is on an average of 15.6 kg/ha, compared with 64 kg/ha (South Africa) or 357 kg/ha (Egypt).

5.0 ENVIRONMENTAL CHANGE AND WATER RESOURCES

John Pallett (1997) states, and I quote" There is much controversy over climate change. It is a scientific fact that climates have changed throughout the earth's history. with the most recent ice age occuring only 11 000 years ago. But are the changes in the world's climate in the last few decades the result of human activity, or are they just part of the natural cycle of events? "

Some 25 years ago, scientists predict that the concentration of atmospheric CO_2 could reach 600 ppm by the middle ofthis century (National Research Council, 1983). As this happens, the earth's surface is expected to become warmer. Global warming is also expected to increase the intensity of the global hydrologic cycle; regional hydrologic cycles are, of course, components of the global hydrologic cycle. However, it is clear that changes in mean temperatures and precipitations shall not be uniformly distributed spatially and seasonally.

Changes in temperature and precipitation patterns, because of a buildup of CO_2, affect soil moisture requirements and the physical structure of the vegetation canopy, and these play important roles in the hydrologic system of a drainage basin - quantity, quality, timing and spatial distribution of water available in a basin to satisfy the many demands of society are all affected.

Water resource issues arise when the services provided by the hydrologic system of a drainage basin are no longer consistent with the needs of water users.

While a 1°_2°C increase in mean annual temperature, coupled with a 10% reduction in mean annual precipitation, may produce large decreases in average annual runoff in some climatic regions, these changes are already common in semi arid and tropical climatic systems, and yet the ambient CO_2 concentration still remains at an average of 310 ppm (Martins, 1988a; Martins & Olofin,1992). It should, therefore be noted that multiple impacts on land and water use are capable of generating changes of physical, hydrological, chemical and biological processes that affect the occurence and fluxes of water resources on a relatively short time-scale. Pertinent questions are

- How have water resources been modified by human activities? and
- How have these changes affected the flux of materials through surface and ground waters?

Current observations seem to indicate that human activities are the main drivers of environmental changes, and not the climate. Cumulative effects of changes observed in the hydrologic cycle at a global scale are driven by such activities as river damming, water diversions and withdrawals. These modify the physical components of aquatic environments, in terms of sediment retention, and reduction in water discharge. Land use changes through engineering constructions, deforestation and agriculture, which have been of increasing influence in the last 2000 years, are proceeding at an accelerated rate, particularly in the less developed world. Increasing water demand for irrigation is expected to cause severe drops in water quality through salinization of surface and groundwaters.

Global climate change might not be the most immediate critical issue, partly because it occurs over a longer time scale compared to human-induced changes. However, it cannot be totally ruled out that in areas where specific geographic settings are more sensitive to changes in the water balance, global climate change may exert an important pressure. Such areas include the coastal zones where salt water intrusion will affect coastal aquifers as a result of sea level rise.

5.1 Dams and their Effects

According to FAO (1998), the total number of dams in Africa is 1272, about 70% of which are located in South Africa (539) , Zimbabwe (213), and Algeria (107).
About 81% are single purpose dams of which 66% are for irrigation and 25% for water supply.

- The five largest dams in Africa by reservoir capacity are :
    - Kariba Dam, River Zambezi, Mozambique, 180 billion cubic meters
    - High Aswan Dam, Nile River, Egypt, 162 billion cubic meters

- Akosombo Dam, Volta River, Ghana, 150 billion cubic meters
- Cahora Bassa Dam, Zambezi river, Mozambique, 52 billion cubic meters
- Kossou Dam, Bandama River, Cote d'Ivoire, 28 billion cubic meters

With a total number of more than sixty completed multipurpose dams and more than equal number of different forms of barrages, mainly for irrigation and water supply, Nigeria has the highest concentration of surface water in the West African sub-region. Dams have gradually become popular in Nigeria as they have found relevance in the development of the people, mainly in respect of irrigation, water supply, livestock farming and hydroelectric power generation. Most of the dams however (about 70% of them), are located in the northern parts of Nigeria. The concentration of dams in the north results from the need to supply adequate water to the major towns, and more importantly, the dependence of its agriculture on irrigation due to inadequate rainfall – Kano State alone accounts for over 30% of the number of small –and medium-scale dams in Nigeria, while all the 3 hydropower dams are located in Niger State. Of the 70 000 Ha under formal irrigation in Nigeria, only about 4 400 Ha, i.e. about 6%, is in the south (Fatokun and Ogunlana,1992).

The impacts of dam construction can be socio-economic and environmental (Ayoade, 1988; NEST, 1991; Martins and Olofin, 1992) and can both be positive and negative (Ruhe, 1975; Matlock, 1985; Adams, 1986).

