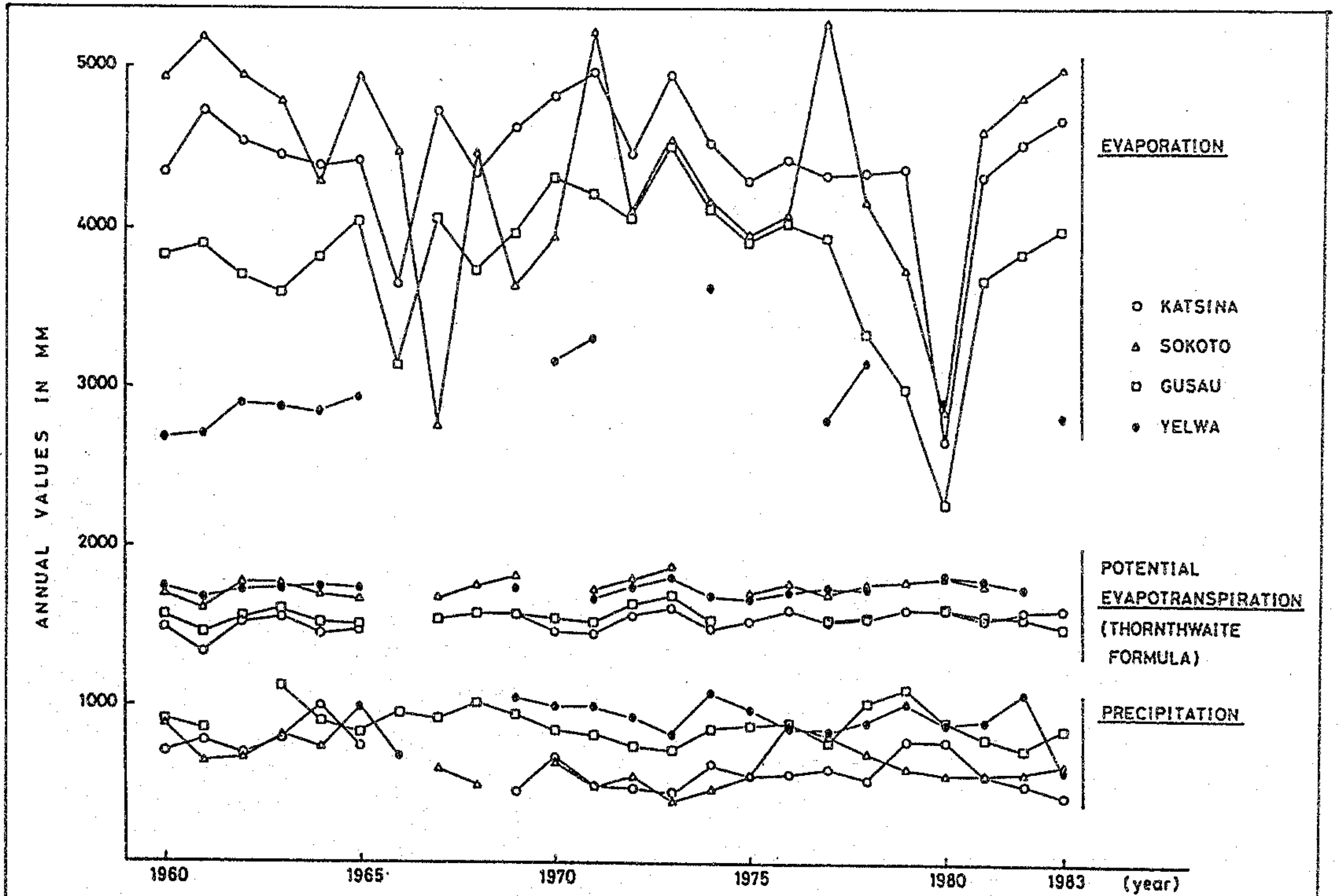
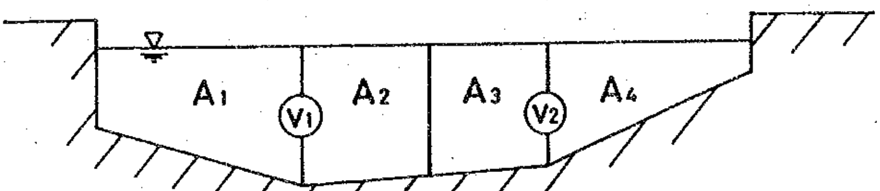


Fig. 3-9 Annual evaporation, potential-evapotranspiration, and precipitation at Katsina, Sokoto, Gusau and Yelwa

3. Bunza on the Rima River

4. Jega on the Zamfara River

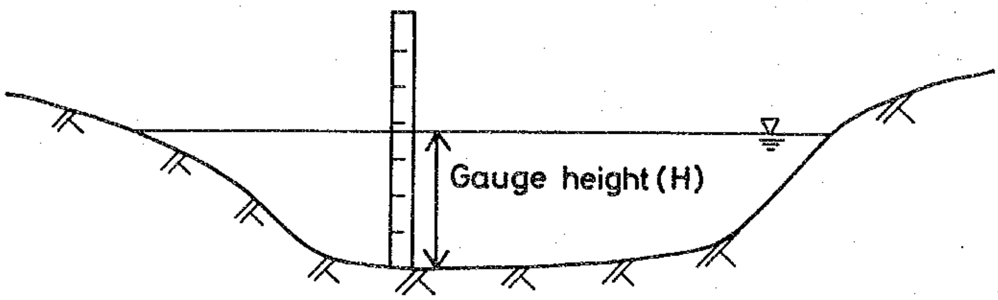
Discharge observation at these points was carried out continuously every month throughout the period of the Study.
Discharge is obtained by multiplying the observed area of the river by the velocity of the river as measured by a current meter. In order to achieve accurate results, current velocity and area were measured at many points and depths in river cross sections.



$$Q = (A_1 + A_2) \times V_1 + (A_3 + A_4) \times V_2$$

3-3-2 Rating curve

Apart from discharge observation, staff gauge height at the observation points, except at Kainuwa, has been continuously read by SSWB and/or FDWR three times every day.

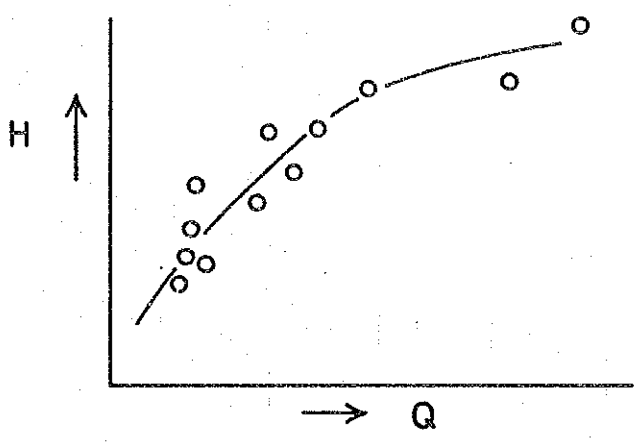


Gauge height (H) and measured discharge (Q) are plotted together to produce a rating curve. In general, the theoretical relationship between H and Q is expressed as:

$$Q = a\,(H - H0)^{b} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3\text{-}1)$$

where H0 is the gauge height at zero discharge, and 'a' and 'b' are constants. The most suitable values for 'a' and 'b' to express the relationship are chosen through mathematical trial.
Once the equation is established, discharge can be translated from gauge height without discharge observation, provided that the riverbed morphology does not change significantly.

Rating Curve



3-3-3 Observation results

Observed discharge and unit discharge are given in Table 3-9 and Fig. 3-10 (1)-(4). The flow system is given schematically in Fig. 3-11.

The discharge at every point for 1988, recorded as largest from the end of September to the beginning of October. After that, the discharge decreased until the end of April, 1989, when the value became the smallest for the period of the observation. After May, 1989, the discharge again started to increase became the largest for 1989.
As is evident from Fig. 3-10, the largest discharge at each point recorded in 1988 is significantly greater than that in 1989. This difference apparently reflects the difference in annual precipitation in 1988 and 1989.

Rating curves established from the measured discharge and gauge height are :

Argung	Q=0.001414	* (H-0) **6.984	$H > 3.4$m	.... (3-2)
	Q=1.209	* (H-0) **1.555	$H < 3.4$m	
Bunza	Q=0.84	* (H-0) **3.93		.... (3-3)
Jega	Q=2.376	* (H-0) **3.021	$H > 1.35$m	.... (3-4)
	Q=4.990	* (H-0) **0.4901	$H < 1.35$m	

Tab. 3-9 Discharge at Observation Points

LOCATION	LAKE KAINUWA			ARGUNGU ON THE RIVER RIMA				BUNZA ON THE RIVER RIMA				JEGA ON THE RIVER ZAMFARA			
DRAINAGE AREA	A=25㎢			A=67310㎢				A=76676㎢				A=14094㎢			
	DATE	Q(㎥/S)	UnitQ	DATE	Q(㎥/S)	H(m)	UnitQ	DATE	Q(㎥/S)	H(m)	UnitQ	DATE	Q(㎥/S)	H(m)	UnitQ
1	12/7/88	0.12	4.800	14/7/88	10.60	4.78	0.157	13/7/88	16.47	2.18	0.215	13/7/88	81.67	1.70	5.795
2	2/8/88	0.12	4.920	29/7/88	17.21	4.10	0.256	28/7/88	24.17	2.40	0.315	30/7/88	122.60	3.40	8.699
3	31/8/88	0.17	6.680	31/8/88	69.48	5.20	1.032	30/8/88	47.22	2.84	0.616	30/8/88	204.60	4.49	14.517
4	29/9/88	0.37	14.800	1/10/88	393.40	5.80	5.845	30/9/88	456.70	4.54	5.956	30/9/88	284.40	5.01	20.179
5				17/10/88	182.10	4.85	2.705	19/10/88	294.90	4.00	3.846	20/10/88	13.02	1.80	0.924
6	30/11/88	0.30	11.800	30/11/88	8.23	2.17	0.122	29/11/88	11.53	1.88	0.150	28/11/88	6.51	1.40	0.462
7	14/12/88	0.25	9.960	15/12/88	7.06	2.04	0.105	16/12/88	9.88	1.70	0.129	16/12/88	5.77	1.22	0.409
8	30/1/89	0.23	9.200	30/1/89	7.24	2.02	0.108	31/1/89	7.54	1.60	0.098	31/1/89	3.84	1.22	0.272
9	28/2/89	0.05	2.080	28/2/89	4.41	1.97	0.066	1/3/89	6.48	1.45	0.085	1/3/89	4.70	1.22	0.333
10	4/4/89	0.22	8.880	31/3/89	1.54	1.93	0.023	30/3/89	2.45	1.25	0.032	30/3/89	4.13	1.17	0.293
11	25/4/89	0.11	4.560	25/4/89	1.01	1.04	0.015	26/4/89	2.06	1.18	0.027	26/4/89	2.45	0.23	0.174
12	1/6/89	0.15	5.800	31/5/89	1.09	2.32	0.016	30/5/89	2.43	1.34	0.032	31/5/89	3.00	0.27	0.213
13	27/6/89	0.15	6.040	27/6/89	4.38	3.09	0.065	28/6/89	5.78	1.45	0.075	28/6/89	2.93	0.61	0.208
14	27/7/89	0.02	0.840	27/7/89	17.60	3.85	0.261	28/7/89	13.90	2.21	0.181	28/7/89	64.70	4.59	4.591
15	30/8/89	0.23	9.040	30/8/89	9.99		0.148	31/8/89	12.78	2.94	0.167	31/8/89	16.06	3.87	1.139
16	24/9/89	0.20	7.840	24/9/89	10.02	5.00	0.149	25/9/89	8.12		0.106	25/9/89	7.96	4.44	0.565
17	28/10/89	0.28	11.200	27/10/89	10.73	4.70	0.159	26/10/89	58.36	3.53	0.761	26/10/89	0.95	1.65	0.067
18	22/11/89	0.21	8.440	22/11/89	2.47	4.40	0.037	23/11/89	6.40	3.05	0.083	23/11/89	1.23		0.087

note : UnitQ = Q (discharge) ÷ A (drainage area) ×1000　　(㎥/sec/1000km)

