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FEDERAL DEPARTMENT OF WATER RESOURCES
MINISTRY OF AGRICULTURE, WATER RESOURCES
AND RURAL DEVELOPMENT
FEDERAL REPUBLIC OF NIGERIA

THE STUDY FOR GROUNDWATER DEVELOPMENT IN SOKOTO STATE

VOLUME 1
SUMMARY REPORT

JULY, 1990

JAPAN INTERNATIONAL COOPERATION AGENCY

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PREFACE

In response to a request from the Government of the Federal Republic of Nigeria, the Japanese Government decided to conduct a study on groundwater development in Sokoto State and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to Nigeria a survey team headed by Dr. Akira KAMATA, Kokusai Kogyo Co., Ltd., composed of members from the above company and the Sanyu Consultants Inc. from April to July, 1988; October, 1988 to March, 1989; May to July and September to December, 1989; February, 1990.

The team held discussions with concerned officials of the Government of Nigeria, and conducted field surveys. After the team returned to Japan, further studies were made and the present report was prepared.

I hope that this report will contribute to the promotion of the project and to the enhancement of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of the Federal Republic of Nigeria for their close cooperation extended to the team.

July, 1990

Kensuke Yanagiya

Kensuke Yanagiya
President
Japan International Cooperation Agency

July, 1990

Mr. Kensuke YANAGIYA
President
Japan International Cooperation Agency

Dear Sir :

LETTER OF TRANSMITTAL

It is our pleasure to submit you the Final Report of the Study for Groundwater Development in Sokoto State, Federal Republic of Nigeria.

The field survey and study have been conducted during the period from March, 1988 to February, 1990.

This Report consists of five volumes: VOLUME ONE - Summary Report which describes the summary of the study and recommendation; VOLUME TWO - Main Report, which describes the results of the study and analysis; VOLUME THREE and FOUR - Supplementary Reports which contain hydrogeological maps and a manual of the Database; VOLUME FIVE - Data Report, which contains the results of geophysical prospecting, drilling and pumping test.

We hope that realization of the proposed groundwater development scheme would greatly contribute to the water supply conditions in Sokoto State, Nigeria.

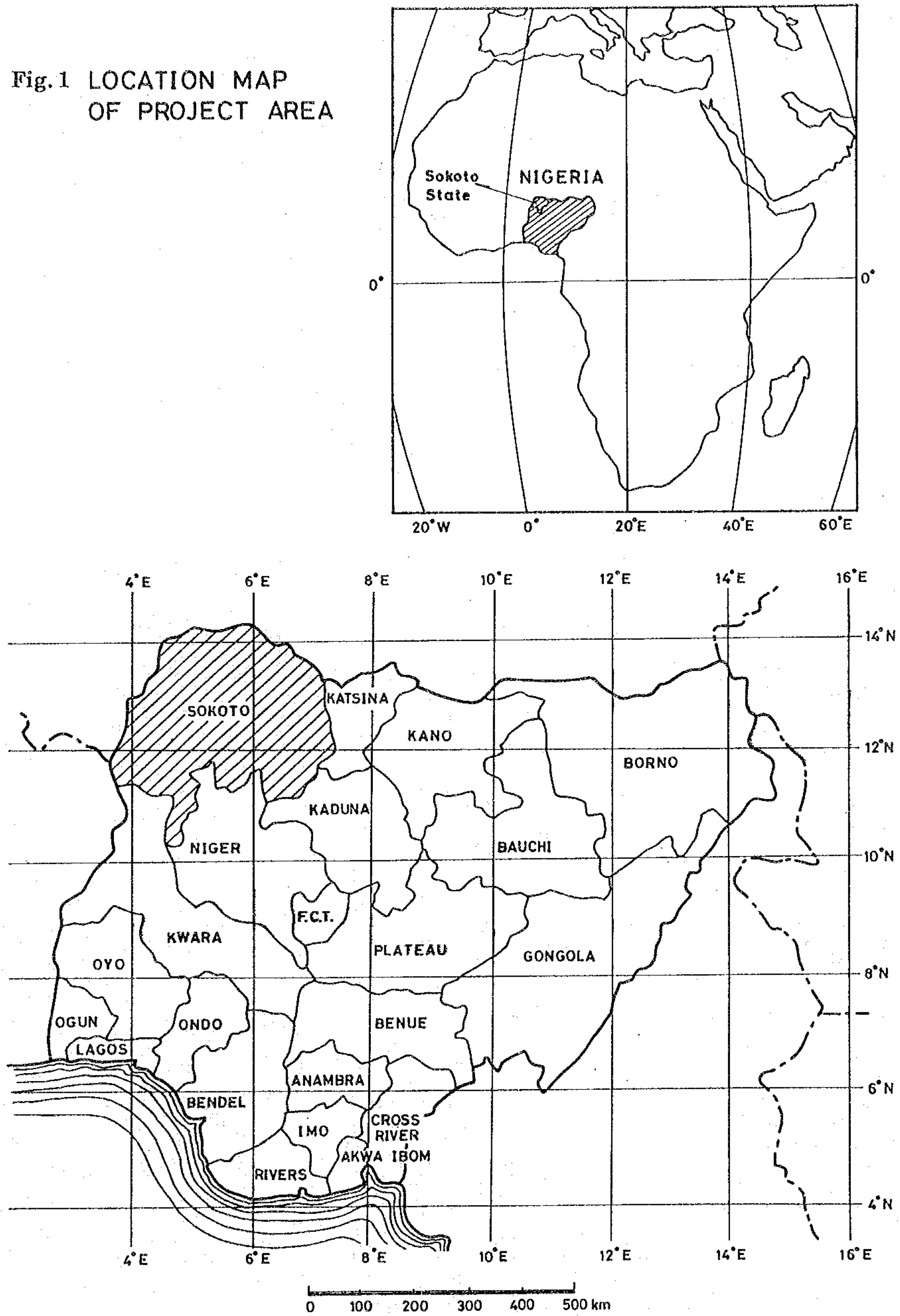
Finally, we take this opportunity to express our sincere gratitude to Japan International Cooperation Agency, the Embassy of Japan in Lagos and the officials concerned of the Government of Federal Republic of Nigeria which gave useful advice to the Study Team during the study period.

Respectfully yours,

鎌田 烈

Akira KAMATA
Team Leader for the
Study for Groundwater Development
in Sokoto State

Fig. 1 LOCATION MAP OF PROJECT AREA



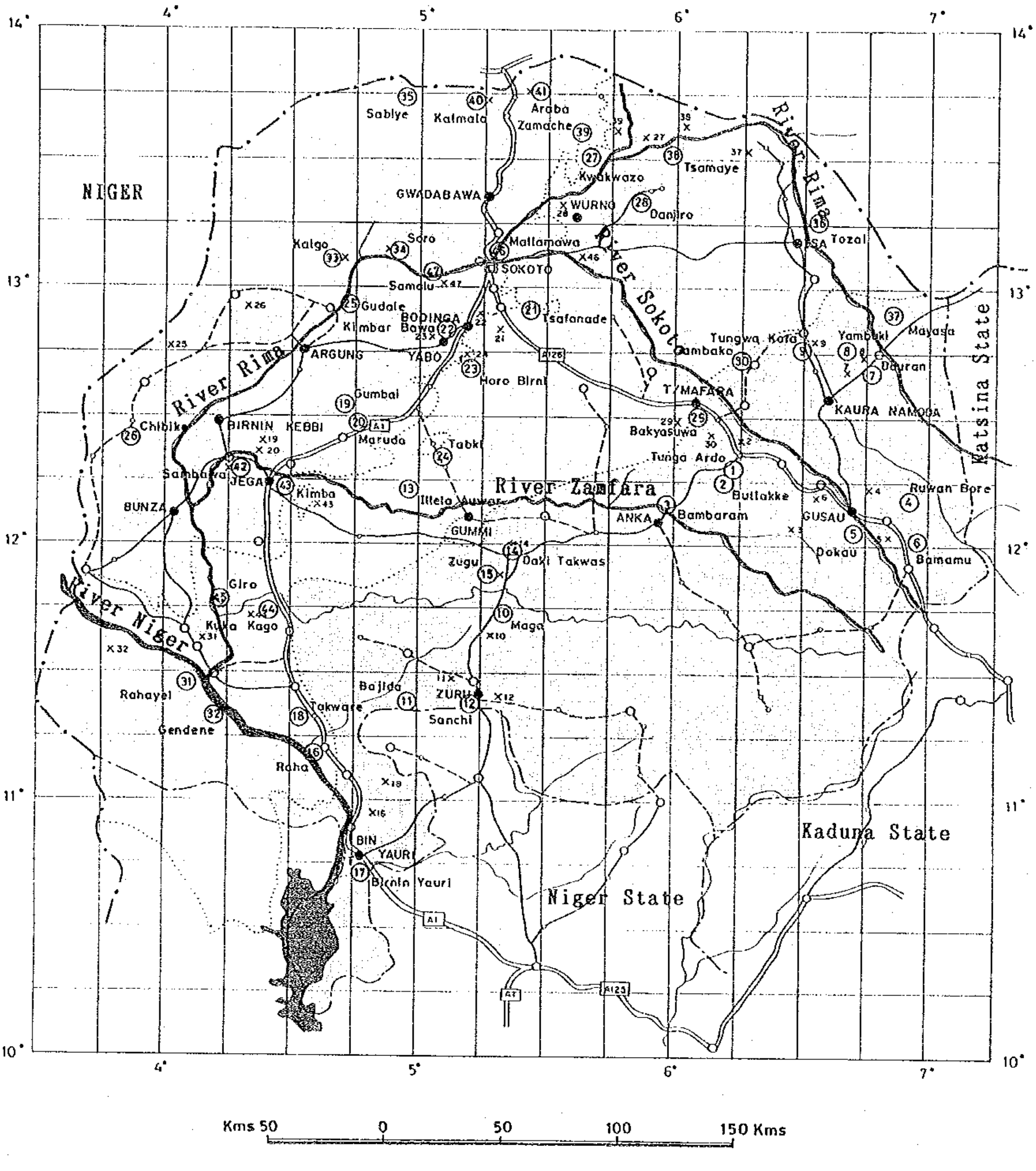


Fig.2 Location Map of the Candidate Villages

	Sedimentary rock area
	Basement rock area

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ABBREVIATION

Organization

AfDB	:	African Development Bank
DFRRI	:	Directorate for Food, Road Rural Infrastructure
FDCA	:	Federal Department of Civil Aviation
FDWR	:	Federal Department of Water Resources
IBRD	:	International Bank for Reconstruction and Development
JICA	:	Japan International Cooperation Agency
KSWB	:	Katsina State Water Board
LGA	:	Local Government Authority
MOE	:	Ministry of Education
MOW	:	Ministry of Works
MRD	:	Ministry of Rural Development and Cooperation
NMS	:	Nigerian Meteorological Service
NWRI	:	National Water Resources Institute
SARDA	:	Sokoto Agriculture and Rural Development Authority
SMA	:	State Ministry of Agriculture
SRRBDA	:	Sokoto Rima River Basin Development Authority
SSWB	:	Sokoto State Water Board
USGS	:	United States Geological Survey
WHO	:	World Health Organization

Unit

Mm^3	:	$\times 10^6 m^3$
PPM	:	Parts Per Million

Method

ELFMT	:	Extremely Low Frequency Magnetotelluric Method
ERS	:	Electrical Resistivity Sounding
MT	:	Magnetotelluric Method
PLMT	:	Power Line Magnetotelluric Method
TEM	:	Transient Electromagnetic Survey
VES	:	Vertical Electric Sounding

1. Introduction

1.1 Background

Nigeria, one of the western African countries facing Guinea Bay, is situated in longitude from 3 to 15E and in latitude from 4 to 14 N.It stretches 1,300km from west to east and 1,100 km from north to south. The area is about 920 thousand square kilometers, which is 2.5 times bigger than Japan and occupies about 1 / 7 of the total area of Africa. Nigeria's present population is about 100million, the about 1 /5 of Africa's total population.

Nigeria is the biggest oil producing country in Africa, but its national economy has faced many difficulties since the end of the 1970's, due to stagnancy in the price of oil.

In order to improve the standard of living and reconstruct the national financial situation based on a self-supporting economy, the Government of Nigeria is planning many kinds of development schemes.It's main emphasis is on the establishment of a self-supporting system of food provision through measures which promote agriculture.

Sokoto State, the investigated area, is located in the north-western part of Nigeria. It stretches from 10 to 14N in latitude and from 4 to 7 E in longitude, and covers 100 thousand square kilometers. It has a total population of 8.2 million (1987).
In the northern states of Nigeria, lying in the savanna, there is scanty, traditional self-sufficency farming. Thus, this area far lags behind, as a result of stagnancy in the national economy and population growth.

A basic condition necessary for economical development in this region is to secure a stable water source as a basic human need. However, in the rural area of Sokoto State, there is an inadequate supply of drinking water, in terms of quantity and quality, due to natural constraints, such as the climate, topography and geology. In addition, shortages of technology, funds and human resources in water development are worsening this problem . Inadequate water supply causes the spread of water borne diseases and depresses productivity. In short, it is one of the main obstructions to regional development.

In response to the above circumstances the State Governments have made water supply plans in small scale villages with populations of 500-1,000 which provide for boreholes with hand pumps. These plans have been financed by foreign funds such as IBRD and AfDB. On the other hand, the Federal Government planned the "National Borehole Program", in order to supply water to middle to large scale villages with populations of several thousands to several tens of thousands. The program was started in 1981, but was discontinued three years later due to a lack of funds.

Taking this into consideration, the Government of Nigeria has made a request to the Government of Japan for technical cooperation in the groundwater development study concerning the water supply program in the northern states of Nigeria, in particular, Sokoto and Niger State.