5.2 Decrease in discharge rate

A review of the discharge through the Niger River system at Onitsha between 1982 and 1987 showed that within the six-year period, an annual average of 127 km^3 of water is discharged through the river system. The flow of most African rivers has been modified over the years by natural changes, like frequent drought occurrences in the arid- and semi-arid-dominated basins, and by changes in land-use pattern, such as large irrigation schemes and hydropower plants through impoundments. The net effect is reduction in annual water volume reaching the adjoining seas (Martins, et al., 2000)

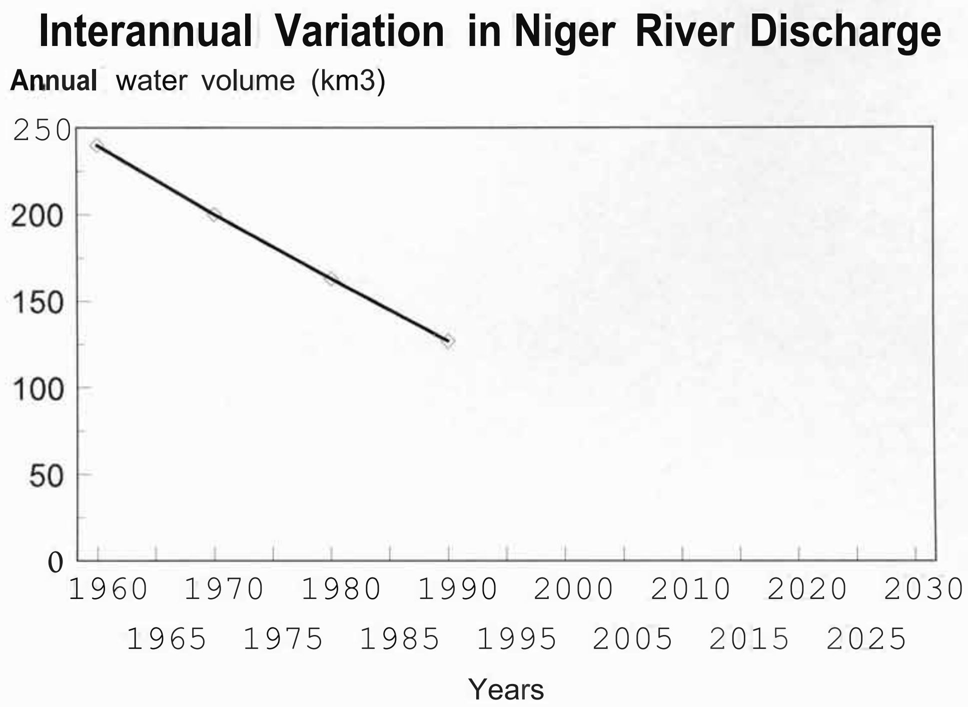

Figure 19. Interannual variarion of Niger river discharge between 1960 and 1990

Between 1963 and 1990, the Niger water volume has thus shrunk by over 50%, (Fig. 19) and the tendency still perssits. If this trend continues, then Niger river discharge into the Atlantic Ocean may stop totally before the year 2050.

Over the years, observation made on the Chad lake revealed that the lake that used to have a surface areal extent of over 400 000 sq.km , some 60 000 years ago (according to ancient shoreline mapping), now has an area of only 1 500 sq. km (UNEP,1999). Barely 40 years ago, the surface area of the lake was still 25 000 sq. km. Shared by 5 countries (Cameroon, Chad, Niger, Nigeria, and Central African Republic), lack of coordination in the usage of the land and water resources among the riparian countries, has been the major cause of the deteriorating situation. Intensive irrigation activities on Chari and Logone river valleys (Cameroom and Chad), and on the Tiga and Challawa rivers (Nigeria) have reduced inflow from the rivers into the lake by over 85%. Today fish stocks, crops and political relations are being threatened by the ever decreasing water resource of the region.

6.0 COST OF WATER

Traditionally, water serVIces have been regarded as one of governments many responsibilities - it must be supplied regularly and free of charge. In some parts of the country, inhabitants still do not understand why they must be made to pay for this" free gift from heaven ".The development, distribution,and treatment of water includes costs for design, initial investments, and operation and maintainance of the service.
Putting a price to water is a reflection of water's economic value and it affects water use efficiency; it is a key way to improve water allocation, discourage wastage, and improve conservation. However, the current practice whereby State Water Corporations charge fixed rates for services rendered only intermittently does not encourage consumers to pay. In most urban areas, there is scarcely a household that does not have, or nurse the ambition to have, an alternative source of domestic water supply by constructing a hand-dug well or a borehole. State Water Agencies should consider the introduction of water meters, particularly in urban centers; this simple act of measuring consumption can help people control the actual amount of water they use and *lor* waste; it is also a

more accurate, equitable and just way for the Water Agencies to commensurately get paid for services rendered.

7. CONCLUSIONS AND RECCOMENDATIONS

Water is a finite and vulnerable resource, essential to maintain life, environment and development.. It is intimately related to agricultural and rural development... Land is indispensable for agricultural production, yet it is water that determines success or failure.