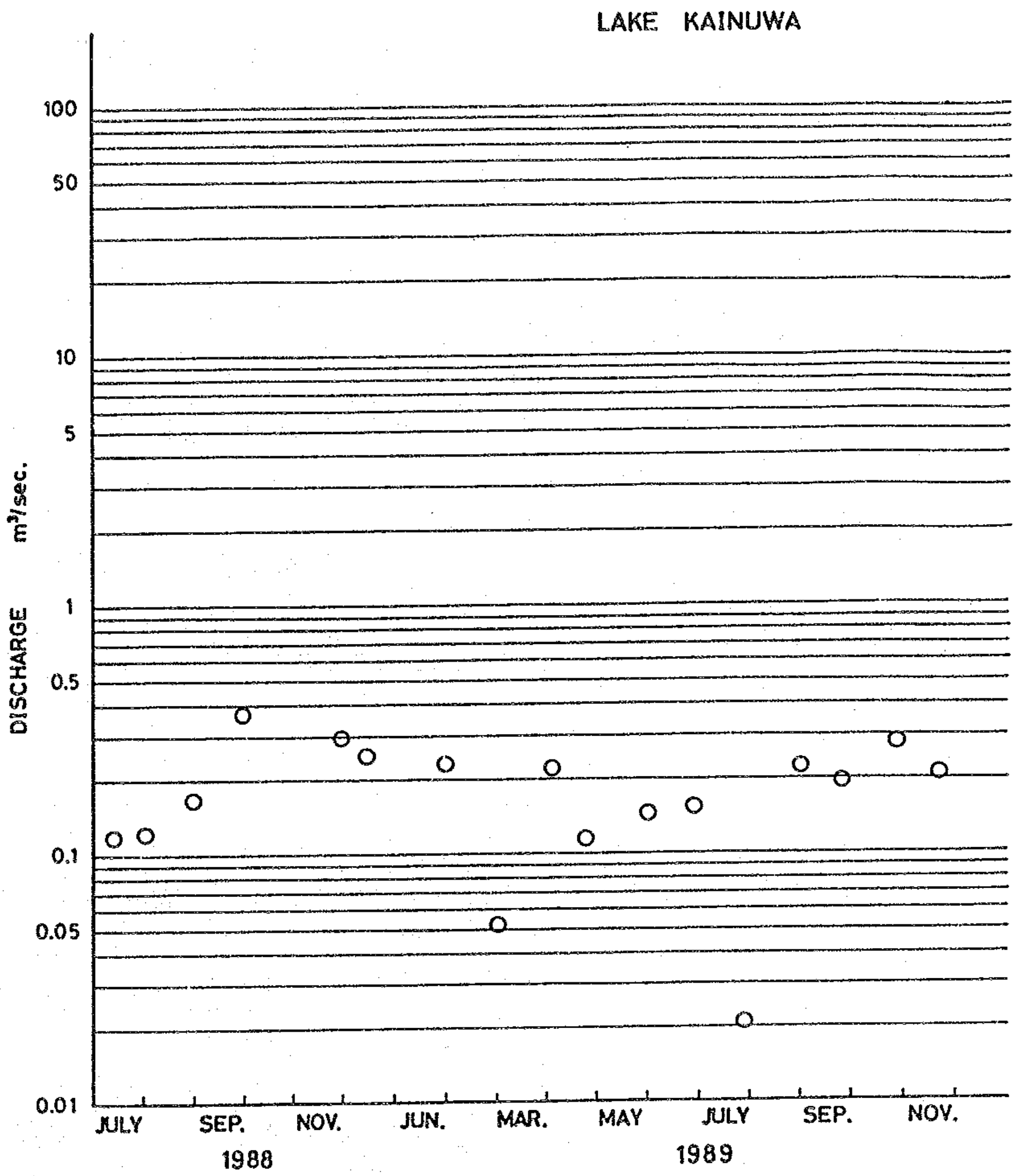


Fig. 3-10 (1) Results of Discharge Observation

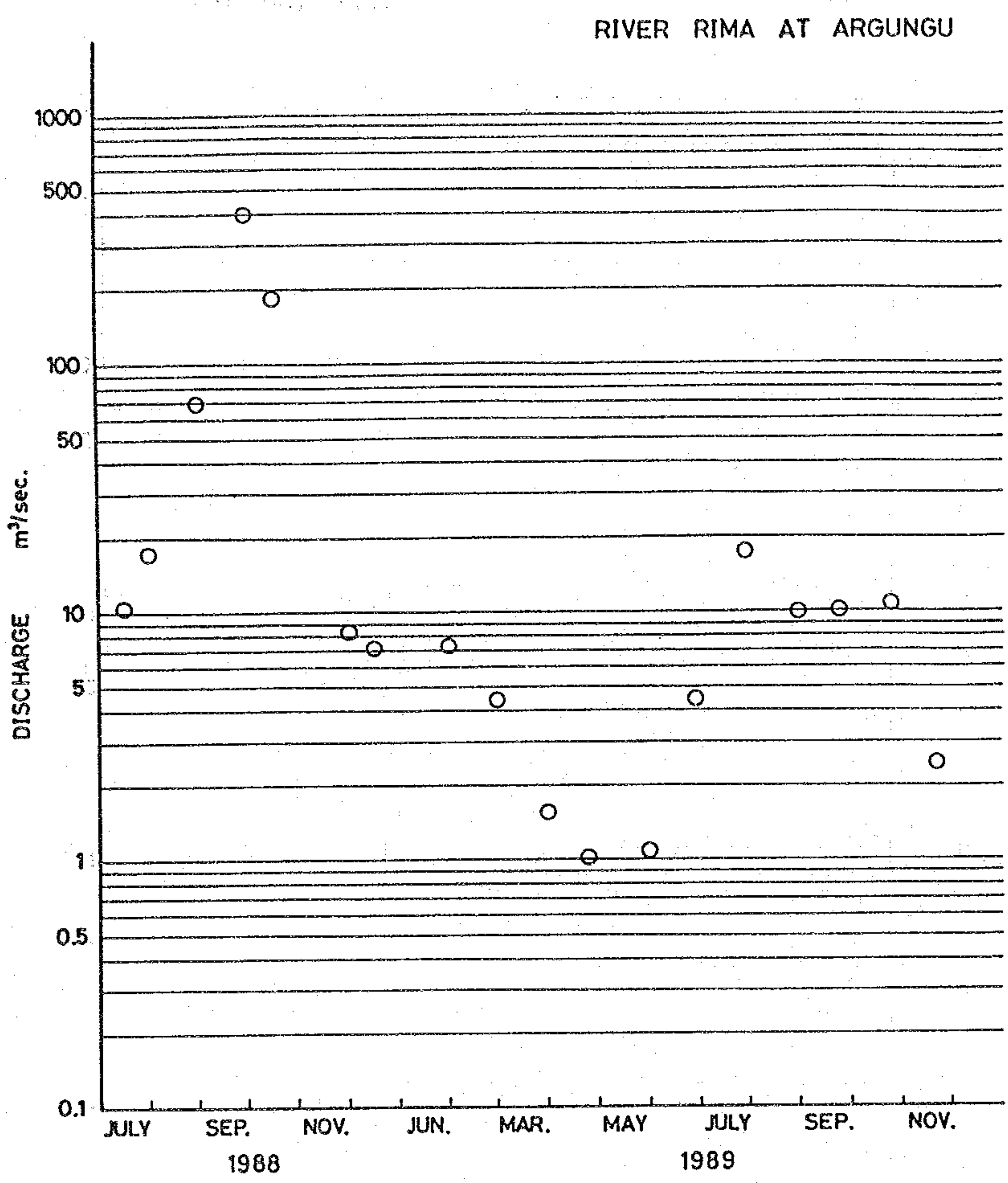


Fig. 3-10 (2) Results of Discharge Observation

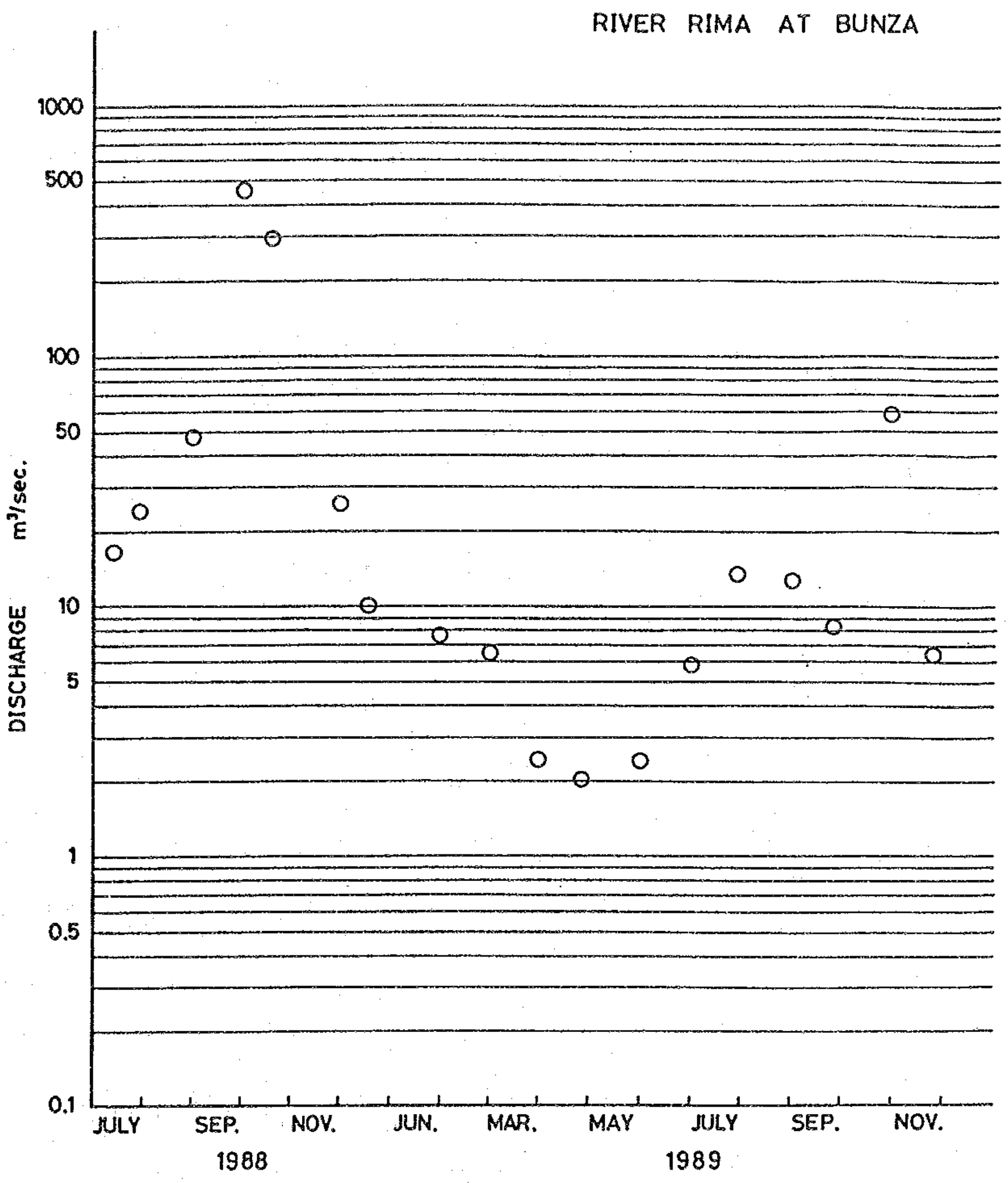


Fig. 3-10 (3) Results of Discharge Observation

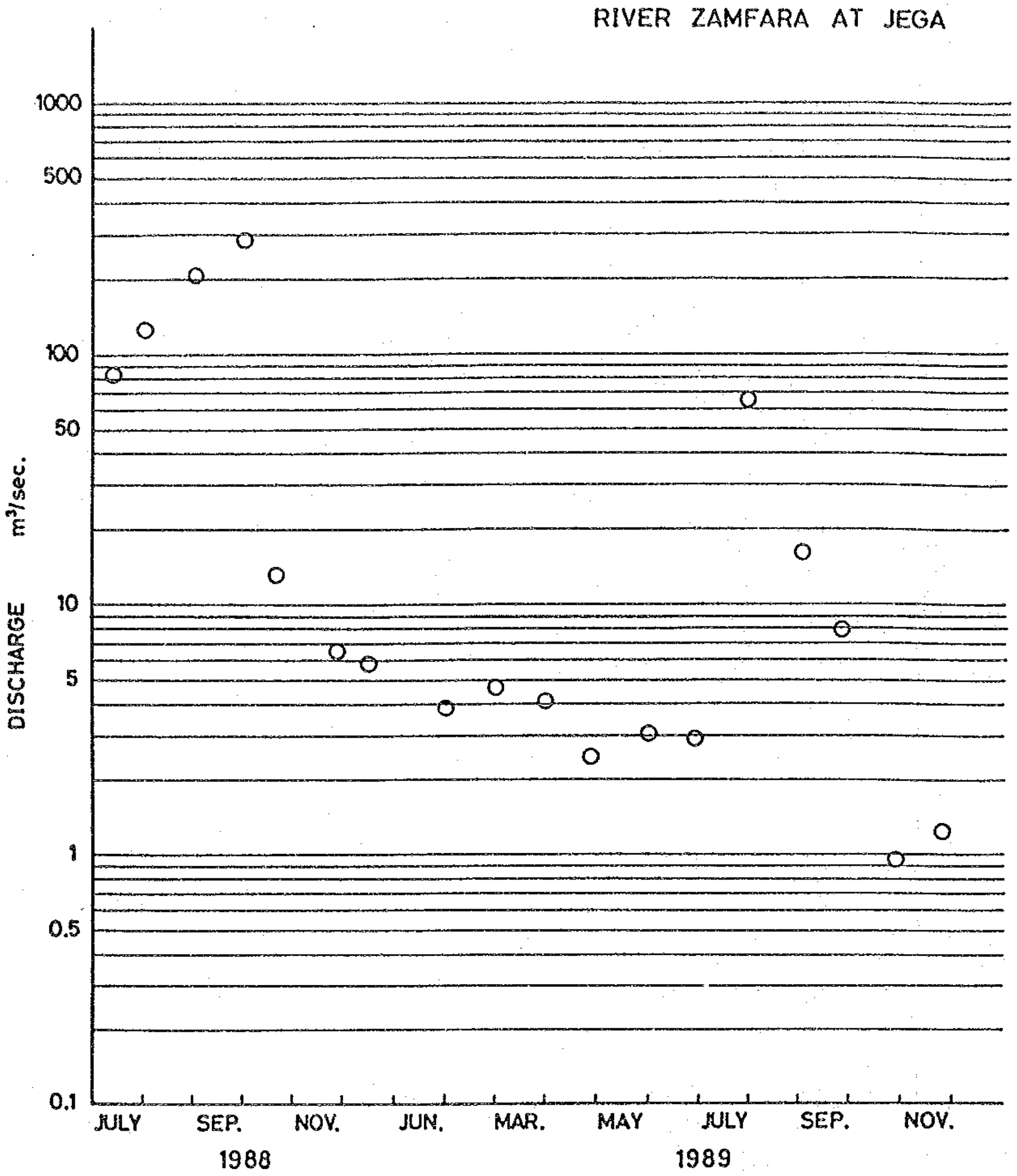


Fig. 3-10 (4) Results of Discharge Observation

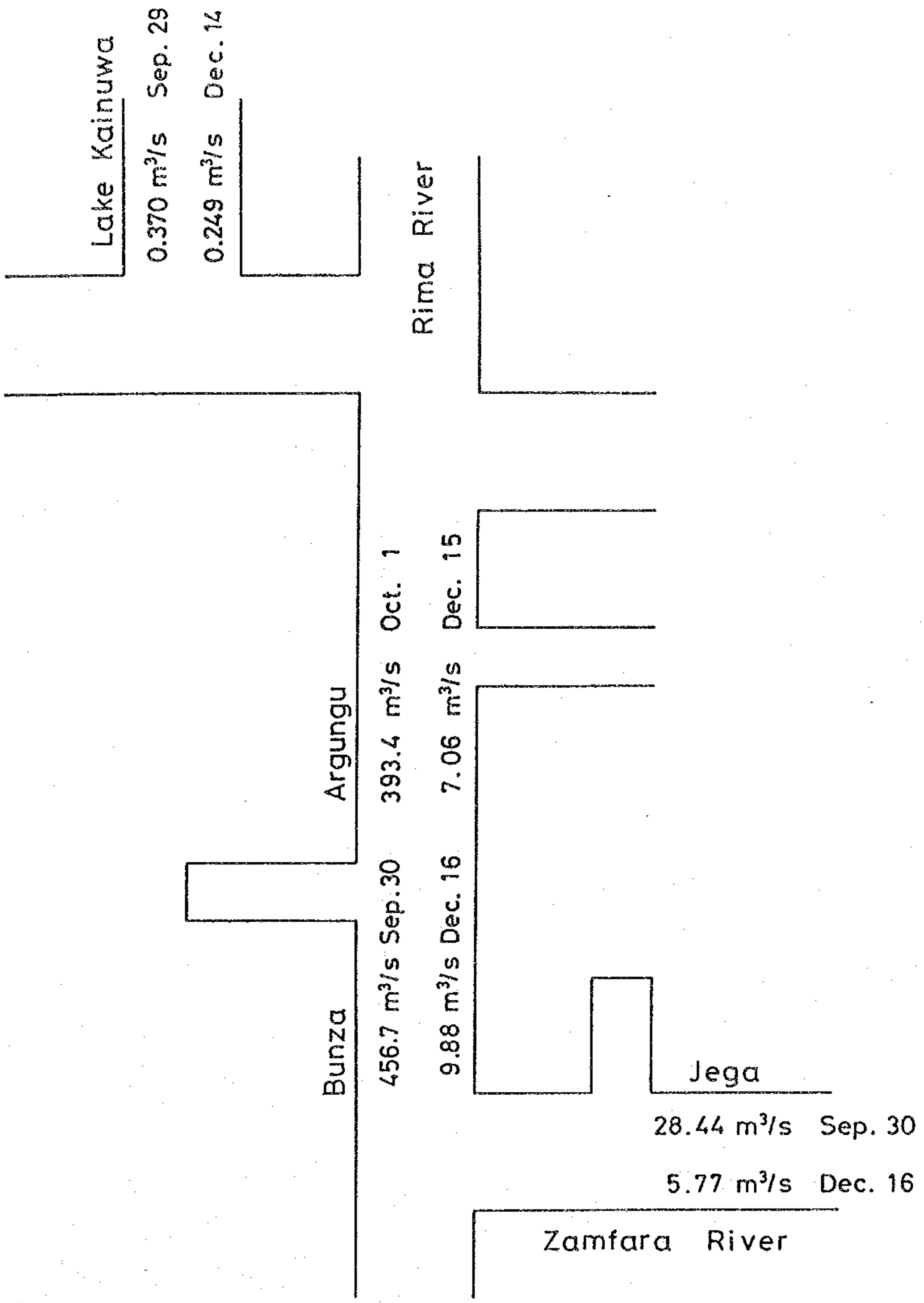


Fig. 3-11 Schematic Diagram of the Flow System

Fig. 3-12 (1) Rating curve at Argungu on the River Rima

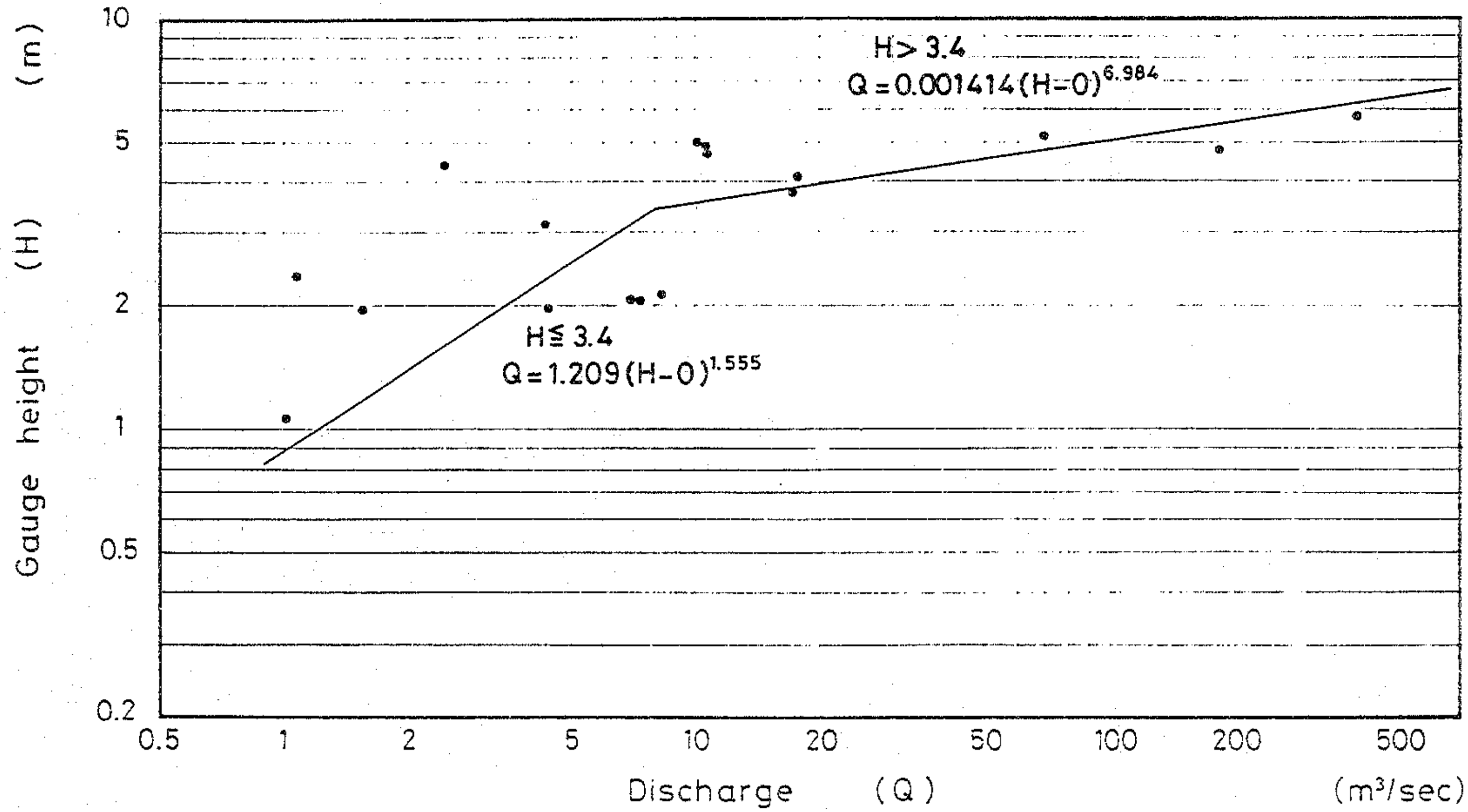


Fig. 3 - 12 (2) Rating curve at **Bunza** on the River **Rima**

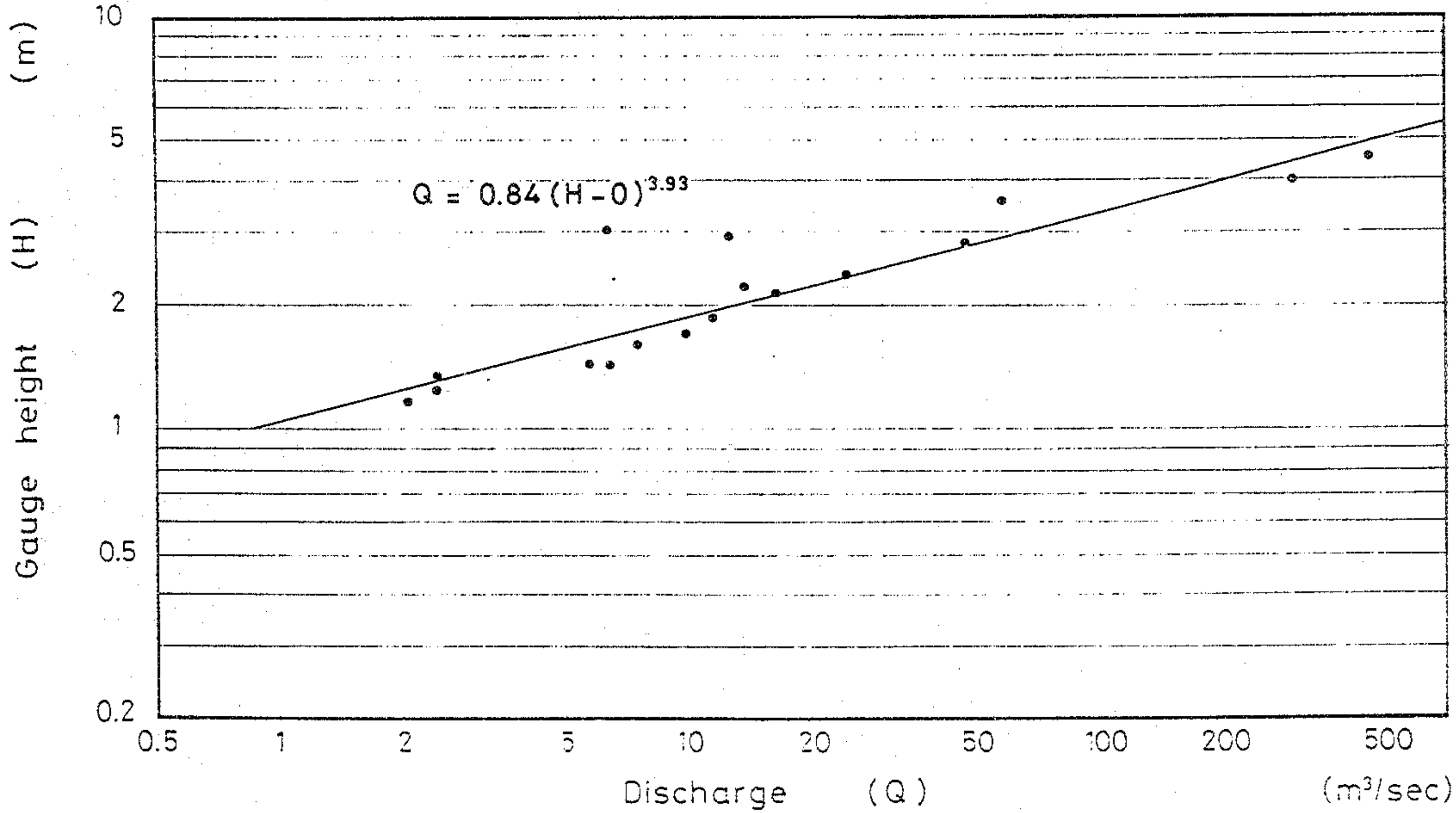
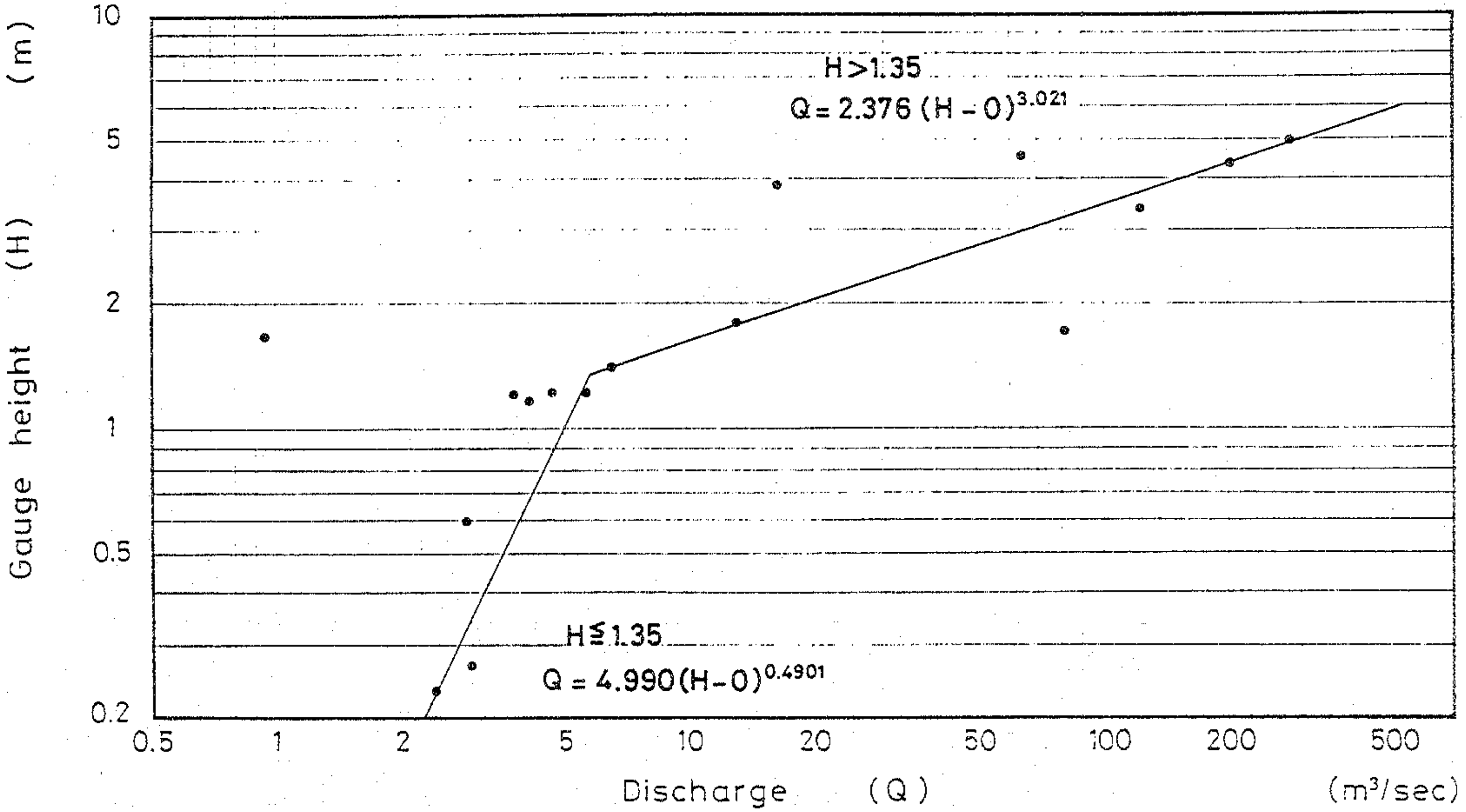


Fig. 3-12 (3) Rating curve at Jega on the River Zamfara



The least square method was used to determine the constants in the rating curves.

A set of rating curves is required to represent the relation between the discharge and gauge height at Argung and Jega.

3-4 Stream Hydrology

Stream discharges in the study area are characterized by two types of rivers: intermittent streams which dry up during the dry season and perennial streams which keep flowing throughout the whole year.

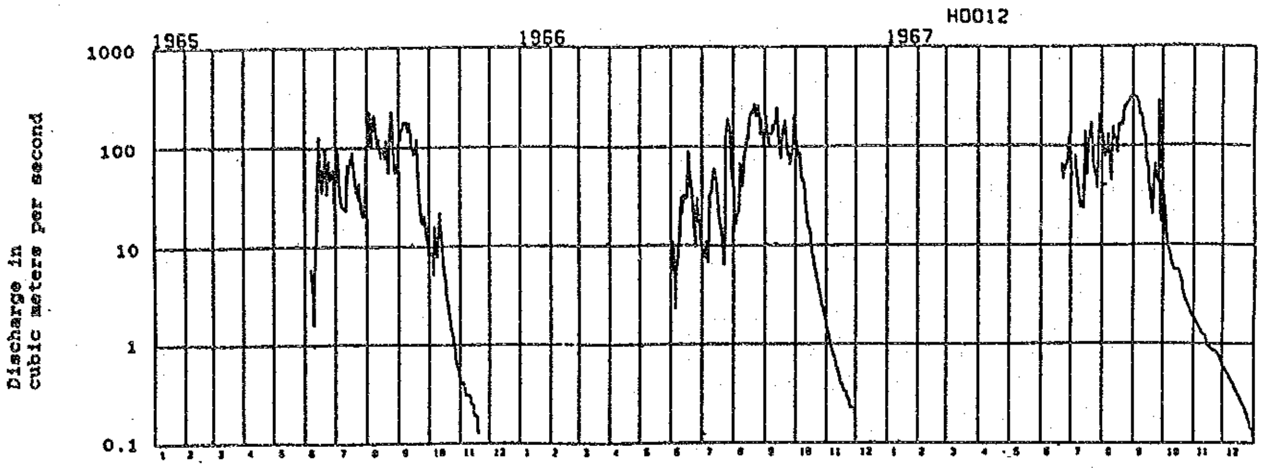
Almost every river flowing in the basement complex area is intermittent. With the end of the rainy season, their flow rapidly decreases until they dry up. They resume flow with the beginning of the rainy season. Generally, the response of the stream discharge to the rainfall is very quick. Fluctuations in river discharge is very high, in accordance with tropical precipitation in the rainy season. Impermeable basement rocks underlying the area determine the characteristics of the discharge.

Main rivers flowing in the lower reaches of the sedimentary area, such as the River Rima and the River Zamfara, are perennial. During the rainy season their discharges consist of downflow from the basement complex areas and overflow from their own catchment areas. Despite the fact that downflows from the basement complex areas disappear during the dry season, their discharges are maintained by groundwater baseflow.

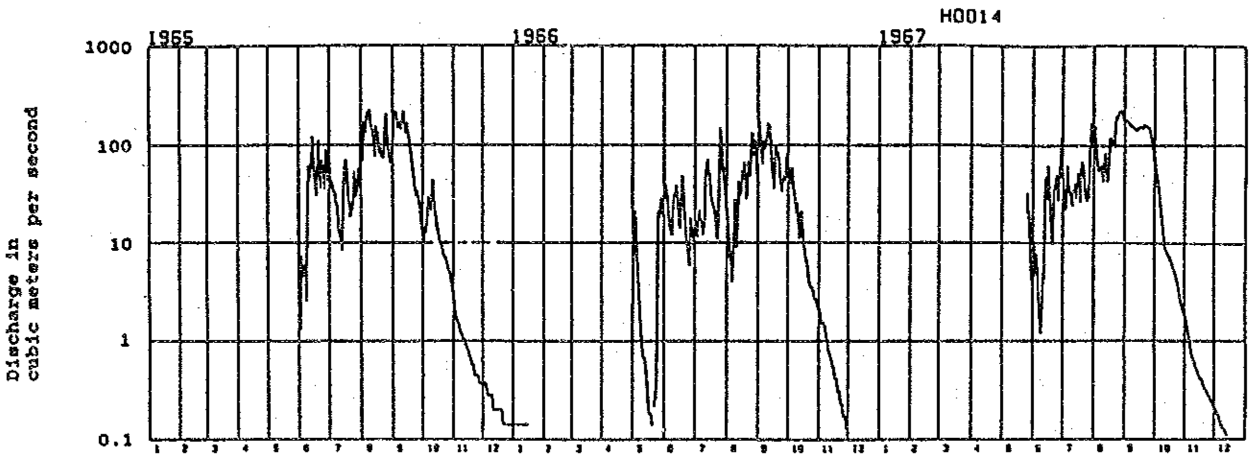
The discharges of the River Rima at Sabon-Birni, the River Rima at Wamako, and the River Sokoto at Gidan-Doka, from 1965 to 1967, are shown in Fig.3-13. Their locations and a schematic drainage system map are shown in Fig.3-14 and Fig.3-15 respectively. The discharge at Sabon-Birni, on the River Rima, and Gidan-Doka, on the River Sokoto, is intermittent, and the discharge fluctuation for each is high. In contrast, the discharge at Wamako on the River Rima, is perennial, and the discharge fluctuation is lower than that of the others. The water balance of surface water calculated from the average discharge and precipitation of 1965 and 1966 indicates that run-off ratios range from a low of 3.9% at Wamako to a high of 7.1% at Gidan-Doka (Table 3-10). More than 92% of the water supplied by precipitation is assumed to be lost to evapotranspiration or infiltration into the ground. Assuming that infiltration is very small compared to evapotranspiration, it is evident that most of the water is lost to evapotranspiration.