In response to the official request, the Government of Japan decided to carry out a study and dispatched a preliminary study team to Nigeria from October to Novermber, 1987 and February, 1988. The preliminary study team had a series of discussions with the Ministry of Planning, the Federal Ministry of Agriculture, Water Resources and Rural Development, and other agencies concerned with the contents and nature of the request.

Based on the preliminary study, the Government of Japan decided to implement the study for groundwater development in Sokoto State where the water requirement is more urgent.

1.2 Objectives and Area of the Study

The objectives of the study are:

1) to evaluate the groundwater resource potential in the Sokoto State
2) to prepare a groundwater development plan in the selected area
3) to transfer technology to the Nigerian counterpart throughout the Study

The study area covered is alomost the whole area of Sokoto State (100,000km^2), where forty seven (47) villages preferentially proposed as the candidates for water supply are scattered. The number of villages to be surveyed in detail were narrowed down from 47 to 21, based on the preliminary site survey, in view of the groundwater potential, accessibility and urgent demand for water supply.

The geological characteristics of Sokoto State are diveded largely into two: a sedimentary rock area consisting of Cretaceous-Tertiary formations and a basement rock area consisting of pre-Cretaceous granite and metasediment. Twenty eight (28) of the candidate villages are located in the basement rock area and nineteen (19) in the sedimentary rock area.

The basement rock area, composed of hard impermeable rock, is termed a "difficult area "for groudwater development.The inhabitants of the village are utilizing dug wall, pond and river bed water as their water source in the dry season because of rapid runoff and drying up of surface water.

Due to inadequate water supply in quantity and quality, there are cases of water born diseases in every village.

One of the objectives of this study in particular is to establish an effective method for groundwater exploration for so-called "difficult area".

1.3 Organization of the Study

The Federal Republic of Water Resources (FDWR), the Ministry of Agriculture, Water Resources and Rural Development of the Federal Republic of Nigeria acted as the counterpart agency and the Japan International Cooperation Agency (JICA), the official agency responsible for the implementation of technical cooperation programs of the Government of Japan, undertook the study.

The period of the study was 24 months, from March, 1988 to February, 1990.

The Study was carried out by the joint study team composed of the JICA team and the three Nigerian organizations as follows.

(1) JICA team

Team Leader	Akira KAMATA	Hydrogeologist
Co-team leader	Atsuo KANDA	Hydrogeologist
	Motoo FUJITA	Geologist
	Toichiro MAEKAWA	Hydrologist
	Eiji TANAKA	Geophysicist
	Kunio FUJIWARA	Geophysicist / Geologist
	Kohmei OZAKI	Geophysicist
	Toyoharu NAKAMURA	Drilling Supervisor
	Ko KAWAMURA	Water Supply Planner (Stage I)
	Akira NAOTSUKA	Water Supply Planner (Stage II)
	Shigeru KIMURA	Economist

(2) Nigerian Team

General Control	J.A.HANIDU	Acting Director, FDWR
	J.A.SHAMONDA	Chief, FDWR Sokoto
	R.C.OTY	Hydrogeologist, FDWR
	S.A.AYUBA	Hydrogeologist, FDWR
	O.M.OLATINWO	Hydrogeologist, FDWR
	P.OBURO	Geophysicist, FDWR
	J.OCHIGBO	Hydrogeologist, FDWR
	B.C.OWUNNA	Hydrogeologist, SRRBDA
	P.M.BUBA	Hydrologist, SRRBDA
	U.U.IBRAHIM	Hydrogeologist, SSWB
	M.SANI	Hydrogeologist, SSWB
	A.EZEH	Hydrogeologist, SSWB
	M.JUNAIDU	Hydrogeologist, SSWB
	M.KENDE	Hydrologist,FDWR
	O.EMOIKHARE	Hydrologist,FDWR

1.4 Outline of the Study

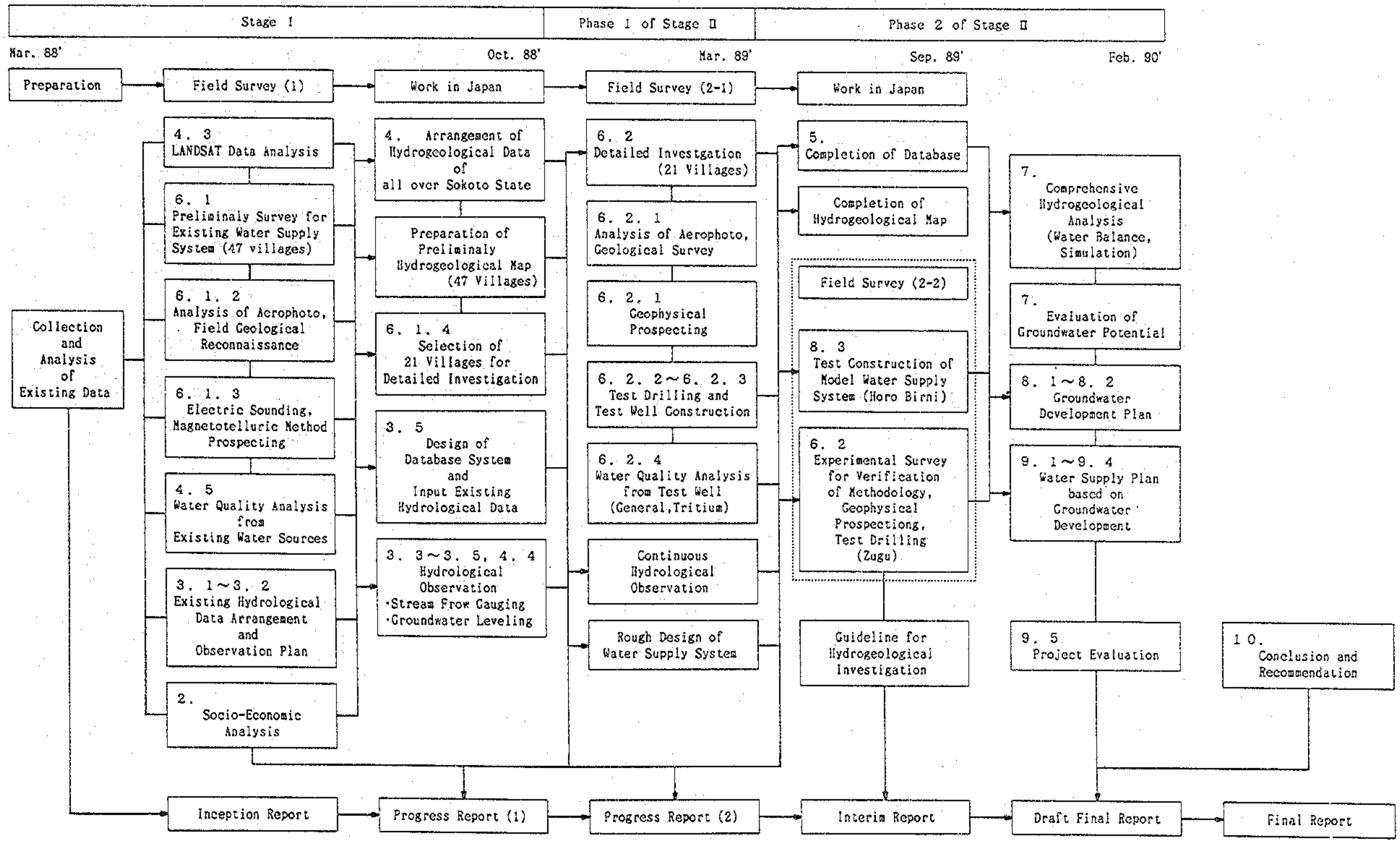
This study has been carried out in two two-year stages lasting from March 1988-February 1990. In Stage Ⅰ, LANDSAT image analysis, hydrogeological data collection and analysis, and hydrological data collection and observation were carried out for the entire Sokoto State, as well as a preliminary hydrogeological study for the 47 candidate villages. Finally, the candidate villages were narrowed down to 21.

In Phase 1 of Stage Ⅱ, hydrological observation was continued and a data base for Sokoto State was created. Detailed geological survey and geophysical prospecting were carrried out for the 21 candidate villages, and in 8 of these villages, test well drilling and pumping tests were carried out.

In Phase 2 of Stage Ⅱ, additional experiment surveying in the basement rock area was carried out and data was obtained for the establishment of a method for groundwater development in the basement rock area. The construction of a model water supply system was also carried out and data necessary for the preparation of a water supply plan was obtained. In addition, the data base was completed and a comprehensive analysis of all of the results on groundwater survey carried out in Stages Ⅰ and Ⅱ was performed, as well as an evaluation of the potential for groundwater development in all of Sokoto State and the establishement of a groundwater development plan.

The flow chart on the study is shown in Figure 3.

Fig.3 Flow Chart for the Study for Groundwater Development in Sokoto State



* Figure in " ▭ " shows the chapter and section in this report.

1.5 Constitution of Report

This report consists of five volumes : -Summary Report, Main Report, Supplementary Report Ⅰ, Supplementary Report Ⅱ and Data Report.

The summary report includes the summary of the study, conclusion and recommendations. The main report describes the results of the study and analysis of the hydrology and hydrogeology in Sokoto State; detailed survey of candidate villages ; evaluation of the groundwater potential and development plan. A water supply program for the middle to large scaled villages is proposed , and conclusion and recommendations are summarized in the final chapter.

The supplementary report Ⅰ contains hydrogeological maps of the 47 villages and report Ⅱ includes database manual and explains the groundwater simulation. The data report contains the results of geophysical prospecting, drilling and pumping tests.

2. Socio-Economic Conditions

The economic development of Nigeria was hindered by the second oil shock. As a consequence, the country focused on raising the level of economy through a 4th 5-year economic development plan (1981-1985), with the following as objectives.

1) Expansion of the annual GNP by 7.2% and raising of the income per person from 568 Naira (1980) to 931 Naira

2) Adjustment of the income gap

3) Increase of employment and proper distribution of the labor force in each sector

4) Diversification of the economy and balancing of development

5) Reinforcement of an independent economy

6) Promotion of the economic activity of Nigeria

7) Increase of production

8) Raising of the consciousness of the people

However, due to the decrease in the value of oil beginning at the onset of the 1980's, the economy was declared in a state of emergency in January 1985, the above 4th 5-year plan was halted and the 5th of these plans which was to follow was greatly postponed.

Then, in 1986, the Government of Nigeria began a "Structural Adjustment Program" (SAP), for the rebuilding of the economy. The main aims of this policy were the diversification of production for this oil-dependent economy and the financial stabilizaion of the balance of payment. The results of this program for the manufacturing sector were a revitalization of production activities due to inflow of foreign currency, and in the agricultural sector, an increase in the production of cash crops. As a consequence, in 1987, the economic growth rate recovered.

However, this program brought along a major decline in the Naira, and thus an increase in the value of imported goods. In addition, with the domestic supply capacity being at a low standard, there resulted a gross increase in consumer prices. Resulting was unemployment continuing at a high level, agricultural production remaining in an insecure state, with the exception of cash-crops, and an overall worsening of the situation.

The government, in order to improve this state of affairs, implemented a comprehensive economic restoration plan in July 1988, and from 1989, put into operation the long-postponed 5th 5-year plan. This plan emphasized the expansion of agricultural products, through the establishment of a self-supporting system. However,basic living conditions of inhabitants were not consolidated, making it difficult to secure water for everyday use.

Therefore, the inhabitants consumed a lot of time collecting water and at the same time, were liable to water borne diseases due to insanitary drinking water. This hindered development in rural areas where farming is carried out by labor intensivbe agriculture.

Accordingly, the implementation of a water supply program is urgently required in order to provide the inhabitants of the rural area with stable and sanitary water. (Table 1).

Table 1 (1) Health Indicators

(Person)

Diseases (Cases Reported)	1980	1981	1982	1983	1984	※
Malaria	1,171,071	1,471,561	1,147,518	1,273,090	1,242,882	1.5%
Dysentery	234,071	293,747	272,079	251,241	222,879	-1.2%
Measles	142,106	129,671	139,785	136,778	188,591	7.3%
Pneumonia	88,595	114,692	96,364	99,070	101,455	3.4%
Gonorrhoea	65,914	68,087	56,731	53,732	55,139	-4.4%
Whooping Cough	48,696	56,913	77,830	70,024	62,751	6.5%
Chickenpox	19,161	26,384	34,573	41,203	65,932	36.2%
Filariasis	22,561	27,521	14,640	14,970	12,746	-13.3%
Schistosominsis	24,550	41,662	40,028	41,889	36,710	10.6%
Tuberculosis	9,694	10,838	10,949	10,212	10,677	2.4%

Source : Federal Ministry of Health

※ The average rate of increase from 1980 through 1984

Table 1 (2) Water Realted Health Problems of the 47 Candidate Villages

Area / Disease	Basement Rock Area	Sedimentary Rock Area
Dysentery, Enteritis, other disease	Many villages	Many villages (Kukakogo is in a miserable condition)
Guinea Worm	Tunga Ardo, Dokau, Bamamu, Yambuki (4 villages) (Yambuki is in a miserable condition)	Kalmalo (1 village) (where many people take water from Kalmalo Lake)

3. Hydrology of the Sokoto-Rima River Basin

3.1 Feature of the Basin and Exisiting Gauging Stations

The Rima river, the Sokto river and the Zamfara river flow into the Sokoto-Rima river basin. These rivers are tributaries of the Niger river, which flows into Nigeria from Republic of Niger, through the south-western part of Sokoto State and flows out to Niger State. The flowing distance within Sokoto State is about 150 km.