Traditionally, water resource management has been unidimensional, with actions designed to address single-purpose needs such as hydropower, irrigation, or navigation. A resource-sensitive approach is needed, which takes into account all aspects of demand and supply and aims for efficiency and long-term sustainability of the resource. Managing water resources should take place at the community level, where the needs and constraints are most felt.

Water resources affect and is affected by all other forms of land use - agriculture, industry, environmental needs- and therefore must be practised at levels where effective interaction between these sectors can be achieved.

The recognition that water has an economic value has increased the relevance of water managers in the Nigerian society and this is also driving integration in water management.. Integration, in this sense, is only achievable through a process of joint planning, programming, and implementation, in order to optimize the utilization of the resources through the application of social, economic, political and technical instruments. The recognition of the hydrological drainage basin as the most appropriate unit of reference, through operation of the River Basin Authorities, is cOinmendable, but Government should remain true to the initial philosophy that defined the role and functions of the Authorities. All resources within a drainage basin are shared between upstream and downstream areas, between urban and rural settings, between natural and the human environment, and amongst all the different people in the river basin. However, we must acknowledge that in Nigeria the over-riding priority is for development, albeit development that is taking place in, and contributing to, a changing global environment. For the development of water resources, much can be achieved through the application of existing knowledge, particularly in the framework of Integrated Land and Water Management..

The United Nations Conference on the Environment and Development (UNCED) in Rio de Janeiro, Brazil in 1992 came up with a plan for the world environmental crisis, called Agenda 21. Paragraph 18.19 of the Agenda lists four main objectives of integrated water resources management:

1. To promote a dynamic, interactive, and multisectoral approach to water resources management, including identification and protection of potential sources of freshwater supply that integrates technological, socio-economic, environmental and human health considerations.
2. To plan the sustainable and rational utilisation, protection , conservation and management of water resources based on community needs and priorities within the framework of national economic development policy.
3. To design, implement, and evaluate projects and programmes that are both economically efficient and socially appropriate within clearly defmed strategies, based on an approach of full public participation, including that of women, youths, indigenous people, local communities and people under occupation in water

management policy-making and decision-making. (This is the so-called bottom-up approach).

4. To identify and strengthen or develop, as required, in particular in developing countries, the appropriate institutional, legal and fmancial mechanisms to ensure that water policy and its implementation are a catalyst for sustainable social progress and economic growth.

Integrated Land and Water Management must, therefore, be recognised as the essential framework needed to bring together the physical, social, economic and legal aspects of water resources management and development. This entails horizontal integration, that is integration among adjacent land users and land uses within catchments; between upstream and downstream users; among domestic, industrial, urban and other users; and among governments sharing river systems; and vertical integration: integration among the range of organisations and institutions functioning at different scales, and striving to achieve maintenance of adequate amounts and quality of water to all water users.

The development of water supply for all purposes is in dire need of re-evaluation, in view of the need to ensure infrastructural development of Nigeria. Short-term considerations, lack of coordination and cooperation among the different agencies responsible for water resources development in Nigeria, inconsistency in government polices and priorities, are the bane of water supply in Nigeria. These are worsened by lack of basic data for planning, placement of personal benefits above social benefits and failure to adopt a bottom-up approach. A comprehensive evaluation of strategies for water development is needed, central of which should be the up-to-date acquisition and storage of data, not only related to water supply, but also related to other areas that would make for effective planning, execution and management of water , in the long term.

For these actions to be successful, attempts should be made to

- Coordinate related existing national and state projects dealing on water development whether funded by the same organisation or not.
- Provide the right working relationship for joint programmes for transboundary river basins
- Provide inter-state cooperation, networking and technical assistance to needy states and Local governments
- Encourage training programmes linked to joint research projects in the institutions of higher learning.

The Pro-Chancellor, Mr. Vice Chancellor, Sir, Nigeria has wasted a lot of efforts and financial resources for most parts of the last century. This millenium offers us yet another opportunity to remedy all of our past mistakes. With the air of democracy blowing all around us, and God being our guide, the set goal of water for all users in adequate quantity and quality must be achievable.

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The Vice Chancellor, Sir I am indeed very happy today. I give the glory to Almighty God, my Redeemer, who has spared my life till this day, who has given me so many opportunities in life, who has elevated me to this level of my academic career, and who, above all, has deemed it fit to qualify me to give this inaugural lecture.

When I started on this academic journey, I met so many dedicated and commited teachers at the primary, secondary, and tertiary levels. I wish to express my gratitude to all of them. I would like to mention one of them, Professor (now Senator) Afolabi Olabimtan, my English and Latin teacher at Methodist Boys' High School, Lagos, who, very often, would go out of his way to teach us morals and discipline.

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I will like to express my appreciation to all those who have worked behind the scene to ensure a successful inaugural lecture - the Vice Chancellor's Office , the Ceremonials Committee, Academic Office, AMREC , and others – To you all, I say " well done ".

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