Fig. 3-13 Hydrograph of the River Rima and Sokoto, 1965 - 1967

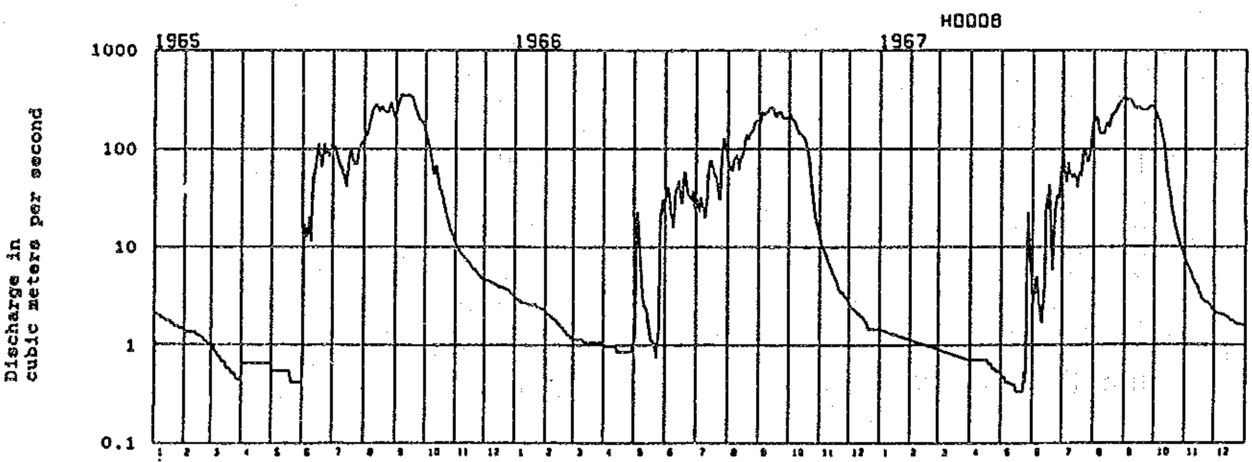
The River Rima at Sabon-Birni



The River Sokoto at Gidan-Doka



The River Rima at Wamako



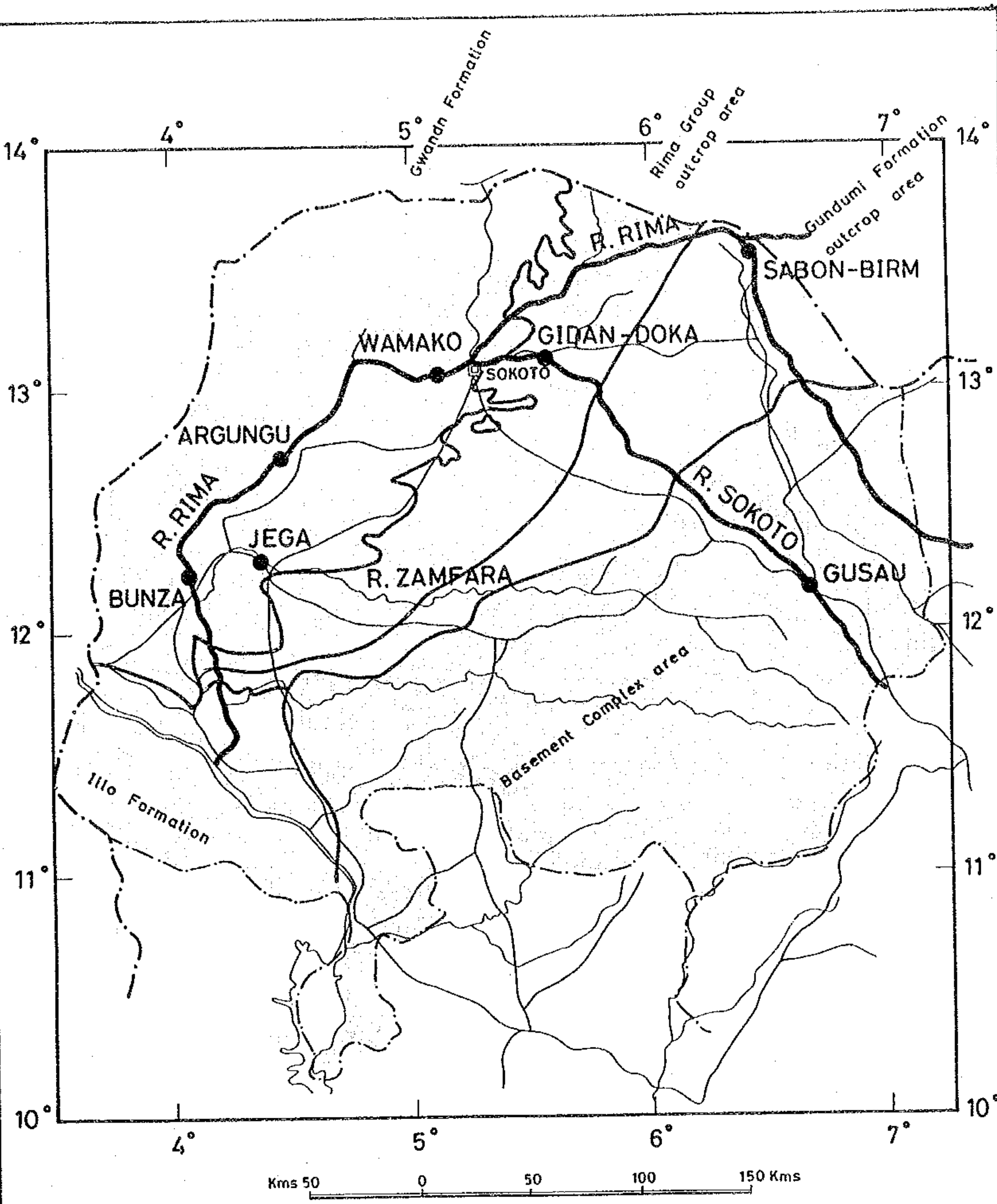


Fig.3-14 Location Map of Hydrological Stations

Sedimentary rock area

Basement rock area

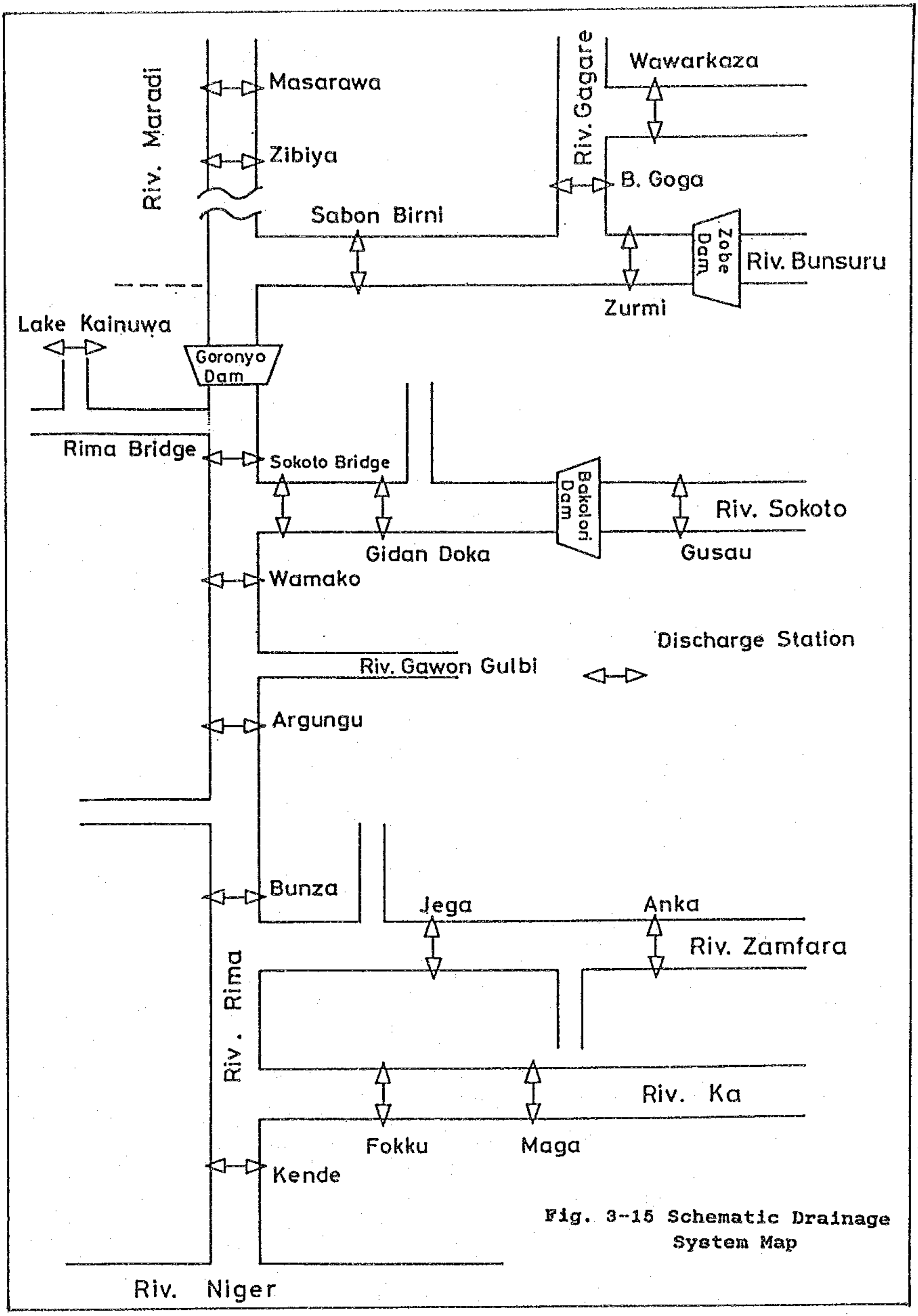


Fig. 3-15 Schematic Drainage System Map

Table 3-10 Water Balance of Sokoto-Rima Basin

	CATCHMENT AREA	MEAN ANNUAL DISCHARGE 1965,1966	MEAN ANNUAL PRECIPITATION 1965,1966	RUN-OFF COEFFICIENT	LOSS TO EVAPOTRANSPIRATION INFILTRATION
RIVER RIMA AT SABON-BIRNI	19,758 (km^2)	885.32 (Mm^3/y) 44.8 (mm/y)	16,512 (Mm^3/y) 835.7 (mm/y)	5.36 (%)	15,627 (Mm^3/y) 790.9 (mm/y)
RIVER SOKOTO AT GIDAN-DOKA	12,249 (km^2)	727.26 (Mm^3/y) 59.4 (mm/y)	10,195 (Mm^3/y) 832.3 (mm/y)	7.13 (%)	9,468 (Mm^3/y) 772.9 (mm/y)
RIVER RIMA AT WAMAKO	56,753 (km^2)	1,703.86 (Mm^3/y) 30.0 (mm/y)	43,696 (Mm^3/y) 769.9 (mm/y)	3.90 (%)	41,992 (Mm^3/y) 739.9 (mm/y)
RIVER SOKOTO AT GUSAU	2,657 (km^2)	362.51 (Mm^3/y) 136.4 (mm/y)	2,199 (Mm^3/y) 827.7 (mm/y)	16.48 (%)	1,836 (Mm^3/y) 691.3 (mm/y)

Water balance at Gusau was calculated from data between 1969 to 1976.

Water balance at the other places were calculated from data of 1965 and 1966.

As shown in the drainage system map in Fig.3-15, Wamako, on the River Rima, is located downstream of both Sabon-Birni, on the River Rima and Gidan-Doka, on the River Sokoto. Discharge at Wamako (Q2) ought to exceed the sum of discharge at Sabon-Birni and Gidan-Doka (Q1), providing no water loss takes place during the course of downflow from Sabon-Birni or Gidan-Doka to Wamako. Fig.3-16 compares monthly Q1 and Q2 from 1965 to 1968. Contrary to the above assumption, Q1 exceeds Q2 from June to August, implying some water loss in the course of downflow. Much of the water is probably lost to the alluvium in the river bed, but part of this may recharge the Rima Group aquifer because the rivers flow over the outcrop area of the Rima Group. Q2 exceeds Q1 from August to May. The first two months correspond to the rainy season, while the eight remaining months correspond to the dry season. A possible explanation is that the water loss in the beginning of the rainy season, which replenishes unsaturated zones of the alluvium river bed, may decrease when the zone becomes saturated. With the decrease of water loss, Q2 accordingly becomes larger than Q1. Although Q1 dries up during the dry season, Q2 is maintained, apparently by effluence from a shallow groundwater body. The springs issuing from the Kalambaina limestones are considered to play an important role in maintaining the discharge at Wamako. The volume of the effluents from November to March, calculated from the discharge data, is 31.35Mm^3 (average volume from Nov. 1965 to Mar. 1967). Discharge observation was carried out at Lake Kalmalo, which is fed solely by the effluent from the Kalambaina aquifer. The total discharge from the lake from 12/7/88 to 27/6/89 is calculated to be 6.34Mm^3, which is almost equivalent to the annual discharge. The drainage area of the lake is 24.987km^2. Assuming that the drainage area of surface water for the lake is coincident with that of the groundwater drainage system, the annual discharge per unit of drainage area is roughly 0.254Mm^3/km^2 (254mm/year). This value appears somewhat excessive, suggesting that the drainage area of the groundwater system may be greater than that of the surface water.

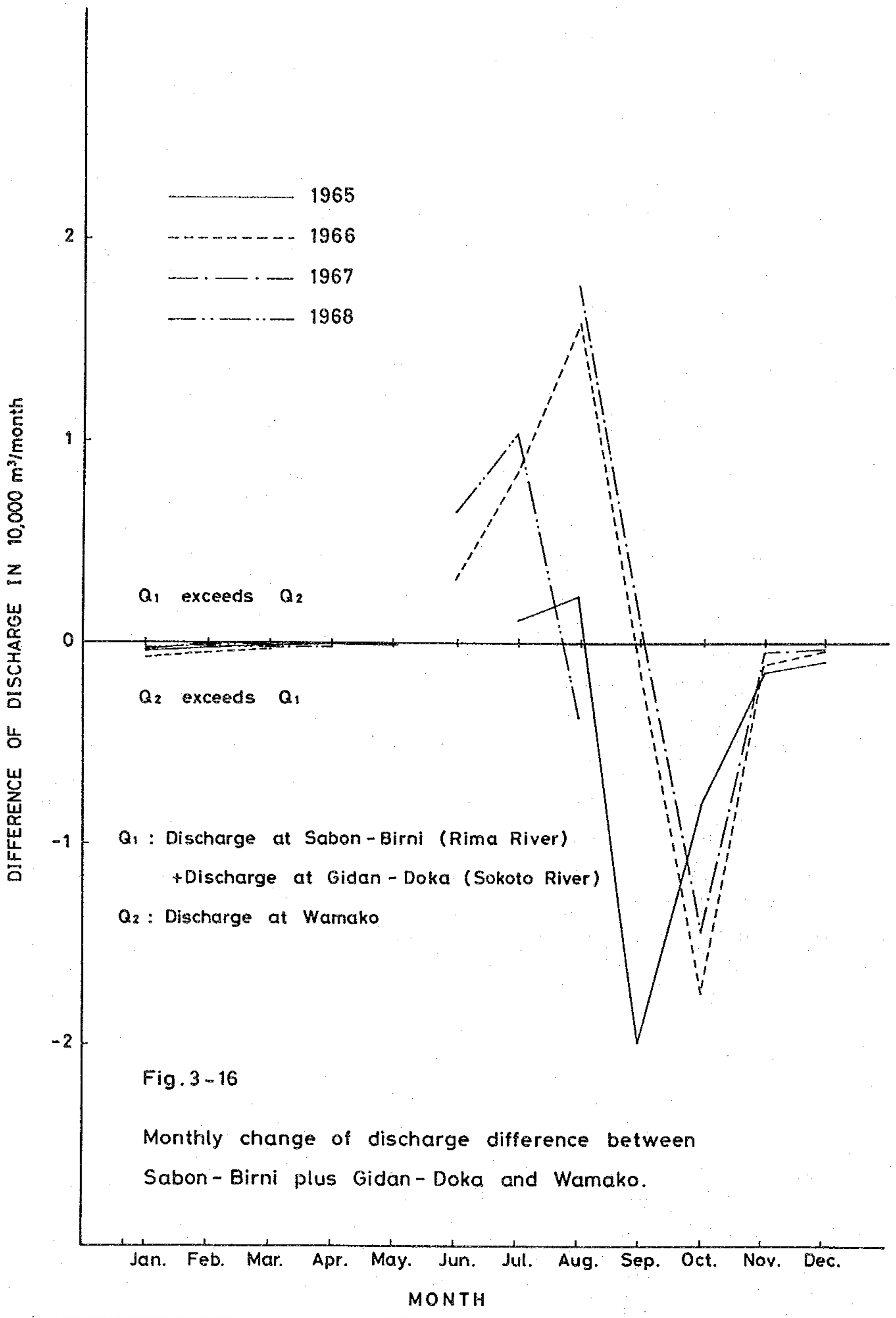


Fig. 3-16

Monthly change of discharge difference between Sabon-Birni plus Gidan-Doka and Wamako.

These assumptions to explain characteristics of the discharge variation appear applicable to the lower reaches of the River Rima. The discharges at Wamako and Argungu, on the River Rima, from 1968 to 1969 are given in Fig 3-17. The discharge fluctuation at Argungu is smoother than that at Wamako. The discharges at Wamako exceed those at Argungu from May to the middle of September. After this, the inequality is reversed. Effluence from groundwater apparently takes place between the two places to maintain discharge in the dry season. While the discharge in the dry season at Wamako seems to be maintained largely by effluence from the Kalambaina aquifer, a large part of the effluence between Wamako and Argungu is probably from the upper unconfined Gwandu aquifer and the alluvium deposit composing the river bed. The integration of differences between the discharges at the two places, which seems to be equivalent to the volume of effluence from groundwater between the two, from 1/11/68 to 31/3/69, is 9.70Mm^3.

Monthly discharge observations were carried out by the study team from July, 1988 to June, 1989 at Argungu and at Bunza in the River Rima.

As shown in Fig. 3-18, the discharges at Bunza, which is located about 100km downstream from Argungu, are larger than those at Argungu. This indicates that groundwater effluence occurs between Argungu and Bunza as well. The volume of the effluence from groundwater calculated from the measured discharges from December, 1988 to May, 1989 is 24.0Mm^3. Most of the effluence is believed to stem from the upper unconfined Gwandu aquifer or alluvium deposit. Discharge observations were also carried out at Jega, on the River Zamfara, a perennial river. The volume of effluence from groundwater to the river from December, 1988 to May, 1989 is calculated to be 67.2Mm^3. The discharge at Jega in the dry season may be maintained partly by effluence from groundwater in the Rima or Gundumi aquifers, since the river flows over their outcrop areas.

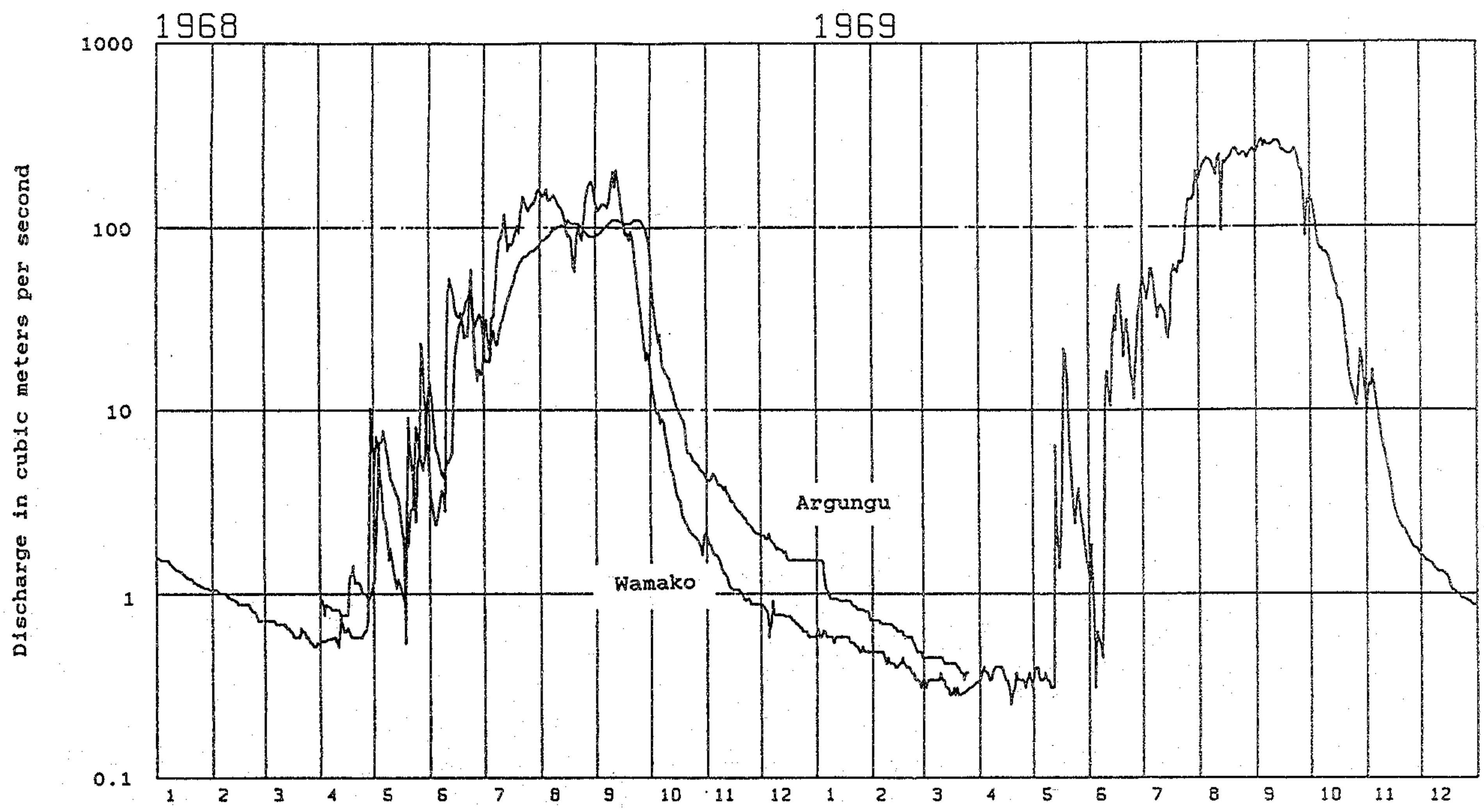


Fig. 3-17 Hydrograph of the River Rima at Wamako and Argungu

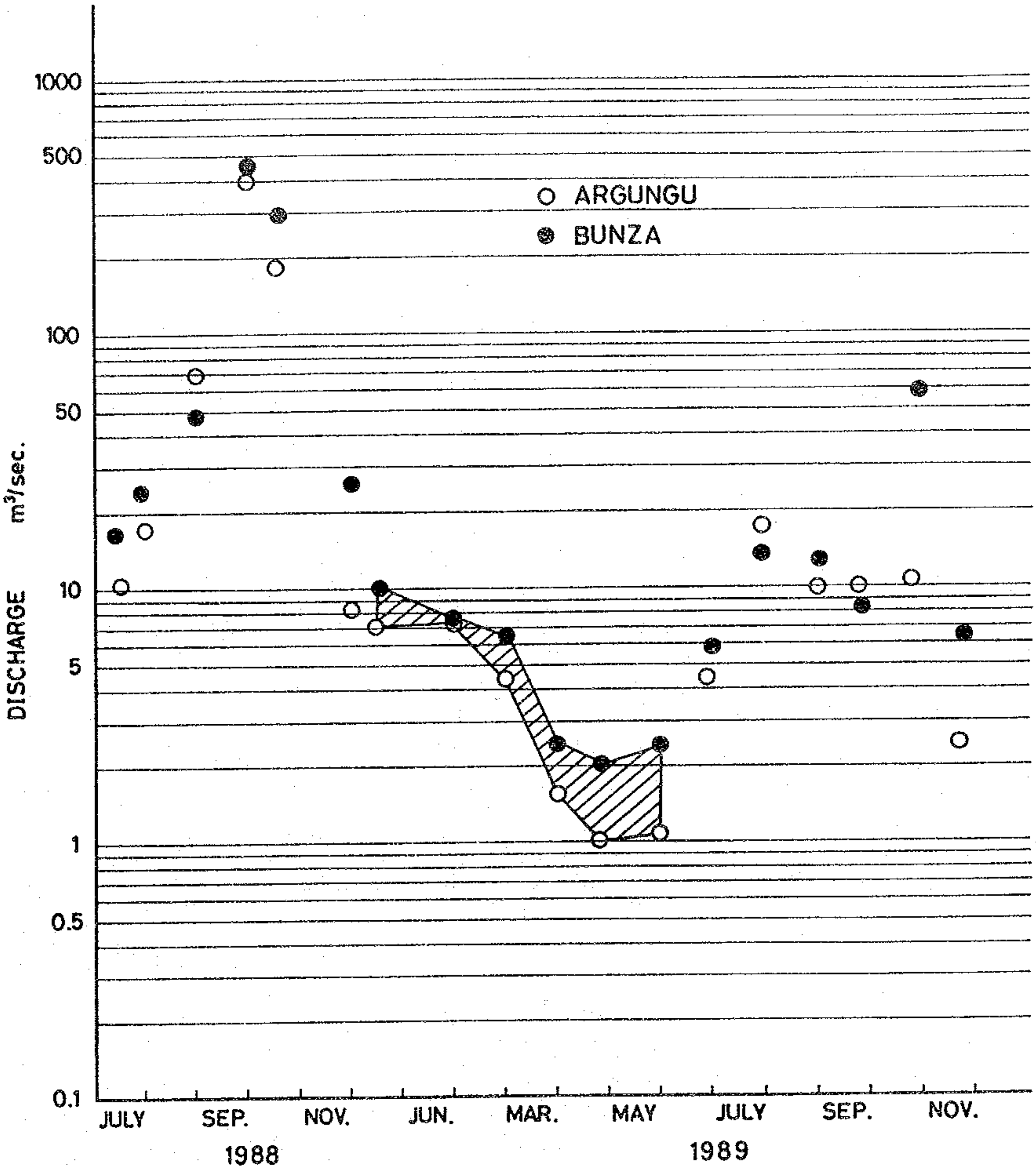


Fig. 3-18 Effluence of Groundwater to the River Rima between Argungu and Bunza

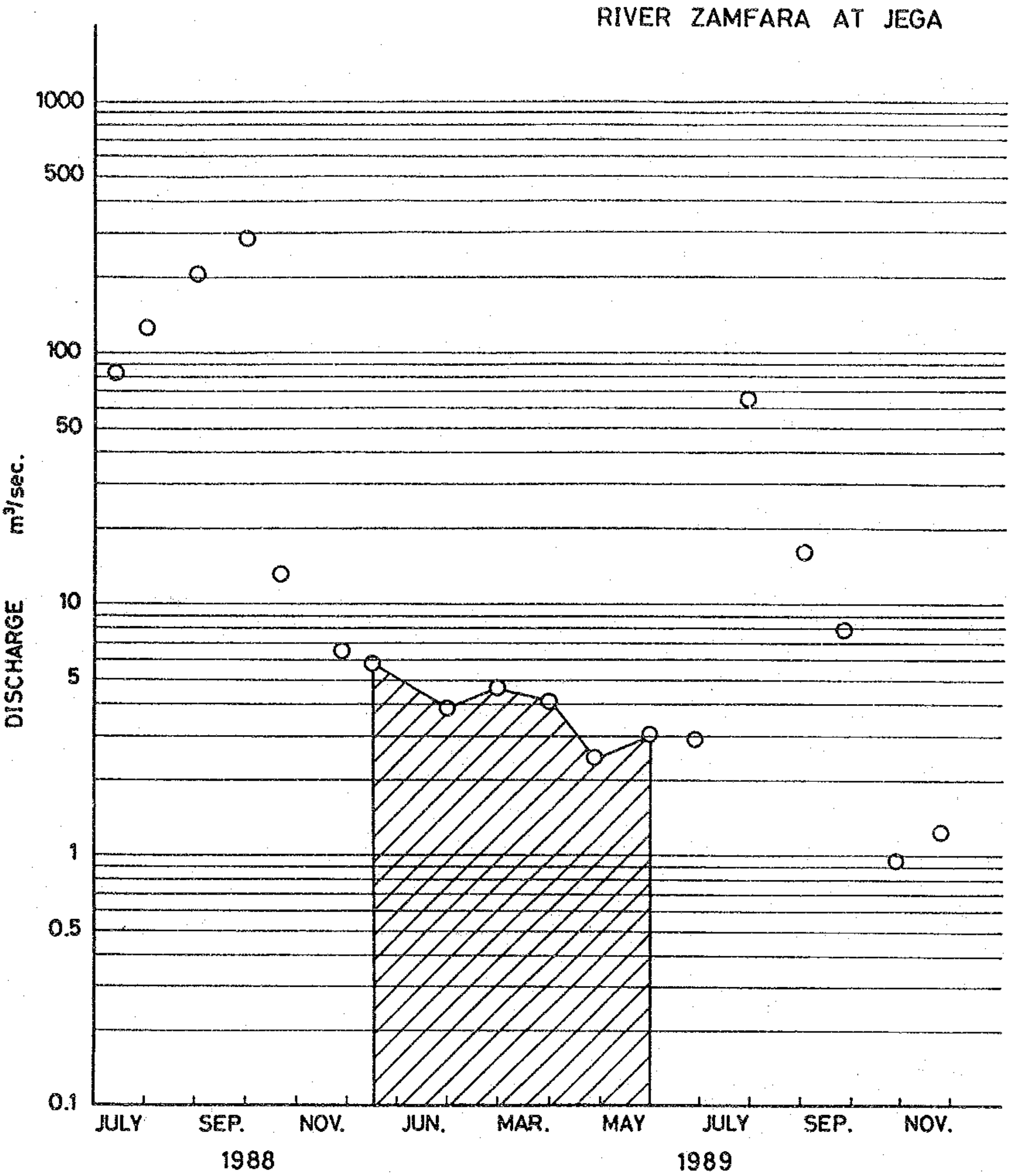


Fig. 3-19 Effluence of Groundwater to the River Zamfara

4. HYDROGEOLOGY

4-1 Hydrogeological Features

4-1-1 General features of hydrogeology

As mentioned in the introductory paragraphs, the study area in Sokoto State is divided into two main geologic provinces, that is, the Sokoto sedimentary basin and the basement complex area. The Sokoto sedimentary basin, which is part of the Iullemeden Basin centered in the Niger Republic, extends northeast to southwest in Sokoto State and consists of semiconsolidated deposits of the Cretaceous to Quaternary Periods. The basement complex area is exposed in the southeastern part of Sokoto State and consists of varieties of igneous and metamorphic rocks of the Pre-cretaceous Period.

The principal water-bearing beds in the Sokoto sedimentary basin are unconsolidated alluvial deposits, sandstone and grit in the Gwandu formation, limestone bed in the Kalambaina formations, sandstone in the Wurno and Taloka formations and grit and sandstone in the Gundumi and Illo formations.

The basement complex is generally regarded as an aquiclude or aquifuge forming a poor source of groundwater. In the basement complex area, groundwater occurrence is limited to the weathered sandy overburden and the decomposed zones with open joints and fractures.

The generalized stratigraphic section for the study area is summarised in Table 4-1, and the general geological map is shown in Figure 4-1. Based on the processing of the existing borehole data, some hydrogeological aspects, such as static water level and specific capacity of the wells, have been arranged and presented in Figures 4-3 and 4-4 . Figure 4-3 shows the average water level and specific capacity of all existing wells in squares of every 15 minutes of longitude and latitude, and Figure 4-4 is the iso-specific capacity map derived from Figure 4-3. The groundwater potential by area is believed to correspond well to the above elements, especially to the specific capacity of the wells. In addition, differences in groundwater potential are clear between the Sokoto sedimentary basin and the basement complex. The contour lines of specific capacity are drawn only in the sedimentary area, because, since the movement or occurrence of groundwater in the basement complex is irregular and in limited areas, such representation of interrelation (contour lines) would have very little significance on a small scale map.

Table 4-1 Generalized Stratigraphic Section for the Sokoto Region (nomenclature after Parker, 1964)

System	Series	Group	Formation	Thickness (feet)	Lithologic Character	Water-Bearing Properties
Quaternary	Recent and Pleistocene			0 to 50	Unconsolidated silt and sand with some gravel in fadama (valley floor) of Sokoto and Rima Rivers and their larger tributaries.	Yields small to moderate supplies of potable water to shallow wells. May have potential for large yields by induced river infiltration.
Tertiary	Post-Eocene and Eocene		Gwandu	0 to 1,000+	Semiconsolidated fine to coarse-grained sand and clay, with dark-colored clay shale.	Basal sand member yields moderate supplies of potable water to boreholes under artesian pressure. Upper member yields small to moderate supplies to wells and boreholes under water-table and subartesian conditions.
			Unconformity			
	Paleocene	Sokoto	Kalambaina	0 to 160+	Semiconsolidated clayey limestone and marl, with some mudstone and plastic shale.	Limestone yields small to moderate supplies of potable water to shallow wells and springs in the outcrop area. Formation is probably not productive at depth.
			Dange	0 to 140+	Semiconsolidated blue to grey, plastic shale, with phosphatic nodules and thin beds of limestone.	Yields little or no water to wells and boreholes. Forms confining bed for artesian water in underlying Wurno Formation.
Cretaceous	Upper Cretaceous (Maestrichtian)	Rima	Wurno	0 to 150+	Friable sandstone and sand inter-bedded with soft mudstone and shale.	Yields moderate supplies of potable water to boreholes under artesian pressure.
			Dukamaje	0 to 88	Dark-colored fossiliferous shale, with thin beds of limestone. Present only in northern part of the region.	Yields little or no water to wells and boreholes.
			Taloka	0 to 600+	Semiconsolidated fine to medium-grained sand, sandstone and shale, with lignite and mudstone.	Yields small to moderate supplies of potable water to boreholes. Under artesian pressure downdip.
			Unconformity ?			
	Lower Cretaceous		Gundumi and Illo	0 to 1,000	Semiconsolidated fine to coarse-grained sand, with clay, sandy clay, and conglomerate near the base.	Yields small to moderate supplies of potable unconfined water to wells on the outcrop area. Yields water under artesian pressure at depth.
			Unconformity			
Pre-Cretaceous			Basement Rock		Granite-gneiss, phyllite, and quartzite.	Yields meager supplies of water to wells in outcrop area.