The Rima River originates from the basement rock area in the north-eastern part of Sokoto State. This river flows north to north-west up to Sabon-Birni and sourth-west up to Wamako, where it meets the Sokoto River,which flows nort-west through the basement rock area. The Rima River then flows south, joining the Zamfara River at Bunza and meeting the Niger River at the southern boundary of the state.

The catchment area of the Rima River is about 57,000 km^2 at Wamako and its annual volume of run off is about 1.7 billion m^3. On the other hand, the catchment area of the Sokoto River is about 12,000km^2 and its annual volume of run off is about 0.73 billion m^3 at Gidandoka (both of these data were recorded from 1965 to 1966). Discharge rate measured during the study period shows 284m^3/sec in maximum (September,1988) and 0.95 m^3/sec in minimum (October, 1989) at Jega on the Zamfara River.

The meteorological observation stations in the Sokoto-Rima river basin were established by the Federal Department of Civil Aviation (FDCA), the State Ministry of Agriculture (SMA) and the Sokoto-Rima River Basin Development Authority (SRRBDA), etc., and were found at 50 locations during the study period.

There are 50 hydrological stations located throughout the area, however only 18 among these are for discharge measurement with the rest for water level measurement. These facilities are poor, and half of these require serious repair (Figure 4).

3.2 Discharge Observation

In order to observe the water balance of the Rima River, 4 sites were chosen at Kainua (Kainua Lake), Argung (Rima River), Bunza (Rima River) and

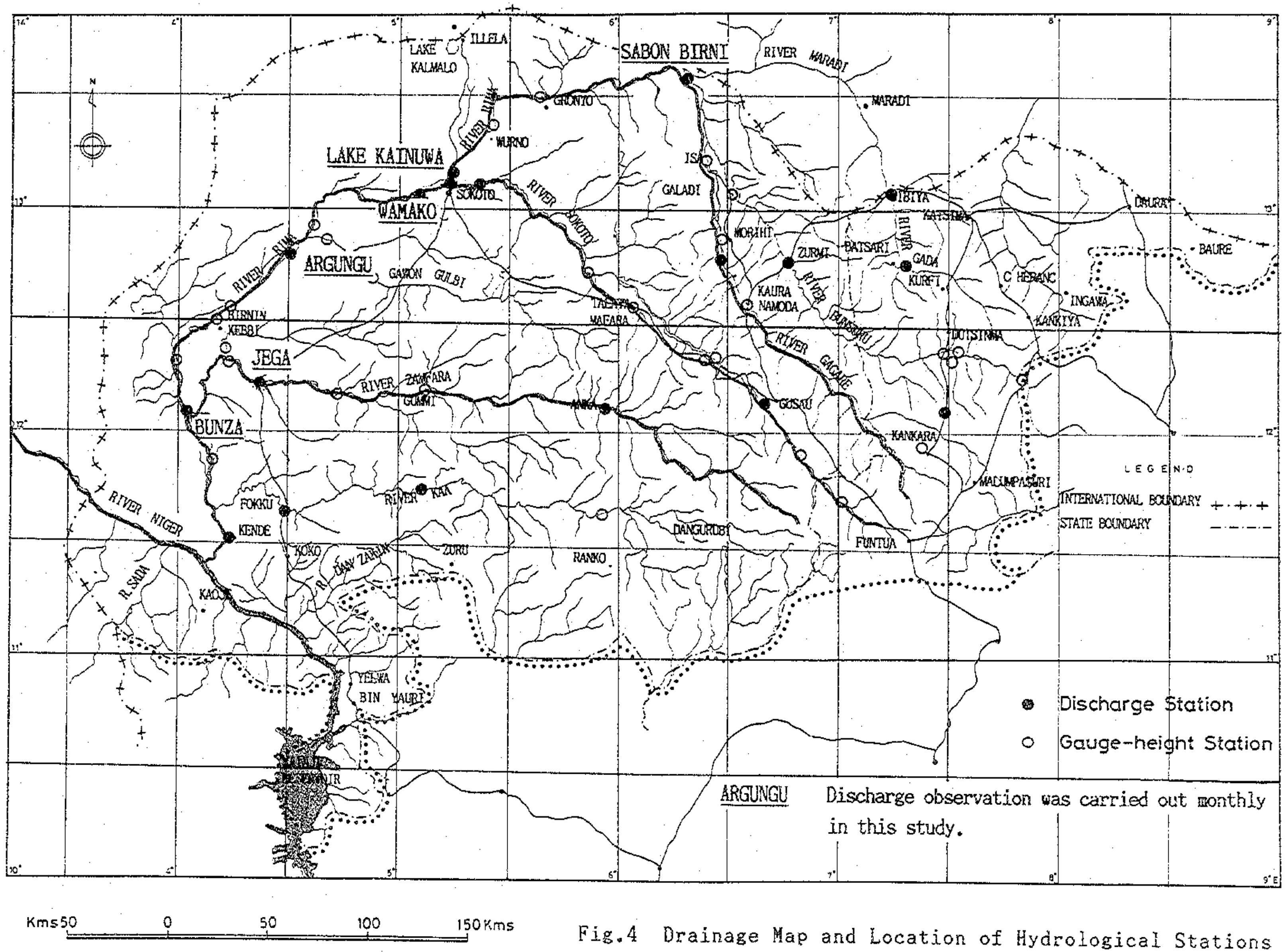


Fig.4 Drainage Map and Location of Hydrological Stations

(Zamfara River). Based on the once a month discharge observations, rating curves were prepared.

3.3 Groundwater Level Observation

In order to understand the fluctuations in groundwater flow and level, 4 times during the study, simultaneous observation of the groundwater level at 62 existing boreholes in the sedimentary rock area was carried out. In addition, at 2 existing shallow wells and at 4 boreholes, periodic weekly observation was carried out and water level recorders were installed at 2 test wells and 2 existing boreholes during 16 months of the study period.

3.4 Hydrological Climate

The climate of Sokoto State is divided into two : a rainy season from May to September and a dry season from Octover to April of the follwing year. The mean monthly rainfall is rich in August, showing 240mm at Gusau. There is no rainfall from November to February every year and a very small amount of rainfall is recorded in October, March and April.

The average annual rainfall in Sokoto City is 632 mm, which showed a decreasing tendency from the end of the 1970s through the 1980s, with the records reading the lowest at 325 mm in 1987. The average monthly rainfall is the highest in August, with 240 mm at Gusau. Every year from November to February of the following year, there is absolutely no rainfall, with the surrounding periods of October and March-April showing low rainfall.

Judging from the distribution of the rainfall north of Sokoto State, going towards the Nigerian border, there is a decrease to below 600 mm/year. However, going towards the southern portion of the state, the rainfall gradually increases exceeding 900 mm south of the line connecting Talata-Mafara and Bunza.

The daily maximum and minimum temperature average yearly values are 34.8°C and 21.2°C, respectively. The daily maximum temperature by monthly average value is the highest in April at 40.1°C. In addition, the daily minimum temperature by monthly average is lowest in August at 30.5°C. There is no great difference in the area distribution for temperature, however the hottest area of Sokoto State surrounds the city of Sokoto.

The annual potential evapotranspiration amount for Katsina, Gusau, Sokoto and Yelwa, by the Thornswait method, is 1526 mm 1553 mm, 1739 mm respectively. They are not acutal evapotranspiration amounts, however they clarify the fact that the most of the water supplied by rainfall is lost to evapotranspiration (Figure 5).

3.5 Stream Hydrology

The rivers in the Sokoto-Rima river basin are intermittent rivers in the basement rock area. In addition, they become perennial rivers in the middle and lower reaches of the Sokoto and Rima rivers in the sedimentary rock area.

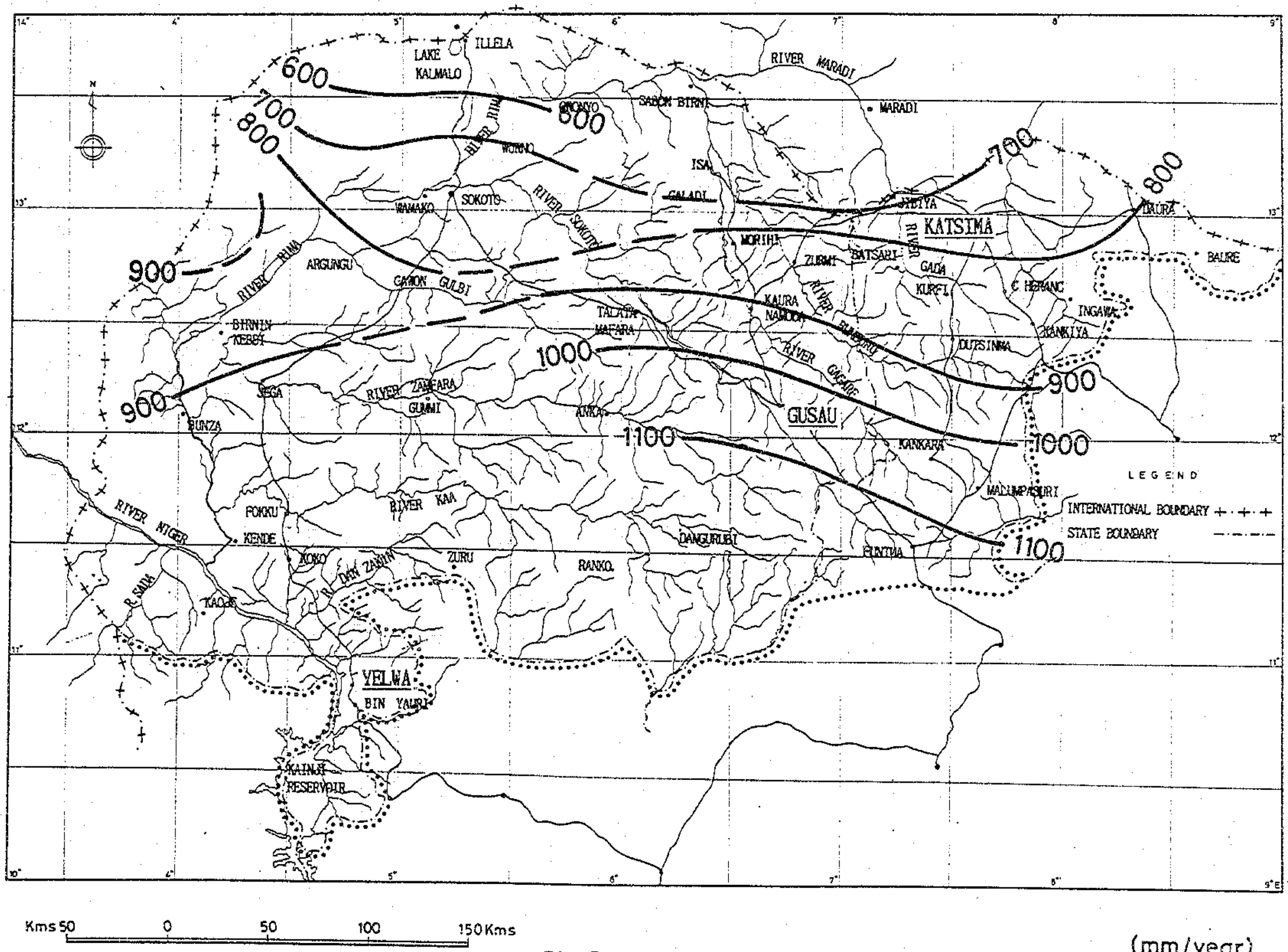
Judging from the flow amount at Gidan Doka in the lower stream of the Sokoto River and at Wamako in the middle stream of the Rima River, the annual run-off rate is 4–7%, and most of the rainfall is loss to evapotranspiration and seepage.

From the discharge observation results of November 1988-March 1989, the Rima River water balance shows the following relationship to the groundwater in the basin (Figure 6).

1) In the rainy season from June to August, the total discharge amount for Gidan Doka and Sabon Birni, in the upper stream of the Rima River, is larger than that at Wamako on the downstream side. This decrease in flow shows effluent recharge into the alluvium bed. However, in the dry season, the Wamako amount becomes larger than that of the upstream. This increase is due to run off from the Kalambaina limestone aquifer.

2) The discharge amount for Wamako and Argung is 10-200 m^3/sec in the rainy season from May to September. However the upstream Wamako amount usually exceeds that of Argung. In the dry season, the amount at both points is 1.0-10 m^3/sec, and that of Argung exceeds that of Wakamo. This increase is due to groundwater run-off from the upper Gwandu aquifer and the alluvium.

3) Even between Argung and Bunza, the discharge increases in the lower stream in the dry season. In this area, there is no inflowing river, thus this increase shows that the groundwater discharge from the Guwandu aquifer and the alluvium play important roles.