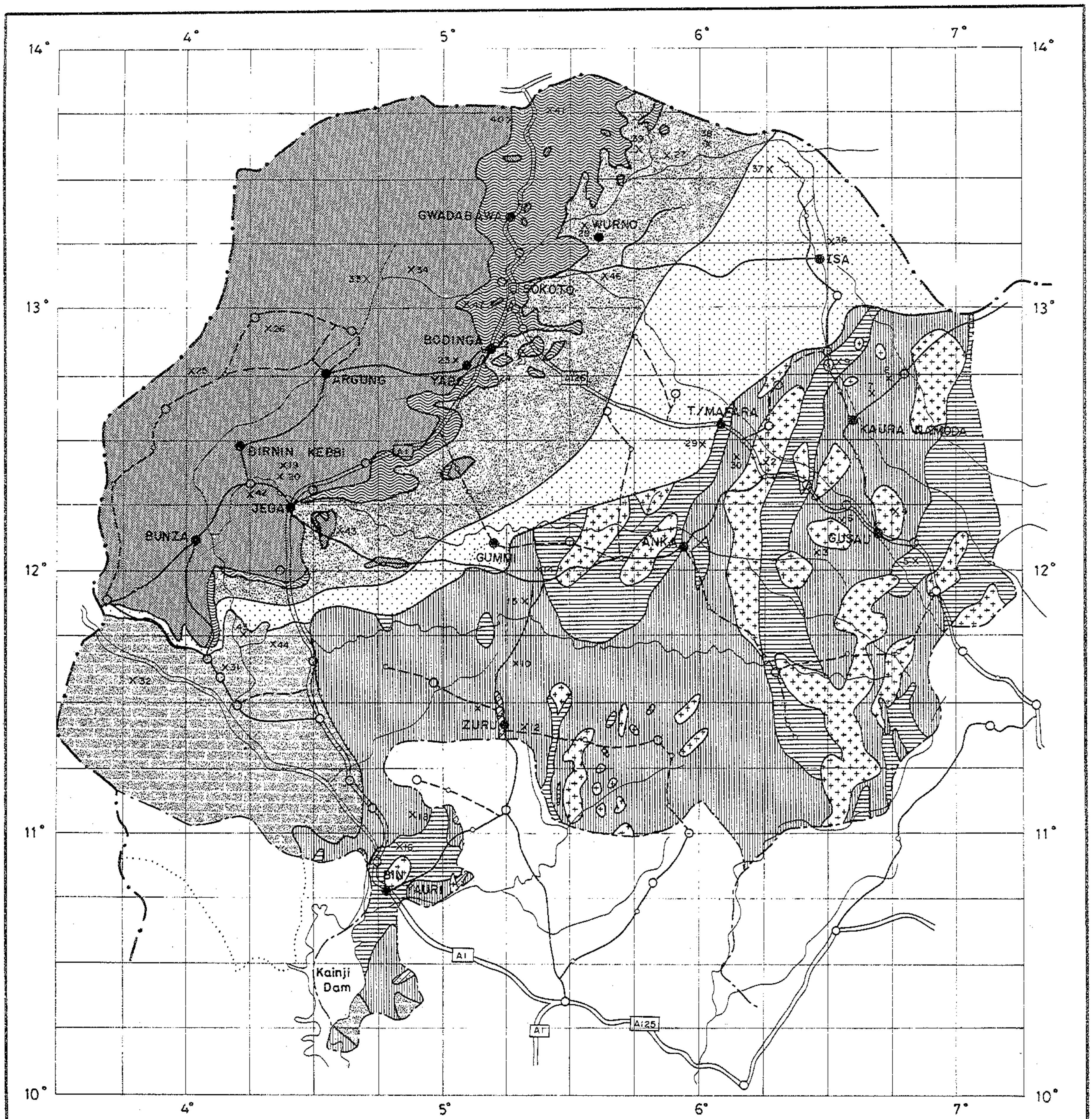
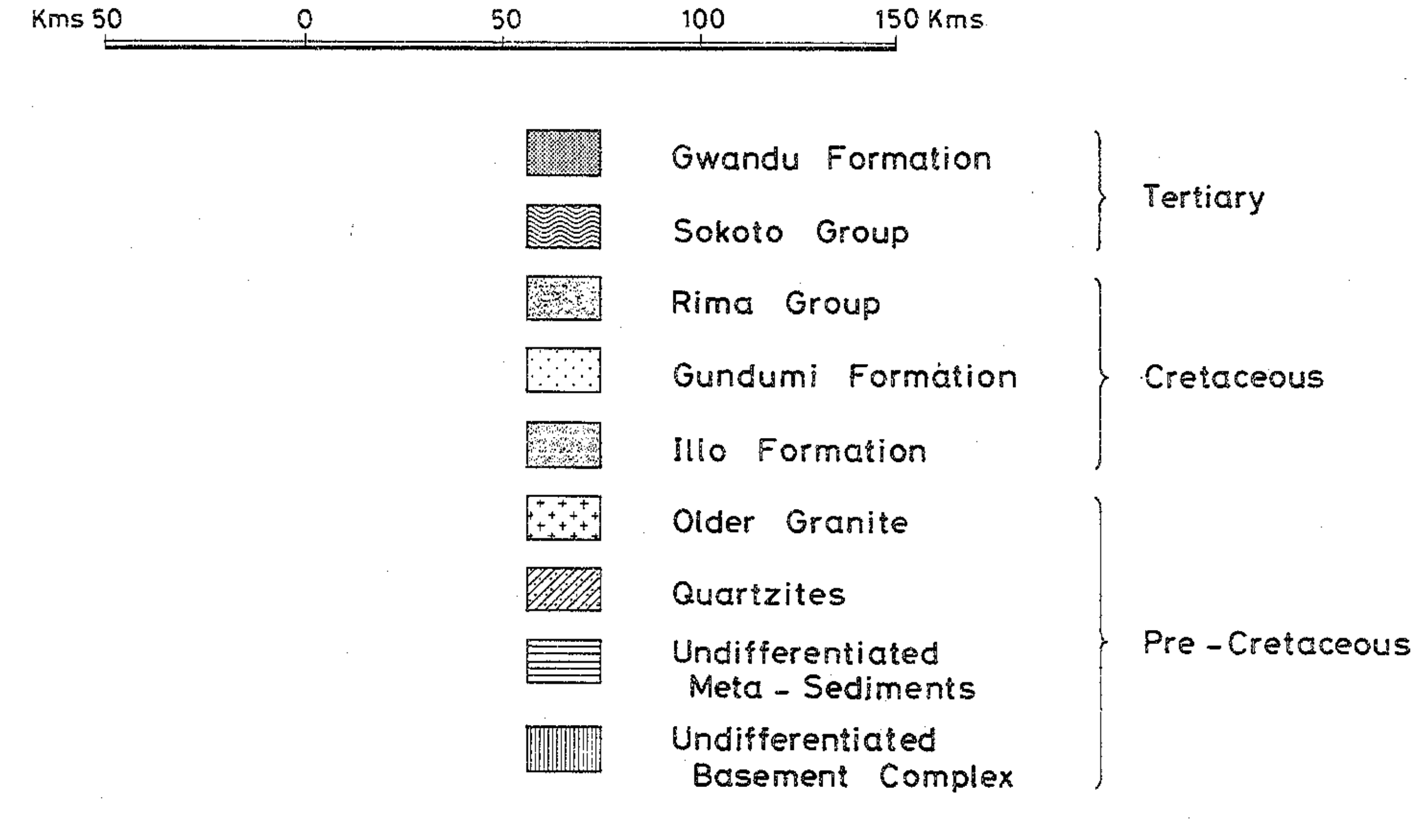


Fig. 4-1 Geological Map of Sokoto State



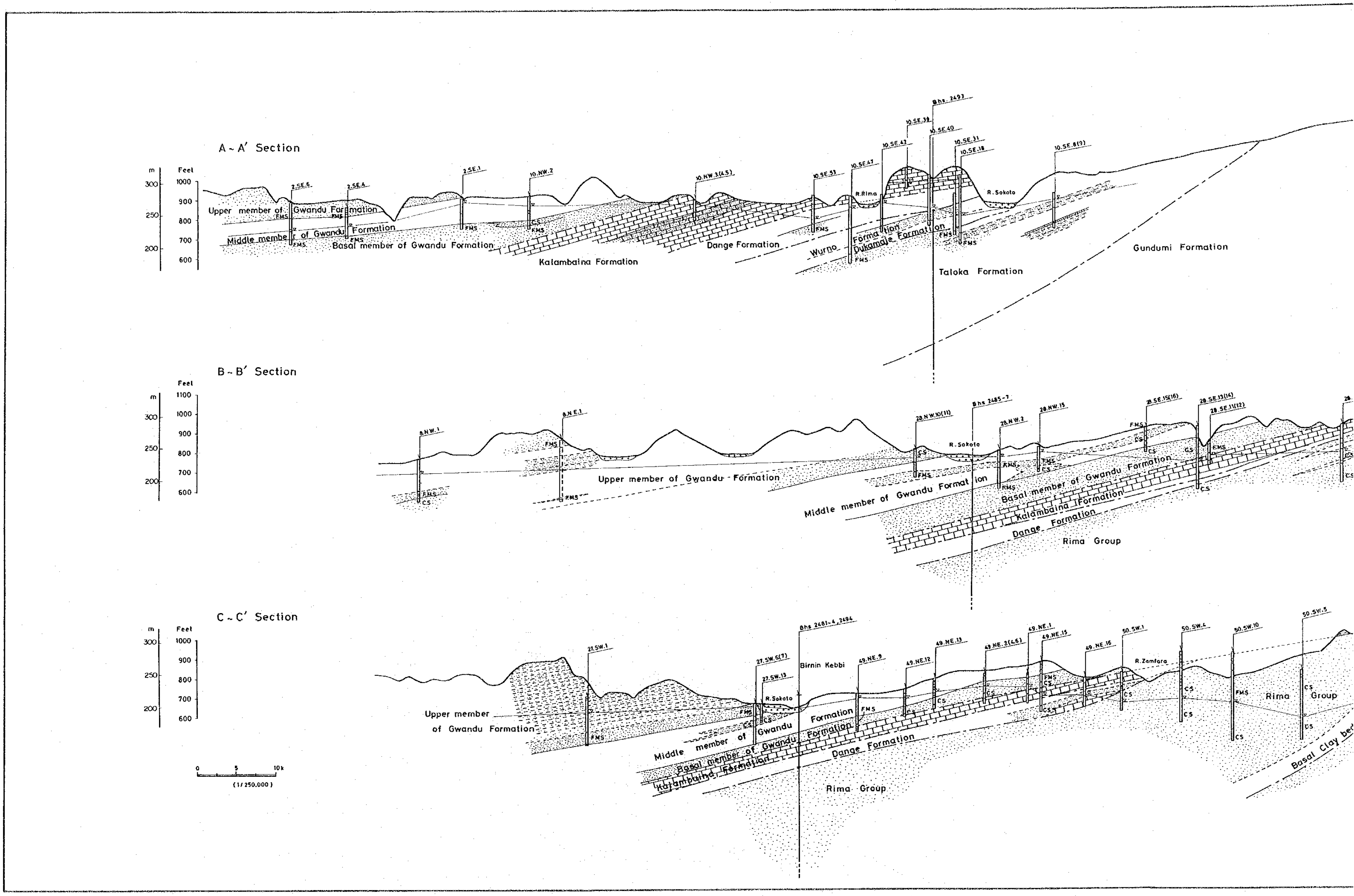
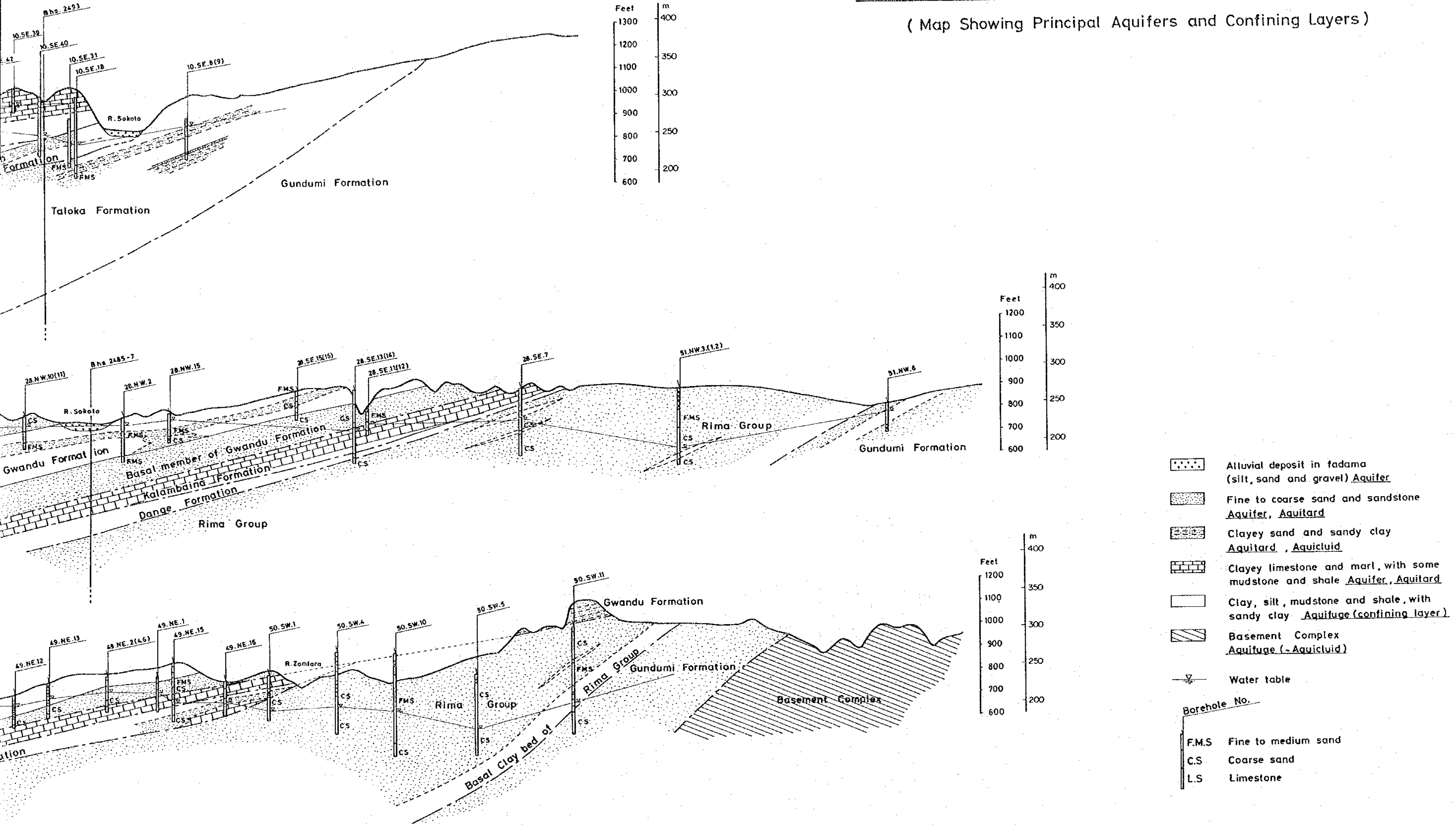

A ~ A′ Section
B ~ B′ Section
C ~ C′ Section
m
Feet
Upper member of Gwandu Formation
Middle member of Gwandu Formation
Basal member of Gwandu Formation
Kalambaina Formation
Dange Formation
Wurno Formation
Dukamaje Formation
Taloka Formation
Gundumi Formation
Rima Group
Basal Clay bed
R. Rima
R. Sokoto
R. Zamfara
Birnin Kebbi
Bhs. 2493
Bhs 2485-7
Bhs 2481-4, 2494
FMS
CS
(1/250,000)

Fig. 4-2 HYDROGEOLOGICAL CROSS SECTIONS OF THE SOKOTO BASIN

(Map Showing Principal Aquifers and Confining Layers)



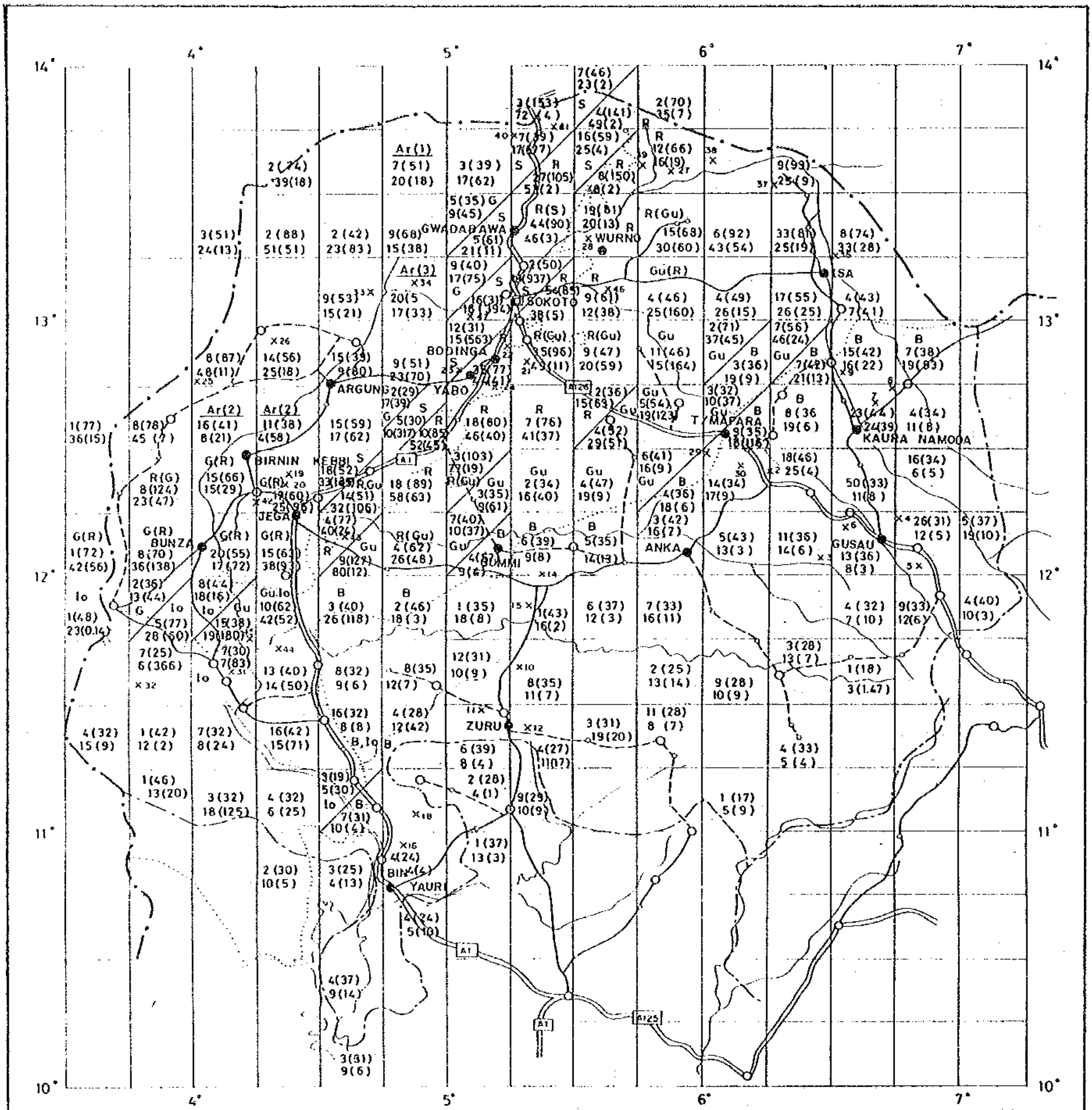


Fig. 4-3 Borehole Data Map in Sokoto State

Kms 50 0 50 100 150 Kms

2(74) — drilled borehole no. — averae drilled lengs
39(18) — averae specifie capacity (m³/d/m) — averae static water level

Ar( ) artesian borehole no.
G : Guwandu Formation
S : Sokoto Group
R : Rima Group
Gu : Gundumi Formation
B : Basement Complex

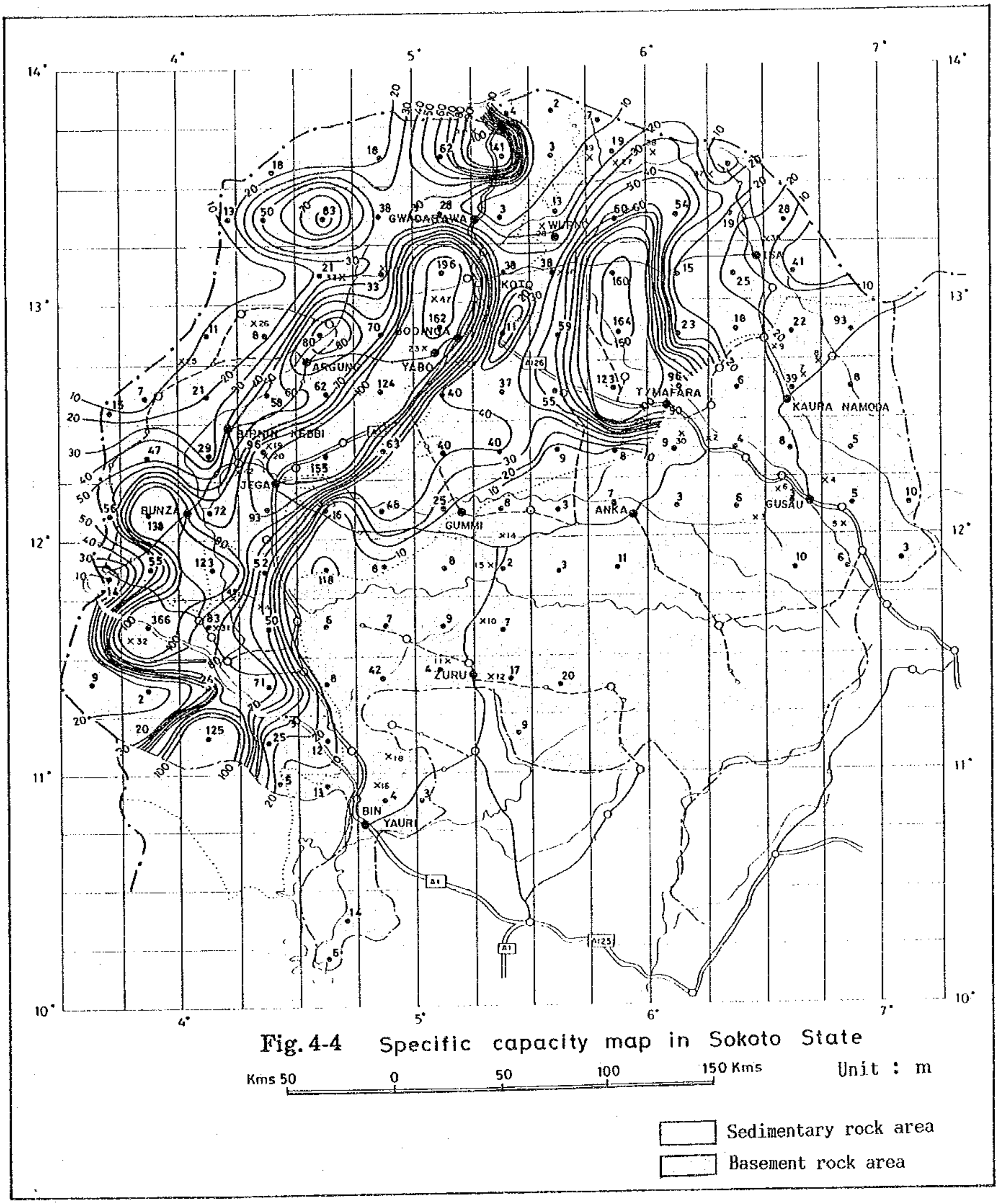


Fig. 4-4 Specific capacity map in Sokoto State

Unit : m

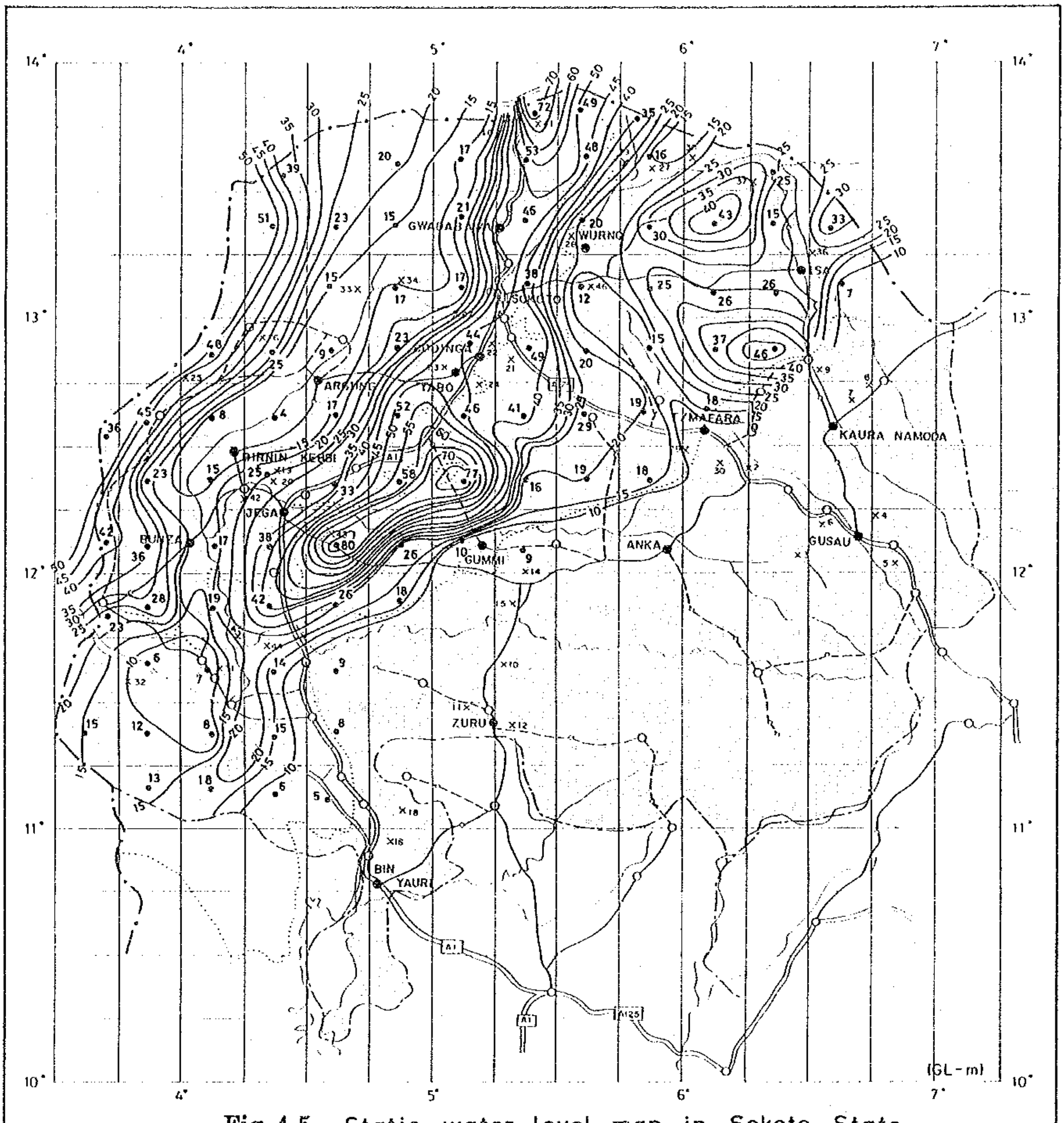


Fig. 4-5 Static water level map in Sokoto State
(Map showing the depth to the water table)

4-1-2 Features of hydrogeological formation

(1) Basement complex

The basement complex area occupies 42% (the southeastern part) of the study area. The area is composed mainly of gneiss, migmatite and granite, some of which are the oldest known rocks in northern Nigeria. There are also extensive areas of schist, phyllite, and quartzite, with sporadic distribution of amphibolite, diorite, gabbro, and marble.