(mm/year)

Fig.5 Location of Meteorological Observation Stations and Iso Annual Precipitation Map

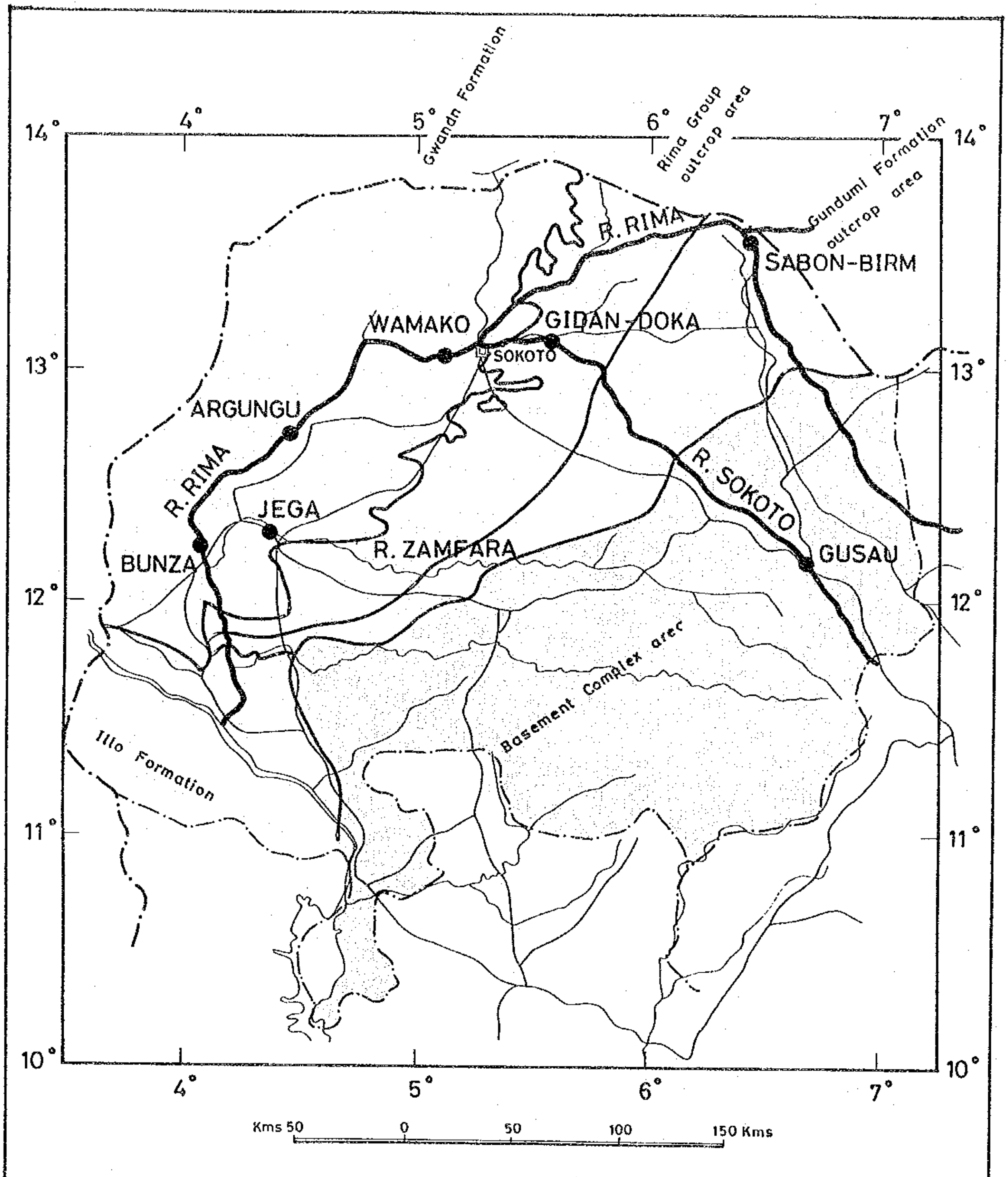


Fig.6 Location Map of Discharge Observation Points

Sedimentary rock area

Basement rock area

4) The discharge amount (1-13 m^3/sec) in the dry season for the Zamfara River in Jega is supported by the the groundwater discharge from the Rima group and the Gundumi formation exposed in this basin.

4. Hydrogeology of Sokoto State

4.1 Geological Distribution and Aquifer

The geology of Sokoto State is largely classified by two types: the sedimentary rock area composed of Cretaceous-Tertiary layers, and the basement rock area composed of Pre-Cretaceous plutonic rock and metamorphic rock. The sedimentary rock area (Sokoto sedimentary basin) extends from the northeast section to the southwest section of Sokoto State. The basement rock area is found in the southeast section and is 42% of the area of Sokoto State (Figure 7).

(1) Basement rocks

This is composed of plutonic and metamorphic rock such as granite, gneiss, crystalline schist and quartzite, and the fresh portion is extremely hard rock. The groundwater exists in the sandy weathering portion, the coarse decomposed portion, the fractured portion of gradually decomposed rock and in the fractured zone associated with dyke. The specific capacity of the exising boreholes is less than 10 m^3/day/m.

(2) Gundumi formation

This is composed of sand, gravel and clay from lake deposit, and covers the basement rock in the lowest layer of the Sokoto sedimentary basin. This occupies about 14% of the entire area of Sokoto State, and extends in a northeast to southwest direction. In the northeastern portion, the groundwater is unconfined and receives recharge from rainfall and rivers. The specific capacity from the existing boreholes is at an average of 57 m^3/day/m, which indicates good aquifer.

(3) Illo formation

This intersects the Gundumi formation, is located in the southwestern section of Sokoto State and covers the upper portion of the Rima group. The condition of the aquifer is the same as that of the Gundumi formation.

(4) Rima group

This is a marine deposit resulting from Cretaceous transgression, and is divided from bottom to top into three layers: the Taloka formation, Dukamaje formation and Wurno formation. The sandy portions in the

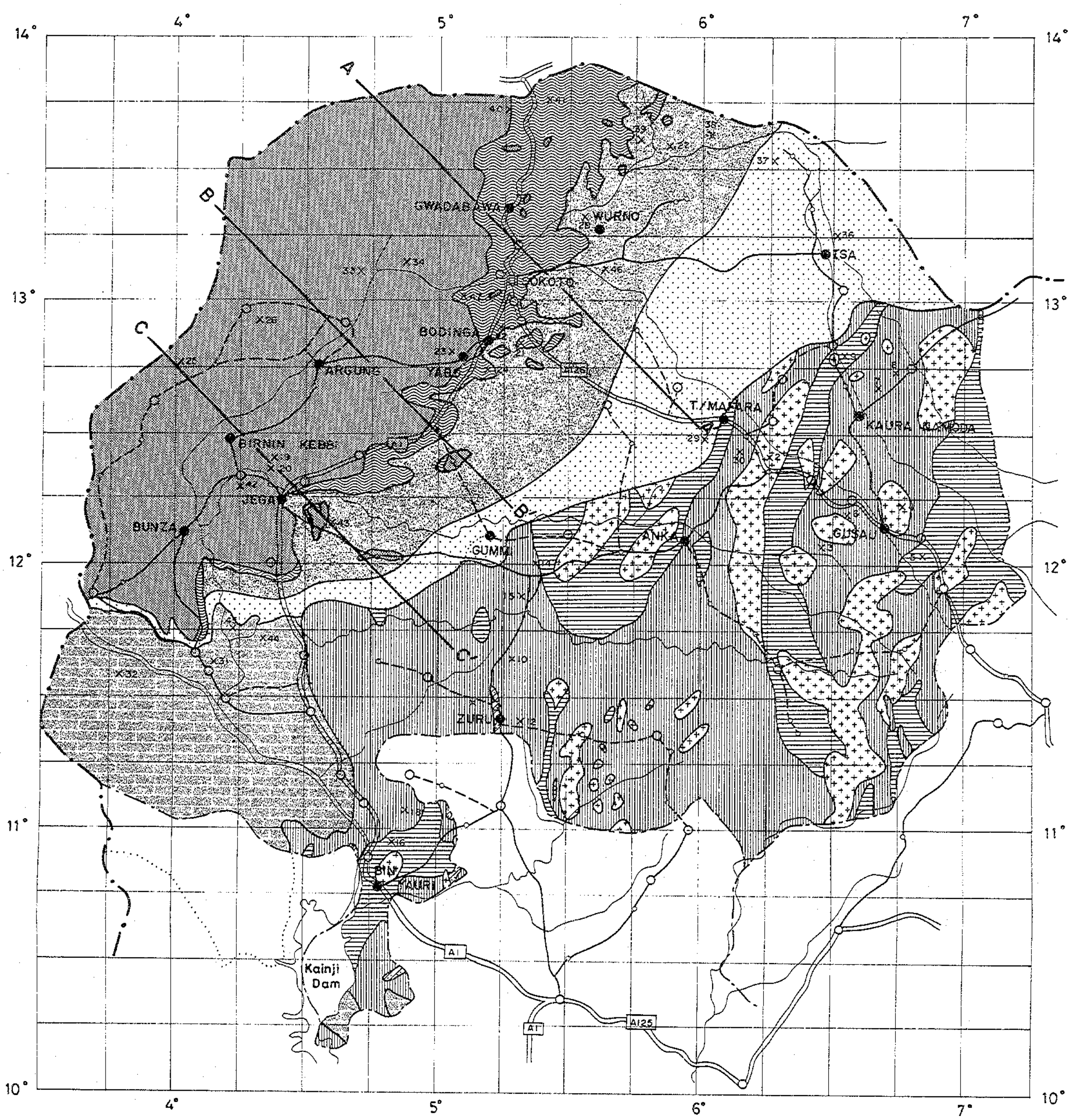


Fig. 7 Geological Map of Sokoto State

Kms 50 — 0 — 50 — 100 — 150 Kms

Gwandu Formation	Tertiary
Sokoto Group	Tertiary
Rima Group	Cretaceous
Gundumi Formation	Cretaceous
Illo Formation	Cretaceous
Older Granite	Pre-Cretaceous
Quartzites	Pre-Cretaceous
Undifferentiated Meta-Sediments	Pre-Cretaceous
Undifferentiated Basement Complex	Pre-Cretaceous

Taloka formation and in the Wurno formation are the aquifer of each. The Dukamaje formation is principally shale and is aquiclude.

The aquifer of the Rima group has a low specific capacity of 3-20 m^3/day/m, in the north of Sokoto city. However, in its southern portion, the value is 23-63 m^3/day/m, which is fairly good. Nonetheless, the groundwater level in both places is low and the water quality is poor.

(5) Sokoto group

This is composed of Dange formation and Kalambaina formation from the bottom to the top. The distribution area comprises 3% of Sokoto State. The Dange formation is principally composed of marine clay and is aquiclude. The Kalambaina formation is composed of clayey limestone and marl, and in this area, forms an unconfined aquifer. Numerous springs and lakes are distributed along the terraces formed by the Kalambaina formation. there are.

(6) Gwandu formation

The Gwandu formation occupies 22% of the area of Sokoto State and the deposits occured in the Tertiary age. It is widely distributed from the northeast of the state to the southwest. This formation is divided into an upper, middle and lower layer. The upper and lower sandy portions form unconfined and confined aquifer, respectively. The middle portion is clayey aquiclude. The specific capacity is 50-100 m^3/day/m, however there are areas where this exceeds 150 m^3/day/m, and is a good aquifer.

(7) Quaternary sediments

In the fadama of the Sokoto and Rima Rivers, alluvium, sand and gravel form an unconfined aquifer. The groundwater is taken by shallow wells.

4.2 Hydrogeological Structures

The main aquifer of the Sokoto-Rima river basin can be classified into four groups from the top down: the upper portion of the Gwandu formation (first aquifer), the lower portion of the Gwandu formation (second aquifer), the Wurno and Taloka formations (third aquifer), and the Gundumi and Illo formations (fourth aquifer). The aquifer system formed by these is called the Sokoto groundwater basin.