The water bearing zones in the basement complex area are generalized as follows , and schematically represented in Figure 4-6;

a) Weathered sandy overburden,

b) Moderately decomposed coarse grained rocks,

c) Joints and fractures in poorly decomposed rocks, and

d) Fractured contact zones with pegmatite or aplite veins and dykes of igneous rock.

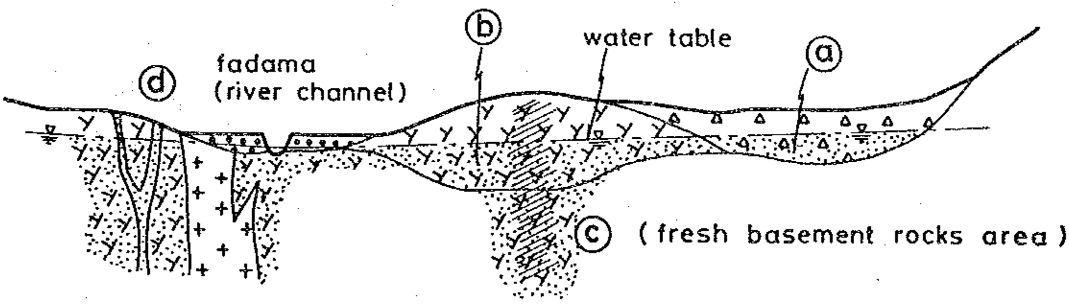


Figure 4-6. Schematic profile for water occurrence in the basement complex area.

Although a variety of comparatively higher potential water bearing zones is listed above, the groundwater potential in the basement complex area is generally low, so the area is usually classified as a "difficult" area.

However, if careful investigation is done for the proper location of wells, it will not be impossible to supply the necessary amount of water in or near some of the villages. According to existing borehole data on the basement complex area, the specific capacity of the wells is usually low, with less than 10 m^3/day/m. However, in some parts of the area, such as in Kaura Namoda L. G., 40 to 100m^3/day/m is recorded.

(2) Gundumi Formation

The Gundumi formation is the oldest sedimentary unit in the Sokoto Basin unconformably overlying the Pre-cretaceous crystalline rocks of the basement complex area. The outcrop of this unit forms a wide zone striking northeast across the state and occupying about 14% of the study area.

The Gundumi formation consists principally of lacustrine deposits of continental origin including semiconsolidated clay, sandy clay, fine- to coarse-grained sand, and some conglomerate near the base.

The strata show generally lateral and vertical variation in lithology. The Gundumi formation is recharged mainly by infiltration of rain water from the surface, and partly by effluent seepage from streams. The groundwater potential in the Gundumi formation is generally high, and the average specific capacity of 175 boreholes is 57m^3/d/m. The northern part of Talata mafara has a particularly high potential, with an average specific capacity of more than 150m^3/day/m. On the eastern side of the Gundumi formation, groundwater occurrence is chiefly free water. On the other hand, water is pumped mostly from confined aquifers on the western side.

(3) Illo Formation

The outcrop of the Illo formation is limited to the southwestern area of the Sokoto sedimentary basin, and is overlain by the Rima group and interfingers with the Gundumi formation, at least at their surface boundaries. The lithology as well as groundwater potential of this formation is similar to that of the Gundumi formation.

(4) Rima Group

The Rima group consists mainly of marine transgressive deposits overlying the Gundumi and Illo formations and partly being overlain by the Tertiary deposits of the western part of Sokoto State. An outcrop of the Rima group extends northeast to southwest across Sokoto State, occupying about 10% of the study area. In the northern part of the

Sokoto Basin (north of the Sokoto River), the Rima group is divided into three (3) formations : the Taloka Formation, the Dukamaje formation and the Wurno formation, in ascending order. (Jones, 1948 ; Parker and others, 1964)

The Taloka formation consists mainly of fine-grained sandstone containing some thin intercalated beds of carbonaceous mudstone or shale. The Dukamaje formation consists of shale, mudstone, thin limestone and some gypsum beds.

The Wurno formation, the uppermost formation of the Rima group, consists of semiconsolidated fine sand and some silt.

Groundwater in the Rima group occurs under unconfined conditions in the outcrop area. In a few cases, however, some beds are confined between a plastic clay bed in the basal part of the Rima group and clay in the Dange formation of the Sokoto group. The Wurno and Taloka formations are the aquifers in the Rima group. The water bearing zones are thin beds of semiconsolidated fine sand of the Wurno formation and semiconsolidated fine- to medium-grained sand and sandstone of the Taloka formation. Recharge sources of the Rima group are mainly infiltration from precipitation, infiltration from streams during floods and leakage from overlying perched water bodies in limestone of the Kalambaina formation.

As seen in Figures 4-3, 4-4, and 4-5, the groundwater potential in the Rima group is divided into two (2) areas, that is, the area northwest of the Sokoto-Goronyo Road and the area south of Sokoto City. In the former area of the Rima group, the aquifer consists generally of very fine grained sand and silty sand, and average specific capacity is very low, with a range of from 3 to 19 m^3/day/m. Static water levels are quite deep (50m to 70m from the surface), and water quality is generally poor. On the other hand, the groundwater potential in the latter area of the Rima Group is generally high, with average specific capacities ranging from 23 to 63 m^3/day/m. Static water levels are, however, quite deep, and water quality is also generally poor.

(5) Sokoto Group

The Sokoto group consists of the Dange formation as the lower unit and the Kalmbaina formation as the upper unit of the group. Both are considered to be marine or submarine deposits.

The outcropping area of the Sokoto group forms a wide band extending northeast to southwest, becoming narrower in the southwest until it disappears near Jega. The area occupies about 3% of the study area.

The Dange formation consists mainly of a marine clayey shale.

The upper part contains phosphatic nodules and gypsum, and the lower part is composed generally of calcareous materials with some limestone beds. The Kalambaina formation consists mainly of semiconsolidated clayey limestone and marl, with some mudstone and plastic shale.

The main water-bearing bed in the Sokoto group is the semiconsolidated clayey limestone of the Kalambaina formation. The Dange formation is relatively impermeable and serves as a confining layer above the Rima aquifer. Near the outcrop of the Kalambaina formation, it is known that a large amount of groundwater is stored in the limestone as a perched water body. Water springs here and there from the limestone escarpment, and a number of water-table lakes have been formed on the dip slope of the formation. The Kainuwa Lake in the north of Sokoto City is one example. As seen in Figures 4-3 and 4-4, it is quite evident that a high specific capacity zone is formed along the escarpment of the outcropping area of the limestone of the Kalambaina formation between Illela and Jega.

(6) Gwandu Formation

The Gwandu formation consists mainly of sediments of terrestrial origin which are made up of interbedded semiconsolidated sand and clay containing some limonite and lignite beds. The Gwandu formation unconformably overlies the Kalambaina formation, and its outcropping area occupies about 22% of Sokoto State, i.e., the western one third of the Sokoto sedimentary basin.

According to existing borehole data, the Gwandu formation is generally subdivided into three (3) members. The basal member of the formation consists of fine- to coarse-grained sand with some thin beds of clay. The middle member includes mainly plastic clayey shale and silty clay which serve as a confining layer above the basal aquifer of the Gwandu formation. The upper member consists generally of fine- to medium-grained semi consolidated sand interbedded with clay.

Groundwater in this formation is free water and some perched water bodies in the upper member, and confined water in the basal member. The groundwater potential in the Gwandu formation is generally high, especially along the fadama area which extends northeast to southwest from Lake Kalmalo, through Argungu and Birnin Kebbi, to Bunza.

The confined aquifer of the basal Gwandu formation increases in thickness toward the northwest. However, toward the northwest, clay and lignite beds become increasingly abundant in the basal portion, so that the specific capacity of the aquifer generally decreases in the northwestern area of Sokoto State, and static water levels become lower.

(7) Superficial deposits (Quaternary deposits)

Superficial deposits of Quaternary Age, consisting generally of unconsolidated sediments of alluvial sand, silt and gravel,are found in the fadama (valley floor) of the Sokoto and Rima Rivers and their tributaries.

The riverbed water in these fadamas is one of the most important water sources for domestic use in the region.

4-1-3 Hydrogeological structure

The major aspects of the hydrogeological structure in the study area are summarized below.

(1) The study area in Sokoto State is divided into two main geologic provinces, i.e. the Sokoto sedimentary basin in the northwestern half and the basement complex area in the southeastern half of the state.

(2) The Sokoto sedimentary basin runs northeast to southwest through Sokoto State and is composed of semiconsolidated deposits of the

Cretaceous to Quaternary Periods. The general formational strike in the Sokoto Basin is about N30 °E and the dip is about 4.5m per 1.6km toward the northwest (0.2°NW).

(3) The principal water-bearing beds in the Sokoto Sedimentary Basin are the alluvial sand, silt and gravel in the fadama, sandstone and grit in the Gwandu formation, limestone beds in the Kalambaina formation, sandstone in the Wurno and Taloka formations, and grit and sandstone in the Gundumi and Illo formations.

(4) Figure 4-2 shows hydrogeological cross sections of the Sokoto sedimentary basin, and Figure 4-8 shows a schematic profile of groundwater occurrence in the Sokoto sedimentary basin.

According to these figures, the major aquifers in the basin can generally be divided into four (4) units :

① Unit I is the upper member of the Gwandu formation, with fine- to medium-grained semiconsolidated sand. Groundwater is mostly unconfined free water.

② Unit II is comprised of the basal member of the Gwandu formation, with fine- to coarse-grained sand, and the limestone beds of the Kalambaina formation. Groundwater is free water in the outcropping areas and pressure-water where this unit is confined between the clay of the Dange formation and the plastic clayey shale of the middle member of the Gwandu formation. In the outcropping area of the Kalambaina formation, groundwater occurs mainly as perched water bodies.

③ Unit III consists of semiconsolidated fine sand of the Wurno formation and fine- to medium-grained sand and sandstone of the Taloka formation in the Rima group. Groundwater in the Rima group occurs generally under unconfined conditions in the outcrop area. However, in a few cases, the Rima group is confined between a plastic clay bed in the basal part of the Rima group and clay of the Dange formation in the Sokoto group.
As mentioned above, groundwater resource potential in the Rima group is divided into two areas . The lower potential area northwest of

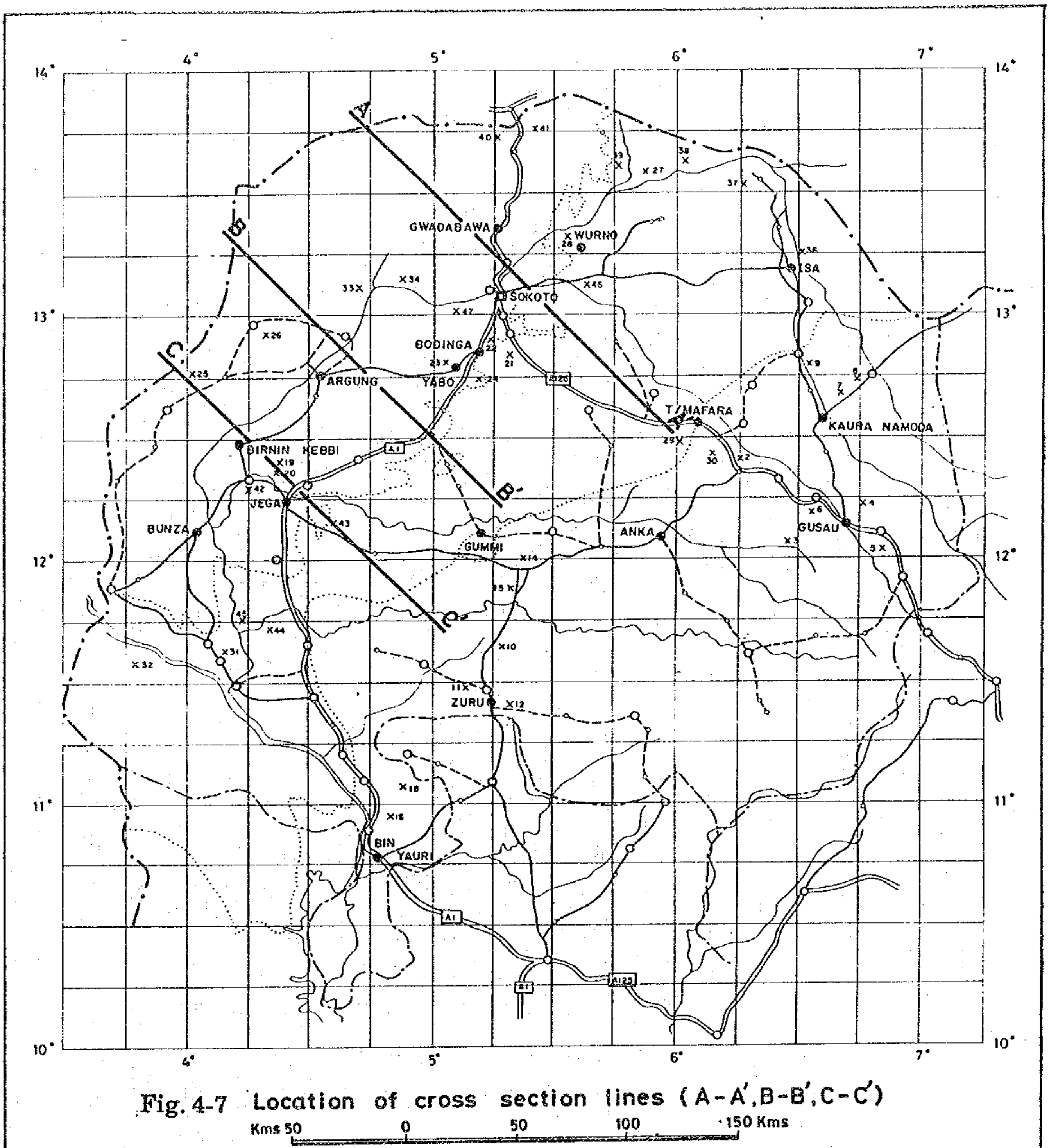


Fig. 4-7 Location of cross section lines (A-A', B-B', C-C')

Kms 50 0 50 100 150 Kms

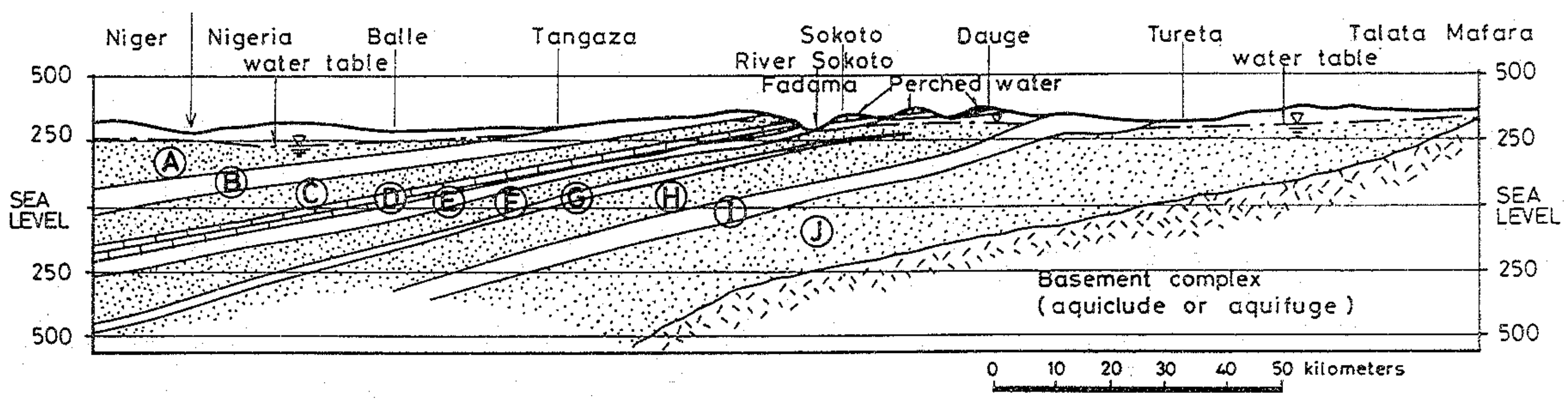


Fig. 4-8 . Schematic Profile for Groundwater Occurrence in the Sokoto Basin

Ⓐ : Upper member of the Gwandu Formation (Aquifar of Unit I)

Ⓑ : Middle member of the Gwandu Formation (Confining clayey bed)

Ⓒ : Basal member of the Gwandu Formation } (Aquifer of Unit II)

Ⓓ : Kalambaina Formatiom } (Aquifer of Unit II)

Ⓔ : Dange Formation (Confining layer)

Ⓕ : Wurno Formation } (Aquifer of Unit III)

Ⓖ : Dukamaje Formation (Semi-confining layer) } (Aquifer of Unit III)

Ⓗ : Taloka Formation } (Aquifer of Unit III)

Ⓘ : Basal clayey bed of the Rima Group (Confining clayey bed)

Ⓙ : Gundumi and Ills Formations (Aquifer of Unit IV) the Sokoto-Goronyo Road, and the high potential area south of Sokoto City.

④ Unit IV are the aquifers of the Gundumi and Illo formations, with semi-consolidated sandstones and grits. Groundwater in these formations occurs as free water in the outcropping area. On the other hand, in the northwestern area, groundwater is pressure-water confined by intra-formational clay beds of the Gundumi, Illo, and Taloka formations.

4-2 Geographical and Geological Features Interpreted on LANDSAT Image

Since general geography and geology of the study area is described in the former section and reference materials, only the peculiar features interpreted on LANDSAT image and supplemental aerial photographs are to be discussed here.

The LANDSAT data used in this Study are 12 scenes of 1/250,000 scaled black-and-white pictures of "Band 7" (spectral band of infrared) covering the whole area of Sokoto State. The row-path number of the images are:

Path 189 ----------	Row 51~53	3 scenes
Path 190 ----------	Row 51~53	3 scenes
Path 191 ----------	Row 51~53	3 scenes
Path 192 ----------	Row 51~53	3 scenes

The aerial photographs purchased in Lagos (Federal Dept. of Survey) were about 1,000 pcs. of black-and-white photos of 1/40,000 scale, which were intended to be used for interpretation focusing on each candidate village and its surroundings.
However, about half of the photos do not cover the target area due to mis location of the sites on the given map, thus these photos were mainly used supplementarily at the places for which information on LANDSAT images was not clear.

The following are the points interpreted on the pictures, and the matters taken into account for the preparation of the preliminary hydrogeological map.

(1) Area classification by features in the basement rock area.

There are two classifications :
the "older granite" area and the "metasediment" area, by the difference of tone of the picture, different trends of lineament (linear structures) and other features. The table below shows the points differentiated.

Table 4 - 2 Different patterns between older granites and metasediments in basement rock area interpreted on LANDSAT image

Item of interpretation	Characteristics of features	
	Older granite area	Metasediment area
Tone of picture	Generally light tone except in the places of burnt field, due to sandy material coverage	Generally dark tone provided rocks are mostly exposed to the air
Shadow pattern and peculiar topography	Vague shadow pattern due to gently sloped topography, but characterized by features of sporadically exposed granite dome	Sharp shadow pattern is predominated by the range of mountains, particulary north-south ranged mountains composed of quartzite
Lineament	Lineament trend of N-S and ENE-WSW with not so clear a pattern	Frequent and clear lineament with predominated north-south trend

(2) Area classification by characteristics in sedimentary area

a: Gundumi Formation
The outcrop area of this formation is bordered by basement rocks in the east and by upper formation in the west. This area is characterized by a dark tone and smooth surface apparent in the photo. The clear and smooth curved boundary line with the basement rock area indicates that large scaled surface irregularity in the basement rock did not exist before the basement rock became unconformably covered with the Gundumi formation.

b: Taloka and Wurno Formations

Both of these formations are characterized by a very light tone, which indicates that the exposed zones of these formations are mostly composed of sandy material. No difference in tone is found between the two formations, but a faint steppe is recognized, which may correspond to the boundary of upper (Taloka) and lower (Wurno) formations.

c: Dange and Kalambaina Formations

Tones of the photos in these formations are different from each other and also different from other adjacent formations. The very dark tone of the Dange formation suggests the composition of pelitic materials like shale, or the water-saturated beds. The Kalambaina formation shows a grey tone, which is lighter than that of the Gwandu formation, and darker than those mentioned in " b".

Two of these formations are characterized, not only by the tone, but by the peculiar pattern derived from the escarpments.

d: Gwandu Formation

This formation is characterized by a dark tone, and the pattern of the escarpments not as remarkable as that in the Kalambaina formation.

(3) Differentiation of alluvial deposit area along rivers

Areas of recent river deposits, which are usually called "fadama" in Nigeria, is one of the most important water sources (underflow water) in many places in Sokoto State.

The fadama is differentiated on the photos by a dark tone and flat area along the rivers. The scale of a fadama, interpreted on LANDSAT image, is generally small in the basement rock area. The large scale fadama found in the sedimentary area reaches 5 to 10 km in width along the Rima River.

(4) Lineament interpretation in the basement rock area

In the basement rock area, the fractured zones or fissure-concentrated zones caused by tectonic movement or fault are generally accompanied by groundwater.

Therefore, to locate such linear structure is particularly effective for

groundwater development. Large-scale lineaments with extension of several tens to hundreds of kilometers are easily recognized on LANDSAT images, and the minor lineaments of several kilometers or hundreds of meters are interpreted on aerial photographs. The pattern of the lineament (sharp or faint) is closely related to the weathering conditions which are also related to groundwater potential. The sharp and dense lineaments suggest the possibility of fissure water.
On the contrary, the vague lineaments showing comparatively gentle topographic features of the surroundings suggest deep weathering and the probability of stored groundwater in decomposed portions as shown in schematic section below;

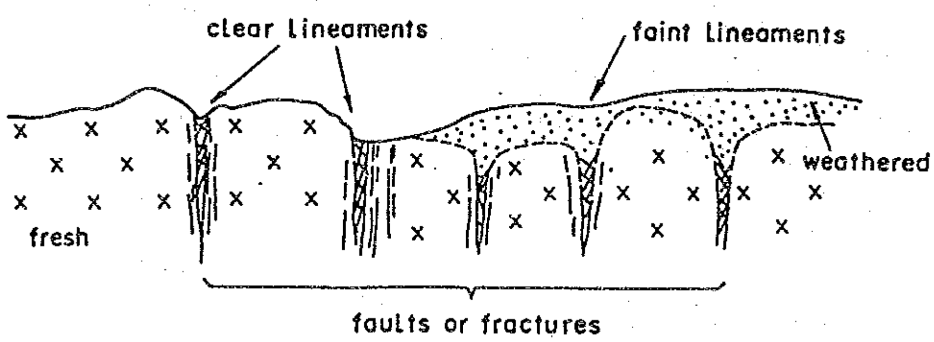


Figure 4 - 9 Relation between lineament and weathering conditions

4-3 Water Level Observation of Existing Wells

Groundwater level at several boreholes and dug wells was observed in order to determine the configuration and fluctuation of the groundwater table.
In terms of water balance, including groundwater, groundwater level data is essential. Water level records were obtained from reports on some existing studies and projects undertaken in the Sokoto basin. Many of the borehole records in the area have static water level records as well. Therefore it was possible to determine the general configuration of the groundwater table from existing records. However, there are not records available on every borehole. Furthermore, water levels measured earlier may not equal recent water levels. Consequently, groundwater

observation, in addition to existing records, was considered necessary to obtain an up-to-date configuration of the water table.
It was equally necessary to establish the fluctuation of the water table, which is affected by seasonal changes in recharge, abstraction rate, and other natural effects and/or artificial operations. Few long-term continuous observation records have been found in the study area. Based on these aspects, two types of water level observations were carried out: simultaneous observation and continuous observation.

The results of the observations have been discussed in Section 4-8.

4-3-1 Simultaneous observation

Sixty-two boreholes were chosen as observation boreholes out of many boreholes visited through preliminary field reconnaissance, and a level survey was carried out to determine the elevations of the borehole-casing-tops. The locations and specifications of the observation boreholes are given in Fig. 4-10 and Table 4-3, respectively. The criteria in selecting these observation boreholes was as follows:

1. Observation boreholes should be equally distributed, both in place and aquifer.

2. The casing head should have an open hole or slit to let the water level probe be inserted into the borehole.

3. A reliable borehole record should be available.

4. Access to the borehole should be good in all weather.

5. The owner and the operator of the borehole should be cooperative with the study team.

Although the boreholes selected do not all necessarily satisfy all the above criteria, the observation network established in the first stage study is considered to be useful in determining the configuration of water tables and practical in carrying out observation over a long period of time.
To be considered simultaneous, observations had to be carried out within just a few days of each other in order to eliminate non-correspondence in water level.
Simultaneous observations were carried out four times over the course of

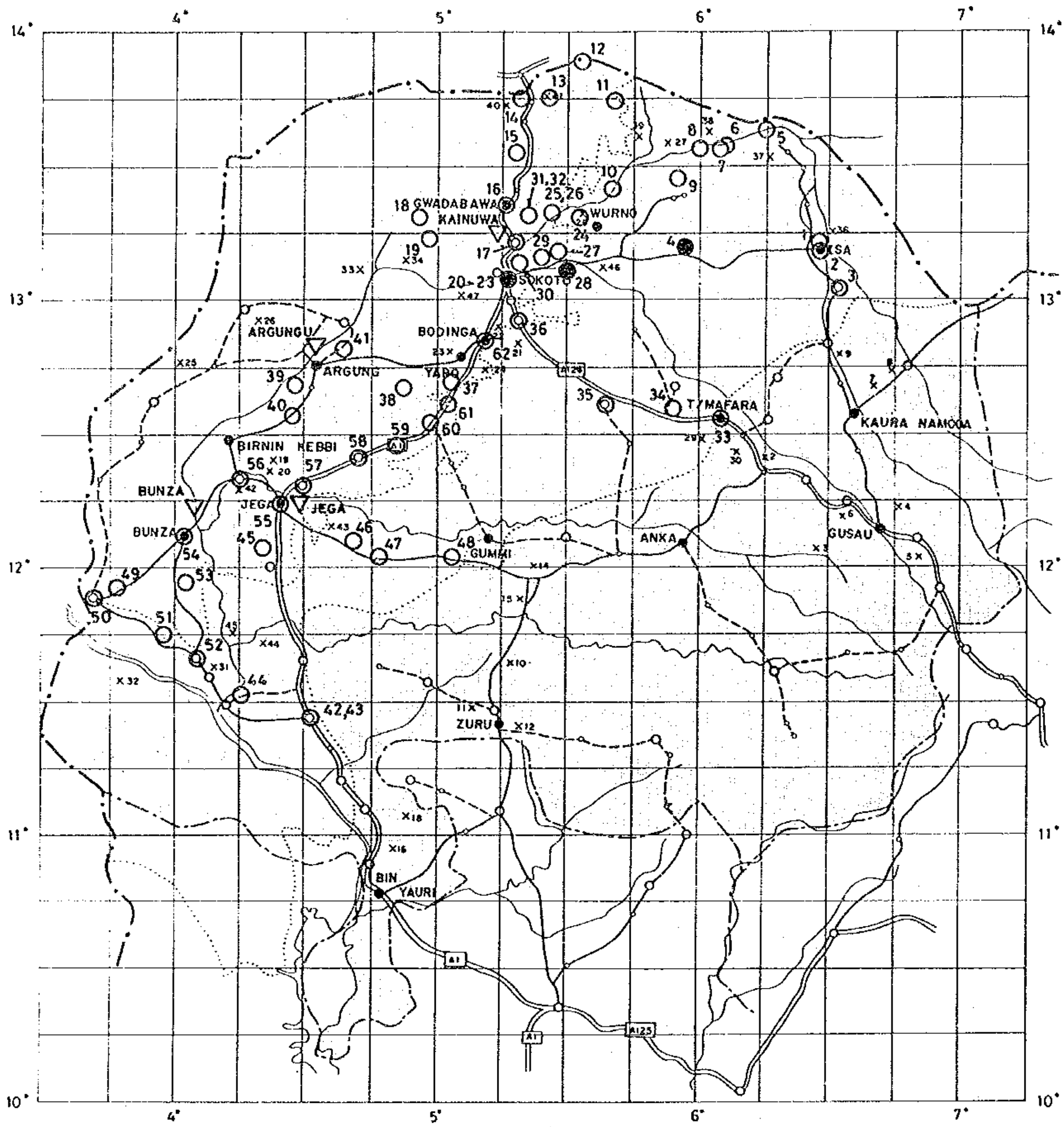


Fig.4-10 Location Map of Hydrological Survey Points

○ BOREHOLES FOR SIMULTANEOUS OBSERVATION

● BOREHOLES FOR CONTINUOUS OBSERVATION

▽ DISCHARGE MEASUREMENT POINTS

Sedimentary rock Area

Basement Rock Area

Kms 50 0 50 100 150 Kms

Table 4-3 (1) Inventory of Boreoles for Water Level Observation

No.	Local Name	Latitude / Longitude	Agency	Purpose	Total Depth(m)	Casing Dia.(mm)	Screen Posi.(m)	Aquifer	Elevation (m)	Casing head E.l(m)	Remarks
1	ISA-DUGWELL	13°12′30″ / 6°24′30″						GUNDUMI	315.310	315.375	
2	ISA	13°12′10″ / 6°24′10″	S.S.W.B	DOMESTIC SUPPLY	36.6	168	30.5 / 36.5	GUNDUMI	316.810	318.448	
3	SHINKAFE BH. No1	13°04′30″ / 6°30′30″	S.S.W.B	DOMESTIC SUPPLY	48.8	168	36.6 / 45.2	GUNDUMI	303.165	303.655	
4	KUNAWA	13°11′25″ / 5°57′40″	S.S.W.B	NOT IN USE	166.1	168	100.3 / 110.9	GUNDUMI	306.188	306.141	CONTINUOUS OBSERVATION
5	MALAM BUZU	13°36′45″ / 6°14′20″	F.M.W.R	NOT IN USE	216.0	168	153.0 / 158.0	GUNDUMI	305.763	306.055	
6	GADJIT	13°35′30″ / 6°10′10″	S.S.W.B	NOT IN USE				GUNDUMI	308.731	309.084	
7	MASHAYA	13°34′20″ / 6°04′20″	S.S.W.B	DOMESTIC SUPPLY				GUNDUMI	302.116	302.234	
8	KURU KURU	13°32′20″ / 6°00′20″	S.S.W.B	DOMESTIC SUPPLY	243.8	152	219.5 / 233.2	RIMA	296.864	297.054	
9	S.R.R.B.D.A.COMPLEX GORONYO BH.2	13°28′30″ / 5°52′00″	S.R.R.B.D.A	DOMESTIC SUPPLY				RIMA	326.954	325.939	
10	GORONYO	13°26′10″ / 5°40′10″	S.S.W.B	DOMESTIC SUPPLY	157.0		142.0 / 152.0	RIMA	306.714	306.667	
11	GADA	13°45′30″ / 5°09′00″	M.O.W	HOSPITAL				RIMA	306.288	306.806	
12	RAFIN DUMA	13°52′00″ / 5°33′00″	S.S.W.B	DOMESTIC SUPPLY				RIMA	309.418	309.525	
13	GIDAN CIWAKE	13°45′30″ / 5°25′30″	S.S.W.B	NOT IN USE				RIMA	312.811	312.977	
14	ILLELA	13°44′30″ / 5°18′00″	S.S.W.B	NOT IN USE				SOKOTO	266.150	266.540	
15	MAMMAN SUKA	13°33′10″ / 5°19′00″	F.M.W.R	NOT IN USE	124.0	168	80.0 / 96.0	RIMA	275.780	273.204	
16	GWADABAWA	13°21′45″ / 5°18′00″	S.S.W.B	DOMESTIC SUPPLY	59.0	340	12.5 / 15.5	SOKOTO	266.875	267.035	

Table 4-3 (2) Inventory of Boreoles for Water Level Observation

No.	Local Name	Latitude Longitude	Agency	Purpose	Total Depth(m)	Casing Dia.(mm)	Screen Posi.(m)	Aquifer	Elevation (m)	Casing head E.l(m)	Remarks
17	KWARE	13°13′00″ 5°17′00″	S.S.W.B	NOT IN USE				RIMA	272.326	272.751	
18	TANGAZA	13°22′10″ 4°22′10″	S.S.W.B	DOMESTIC SUPPLY				GWANDU	285.477	256.710	
19	GIDAN MADI	13°18′00″ 4°58′40″	S.S.W.B	DOMESTIC SUPPLY	109.7			GWANDU	267.696	267.792	
20	SOKOTO YAURIRD BH No1	13°01′45″ 5°13′40″	S.S.W.B	NOT IN USE				SOKOTO	295.045	295.631	CONTINUOUS OBSERVATION
21	SOKOTO YAURIRD BH No2	13°01′45″ 5°13′40″	S.S.W.B	NOT IN USE	330.7	203	219.5 274.3	RIMA	295.143	295.341	CONTINUOUS OBSERVATION
22	SOKOTO YAURIRD BH No3	13°01′45″ 5°13′40″	S.S.W.B	NOT IN USE				RIMA	294.905	295.307	
23	SOKOTO POLO GLUB	13°01′10″ 5°14′00″	POLO GLUB	DOMESTIC SUPPLY				SOKOTO	296.143	296.268	
24	BARAN ZAKI	13°18′00″ 5°33′50″	F.M.W.R	NOT IN USE	124.0	168		RIMA	263.502	263.870	
25	WURNO No3	13°17′15″ 5°25′15″	S.S.W.B	DOMESTIC SUPPLY	158.5	172	147.0 150.9		334.311	334.429	
26	WURNO No1	13°17′15″ 5°25′15″	S.S.W.B	DOMESTIC SUPPLY					326.686	326.660	
27	GIDAN TUDU	13°13′00″ 5°31′00″	S.S.W.B	NOT IN USE	227.1		193.9 207.6	RIMA	310.794	311.248	
28	G.C.S.S RABAH	13°07′30″ 5°30′10″	M.O.E	SCHOOL	146.3	152		RIMA	254.589	255.131	CONTINUOUS OBSERVATION
29	ACIDA	13°10′20″ 5°24′10″	S.S.W.B	DOMESTIC SUPPLY				RIMA	312.861	312.972	
30	KANDAM	13°08′20″ 5°20′30″	G.STOW	DOMESTIC SUPPLY					305.724	305.753	
31	CHIMOLA No1	13°18′20″ 5°21′45″	S.S.W.B	NOT IN USE				RIMA	264.938	264.858	
32	CHIMOLA No2	13°18′45″ 5°21′45″	S.S.W.B	NOT IN USE	264.0	203		RIMA	291.775	291.775	

Table 4-3 (3) Inventory of Boreoles for Water Level Observation

No.	Local Name	Latitude / Longitude	Agency	Purpose	Total Depth(m)	Casing Dia.(mm)	Screen Posi.(m)	Aquifer	Elevation (m)	Casing head E.l(m)	Remarks
33	SRRBDA BH5 TALATA MAFARA	12°34′00″ / 6°04′30″	S.R.R.B.D.A	NOT IN USE				GUNDUMI	305.676	306.008	
34	LAMBA BAKURA	12°35′00″ / 5°53′00″	S.S.W.B	NOT IN USE				GUNDUMI	315.541	315.840	
35	LAMBA TURETA G.S.S TURETA	12°40′45″ / 5°33′00″	M.O.E	SCHOOL				GUNDUMI	281.119	281.586	
36	DANGE BH No1	13°51′10″ / 5°21′00″	S.S.W.B	DOMESTIC SUPPLY	198.1	168	176.8 / 185.9	RIMA	336.920	336.740	
37	YABO	12°44′30″ / 5°00′00″	S.S.W.B	DOMESTIC SUPPLY				RIMA	297.854	298.075	
38	SAYINA	12°42′00″ / 5°53′00″	S.S.W.B	NOT IN USE					236.259	235.132	
39	HELENDE	12°41′00″ / 4°29′00″	S.S.W.B	DOMESTIC SUPPLY	129.0			GWANDU	223.080	223.071	
40	ALWASA	12°37′00″ / 4°26′00″	S.S.W.B	DOMESTIC SUPPLY	82.3	203	49.1 / 58.8	GWANDU	212.238	212.355	
41	BAYAWA	12°51′10″ / 4°41′30″	S.S.W.B	DOMESTIC SUPPLY	79.2	219	30.5 / 40.2	GWANDU	234.151	234.091	
42	KOKO BH No3	11°26′00″ / 4°29′00″	S.S.W.B	DOMESTIC SUPPLY				ILLO	211.293	221.698	
43	KOKO BH No1	11°26′00″ / 4°29′00″	S.S.W.B	DOMESTIC SUPPLY	36.6			ILLO	193.159	193.265	
44	KENDE	11°31′00″ / 4°15′30″	S.S.W.B	DOMESTIC SUPPLY	52.1	219		ILLO	159.252	159.309	
45	GIWA TAZO	12°08′00″ / 4°25′00″	S.S.W.B	NOT IN USE				RIMA	226.880	226.905	
46	UMBUTU	12°09′10″ / 4°40′30″	F.M.W.R	NOT IN USE				RIMA	202.900	203.250	
47	KEBBE	12°07′30″ / 4°43′30″	S.S.W.B	DOMESTIC SUPPLY				RIMA	197.592	198.372	
48	BARDOKI	12°06′20″ / 5°00′20″	S.S.W.B	NOT IN USE					189.801	190.214	

Table 4-3 (3) Inventory of Boreoles for Water Level Observation

No.	Local Name	Latitude / Longitude	Agency	Purpose	Total Depth(m)	Casing Dia.(mm)	Screen Posi.(m)	Aquifer	Elevation (m)	Casing head E.l(m)	Remarks
49	HINGILLA	11°54′00″ / 3°47′00″	S.S.W.B	DOMESTIC SUPPLY				ILLO	217.371	215.639	
50	KAMBA	11°51′00″ / 3°47′00″	S.S.W.B	DOMESTIC SUPPLY	93.0	203	54.9 / 67.1	ILLO	182.166	181.046	
51	FANNA	11°43′30″ / 3°51′30″	S.S.W.B	DOMESTIC SUPPLY	117.0			ILLO	180.453	180.514	
52	DAKIN GARI	11°50′00″ / 4°08′00″	S.S.W.B	DOMESTIC SUPPLY				ILLO	190.620	191.440	
53	KWANDAGE	11°50′00″ / 4°02′00″	S.S.W.B	DOMESTIC SUPPLY				ILLO	228.170	228.345	
54	BUNZA	12°05′00″ / 4°01′00″	S.S.W.B	DOMESTIC SUPPLY				GWANDU	186.828	187.516	
55	JEGA	12°12′00″ / 4°22′00″	S.S.W.B	DOMESTIC SUPPLY	93.0			RIMA	212.518	212.790	
56	BIRNIN KEBBI	12°28′00″ / 4°12′00″	S.S.W.B	DOMESTIC SUPPLY	97.5		73.2 / 96.3	GWANDU	211.495	211.657	
57	ALERU	12°17′00″ / 4°28′00″	S.S.W.B	DOMESTIC SUPPLY					264.940	264.466	
58	TAMBAWAL BH No1	12°22′00″ / 4°39′00″	S.S.W.B	DOMESTIC SUPPLY	97.5	203	72.5 / 89.9	GWANDU	241.608	241.799	
59	DOGON DAJI	12°27′00″ / 4°48′00″	S.S.W.B	DOMESTIC SUPPLY				RIMA	256.288	256.370	
60	KAJIJI	12°38′00″ / 4°56′00″	S.S.W.B	DOMESTIC SUPPLY	125.0			RIMA	285.448	285.788	
61	SHAGARI	12°38′00″ / 4°59′55″	S.S.W.B	DOMESTIC SUPPLY				RIMA	276.954	276.943	
62	BODINGA	12°30′30″ / 5°09′30″	S.S.W.B	DOMESTIC SUPPLY				RIMA	292.273	292.562	
63	DUG-WELL1 DANTASAKO							RIMA	293.821	294.385	CONTINUOUS OBSERVATION
64	DUG-WELL2 RIJIYAR HIDO							RIMA	235.824	236.375	CONTINUOUS OBSERVATION

Tab. 4-4 Water Levels in Boreholes - Simultaneous Observation -

NO.	AGUIFER	BOREHOLE NAME	ELEVATION (M.S.L)	31/5/88-15/7/88 MEAS. (GL-m)	31/5/88-15/7/88 G.W.L (M.S.L)	19/7/88- 1/8/88 MEAS. (GL-m)	19/7/88- 1/8/88 G.W.L (M.S.L)	23/1/89-31/1/89 MEAS. (GL-m)	23/1/89-31/1/89 G.W.L (M.S.L)	16/5/89-21/5/89 MEAS. (GL-m)	16/5/89-21/5/89 G.W.L (M.S.L)
1	GUNDUMI	ISA DUGWELL	315.38	9.57	305.80	9.30	306.08	8.19	307.18	8.18	307.20
2	GUNDUMI	ISA	318.45	10.67	307.78	10.12	308.33	9.11	309.34	9.76	308.69
3	GUNDUMI	SHINKAFE	303.65	3.53	300.13	2.80	300.86	2.61	301.05	3.06	300.60
4	GUNDUMI	KUNAWA	306.14	35.54	270.60	35.53	270.61	35.41	270.73	35.44	270.70
5	GUNDUMI	MALAM BUZU	306.05	0.86	305.20	0.77	305.29	0.68	305.38	0.76	305.29
6	GUNDUMI	GAJIT	309.08	10.35	298.73	10.25	298.83	8.97	300.11	9.32	299.76
7	GUNDUMI	MASHAYA	302.23	13.30	288.93	12.80	289.43	12.59	289.64	12.79	289.44
33	GUNDUMI	TALATA MAFARA	306.01	12.85	293.16	12.55	293.46	12.04	293.97	12.29	293.72
34	GUNDUMI	LAMBA BAKURA	315.84	36.39	279.45	36.37	279.47	35.83	280.01	35.85	279.99
35	GUNDUMI	TURETTA	281.59	24.05	257.54	24.05	257.54	23.92	257.67	23.95	257.64
42	ILLO	KOKO POLICE	211.70	12.74	198.96	12.62	199.08	12.27	199.43	12.47	199.23
43	ILLO	KOKO(NO1)	193.26	4.43	188.84	4.23	189.04	4.00	189.26	4.39	188.88
44	ILLO	KENDE	159.31	3.50	155.81	3.16	156.15	2.98	156.33	3.35	155.96
49	ILLO	HINGILLA	215.64	30.65	184.99	30.58	185.06	30.37	185.27	30.41	185.23
50	ILLO	KAMBA	181.05	7.18	173.87	7.28	173.77	7.31	173.74	7.64	173.41
51	ILLO	FANNA	180.51	11.64	168.87	0.00	0.00	11.27	169.24	11.28	169.23
52	ILLO	DAKIN GARI	191.44	15.00	176.44	53.00	138.44	15.42	176.02	14.32	177.12
53	ILLO	KWANDAGE	228.35	48.04	180.31	48.04	180.31	27.77	200.57	48.09	180.26
8	RIMA	KURU KURU	297.05	8.57	288.48	8.34	288.71	8.06	288.99	8.17	288.88
9	RIMA	GORONYO COMPLEX	325.94	33.00	292.94	30.56	295.38	30.38	295.56	30.45	295.49
10	RIMA	GORONYO	306.67	12.00	294.67	11.65	295.02	11.37	295.30	11.40	295.27
11	RIMA	GADA	306.81	43.35	263.46	43.17	263.64	43.10	263.71	43.10	263.71
12	RIMA	RAFIN DUMA	309.52	42.14	267.39	41.72	267.80	41.99	267.54	42.15	267.38
13	RIMA	GIDAN CIWAKE	312.98	60.25	252.73	60.26	252.72	60.07	252.91	60.15	252.83
15	RIMA	MAMAN SUKA	273.20	35.03	238.17	34.98	238.22	34.98	238.22	35.00	238.20
17	RIMA	KWARE	272.75	31.21	241.54	31.17	241.58	30.90	241.85	30.93	241.82
21	RIMA	SOKOTO YAURI RD2	295.34	54.97	240.37	54.91	240.43	0.00	0.00	0.00	0.00
22	RIMA	SOKOTO YAURI RD3	295.31	55.20	240.11	55.19	240.12	54.80	240.51	0.00	0.00
24	RIMA	BARAN ZAKI	263.87	1.17	262.70	1.07	262.80	0.91	262.96	0.92	262.95
28	RIMA	RABBAH	255.13	3.54	251.59	3.50	251.63	3.23	251.90	3.24	251.89
29	RIMA	ACHIDA	312.97	69.21	243.76	69.11	243.86	68.73	244.24	68.94	244.03
31	RIMA	CHIMOLA 1	264.86	3.65	261.21	3.59	261.27	3.71	261.15	3.64	261.22
32	RIMA	CHIMOLA 2	292.06	31.37	260.69	31.31	260.75	31.15	260.91	31.17	260.89
36	RIMA	DANGE	336.74	84.07	252.67	84.01	252.73	83.88	252.86	83.94	252.80
37	RIMA	YABO	298.08	57.01	241.07	57.07	241.01	56.98	241.10	56.87	241.21
45	RIMA	GIWATAZO	226.90	34.49	192.41	34.50	192.40	34.46	192.45	34.49	192.41
46	RIMA	UMBUTU	203.25	7.86	195.39	7.65	195.60	7.59	195.66	7.84	195.41
47	RIMA	KEBBE	198.37	4.01	194.36	3.79	194.58	3.83	194.54	3.95	194.42
55	RIMA	JEGA	212.79	28.34	184.45	28.17	184.62	27.97	184.82	0.00	0.00
59	RIMA	DOGON DAJI	256.37	34.03	222.34	33.97	222.40	33.66	222.71	33.76	222.61
60	RIMA	KAJIJI	285.79	47.46	238.33	47.46	238.33	47.43	238.36	47.79	238.00
61	RIMA	SHAGARI	276.94	37.67	239.27	37.45	239.49	37.15	239.79	0.00	0.00
62	RIMA	BODINGA	292.56	43.19	249.37	43.06	249.50	51.05	241.51	42.60	249.96
14	KALAMBINA	ILLELA	266.54	7.42	259.12	7.44	259.10	7.52	259.02	7.66	258.88
16	KALAMBINA	GWADABAWA	267.04	13.58	253.46	13.58	253.46	10.35	256.68	10.59	256.45
20	KALAMBINA	SOKOTO YAURI RD1	295.63	22.68	272.95	22.63	273.00	21.91	273.72	0.00	0.00
23	KALAMBINA	SOKOTO POLO CLUB	296.27	15.57	280.70	15.33	280.94	13.82	282.45	14.59	281.68
18	GWAMDU	TANGAZA	256.71	0.00	256.71	0.00	256.71	0.00	256.71	0.00	256.71
19	GWAMDU	GIDAN MADI	267.79	15.78	252.01	15.79	252.00	15.37	252.42	15.44	252.35
39	GWAMDU	HELENDE	223.07	0.75	222.32	0.49	222.58	0.41	222.66	0.60	222.47
40	GWAMDU	ALWASA	212.35	1.55	210.80	1.43	210.93	1.25	211.10	1.37	210.99
41	GWAMDU	BAYAWA	234.09	9.43	224.66	9.16	224.93	5.95	228.14	6.90	227.19
54	GWAMDU	BUNZA	187.52	8.52	179.00	8.15	179.37	8.19	179.33	8.51	179.01
56	GWAMDU	BIRNIN KEBBI	211.66	28.68	182.98	28.83	182.83	28.51	183.15	27.97	183.69
58	GWAMDU	TAMBAWAL	241.80	30.76	211.04	30.62	211.18	30.32	211.48	30.40	211.40
27		GIDAN TUDU	311.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25		WURNO	334.43	24.58	309.85	24.88	309.55	24.72	309.71	24.81	309.62
26		WURNO	326.66	18.95	307.71	18.85	307.81	18.73	307.93	18.95	307.71
30		KANDAN	305.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
38		SANYINA	235.13	24.14	210.99	23.76	211.37	23.18	211.95	23.28	211.85
48		BARDOKI	190.21	7.85	182.36	7.69	182.52	7.27	182.94	7.68	182.53
57		ALIERO	264.47	13.46	251.01	12.29	252.18	11.56	252.91	13.14	251.33

the study; 31/5/88-15/7/88, 19/7/88-1/8/88, 23/1/89-31/1/89, 17/5/89/-21/5/89. The results of the observations are given in Table 4-4.

4-3-2 Continuous observation

(1) Weekly observation

Four boreholes and two dug-wells were chosen as observation borehole/wells. They are:

① Yauri Road Borehole –1 in Sokoto City	Sokoto Group
② Yauri Road Borehole –3 in Sokoto City	Rima Group
③ Kunawa (SSWB Borehole)	Gundumi Formation
④ Rabah (GGSS Borehole)	Rima Group
⑤ Dan Tasako (Dug-well, 70Km from Isa)	Rima Group
⑥ Rijiyar Hido (Dug-well)	Rima Group

The boreholes and wells were visited weekly for measurement of their water levels.

Criteria for selecting them was nearly the same as those for selecting simultaneous observation boreholes. Since observation had to be carried out every week, accessibility to the borehole/well was an especially important criterion.

(2) Automatic water level recording

Automatic water level recorders provided by JICA were installed at the four boreholes shown in Table 4-5.

Table4-5 Automatic water level recording

No.	Name	Depth (m)	Aquifer	Type
1	Horo Birni	120	Rima	Float
2	Tunga Ardo	84	Basement	Pressure
3	Yauri Rd. No.1	331	Rima	Float
4	Yauri Rd. No.2	—	Sokoto	Float

Two types of automatic water level recorders have been used. One is the floating type, in which the movement of the water table is reflected in the up-and-down movement of the float. The other is the pressure type, in which the movement of the water table is reflected in the change in water pressure detected by a submerged sensor. With both types, the movement of the water table is recorded analogically on a recording chart.

4-4 Chemical quality of water

4-4-1 Chemical quality of water for domestic use

Water samples taken from boreholes and dug wells in several candidate villages, and from spring-originated streams and lakes, were tested for potability by use of a chemical quality test kit provided by JICA. The international standards for drinking water recommended by the World Health Organization are given in Table 4-6. These standards are commonly used in Nigeria.

The chemical quality of water tested is generally good, as shown in Table 4-7. However, some water samples taken from the Kalambaina Formation had a total hardness exceeding the maximum limit of 500 mg/liter. (Iron concentration determined by the testing is not reliable because of the rapid iron precipitation in stored samples. Higher iron concentration, than indicated by the testing, is assumed because the water sample was discolored when tested.)