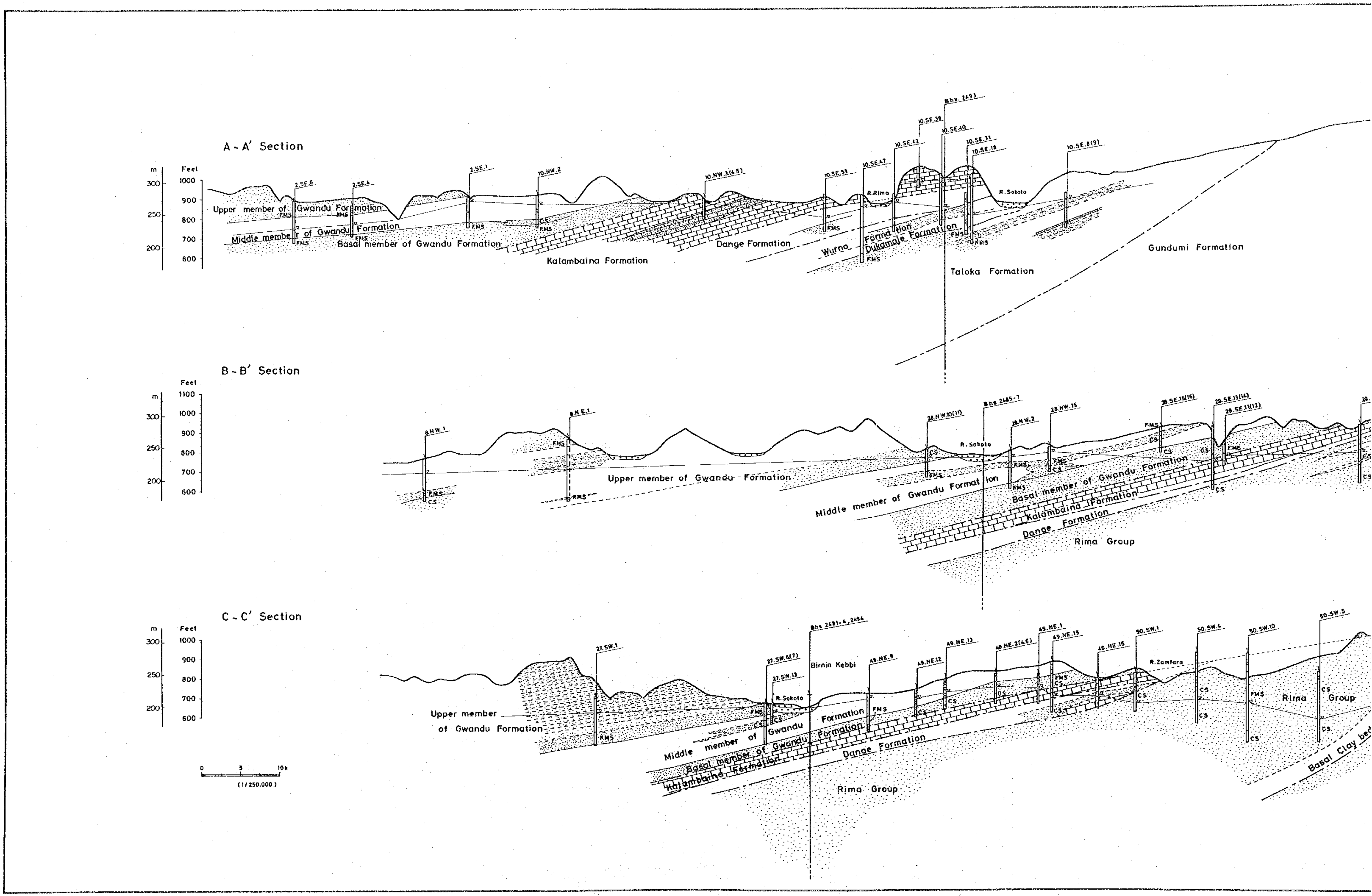
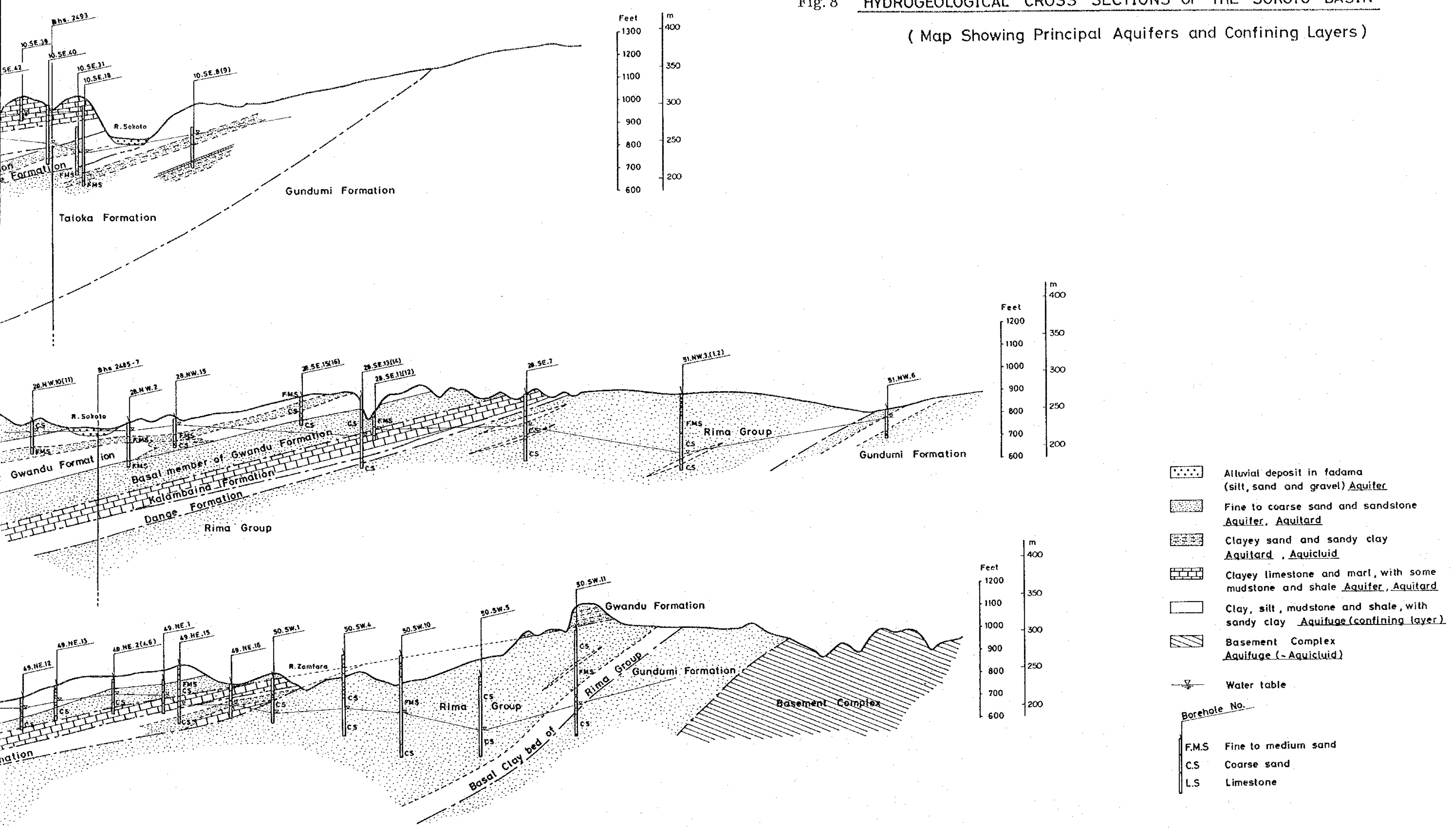

A ~ A′ Section
B ~ B′ Section
C ~ C′ Section
m
Feet
Upper member of Gwandu Formation
Middle member of Gwandu Formation
Basal member of Gwandu Formation
Kalambaina Formation
Dange Formation
Wurno Formation
Dukamaje Formation
Taloka Formation
Gundumi Formation
Rima Group
Basal Clay bed
R. Rima
R. Sokoto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

Fig. 8 HYDROGEOLOGICAL CROSS SECTIONS OF THE SOKOTO BASIN

(Map Showing Principal Aquifers and Confining Layers)



The hydrogeological structure of the Sokoto groundwater basin covers the widely distributed basement rock in the southeast and a mono-clinic structure is formed from the first to the fourth aquifers, from the bottom up, extending from the southeast to the northwest (Figure 8).

4.3 LANDSAT Data Analysis

According to a Band 7 (infrared) LANDSAT image (1/250,000), the lithology and geological structures (faults, lineaments) were interpreted and the image was used for a preliminary hydrogeological study.

Different patterns between older granite and metasediment in the basement rock area interpreted by 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 of not so clear a pattern	Frequent and clear lineament with predominated north-south trend

The classification of the lithological facies in the sedimentary rock can be interpreted by the tone and topographic pattern as for the basement rock area. In particular, the tone of the the fadama is dark which indicates unconfined aquifer, and the area of distribution was clearly interpreted.

In the basement rock area, the existing condition of the groundwater is related to concentrated zones of faults, fractures and fissures. The structure of these can be estimated from the lineament interpretation, however according to the LANDSAT image, a large-scale lineament of some-10 to some-100 km was interpreted. In addition, for interpretation of the small-scale lineament of some-km to some 100 m, aerial photos were effective.

4.4 Groundwater Level

From the results of simultaneous observation of the existing boreholes, a groundwater contour map was prepared and the movement of groundwater in each layer was examined.

(1) Gundumi formation/Illo formation

Flow begins from the northeast edge of the distribution area of the Gundumi formation and runs towards the west, and changes to a southwestern direction to the south of Sokoto city. It forms a regional flow system and after flowing through the point of the interfinger with the Illo formation, it discharges into the Niger River.

(2) Rima group (Taloka formation)

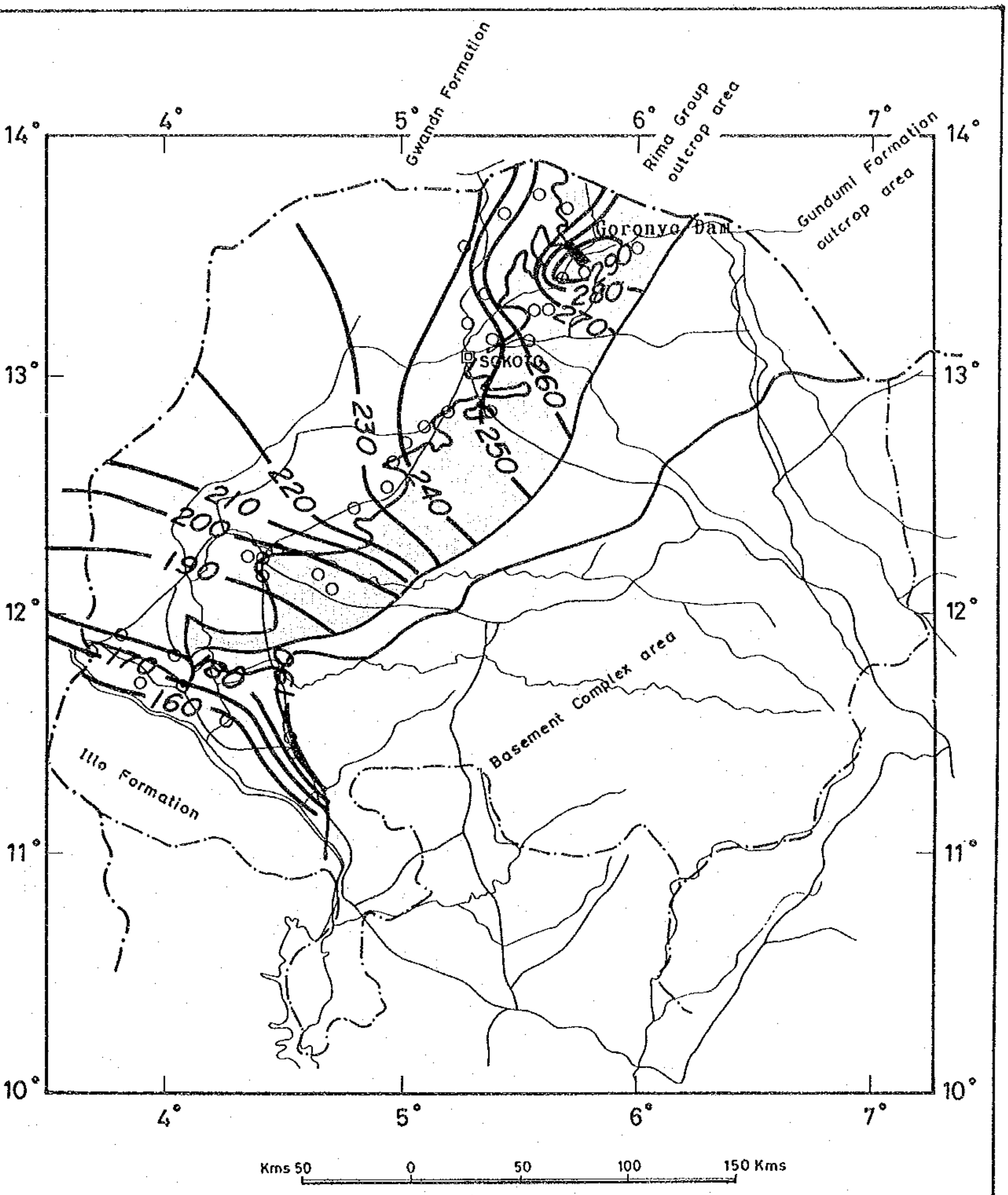
The groundwater movement of the Taloka formation is also basically the same as that of the Gundumi formation. However, in this layer, there is an increase recognized in the groundwater level in the vicinity of the Goronyo Dam. In addition, there is a decrease in the groundwater level near Sokoto city, which is affected by the pumping (Figure 9).

(3) Sokoto group (Kalambaina formation)

The distribution of the Kalambaina formation is limited to along the Sokoto-Illera Road, however groundwater flows from the eastern section of Sokoto city to the northeast. Comparing with the existing observation records, the groundwater level of the Kalambaina formation for the past 5 years has been low at 2.2-5.7 m.

(4) Gwandu formation

The overall movement forms a regional flow system which flows from the northeast to the southwest. The southern edge of the Gwandu formation joins the Illo formation, thus the groundwater flow continues into the Illo formation and finally discharges into the Niger River.



○ Groundwater level observation points

—220— Contour line of groundwater level (above the sea level : m)

Fig.9 Map of the Water Table Configuration
- Rima Group - observed 31/5/88' to 15/7/88'

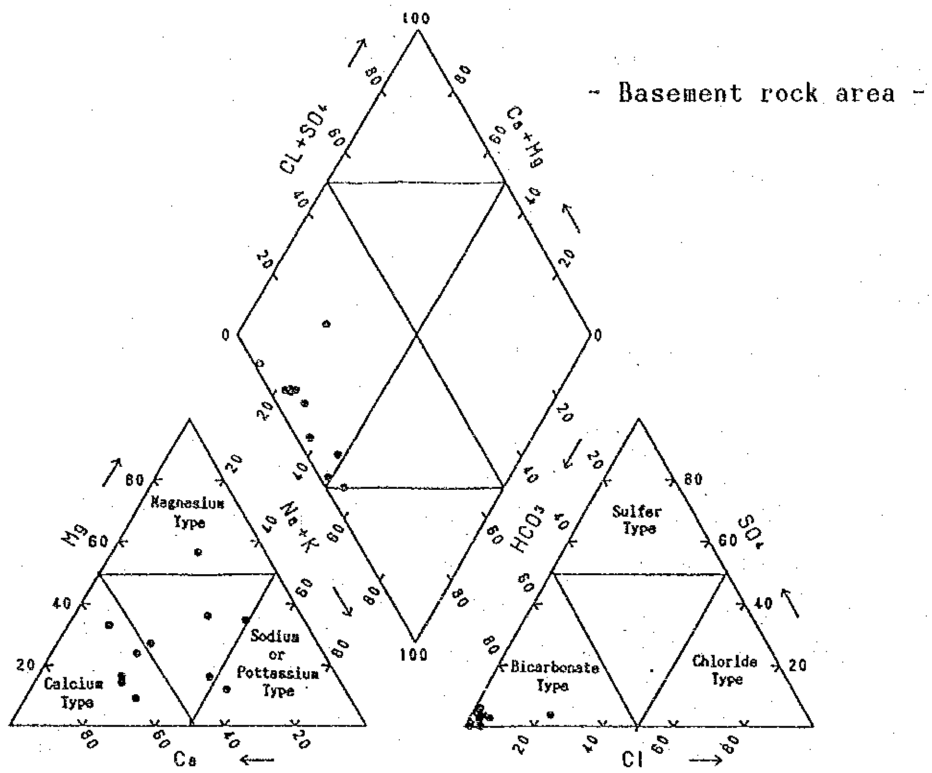
Groundwater forms intermediate and local flow systems which respond to the changes in topography and geology and then finally flow into the Sokoto-Rima and Zamfara Rivers. These become the base flow of each river.

4.5 Groundwater Water Quality

The water quality composition of the groundwater in the basement rock area greatly resembles that of the river water, and appears as a calcium-bicarbonate-type. On the other hand, the water quality composition of the groundwater in the sedimentary rock area appears as a calcium or sodium-bicarbonate type or a calcium-sulfate type (Figure 10).

The total hardness is generally high, 200-500 mg/ℓ in many places. However in the Gundumi, the Rima and the Sokoto formations, there are areas recognized where the value exceeds 1,000 mg/ℓ. In addition, a portion of the wells in the Gundumi formation and the Rima group have a high irom concentration of 15-32mg/ℓ. This concentration in all cases exceeds the WHO standards (1.0 mg/ℓ). In addition, in a portion of the village shallow wells, there are high concentrations of chloride (245-702 mg/ℓ) and nitrate(more than 1,000 mg/ℓ) , which clearly show human-generated pollution.

The tritium concentration in the test wells is 4.6-20.5 TR in the basement rock area, and there seems to be relatively rapid water circulation. On the other hand, the value in the sedimentary rock area is lower than that of the basement rock area at 2.5-3.5 TR, and shows a combination of old water mixed with new water due to recharge by rainfall.



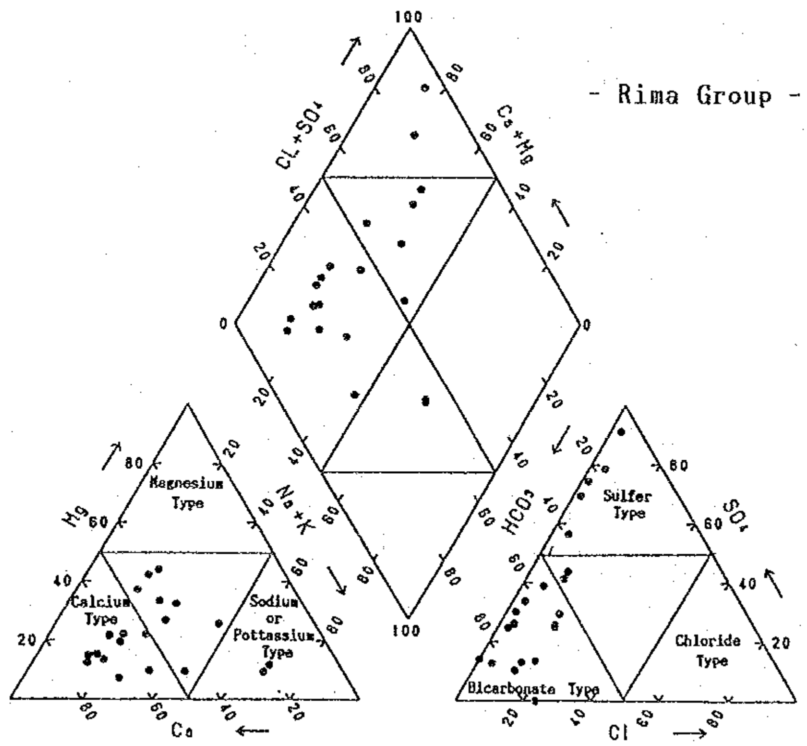


Fig.10 Chemical Quality of Groundwater

5. Preparation of the Data Base

A data base was prepared in order to preserve and control the hydrological and hydrogeological data on Sokoto State, and to insure potential effective usage of the data relating to the groundwater development plan.

There are four types of data included in the data base; meteorological data, hydrological data, hydrogeological data and references.

The basic functions of the data base are data input, file management, data revision and data output.

The hardware is comprised of a microcomputer, a 14" color display, a plotter and a digitizer. The software is d-BaseIII.

6. Hydrogeological Survey of Candidate Villages

6.1 Preliminary Survey

6.1.1 Survey of conditions in villages

On-site survey was conducted on the present conditions of water supply at 47 candidate villages for which water supply schemes by groundwater development are planned.

(1) Village Population

The population of the middle- to large-sized villages is 3,000-20,000, however in conducting verbal interviews during this study it was found that there are actually 3 villages of under 1,000 people and 5 villages of over 20,000 people. The size of the villages in the basement rock area is generally big and the villages of over 5,000 people account for 12 of the 18 villages. In contrast to this, in the sedimentary rock area, 10 out of 29 villages have a population of over 5,000. There are many villages with populations between 1,000 and 5,000.

(2) Villages Formation and Size

The formation of the villages is characterized as either concentrated or scattered. The concentrated-type of village is where the population resides within a 5-50ha area. The scattered-type is where groups of people live in separation of some 100 m each other, which is very common in the basement rock area.

(3) Existing Water Sources

Among the villages, in 3 there are semi-urban water supply systems set up (borehole with powered pump). However, due to lack of maintenance, they are not functioning. In addition to this, there are 10 villages with drilled boreholes with hand-pumps, however these are out of use due to pump breakdown and dry up.

In the other 34 villages there are no boreholes, with 18 of these villages having shallow hand-dug wells, 11 of these using both surface flow and shallow wells, and 5 of these having only surface flow available for use. The

surface flow and shallow wells dry up during the dry season, thus the quantity and quality of as potable water supply are poor.

Among the 47 villages, only 2 achieve adequate water supply throughout the year.

(4) Health Environment

As there are no pollution prevention policies for the water in the shallow wells and water canals, the health environment in most of the villages is quite degraded. In the villages which use surface flow from lakes, ponds and reservoirs, water borne diseases occur, and 5 of the 47 villages have even been victim to the especially devastating Guinea Worm Disease (Table 1).

(5) Village Access

Thirty-one of the 47 villages have general vehicle access, except during the rainy season. However, from among these villages, there are only 7 with asphalted access, 6 of good yet unpaved access, and except for in the rainy season, 18 of relatively good access.

In addition, general vehicle access, villages of difficult access for general vehicles totaled 18, and those of difficult access by even 4-wheel drive vehicles were 2.

6.1.2 Topographic and geological survey

Interpretation of LANDSAT image and aerial photo was carried out for the candidate villages and their surroundings, and upon a preliminary hydrological survey based on existing data, a topographic survey was carried out and a preliminary hydrogeological map of a 1/5,000 scale was prepared.

The items entered on the hydrogeological map included characteristic topography (rivers, terrace, hills, cliffs, ponds, marshes, fadama, etc.), geologic structures, litology, location of inhabitants, types and locations of existing water sources (boreholes, shallow wells, etc.) and geophysical prospection sites.

6.1.3 Geophysical prospecting

In order to investigate the underground geological structures in the candidate villages, vertical electric sounding (VES) and magnetotelluric method (PLMTand ELFMT) prospection were carried out. The results of these are shown below.

1) In the basement rock areas the aquifer is principally made up of weathered and decomposed zones. The resistivity of fresh bedrock is generally approximately 3,000 ohm-m, the depth (thickness of the weathered decomposed layer) varies remarkably from place to place. By appropriate prospecting preceding the drilling of boreholes, groundwater development is possible even in so-called "difficult areas". In addition, it is very effective to place the VES points in a checker-board pattern.

2) In the sedimentary rock area, variation of resistivity with depth is in harmony with the variation in the lithology. Generally, layers which show high resistivity value of 150~1,000Ωm are possible aquifers. However, depending on the area, there is an irregular sedimentary environment and there is a pattern showing remarkable difference between the variation of resistivity with depth between neighboring points. Consequently, the VES line is most effective if placed so as to cross the strike of the layer.

6.1.4 Selection of villages for detailed survey

In order to select the villages for the detailed survey, standards were established regarding the population, area, access, health environment, condition of existing water sources, and the potential for groundwater development for each candidate village. Then, 21 villages were selected from among the 47 (Figure 11). Ten of these villages were in the basement complex area and 11 in the sedimentary rock area (Figure 12).

6.2 Detailed Survey

6.2.1 Hydrogeology

The following items became clear after aerial photo interpretation, geological survey and geophysical prospecting.

(1) Basement rock area

In general, layers of high resistivity exceeding 2,000 ohm-m indicate fresh bedrock, aquiclude or impermeable base rock. The depth down to the fresh bedrock varies form place to place, however the deep-weathering shape is classified into the following 5 types.