Tab. 4-6 Drinking Water Quality Standard

(1) Physical Condition

Item	WHO Highest desirable	WHO Maximum permissible	Japan
Colour	15	50	5
Taste	not offensive	not offensive	not offensive
Odour	〃	〃	〃
Turbidity	5	25	2
PH	6.5 to 8.5	6.5 to 9.2	5.8 to 8.6

(2) Chemical condition

Item \ PPM	WHO Highest disirable	WHO Maximum permissible	Japan
Total solids	500	1,500	-
Fe	0.1	1.0	0.3
Mn	0.05	0.5	0.3
Fe + Mn	-	-	-
Cu	0.05	1.5	1.0
Ca	75	200	-
Mg	30	150	-
SO_4	200	400	-
Cl	200	600	200
F	0.6	-	0.8
NO_3	10	-	10
Alkylbenzal Sulfohates, ABS	0.5	-	0.5
Phenolic-substance as phenol	0.001	-	0.005
Hardness	100	500	300

(3) Toxin

Item	WHO	Japan
Hg	0.001	None
Pb	0.1	0.1
As	0.05	0.05
Se	0.01	0.01
Cr^{b+}	0.05	0.05
CN	0.1	None
Cd	0.005	0.01

(4) Bacteriological condition

Item	WHO	Japan
Standard Plate count (Coloines/cm^3)	-	100
MPN (Coliform organism/$100m^3$)	-	None
E.Coli	-	-

Tab. 4-7 (1) Chemical Quality of Water for Domestic Use

(1)

Substance / Content	Drinking Water Quality Standard: Nigeria	W. H. O. Desirable Level	W. H. O. Maximum Permissible Level	Result of Test												
Sampling place: Village number				1	2	3	4		5	6	7	8	9	10	11	12
Sampling place: Village name (well number)				Tunga Ardo	Bullakke	Bambaram	Ruwan Bore: Ruwan Bore	Ruwan Bore: Gusau L.G.A.	Dokau	Bamamu	Dauran	Yambuki	Tungwa Kofa	Kaga W-1	Bajida	Sanchi W-1
Kind of water source				Dug Well	Borehole		Stream	Dug well	Dug well	Pond	Borehole	Dug well	Stream	Dug well		Dug well
Static water level (m)				-14.73				-13.73	-12.40			-12.00		-7.8		-4
Sampling date				7- 7-88	4- 7-88		2- 7-88	2- 7-88	3- 7-88	6- 7-88	29- 6-88	30- 6-88	1- 7-88	15- 7-88		6- 7-88
Weather				Sunny	Cloudy		Sunny	Sunny	Fairly cloudy	Bright	Sunny	Sunny	Sunny			
Water temperature (℃)																
Turbidity (°)		5.	25.	>5	>5		≫5	1	>5	>5	>5	>5	≫5	>2, <5		>5
Color (°)		5.	50.	>5, <10	10		≫10	5	>10	>10	>10	10	≫10	>10		>10
Odor (Kind)		Unobjectionable	Unobjectionable	Odorless	Odorless		Odorless	Odorless	Odorless	Choking smell	Odorless	Choking smell	Choking smell	Choking smell		Odorless
Taste (Kind)		Unobjectionable	Unobjectionable	Tasteless	Tasteless		Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	No good	Tasteless	Tasteless		Tasteless
pH		7.0 to 8.5	6.5 to 9.2	6.5	7.0		6.5	7.0	7.5	7.0	7.0	8.5	6.5	6.0		6.5
P.M.D. $KMnO_4$(mg/ℓ)				5	10		5	5	5	>5, <10	5	>5, <10	5	5		5
Nitrogen-Nitrite NO_2-N(mg/ℓ)				<0.006	<0.006		<0.006	<0.006	>0.3	<0.006	<0.006	<0.02	<0.006	<0.006		0.006
Nitrogen-Nitrate NO_3-N(mg/ℓ)				>0.46,<1.15	>0.23,<0.46		>0.46,<1.15	>4.6, <10	>4.6, <10	0.23	>4.6, <10	2.3	2.3	>1.15, <2.3		>2.3, <4.6
Nitrogen-Ammonium NH_4-N(mg/ℓ)				<0.4	<0.4		<0.4	0.6	1.2	0.6	<0.4	<0.4	0.4	<0.4		<0.4
Total-Hardness $CaCO_3$(mg/ℓ)		100	500	200	400		200	380	510	200	390	520	170	170		110
Chloride Cl(mg/ℓ)		200	600	40	60		35	120	80	60	70	60	100	80		110
Hexavalent Chromium Cr^{6+}(mg/ℓ)				<0.05	<0.05		<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.05		<0.05
Total Iron Fe^{+}(mg/ℓ)		0.1	1.0	<0.2	<0.2		0.2	0.3	<0.2	0.2	<0.2	<0.2	<0.2	<0.2		<0.2
Copper Cu(mg/ℓ)		0.05	1.5	<0.5	<0.5		<0.5	<0.5	<0.5	0.5	<0.5	<0.5	<0.5	<0.5		<0.5
Zinc Zn(mg/ℓ)		5.0	15.	0	0		0	0	0	0	0	0	0	0		0
S.C.B. (pcs/mℓ)				0	8		2	17	2	5	0	6	9	0		0
Coliform (pcs/mℓ)				0	0		0	0	0	0	0	5	0	0		0
Electric conductivity (μ℧/cm)				280	660		180	700	1200	54	890	1200	190	95		190
Appearance				Comparatively Clear.	Comparatively Clear.		Solids were Suspending & munutely solids settled.	Comparatively clear. Munutely solids settled.	Solids were suspending & munutely solids settled.	Cosiderable solids were suspending & munutely solids settled.	Comparatively clear.	Highly turbid brownish water & considerable solids settled.	solids were suspending.	Comparatively clear. Munutely solids settled.		Comparatively clear.
Testing date				4- 8-88	4- 8-88		4- 8-88	4- 8-88	4- 8-88	4- 8-88	4- 8-88	4- 8-88	4- 8-88	4- 8-88		4- 8-88
Inspector				Kawamura	Kawamura		Kawamura	Kawamura	Kawamura	Kawamura	Kawamura	Kawamura	Kawamura	Kawamura		Kawamura

Tab. 4-7 (2) Chemical Quality of Water for Domestic Use

(2)

Substance	Content	Drinking Water Quality Standard: Nigeria	W. H. O. Desirable Level	W. H. O. Maximum Permissible Level	Result of Test												
Sampling place	Village number				13	14	15	16	17	18	19	20	21	22	23	24	25
	Village name (well number)				Illela-Auwar	Dakitakwas W-1	Zugu W-1	Raba W-1	Birnin Yauri W-1	Takware W-1	Gumbal No.1	Maruda	Tsafanade	Kiabar Bawa No.1	Horo Birni	Tabki	Gudale No.1
Kind of water source					Dug well	Dug well	Dug well	Dug well	Dug well	Dug well	Dug well	Borehole	Borehole	Dug well	Dug well	Dug well	Dug well
Static water level	(m)					-10.35	-10.90	-2.60	-15.60	-5.00	-6.15			-12.16	-45.46	-47.25	-8.95
Sampling date					16- 1-89	12- 7-88	14- 7-88	18- 7-88	18- 7-88	17- 7-88	14- 6-88	15- 6-88	24- 6-88	18- 6-88	22- 6-88	21- 6-88	16- 6-88
Weather					Fine						Hot	Hot	Fairly hot	Hot	Cool	Cool	Hot
Water temperature	(℃)				30						23.5						23
Turbidity	(°)		5.	25.	<2	2	>5	>5	>5	5	>5	>5	>5	>5	>5	>5	>5
Color	(°)		5.	50.	<2	5	10	>10	>10	10	>10	>5, <10	>10	>10	>10	10	10
Odor	(Kind)		Unobjectionable	Unobjectionable	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless
Taste	(Kind)		Unobjectionable	Unobjectionable	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	No good	No good	No good	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
pH			7.0 to 8.5	6.5 to 9.2	5.5 to 6.0	6.5	7.0	6.5	7.5	6.5	7.0	7.5	6.0	7.0	6.0	6.0	6.0
P.M.D.	$KMnO_4$ (mg/ℓ)				7	5	5	10	5	5	5	5	5	5	5	5	5
Nitrogen-Nitrite	NO_2-N(mg/ℓ)				>1.15	<0.006	0.015	0.015	0.1	0.03	<0.006	<0.006	<0.006	<0.006	<0.006	0.006	<0.006
Nitrogen-Nitrate	NO_3-N(mg/ℓ)				>0.03	>0.46,<1.15	>1.15,<2.3	>1.15, <2.3	>2.3, <4.6	>10	4.6	>2.3, <4.6	<0.23	>2.3, <4.6	>2.3, <4.6	>4.6, <10	1.15
Nitrogen-Ammonium	NH_4-N(mg/ℓ)				<0.5	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4
Total-Hardness	$CaCO_3$ (mg/ℓ)		100	500		110	270	70	360	150	270	430	90	310	290	90	100
Chloride	Cl(mg/ℓ)		200	600	<0.1	70	100	110	100	170	80	120	60	110	120	80	115
Hexavalent Chromium	Cr^{6+}(mg/ℓ)				<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	>0.05, <0.1	0.05	<0.05
Total Iron	Fe^{+}(mg/ℓ)		0.1	1.0	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.1	<0.2	<0.2	<0.2	<0.2
Copper	Cu(mg/ℓ)		0.05	1.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Zinc	Zn(mg/ℓ)		5.0	15.	>0.5	0	0	0	0	0	0	0	0	0	0.2	0	0
S.C.B.	(pcs/mℓ)					0	0	0	1	1	24	15	1	17	7	4	5
Coliform	(pcs/mℓ)					0	0	0	0	0	0	0	0	0	0	0	0
Electric cinductivity	(μ℧/cm)					58	380	330	600	930	510		240	400	300	240	160
Appearance						Comparativery clear & munutery solids settied	Comparativery clear munutery solids settied	Comparatively clear & munutely solids settled.	Comparatively clear & munutely solids settled.	A few small mud balls were on the bottom. Two wrigglers were in the sample.	Comparatively clear & slimy solids settled.	Comparatively clear.	Slightly translucent brownish water. Munutely solids settled.	Comparatively clear & munutely solids settled.	Solids were suspending & munutely solids settled.	Comparatively clear.	Comparatively clear.
Testing date					8- 2-89	4- 8-88	4- 8-88	4- 8-88	4- 8-88	4- 8-88	4- 8-88	4- 8-88	4- 8-88	4- 8-88	4- 8-88	4- 8-88	4- 8-88
Inspector					Ewoikhare	Kawamura	Kawamura	Kawamura	Kawamura	Kawamura	Kawamura	Kawamura	Kawamura	Kawamura	Kawamura	Kawamura	Kawamura

Tab. 4-7 (3) Chemical Quality of Water for Domestic Use

(3)

Substance / Content	Drinking Water Quality Standard: Nigeria	W.H.O. Desirable Level	W.H.O. Maximum Permissible Level	Result of Test												
Sampling place: Village number				26	27	28	29	30	31	62	33	34	35	36	37	38
Sampling place: Village name (well number)				Chibike	Kwakwazo No.1	Danjiro No.1	Bakyasuwa	Jan Bako	Rahayel	Gendene W-1	Kalgo No.2	Soro	Sabiye	Tozai	Xayaxa	Tsauaye No.2
Kind of water source				Dug well	Dug well	Borehole	Borehole	Dug well	Dug well	Dug well	Dug well	Dug well	Dug well	Dug well	Hand pump	Dug well
Static watee level (m)				-36.00	-8.57			-12.73		-7.80	-19.50	-9.00				-39.75
Sampling date				13- 6-88	2- 6-88	7- 6-88	1- 6-88	28- 6-88	10- 1-89	27- 7-88	23- 5-88	26- 5-88	10- 1-89	11- 1-89	12- 1-89	3- 6-88
Weather				Hot	Hot	Fair	Hot	Sunny	Fine	Cloudy/Rain	Sunny	Sunny	Fine	Fine	Fine	Hot
Water temperature (℃)				26	30	30.5	31		30		32	30	30		30	31
Turbidity (°)		5.	25.	>5	>5	>5	>5	>5	1	>5	>5	>5	<2	<2	<2	>5
Color (°)		5.	50.	5	>10	>10	10	10	2	10	10	>10	2	<2	<2	>10
Odor (Kind)		Unobjectionable	Unobjectionable	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless
Taste (Kind)		Unobjectionable	Unobjectionable	Tasteless	Tasteless	Tasteless	No good	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
pH		7.0 to 8.5	6.5 to 9.2	6.5	7.0	7.0	7.5	7.5	<7.0	7.0	6.0	7.0	<7.0	<7.5	7.0 to 7.5	5.5
P.M.D. $KMnO_4$ (mg/ℓ)				5	5	>5, <10	5	5	<8	>0, <5	>5, <10	>10, <15	6	6	<5	5
Nitrogen-Nitrite NO_2-N (mg/ℓ)				<0.006	<0.006	<0.006	<0.006	<0.006		>0.03,<0.06	<0.006	<0.006	>0.23	>1.15	<2.3	<0.006
Nitrogen-Nitrate NO_3-N (mg/ℓ)				1.15	>1.15, <2.3	0.23	>4.6, <10	>2.3, <4.6		<0.23	>2.3, <4.6	>1.15, <2.3	0.06 to 0.15	>0.06	<0.06	>1.15, <2.3
Nitrogen-Ammonium NH_4-N (mg/ℓ)				<0.4	<0.4	0.6	<0.4	<0.4		<0.4	<0.4	<0.4	<0.5	<0.5	<0.5	<0.4
Total-Hardness $CaCO_3$ (mg/ℓ)		100	500	120	400	420	1160	580		1120	410	30				300
Chloride Cl (mg/ℓ)		200	600	110	110	110	240	120		110	110	<200	<0.1	<0.1	<0.1	200
Hexavalent Chromium Cr^{6+} (mg/ℓ)				<0.05	<0.05	<0.05	<0.05	<0.05		<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Total Iron Fe^{+} (mg/ℓ)		0.1	1.0	<0.2	<0.2	<0.2	<0.2	<0.2		<0.2	<0.2	0.2	<0.2	<0.2	<0.2	<0.2
Copper Cu (mg/ℓ)		0.05	1.5	<0.5	<0.5	<0.5	<0.5	<0.5		<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Zinc Zn (mg/ℓ)		5.0	15.	0	0	1	0	0		0	0	0	>0.5	>0.5	>0.5	0
S.C.B.			1	1	15		14	0		7	1	5				6
Coliform (pcs/mℓ)				6	6	0	0	0		3	4	19				0
Electric cinductivity (μ℧/cm)				46	480	460	99	520		1300	280	120				230
Appearance				Comparativery clear A few mud balls, were on the bottom.	Solids were Suspending & munutely solids settled.	Slight clear brownish water munutery solids settled.	Comparatively clear.	Comparatively clear. Munutely solids settled.		Comparatively clear. Munutely solids settled.	Comparatively clear. Munutely solids settled.					Comparatively clear. Munutely solids settled.
Testing date				4- 8-88	4- 8-88	4- 8-88	4- 8-88	4- 8-88	8- 2-89	4- 8-88	4- 8-88	26- 5-88	8- 2-89	8- 2-89	8- 2-89	4- 8-88
Inspector				Kawamura	Kawamura	Kawamura	Kawamura	Kawamura	Emoikhare	Kawamura	Kawamura	Fujita	Emoikhare	Emoikhare	Emoikhare	Kawamura

Tab. 4-7 (4) Chemical Quality of Water for Domestic Use

(4)

Substance / Content	Drinking Water Quality Standard: Nigeria	W. H. O. Desirable Level	W. H. O. Maximum Permissible Level	Result of Test											
Sampling place: Village number				39	40		41		42	43	44	45	46	47	48
Sampling place: Village name (well number)				Zawache No.1	Kalmalo No.1	Kalmalo No.2	Araba No.2	Araba No.3	Sambawa No.1	Kimba No.1	Kuka Kogo	Giro W-1	Mailamawa	Samalu No.1	Kainuwa
Kind of water source				Dug well	Dug well	Dug well	Dug well	Dug well	Dug well	Dug well	River	Dug well	Dug well	Dug well	Lake
Static date (m)				-10.00	-7.65	-8.20	-10.45	-6.98	-8.30	-8.62		-19.50		-23.30	
Sampling date				4- 6-88	31- 5-88	31- 5-88	31- 5-88	31- 5-88	10- 6-88	11- 6-88	28- 7-88	27- 7-88	8- 6-88	24- 5-88	12- 7-88
Weather				Slightly Hot	Sunny	Sunny	Hot	Hot	Hot	Hot	Sunny	Sunny & Rainy	Cool	Sunny	Sunny
Water temperature (℃)				30	30	30	30	30	29	27				31	
Turbidity (°)		5.	25.	>5	>5	>5	>5	>5	>5	>5	>5	2	>5	>2. <5	>5
Color (°)		5.	50.	>10	>10	>10	>10	>10	>10	10	>10	10	>10	10	10
Odor (Kind)		Unobjectionable	Unobjectionable	Odorless	Odorless	Odorless		Odorless	Odorless	Odorless	Choking smell	Odorless	Odorless	Choking smell	Odorless
Taste (Kind)		Unobjectionable	Unobjectionable	Tasteless	Tasteless	Tasteless		Tasteless	Tasteless	Tasteless	No good	Tasteless	Tasteless	Tasteless	No good
pH		7.0 to 8.5	6.5 to 9.2	7.5	7.5	7.5	6.5	7.2	7.5	6.0	6.5	6.5	7.0	5.0	7.5
P.M.D. $KMnO_4$(mg/ℓ)				5	5	5	5	5	5	5	>15. <20	5	5	5	5
Nitrogen-Nitrite NO_2-N(mg/ℓ)				<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	>0.06.<0.15	0.006	<0.006	<0.006
Nitrogen-Nitrate NO_3-N(mg/ℓ)				>2.3. <4.6	>4.6. <10	>1.15.<2.3		>2.3. <4.6	>1.15. <2.3	>2.3. <4.6	<0.23	>2.3. <4.6	1.15	>0.46.<1.15	0.46
Nitrogen-Ammonium NH_4-N(mg/ℓ)				<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	>0.4. <0.8	<0.4	<0.4	
Total-Hardness $CaCO_3$(mg/ℓ)		100	500	720	1500	2200	700	620	410	500	500	200	910	300	800
Chloride Cl(mg/ℓ)		200	600	230	410	610	200	200	120	240	120	120	120	110	110
Hexavalent Chromium Cr^{6+}(mg/ℓ)				<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Total Iron Fe^{+}(mg/ℓ)		0.1	1.0	<0.2	<0.2	<0.2	0.2	0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Copper Cu(mg/ℓ)		0.05	1.5	<0.5	<0.5	<0.5	<0.5	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Zinc Zn(mg/ℓ)		5.0	15.	0	0	0	0	0	0	0	0	0	0	0	0
S.C.B. (pcs/mℓ)				4	1	5	0	2	12	13	0	12	22	13	5
Coliform (pcs/mℓ)				0	0	0	0	5	0	0	23	26	0	0	0
Electric cinductivity (μ℧/cm)				530	1700	2750	520	500	295	680				81	
Appearance				Comparativery clear munutely solids settled.	Comparativery clear munutely solids settled.	Comparativery clear munutely solids settled.	Comparatively clear munutely solids settled.	Comparatively clear munutely solids settled.	Comparatively clear munutely solids settled.	Comparatively clear munutely solids settled.	The water had hight tubidity. It was caused by yesterday's rain.	Comparatively clear. Munutely solids settled.	solids were suspending & munutely solids settled.	Comparatively clear. Munutely solids settled.	Comparatively clear. Munutely solids settled.
Testing date				4- 8-88	4- 8-88	4- 8-88	4- 8-88	4- 8-88	4- 8-88	4- 8-88	4- 8-88	4- 8-88	4- 8-88	4- 8-88	4- 8-88
Inspector				Kawamura	Kawamura	Kawamura	Kawamura	Kawamura	Kawamura	Kawamura	Kawamura	Kawamura	Kawamura	Kawamura	Kawamura

4-4-2 Ion component of the water

The results of chemical analyses of water conducted in the study area by several investigators were collected. The results were classified according to aquifer and combined with the results obtained by the JICA study team (Table 4-8). Trilinear diagrams showing the ion component of the water were drawn from the results (Fig. 4-11).

The water from streams is principally of the calcium-bicarbonate type. The dissolved contents are from a low of 33 mg/ℓ in the River Zamfara, at Jega, to a high of 360 mg/ℓ in the River Rima, at Goronyo.

The ion component of the water from the basement complex area is similar to that of the streams. However, the number of water samples of the sodium-bicarbonate type increases. The dissolved contents are from a low of 99 mg/ℓ at Maga to a high of 1200 mg/ℓ at Dauran.

The Gundumi aquifer is mostly of the calcium-bicarbonate, sodium-bicarbonate, or calcium-sulphate type. An exception is the sodium-chloride type present at Isa and Kaloye. The dissolved contents are from a low of 27 mg/ℓ at Tureta to a high of 2980 mg/ℓ at Kaloye.

The Rima aquifers are mostly of the calcium-bicarbonate or calcium-sulphate type. The contents of sodium ion are low in general with the exception of those at Kaloye and Horo-Birni. The calcium-sulphate type is more dominant than in the Gundumi aquifer. The high content of sulphate in the water is probably caused by contact with gypsum-bearing rocks. The dissolved contents are from a low of 44 mg/ℓ at Gusau-Sokoto-Road BH3517 to a high of 14000 mg/ℓ at the Taloka dug-well. This high content of dissolved solid at Taloka dug-well is exceptionally high compared with that at other places. This is probably caused by pollution of the groundwater because the well is a shallow well, which is easily polluted by waste water and other refuse. The water has a high nitrate content as well. With the exception of that at the Taloka dug-well, the highest dissolved content is 1088 mg/ℓ at Birnin-Kebbi BH3053.

The Sokoto aquifer is mostly of the calcium-bicarbonate type as could be expected from the fact that the aquifer consists of limestone and the water is probably recharged directly by the infiltration of rain water. However, a high potassium content is found in a few places, and the ion component varies widely. This may be connected to the fact that most water samples in the Sokoto group were

TABLE 4 - 8 (1) RESULTS OF WATER QUALITY ANALYSIS (ION COMPONENT)

AQUIFER	LOCATION	B.H. NO.	MG	CA	FE	MN	NA	K	F	CL	NO3	SO4	HCO3	SIO2	T.D.S	PH
STREAM	LAKE KALMALO	G-1	9.1	27.7			15.9	14.3	2.8	9.5			161.0	3.2	274.	
STREAM	LAKE KAINUWA	G-2	25.6	50.4			6.1	0.7	0.3	2.3		2.5	278.0	29.3	269.	
STREAM	LAKE KALMALO	SW	10.0	24.0	0.16		7.1	23.0	1.6	6.5	2.2	2.8	150.0	5.1	157.	8.3
STREAM	NIGER AT DOLE	SW	1.9	6.4	0.14		6.0	4.4	0.2	4.0	0.3	9.4	40.0	18.0	73.	7.8
STREAM	RIMA AT GORONYO	H-2	2.8	1.7			2.0	3.5	0.2	2.7		2.1	12.6	0.4	360.	
STREAM	RIMA AT SOKOTO	SW	3.9	8.0			3.9	3.2		0.5	0.6	2.1	46.0	7.3	50.	7.7
STREAM	SHELLA AT KALGO	SW	4.9	20.0	0.03		16.0	4.4	0.2	3.5	0.2	15.0	111.0	24.0	143.	7.2
STREAM	SOKOTO AT SOKOTO	H-1	3.5	2.9			4.1	3.8	0.1	3.7		0.8	26.5	5.3	230.	
STREAM	SOKOTO AT SOKOTO	SW	0.5	5.2			3.3	3.6				3.0	27.0	7.3	36.	7.5
STREAM	ZAMFARA AT JEGA	SW	1.0	4.4			2.4	3.6		0.5	0.9	2.3	23.0	6.6	33.	7.4
BASEMENT	DAURAN		46.1	171.0			83.1	5.0	0.2	64.5		14.5	354.0	58.7	1200.	
BASEMENT	GUSAU-SOKOTO ROAD	BORE	9.6	27.0	12.00	0.01	4.3	3.0		1.0		0.5	144.0	24.0	142.	7.4
BASEMENT	GUSAU-SOKOTO ROAD	3702	24.0	19.0			63.0	2.0	0.1	2.0	5.7	4.1	340.0	41.0	328.	8.2
BASEMENT	KAURA NAMODA	A-2	5.1	18.7			26.6	3.1	0.6	4.7		3.3	128.0	51.7	206.	
BASEMENT	KWATARKWASHI	WELL NO4	2.4	26.0			13.0	3.2	0.2	3.0	10.0	3.7	116.0	59.0	178.	8.3
BASEMENT	KWATARKWASHI	WELL NO5	6.1	44.0			17.0	4.0	0.2	1.7	3.0	7.6	192.0	61.0	240.	8.1
BASEMENT	MAGA		9.6	5.4			5.7	3.6	0.1	1.4		2.2	84.9	26.7	99.	
BASEMENT	MAINEHI	A-1	10.4	64.2			26.8	0.9	0.6	7.5		0.4	281.0	61.8	334.	
BASEMENT	RUWAN BORE		6.0	27.0			41.8	15.9	0.5	11.5		3.3	469.0	35.3	263.	
BASEMENT	TUNGA ARDO		23.2	28.2			44.7	1.1	0.2	10.3		3.8	569.0	33.0	334.	
BASEMENT	YAMBUKI		22.1	64.3			35.2	7.6	0.3	5.9		35.9	670.0	49.3	443.	

TABLE 4 - 8 (2) RESULTS OF WATER QUALITY ANALYSIS (ION COMPONENT)

AQUIFER	LOCATION	B.H. NO.	MG	CA	FE	MN	NA	K	F	CL	NO3	SO4	HCO3	SIO2	T.D.S	PH
GUNDUMI	DANGE	3512	0.5	4.8	4.00		3.3	1.1	0.1	1.0	0.4	21.0	3.0	13.0	46.	5.1
GUNDUMI	GIRAWSI	3704	4.9	18.0	0.65	0.03	20.0	5.8	0.3	5.5	0.1	31.0	94.0	14.0	146.	7.4
GUNDUMI	GIRAWSI	3704	4.6	18.0	3.70	0.07	20.0	8.0	0.2	5.5	0.1	32.0	100.0	12.0	150.	7.5
GUNDUMI	GIRAWSI	3704	7.3	36.0	6.40	0.24	28.0	5.7	0.8	7.0	0.3	93.0	93.0	19.0	243.	7.0
GUNDUMI	GUSAU-SOKOTO ROAD	3520	0.4	1.0			1.2	1.8	0.1	2.0		6.7	2.0	14.0	28.	5.1
GUNDUMI	GUSAU-SOKOTO ROAD	3519	3.2	5.6	32.00	1.80	3.2	2.6	0.3	1.5		48.0		13.0	79.	3.7
GUNDUMI	GUSAU-SOKOTO ROAD	3524	0.5	9.6	0.03	0.02	2.1	2.4		1.5	0.3	0.6	36.0	14.0	49.	7.8
GUNDUMI	GUSAU-SOKOTO ROAD	3526	5.8	16.0	14.00		26.0	24.0		2.5	0.1	7.7	156.0	21.0	187.	8.7
GUNDUMI	GUSAU-SOKOTO ROAD	3522	0.2	2.0	0.03		5.8	8.5		2.0	0.3	12.0	19.0	17.0	57.	7.4
GUNDUMI	GUSAU-SOKOTO ROAD	3703	0.5	3.2	14.00	0.10	7.3	10.0	0.1	1.0	0.1	5.6	38.0	13.0	60.	7.6
GUNDUMI	ISA	3514	0.6	4.2			265.0	8.0	0.6	238.0	0.5	102.0	175.0	15.0	728.	8.7
GUNDUMI	ISA	B-1	4.4	6.9			8.2	6.2	0.2	4.7			60.0	25.8	94.	
GUNDUMI	KALOYE	3708	21.0	292.0			800.0	27.0	0.8	1640.0		116.0	134.0	13.0	2980.	7.7
GUNDUMI	KAMBA	F-1	3.3	20.4			8.9	2.0	0.1	4.1		0.4	93.1	19.4	116.	
GUNDUMI	KENDE	F-2	5.1	7.9			11.4	22.2		17.0		5.4	52.1	31.8	201.	
GUNDUMI	KUKAKOGO		3.1	0.8			4.0	4.4	0.1	1.9		1.1	33.3	12.0	43.	
GUNDUMI	MUNGADI	3707	3.3	23.0	15.00	0.10	20.0	3.5	0.2	19.0	0.6	69.0	22.0	13.0	163.	6.6
GUNDUMI	RABAH	2490	2.2	12.0	0.07		25.0	8.5	0.2	2.0	0.3	29.0	83.0	15.0	137.	8.4
GUNDUMI	SABON BIRNI	3513	0.4	2.2			74.0	3.8	0.5	8.5	0.5	14.0	158.0	15.0	205.	8.7
GUNDUMI	SALNYINAN DAJI	3709	3.3	17.0	8.40	0.11	20.0	4.8	0.2	3.0		43.0	66.0	15.0	135.	6.8
GUNDUMI	TURETA	B-2	1.1	0.4			1.7	1.0	0.1	0.7		0.8	12.6	13.0	27.	
RIMA	BALLE	BH3053	51.8	137.0			98.0	22.8		11.2	1.0	588.0	238.0		1088.	7.5
RIMA	BALLE	BH3053	55.8	105.0			89.0	18.0		10.2	0.3	470.0	246.0		916.	7.5
RIMA	BIRNIN KEBBI	BH2483	22.7	35.2	0.04	0.80	11.9	10.0		5.2	7.5	70.8	167.0	18.0	258.	6.5
RIMA	BIRNIN KEBBI	BH2484	24.8	50.0			11.9	16.1		4.0		62.0	176.0	9.0	288.	6.6
RIMA	BODINGA	3508	1.6	15.0			9.5	1.6		1.5	29.0	23.0	20.0	18.0	109.	7.4
RIMA	DANGE	WELL	2.9	44.0			11.0	16.0	0.4	17.0	23.0	42.0	100.0	12.0	217.	7.5
RIMA	DANGE	F-4	3.4	4.6			2.1	1.3	0.1	2.7		3.7	26.8	18.4	55.	
RIMA	DOGWANDAJI	WELL	2.9	28.0			4.3	4.3	0.1	2.5	17.0	10.0	83.0	15.0	125.	7.9
RIMA	GIRAWSI	3705	3.0	15.0	3.70	0.07	3.6	4.2	0.4	1.5	0.5	16.0	60.0	14.0	88.	8.1
RIMA	GUSAU-SOKOTO ROAD	3517	0.5	4.0			1.7	4.7	0.2	2.2	0.1	11.0	16.0	12.0	44.	7.5
RIMA	HORO BIRNI		2.3	4.1			7.1	1.3		1.7		1.9	18.3	10.7	71.	
RIMA	KALOYE	3708	4.4	18.0			157.0	5.5	1.4	48.0	2.2	102.0	291.0	15.0	497.	7.5
RIMA	KALOYE	3708	6.0	17.0	0.38	0.01	163.0	4.8	1.2	50.0	0.2	100.0	299.0	14.0	504.	7.9
RIMA	RABAH	BH2488	12.0	50.9			14.1	11.6		16.4	3.9	87.8	115.0	19.0	280.	6.4
RIMA	SHUNI	3511	2.8	23.0	0.06		3.4	7.1	0.6	3.0	0.3	67.0	18.0	17.0	133.	7.5
RIMA	SOKOTO.ECN	3706	4.1	32.0	14.00	0.24	4.4	5.2	0.2	2.5	1.4	100.0	8.0	16.0	170.	6.0
RIMA	SOKOTO.GRA	3505	2.6	19.0	4.40	0.32	2.1	5.4	0.5			9.4	73.0	3.6	79.	7.2
RIMA	SOKOTO.GRA	2856	5.6	26.0	5.10	0.08	5.5	4.6	0.3	3.0	1.1	26.0	89.0	17.0	133.	8.0
RIMA	SOKOTO TOWN	BH 933	0.9	8.5	0.04		4.5	2.5	0.6	7.0	7.5	7.6	50.3	30.0	204.	7.0
RIMA	TALOKA(GORONYO)	WELL	675.0	571.0	0.50	26	206.0	211.0		303.0	1260.0	5670.0		79.0	9650.	3.8
RIMA	TALOKA(GORONYO)	WELL	481.0	467.0			2660.0	120.0	3.0	702.0	3540.0	4660.0	582.0	62.0	14000.	7.8
RIMA	TALOKA(GORONYO)	WELL	572.0	581.0	0.60	27	210.0	200.0		245.0	1030.0	5590.0		72.0	9170.	3.8
RIMA	UMBUTU	C-2	3.3	6.7			1.8	5.0		3.1			17.4	39.1	127.	
RIMA	WURNO	C-1	9.7	37.0			18.1	7.6	0.2	7.5		60.9	109.0	15.4	228.	

TABLE 4 - 8 (3) RESULTS OF WATER QUALITY ANALYSIS (ION COMPONENT)

AQUIFER	LOCATION	B.H. NO.	MG	CA	FE	MN	NA	K	F	CL	NO3	SO4	HCO3	SIO2	T.D.S	PH
SOKOTO	-	WELL	5.4	18.0		0.08	8.8	28.0		16.0	97.0	7.2	20.0	13.0	203.	7.2
SOKOTO	ANGWAH TUDU	SPRL	33.0	42.0	0.44		8.4	2.8	0.7	5.0	35.0	80.0	108.0	27.0	318.	8.3
SOKOTO	BODINGA	WELL	7.5	38.0	0.06		19.0	28.0	0.7	26.0	40.0	17.0	140.0	15.0	260.	7.9
SOKOTO	CHIMOLA	WELL	43.0	214.0	0.04		81.0	421.0	0.2	194.0	1210.0	123.0	82.0	10.0	2340.	8.2
SOKOTO	DANGE	WELL	5.2	78.0			19.0	34.0	0.8	45.0	84.0	36.0	169.0	19.0	400.	8.1
SOKOTO	GWADABAWA	D-2	46.7	107.0			13.4	1.2	0.7	6.1		121.0	366.0	31.1	608.	
SOKOTO	KWARE	WELL	5.4	50.0			2.9	4.3	0.2	3.0	28.0	2.5	155.0	22.0	194.	7.5
SOKOTO	MAMANSKA	D-1	7.2	16.5			8.4	4.2	0.2	14.9		14.0	12.6	25.0	210.	
SOKOTO	MUNGADI	WELL	11.0	26.0	0.01		19.0	74.0	0.3	34.0	89.0	44.0	104.0	35.0	383.	8.2
SOKOTO	SOKOTO		5.8	26.0			6.1	2.6	0.5	3.0	0.1	37.0	76.0	12.0	130.	7.0
SOKOTO	SOKOTO	WELL	4.6	59.0			3.0	2.6	0.2	3.5	21.0	4.9	180.0	24.0	212.	7.7
GWANDU	ARGUNGU	BH2485	2.0	8.0			3.4	2.0		2.0	7.7	2.5	35.0		45.	7.5
GWANDU	BACAKA	BH2674	1.3	9.2			50.0	3.0		8.0	6.6	5.0	149.0		157.	7.5
GWANDU	BALLE	BH3051	5.8	17.6	0.12		4.6	6.2		15.3	5.5	34.3	63.4	8.7	117.	7.2
GWANDU	BALLE	BH3055	6.5	6.2			5.8	2.5		4.0	0.9	4.5	59.0		61.	7.3
GWANDU	BALLE	BH3054	10.3	10.3			7.3	3.0		6.0	3.3	3.0	90.0		123.	7.2
GWANDU	BIRNIN KEBBI	BH2481	11.9	16.8			13.1	12.9		5.6	7.6	18.0	124.0	17.6	151.	6.6
GWANDU	DANZOMU	BH3502	2.4	9.3			3.7	1.7		2.0	8.9	23.1	14.6		58.	7.2
GWANDU	GWANDU	WELL	0.7	9.6			2.6			0.5	11.0	0.3	34.0	11.0	56.	7.5
GWANDU	HELENDE	E-2	5.1	12.9			8.4	7.3		14.2		1.2	32.5	23.3	182.	
GWANDU	KARFJN SARKI	BH3069	6.6	8.0			10.7	4.0		4.0	6.6	14.0	67.0		87.	7.5
GWANDU	KURDULA	WELL	7.5	14.0	0.04		30.0	26.0		16.0	111.0	16.0	52.0	25.0	272.	7.7
GWANDU	KURDULA	BH3056	8.5	11.4			32.5	4.5		6.0	6.6	21.0	124.0		153.	7.4
GWANDU	KWAKWARA	WELL	1.7	6.4	0.21		3.9	10.0		4.5	10.0	1.3	31.0	18.0	71.	7.4
GWANDU	RAFIN KUBU	BH2499	4.8	6.2			7.1	3.0		2.0	2.7	21.0	35.0		64.	7.5
GWANDU	RALLE	WELL	1.2	5.6			5.5			2.5	29.0	0.5	9.0	13.0	64.	6.9
GWANDU	RUAWRI	BH3070	1.1	8.0			10.0	1.5		2.0	7.1	24.0	19.5		64.	7.3
GWANDU	SAFLA	BH3501	0.1	4.1			2.4	0.9			7.1	7.4	7.3		25.	7.3
GWANDU	SORO		3.1	2.1			1.6	1.0	0.1	1.2		6.0	37.5	12.0	40.	
GWANDU	TANGAZA	E-1	1.9	0.5			1.2	0.7	0.3	1.4		0.8	15.8	3.7	23.	
GWANDU	TANGAZA	F-3	3.7	4.2			2.0	1.9		2.7			23.7	28.2	71.	
GWANDU	TANGAZA	BH3059	0.4	3.1			2.0	0.2		2.0	8.8	4.1	3.0		22.	7.5
GWANDU	YELDU	3063	10.0		0.86	0.03	21.0	6.2	0.8	4.5		28.0		14.0	154.	7.3
GWANDU	YELDU	BH3063	5.8	12.3			22.3	4.0		4.0	9.9	4.3	117.0		120.	7.4
GWANDU	YELDU	WELL	0.6	2.2	0.01		2.3	2.7		0.5	5.3	0.2	13.0	13.0	33.	7.3

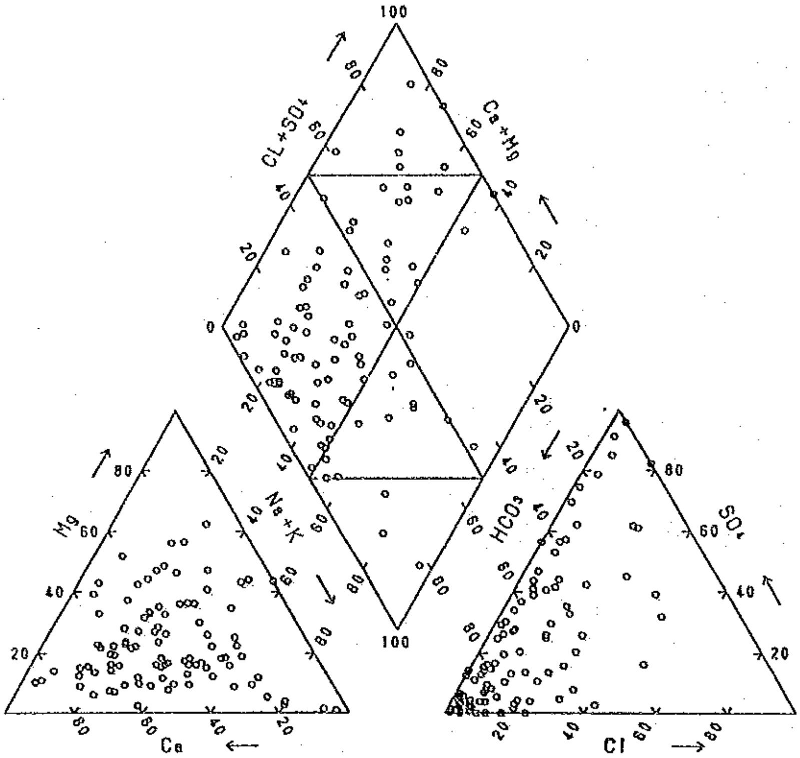


Fig. 4-11 (1) Trilinear Diagram
- Total area -

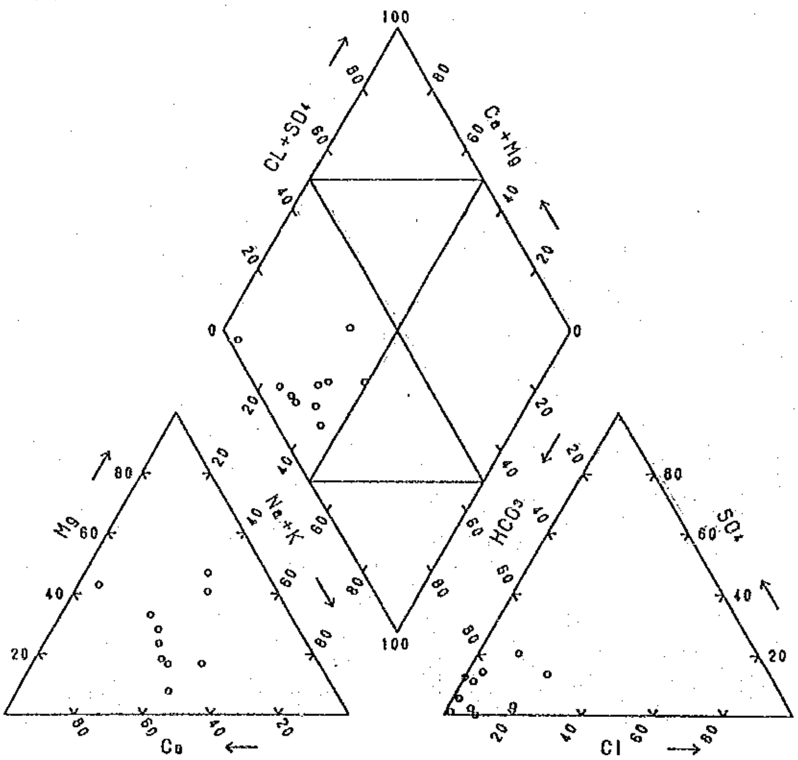


Fig. 4-11 (2) Trilinear Diagram
- Stream water -

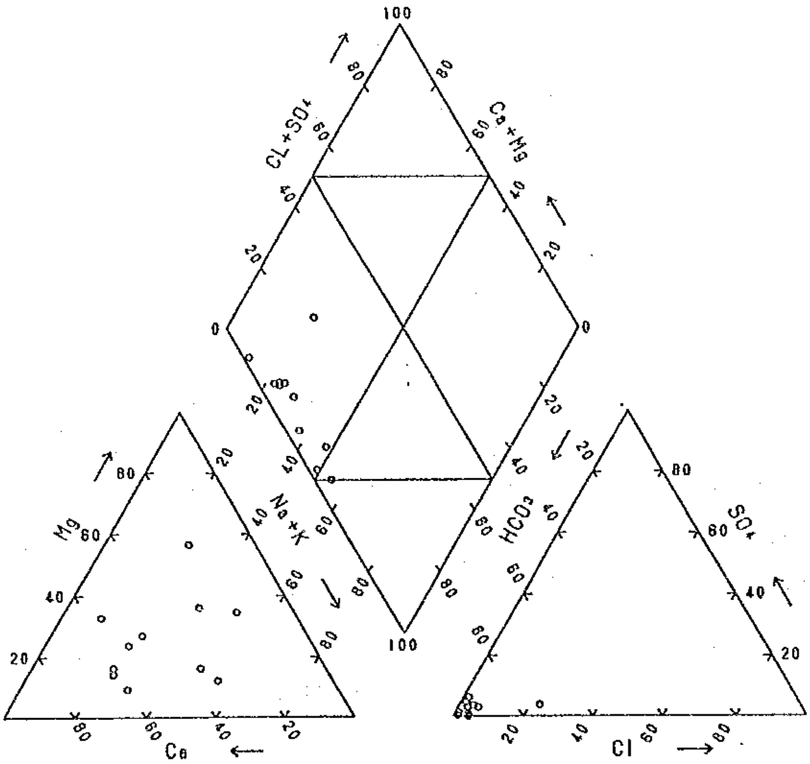


Fig. 4-11 (3) Trilinear Diagram
- Basement Complex area -

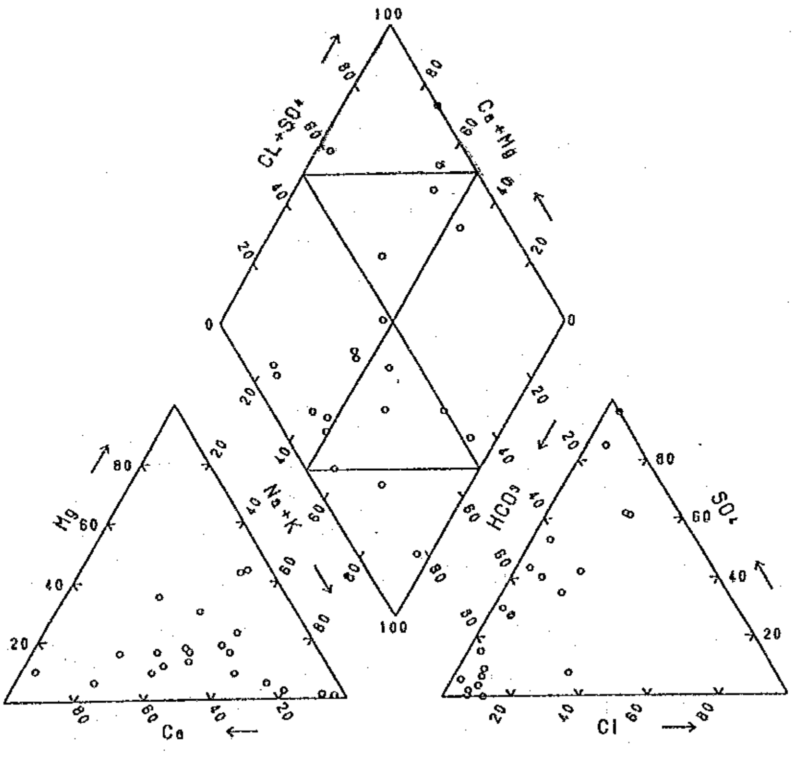


Fig. 4-11 (4) Trilinear Diagram
- Gundumi Formation -

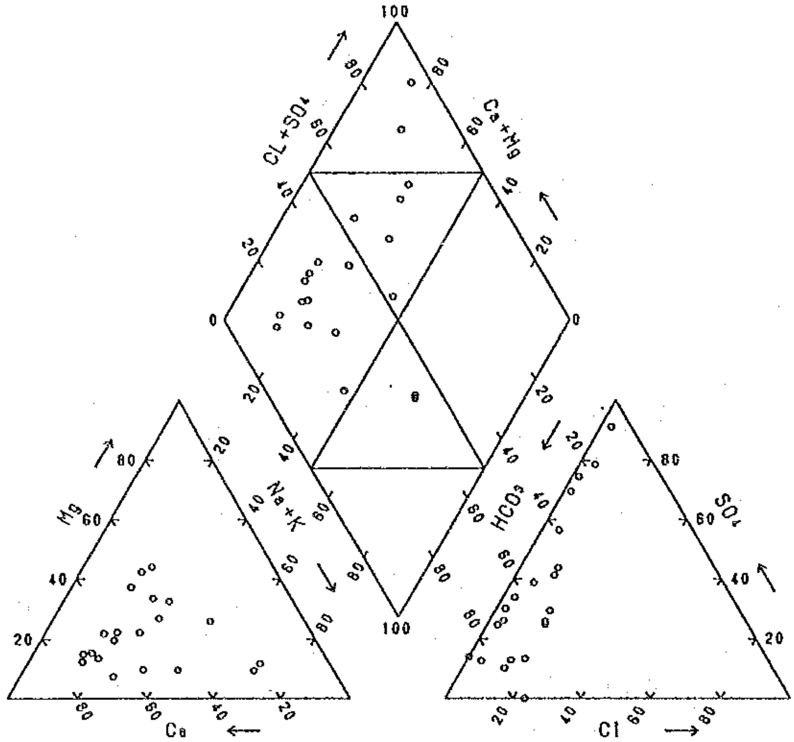


Fig. 4-11 (5) Trilinear Diagram
- Rima Group -

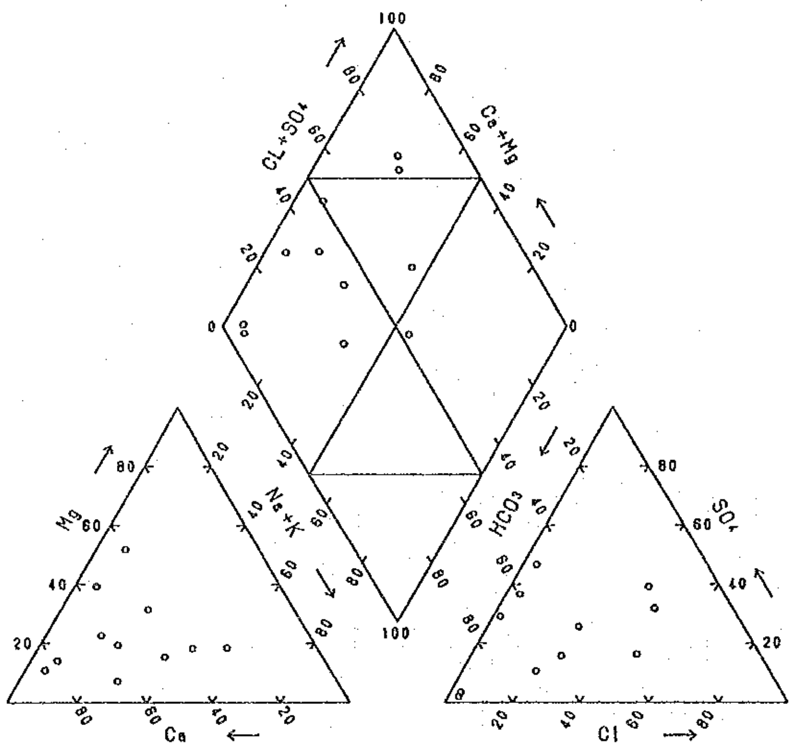


Fig. 4-11 (6) Trilinear Diagram
- Kalambaina Formation -

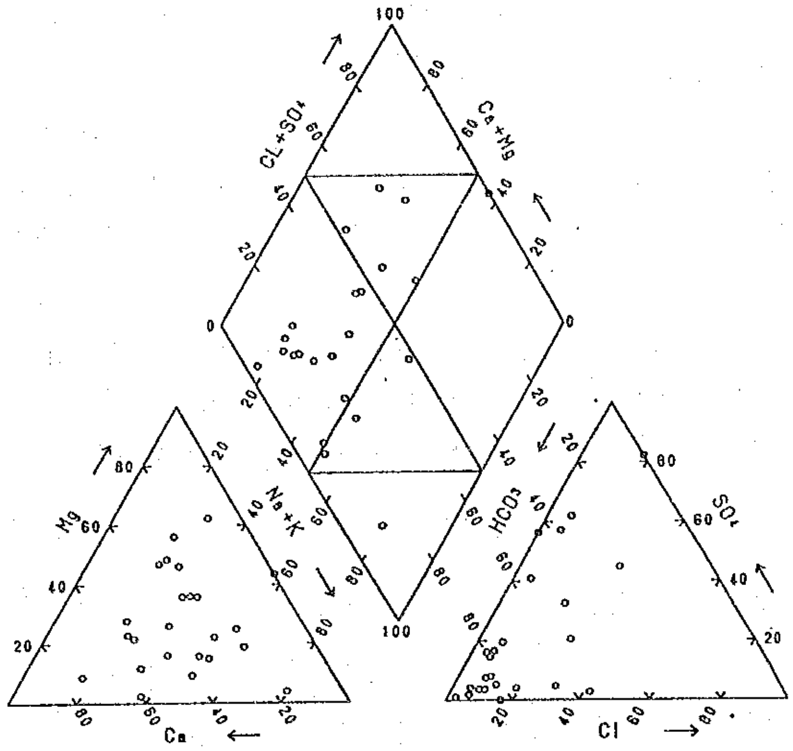


Fig. 4-11 (7) Trilinear Diagram
- Gwandu Formation -

Table 4-9 Tritium concentration

Place	Aquifer	Tr
Maga	Basement Complex	20.5
Ruwan-Bore	Basement Complex	6.8
Dauran	Basement Complex	10.5
Yambuki	Basement Complex	17.4
Tunga-Ardo	Basement Complex	4.6
Kuka-Kogo	Illo Formation	3.3
Horo-Birnni	Taloka Formation	3.5
Soro	Gwandu Formation	2.5

sampled from dug-wells, which are easily polluted. The dissolved contents range from a low of 130 mg/ℓ at one dug-well in Sokoto City to a high of 2340 mg/ℓ at one dug-well in Chimola.

The ion component of the Gwandu aquifer is similar to that of the Rima aquifer. The calcium-bicarbonate type is the most dominant type. The dissolved contents are very low ranging from a low of 22 mg/ℓ at Tangaza BH3059 to a high of 272 mg/ℓ at Kurdula dug-well.

The above discussion of ion components is regardless of the depth, place, or date at which water samples were taken. In order to determine the details of the path and cycle of groundwater flow, these factors must be investigated.

4-5 Tritium Concentration

Determining tritium (T) concentration is a useful technique to estimate the resident time of the water underground.

Tritium is a radioactive isotope of hydrogen, having a half life of 12.3 years. The occurrence of tritium in water of the hydrological cycle arises from both natural and man-made sources. Tritium is produced naturally in the earth's atmosphere by the interaction of cosmic-ray-produced neutrons with nitrogen. Until 1952, the average natural tritium content of precipitation world-wide was in the range of about Tr 5-20. With the beginning of large scale atmospheric testing of thermonuclear bombs in 1952, the tritium contents of precipitations rose greatly. In 1962-1963, they reached a maximum of about Tr 8000 in some localities, over a thousand times greater than that prior to contamination. With the restrictions of atmospheric testing, tritium contents have been declining, but they still remain in larger concentrations than naturally produced. Tritium is widely used for dating in the following contexts:

(1) Very low T concentrations, around the level of detectability, show that the water principally stems from the pre-bomb period. Relatively high T concentrations, (greater than Tr 10) indicate that the water originates partly or wholly from post-bomb precipitation.

(2) For more precise tritium dating the changing activities of rainfall have to be taken into account. Assuming that piston flow occurs, the dating of water can be achieved by applying the following equation of decay.

$$\ln(A) = \ln(B) - t/th * \ln(2) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4\text{-}1)$$

where:

A : Tritium concentration of the sample
B : Tritium concentration in precipitation (t years ago)
t : Age of the water
th : Half-life of tritium (12.262 years)

Assuming that tritium concentration in precipitation in 1952 ranged from Tr 5 to 20, and water movement in an aquifer follows the piston flow, the general tritium concentrations of water entering groundwater in 1952 and sampled in 1989 are presumed to range between Tr 0.6 and 2.5.

Tritium concentration of waters in eight boreholes in the study area are shown in Table 4-9. The tritium concentrations of water in the basement complex area are high, ranging from a low of 4.6 at Tunga-Ardo to a high of 20.5 at Maga. The high tritium concentration indicates the waters or a large fraction of the waters entered the groundwater zone sometime after 1952. These results agree with the results of chemical quality analyses of water that the ion component of groundwater in the basement complex area and the stream water resemble each other, implying that the resident time of water underground has been short. Tritium concentrations of waters in the sedimentary area (tested in the Illo formation, Taloka formation and Gwandu formation) are lower than those in the basement complex area. However, they are relatively high compared with the above presumption, regarding general tritium concentrations, implying a mixture of pre-bomb waters and post-bomb waters. Despite geological age, water taken from the Gwandu aquifer had the smallest concentration (Tr 2.5), whereas water from older age aquifers -- the Illo and Taloka formations --, had larger concentrations (Tr 3.3 and 3.5, respectively). An explanation might be that since the boreholes at Kuka-Kogo and at Horo-Birni are drilled in the outcrop area of the Illo formation and close to the outcrop area of the Taloka formation, respectively, the waters in the boreholes likely receive recharge from precipitation directly. On the contrary, the borehole at Soro is drilled down to the deeper confined aquifer of the Gwandu formation, which is separated from the upper unconfined aquifer by clayey beds, which means