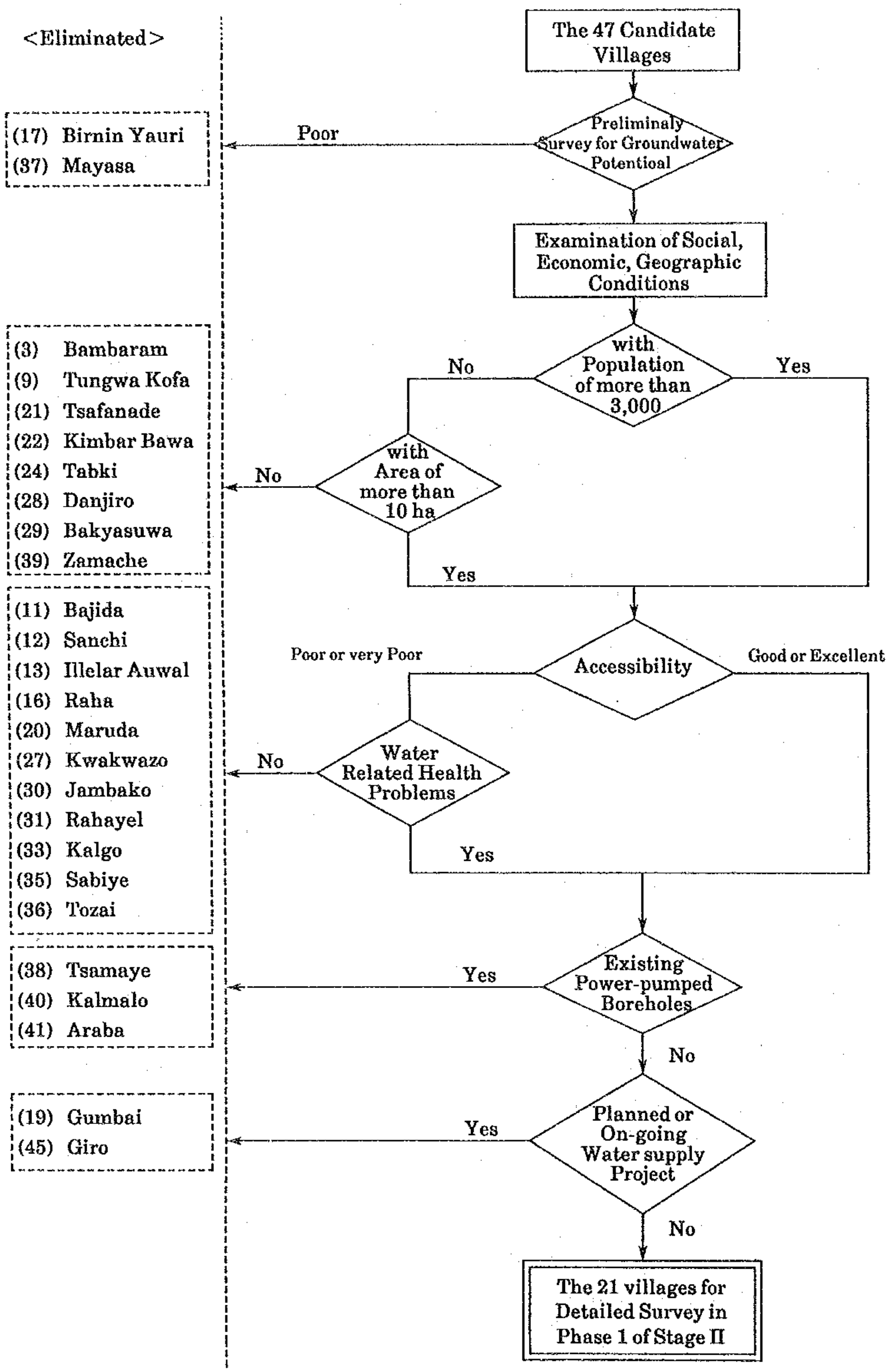


Fig.11 Flow Chart of Site Selection for Detailed Survey

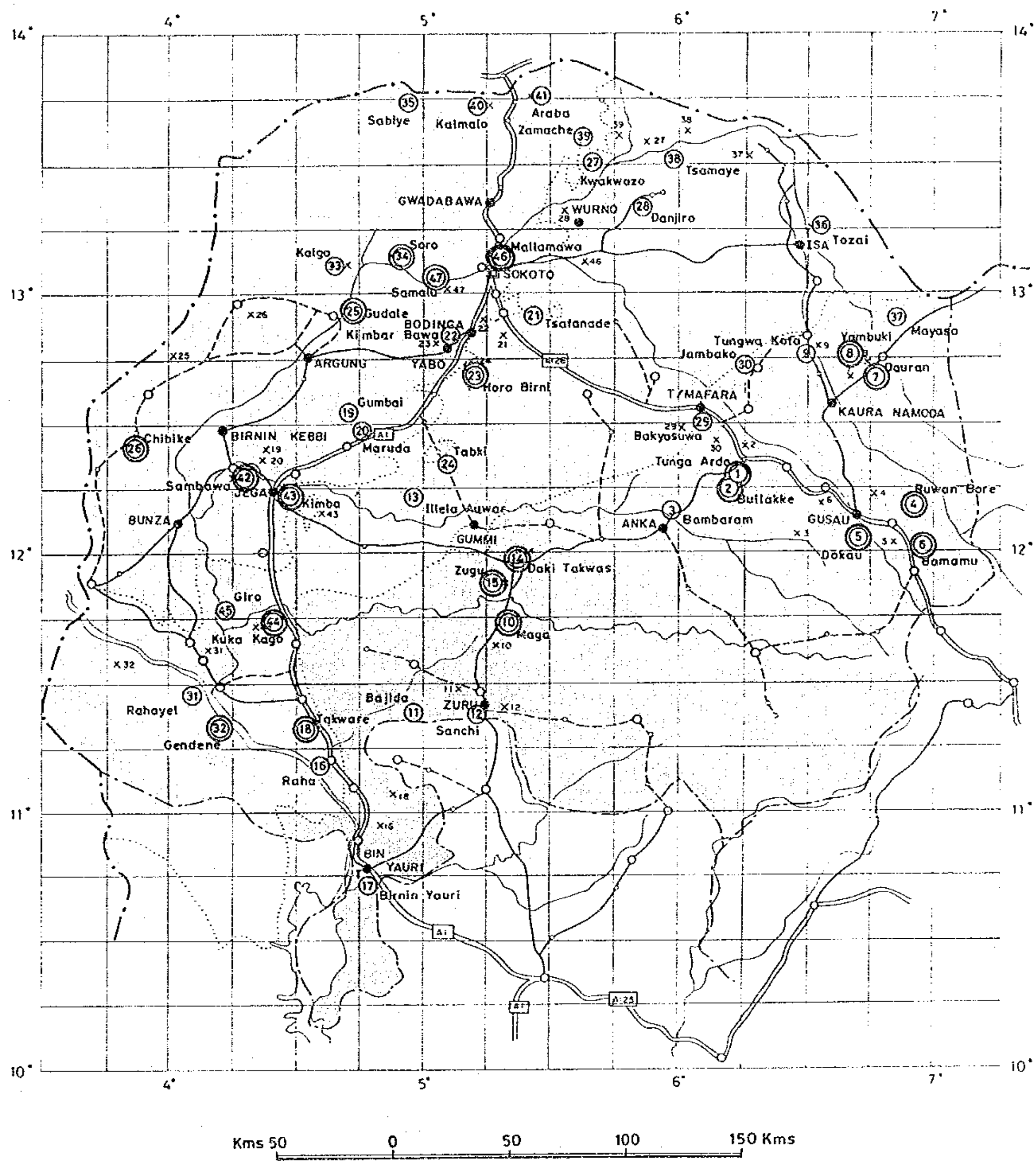


Fig.12 Location Map of Candidate Villages for Water Supply Schemes

◎ Selected villages for the sites of detailed survey

Sedimentary rock area

Basement rock area

2) Valley-shaped deep weathering: Valley-shaped weathering governed by the same geologic structure as in "1)".

3) Riverside deep weathering: Riverside weathering accompanied by fractured zones along with lineament.

4) Shallow weathering: The thickness of the weathered 20-30 m shallow layer has scant changes.

5) Very deep weathering: Wide area deep weathering accompanied by fractured fault clay. The depth exceeds 200 m.

The borehole test drilling sites are established in a checker-board pattern of 50-100 m intervals, VES is carried out, and from the results of this, a fresh bedrock iso-depth contour-line map is drawn and the location of boreholes can be determined.

(2) Sedimentary rock area

For the sedimentary rock area, the resistivity and lithology comparison is shown in the following. The layers of relatively high resistivity exceeding 150Ωm are potential aquifers.

Resistivity (Ωm)	Lithology
10-50	silt, clay, alternation of clay and silt
50-150	sandy clay, alternation of sand and clay or silt
Over 150	sand or sandy rock (aquifer)
Over 1,000	coarse sand or sandstone, gravelly sand, limestone

In the areas of principally Kalambaina formation, limestone and marl are intercalated in lenticular beds. Therefore, the resistivity depth change pattern will vary greatly even from the neighboring measuring points.

6.2.2 Exploratory core boring and test well drilling

In order to understand the characteristics of the aquifers, exploratory core boring was performed in 5 villages and test well drilling and test pumping were performed in 7 villages.

The test well drillings were all successful and the preliminary test pumping by airlift was successful at pumping rates of 80-400 ℓ/min and 380-900 ℓ/min in the basement rock area and in the sedimentary rock area, respectively.

From the results of the exploratory core boring and test well drilling, the following items were clarified.

(1) Basement rock area

Deep weathering zone of strata at over 50 m in depth was distinguished from the lower portion weathering zone, which is governed generally by browrish surface weathering zones and fractured zones and pegmatite and quartzite dykes.

The amount of groundwater increased after continued boring in the lower layer weathering zone. The water quality was also better than that in the upper portion surface weathering zone.

The location of the test drilling was decided for the center of the basin-shaped deep weathering area. The planned drilling depth should be approximately down to the depth of the fresh bedrock. The average depth of the existing boreholes is shallow at 35 m, and as the surface weathering zone was not penetrated completely, it is thought that the groundwater amount generally remains low at 10-20 ℓ/min.

In the basement rock area, other than geophysical logging, it is important to determine the screen position based on inspection of drill cuttings and water flow during drilling. In this case, the most effective drilling for use would be one to which a"down-the-hole hammer" (DTH) could be attached.

(2) Sedimentary rock area

The groundwater development area can be decided in refering to a regional specific capacity map. After the analysis of existing data and the geological survey, the geophysical logging points are decided, and based on these results, the most effective selection of drilling points is achieved.

The geophysical logging is extremely effective if it relates to the verification of aquifer/aquiclude and the decision on the screen location. In the case of the Sokoto sedimentary basin, the layer which shows natural gamma value of less than 5 CPS and resistivity value of over 150 Ωm indicates a good aquifer.

6.2.3 Pumping tests

Step draw down testing, constant drawdown testing and recovery testing were carried out at 7 test wells. The test results were analyzed by a non-equilibrium well equation in order to find the aquifer coefficient.

The specific capacity in the basement rock area was 2.6-32.5 m^3/day/m, and the transmissivity was $1.1\times10^{-3}\sim2.7\times10^{-2}$ m^2/min (Theis Method). The yield at the time of constant drawdown testing was 60~120 ℓ/min.

In the sedimentary rock area, specific capacity was 46-108 m^3/day/m, and the transmissivity was $3.1\times10^{-2}\sim9.8\times10^{-2}$ m^2/min. The yield for the constant drawdown testing was 300~316 ℓ/min (Table 2).

6.2.4 Water quality from test well

In both the basement rock area and the sedimentary rock area, the relative composition of water is a calcium or magnesium-bicarbonate-type. Only that of Ruwan Bore in the basement rock area is a sodium-bicarbonate-type. In Kukakogo and Maga in the basement rock area, the total hardness was low, at below 100 mg/ℓ. However at other sites it was 260-440 mg/ℓ with an extensive high at Dauran of 1,200 mg/ℓ.

In contrast to this, in three sites in the sedimentary rock area, the value was low at 40-70 mg/ℓ. The total hardness at Dauran is below the WHO standards (1,500 mg/ℓ), and the water quality values permit use as potable water.

6.2.5 Establishment of exploration methods

In order to establish groundwater exploration methods for the basement rock area, supplementary on-site study was carried out in Zugu in the southern part of Sokoto State, then the effectivity of each method was investigated.

Table - 2 Results of Test Well Drillings

Village	Lithology	Depth m	Diameter inch	Screen m	S.W.L m	D.W.L m	Pumping Rate l/min
Ruwan Bore	Basement Rock	90.0	4	52.4 ~ 62.0 73.1 ~ 74.7 80.2 ~ 83.9	6.11	44.96	70 (84~168)
Dauran	Basement Rock	84.0	4	35.6 ~ 40.4 51.5 ~ 56.4 73.0 ~ 77.9	12.03	18.36	129 (120~210)
Yambuki	Basement Rock	102.0	4	48.6 ~ 55.1 66.2 ~ 72.7 89.3 ~ 90.9	29.41	37.51	69 (80)
Maga	Basement Rock	138.0	4	42.0 ~ 45.0 123.0 ~ 129.0	7.79	65.62	100 (120~200)
Zugu No.1	Basement Rock	130.0	4	50.7 ~ 58.8 76.9 ~ 80.1 122.4 ~ 124.0	14.0	45.68	28 (30)
Zugu No.2	Basement Rock	120.0	4	54.0 ~ 60.5 78.6 ~ 83.4 95.5 ~ 100.4	10.3	15.72	140 (400)
Horo Birni	Sedimentary Rock	120.0	6	72.0 ~ 80.5	45.73	53.99	300 (120~380)
Soro	Sedimentary Rock	150.0	6	64.6 ~ 76.0	1.71	5.93	316 (900)
Kuka Kogo	Sedimentary Rock	113.0	6	51.0 ~ 60.0	14.6	24.67	316 (800)

Remark : Pumping rate in parentheses by air lifting

S.W.L : Static Water Level

D.W.L : Dynamic Water Level

was carried out, the lithology and geological structures observed were recorded, and the hydrogeologic map was prepared.

Geophysical prospecting involves carrying out VES and MT, and from these results and the existing data, the depth of the basin-shaped deep weathering (depth of the surface of fresh bedrock) is identified.

The test well depths at two sites are 130 m (No. 1) and 120 m (No. 2) and the pumping rate at each was 28 ℓ/min and 140 ℓ/min, respectively.

The basin-shaped deep weathering in the study area is regulated by a SN fault, and the depth of the fresh bedrock, at its deepest, exceeds 200 m. Based on the VES with points established in a checker-board pattern (intervals of 100 m), the distribution pattern of the weathering was clarified. In addition, from resistivity change in traverse line obtained by MT method, a fault zone was detected (Figure 13).

The results of the test well drilling carried out by the application of a series of survey methods were extremely favorable. Since the effectiveness of each method was checked, these survey procedures were compiled as the Hydrogeologic Study Guidelines.

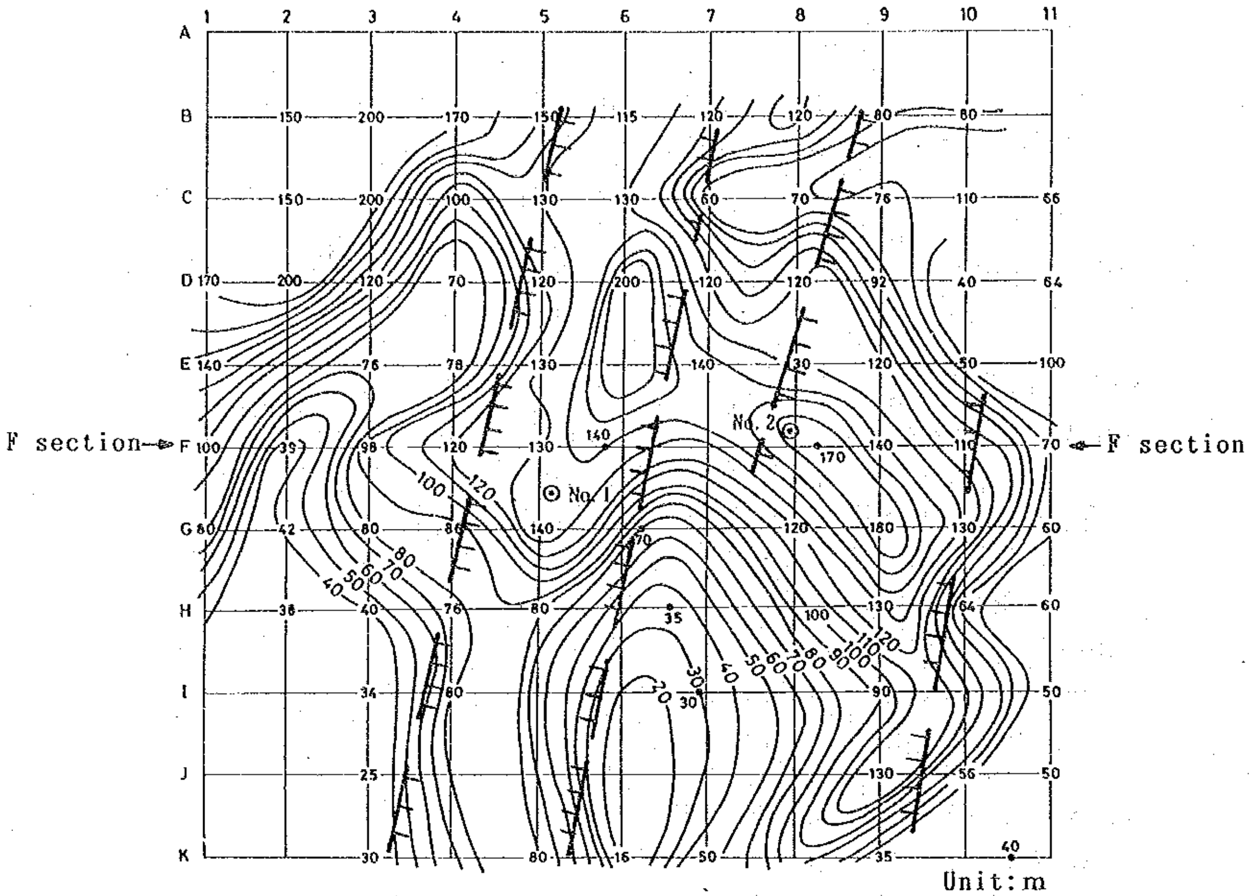


Fig.13(1) Iso-depth Map to the Fresh Basement Rock (Zugu village)

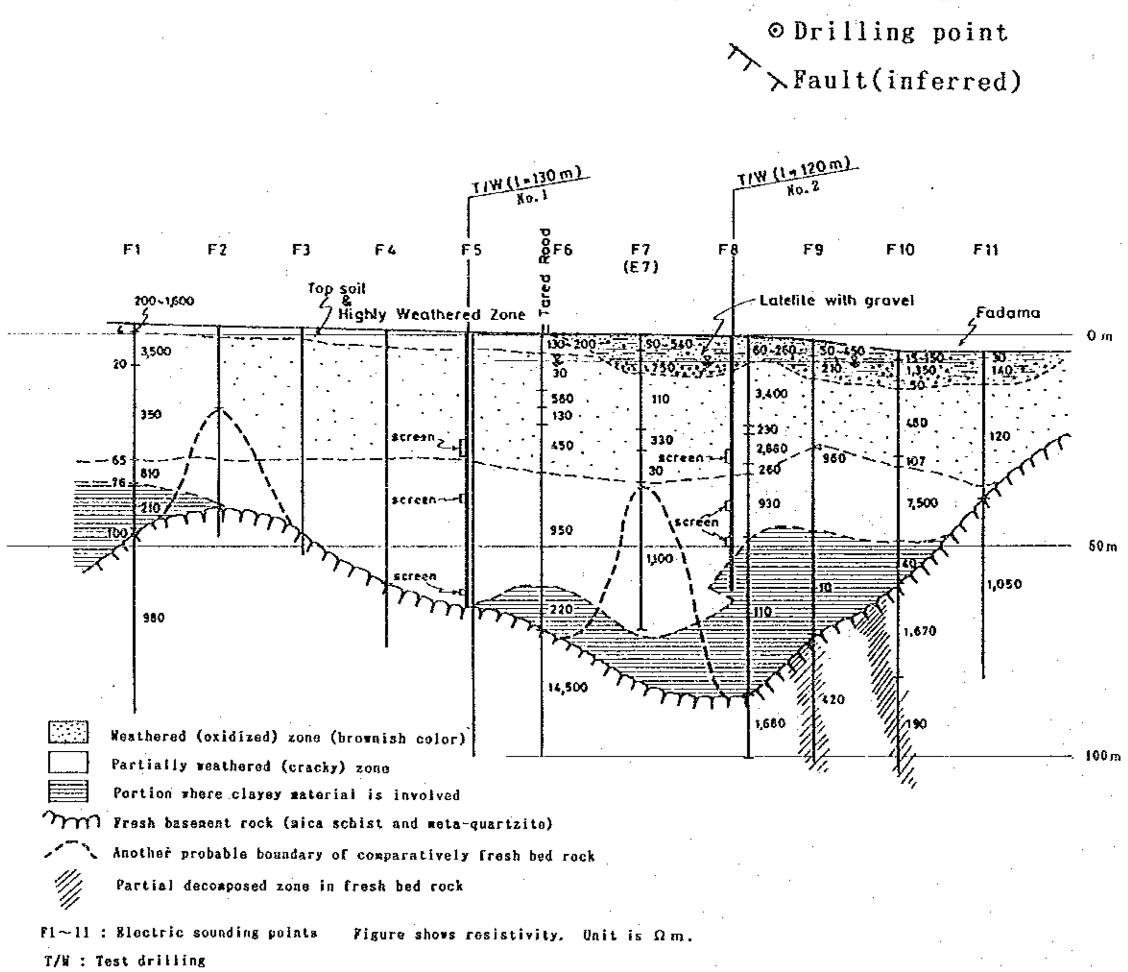


Fig.13(2) Line F Section

7. Evaluation of Groundwater Development Potential

As the basis of the evaluation of groundwater development potential, the water balance of the entire Sokoto State was examined and analyzed to determine groundwater recharge. In addition, groundwater simulation was carried out in the sedimentary rock area, and the regional flow and water balance were examined in detail.

Based on the results of the water balance estimations, the basin yield for each the basement rock area and the sedimentary rock area respectively were estimated, from the point of view of water balance for the former, and from the point of view of water level predictions based on simulation for the latter.

7.1 Basic Concept of Evaluation of the Yield

The characteristics of groundwater in the study area vary from the renewable unconfined aquifers with high circulation velocity found in Fadama, to the weathering zones in the basement rock area and in Kalambaina limestone to the non-renewable confined aquifers with slow circulation velocity in the Sokoto sedimentary basin.

The renewable groundwater yield can be evaluated as perennial yield. In addition, the non-renewable groundwater yield must be evaluated as a mining yield. In this study, the groundwater in the basement rock area is considered to be renewable and yield was evaluated through application of the factor on water balance. In addition, the confined aquifer of the sedimentary rock area is considered to be rather non-renewable. Thus, the yield was evaluated through application of the economic factor regarding the predicted decline in the water level by simulation.

7.2 Analysis of the Groundwater Water Balance

Using long-term records on the water level in the distribution area of the Kalambaina and Gwandu formations, estimation of the water balance of the unconfined groundwater was carried out. The water balance equation is the following.

$$S\,dh/dt = (Q1 - Q2) / F + W$$

Where, $S\,dh/dt$: change in storage
S: coefficient of storage

dh/dt: change in water level
(Q1-Q2)/F: groundwater run-off
Q1: inflow
Q2: outflow
F: area of water balance
W: recharge to groundwater

Then, $W = P(1-c) + E \pm Md$

Where,
P: precipitation
E: evapotranspiration
Md: water content in the soil
c: run-off coefficient

In calculating the annual water balance based on the average precipitation from 1943 to 1981, the precipitation is 674 mm, the run-off is 34 mm, the evapotranspiration and water content in the soil are 523 mm, and the groundwater recharge is 117 mm.

In addition, using same methods in the basement rock area, the results of the water balance calculation for the upstream basin of Gusau show the precipitation at 857 mm, the run-off at 146 mm, the evapotranspiration and water content of the soil at 576 mm and the recharge at 135 mm.

7.3 Simulation in Sokoto Groundwater Basin

In order to predict the groundwater level decline due to pumping, simulation was carried out in the Sokoto groundwater basin.

(1) Simulation model

A quasi-three dimensional FEM model was constructed regarding the multi-aquifer system which is composed of aquifers in the Sokoto sedimentary basin, namely, the Gwandu formation, the Kalambaina formation, the Rima group (Wurno-Taloka formation) and the Gundumi-Illo formation.

(2) Parameters used in the model

From the results of the hydrogeological survey, parameters were abstracted for use in the model concerning the thickness of the aquifer, the permeability coefficient, the storage coefficient and the initial groundwater level, and then the boundary conditions were established. In addition, the pumping rate from the present Sokoto groundwater basin was estimated at 42,200 m^3/day, based on the borehole records.

(3) Verification of the model

In comparing the computed and the observed groundwater levels, the validity of the model was examined.

(4) Prediction of the future water level

Assuming the population continues to increase at the same rate of 2.5%, the groundwater pumping capacity was estimated at 88,500 m^3 for 30 years from now. Substituting the future pumping volume in the verified model, the water level for 30 years from now was predicted.

The results of the prediction show a decline of less than 1.0 m as compared to the present groundwater level of the Gundumi-Illo formation and the Gwandu formation. On the other hand, in the vicinity of Sokoto city, the pumping volume is large, thus in the Kalambaina formation, the maximum groundwater level decline was seen at 2 m, and in the Rima formation at 6.8 m.

7.4 Evaluation of the Yield

7.4.1 Basement rock area

In the basement rock area, the groundwater results from rain infiltrating the weathering zones and fissure zones. In particular, basin-shaped weathering zones formed by the geological structure of faults, fractures and cracks, can be seen everywhere in the basement rock area, and form small-scale groundwater basins.

The groundwater has a renewal characteristic and the yield can be evaluated based on the recharge conditions. It is important to establish a proper development scale for each groundwater basin, based on the water balance calculation results which give the yield as approximately 50 mm/year (140 m^3/day/km^2).

7.4.2 Sedimentary rock area

In the Sokoto sedimentary basin, the velocity of circulation of the shallow unconfined groundwater is rapid, however that of the deep confined groundwater is slow. The storage capacity is large, however as for the evaluation of the yield, the non-renewal factor in the groundwater is rather strong. Thus, importance must not be placed so much on the water balance conditions, but other on the economic risks involved in the increase in pumping cost incurred by the decline in the groundwater level.

In adding the decline in groundwater level obtained from the groundwater simulation to the decline in level at each well, and in estimating the pump capacity, this value is considered as being within the range of pump efficiency and operating cost included in the initial design. Consequently, the pumping rate at approximately 88,500 m^3/day input in the simulation model can be taken as the provisional yield.

Nonetheless, the groundwater level in the Rima formation in the vicinity of Sokoto city was 50 m. Areas where the water level was deeper than 80 m were also seen. Since the groundwater level may decline if the pumping rate increases in the future, the groundwater development for the Kalambaina and Rima formations in this area should be approached prudently.

7.5 Necessity of Groundwater Basin Management

The Sokoto groundwater basin is still under virgin condition, and random development could result in problems such as a decrease in the pumping rate caused by a decline in the groundwater level, a drying up of wells and a deterioration of the water quality. Consequently, from the beginning, planned groundwater basin management must be carried out, for the conservation of this precious water resource.

8. Groundwater Development Planning

The basement rock area is termed a "difficult area" for groundwater development, and even in this area, based on proper groundwater investigation pumping rate of 70-140 ℓ/min is possible with a borehole depth of 90-130 m and a diameter of 100 mm. In addition, in the sedimentary rock area, a potential pumping rate of 300 ℓ/min is possible with a borehole depth of 100-150 m and a diameter of 150mm. This volume is thought to be sufficient for use as potable water.

8.1 Groundwater Development in the Basement Rock Area

(1) Aquifers

The basin-shaped weathering zones and valley-shaped weathering zones which run along large-scale faults and fracture zones form aquifer. Following the proposed guidelines, the narrowing down from wide area to local area and the geophysical prospecting are carried out, the distribution and the thickness of the aquifer are estimated and the borehole locations are determined.

(2) Development scale

In consideration of the recharge, the yield will be 140 m^3/day/km^2. However, in the basement rock area, the distribution of the aquifer and the area of villages is not unified. In the case of water supply to the villages, it is uneconomical to place the boreholes at a distance from the settlements. Consequently, even in the case of the scattered-type of large-scale villages, boreholes with submersible pumps are limited to 3 locations, and other than these, there is an increase in the establishement of boreholes with handpumps.

(3) Standard well design

The depth is determined by geophysical prospecting. However the planned diameter and material for the submersible pump borehole are a 6" steel pipe, and for the hand-pump borehole, a 4" PVC pipe. The screen is a Johnson-type or a similar stainless one, with a ratio of openings over 15% and a slot size of 0.5-1.0 mm. Moreover, the screen length is over 15 m for multi-aquifer collection.

8.2 Groundwater Development in the Sedimentary Rock Area

(1) Aquifer

In the area which extends from the northern section of Sokoto city to the national border and in the area which lies on the inside of the line which connects Gunmi, Jega and Yabo, the groundwater level of the aquifer of the Gundumi formation and the Rima group was locally below 70~80 m, and groundwater development in these areas would be uneconomical by a large pumping lift.

Excluding these areas, the Gwandu formation, the Taloka formation of the Rima group, the Gundumi formation and the Illo formation, judging from the specific capacity map, form fairly good aquifers, making groundwater development possible.

(2) Development scale

The pumping rate per well can be expected to exceed 300 ℓ/min. In the village water supply plan, it is possible to make all of the boreholes with submersible pumps. Consequently, in the plan, the number of wells can be determined to respond to the water requirements, however these wells must be placed appropriately so as to avoid decrease in the pumping rate due to mutual interference.

(3) Standard well design

In the lower portion of the Kalambaina limestone, the lower portion of the Taloka formation and the muddy portion of the Illo formation, the water quality can be estimated as deteriorated, thus the target depth for the borehole is suitable at 100 m.

In addition, the casing diameter and material are a 6" steel pipe, and just as in the basement rock area, it is a Johnson type or similar stainless one, with a ratio of openings of 15% and a slot size of 0.25 to 0.5 mm. The length of the screen is 10~15 m for single aquifer collection.

8.3 Model Water Supply Facility in Horo Birni

The purpose of model construction of a water supply system in Horo Birni in the vicinity of Sokoto city is to understand the various problems which could arise in actual construction and to be able to refer to the information learned in instances of future execution planning. In addition, another important objective is to obtain data for the establishment of more realistic design standards, in monitoring the water usage situation following the completion of the facilities. The proposal for the creation of a water association, self-run by the people, for the operation and maintenance of the facilities, was made and experimentation of this concept was carried out.

A summary of the model water supply facilities is shown below.

(1) Served population : 7,200

(2) Intake facilities
Borehole : 6" diameter, 150 m depth
Submersible motor pump : 2(1 spare) 7.5kw, d.cap. 240 ℓ/min, p.cap. 75m
Generator : 2 (1 spare), 17.5kvA

(3) Distribution facilities

Elevated reservoir tank : efficiency volume, 115m^3, material used is GRP (glass fiber-reinforced plastic) panels which allow for ease in maintenance

Distribution pipe : the faucet pipe, service pipe, principle pipe, material is steel, the principle pipe and faucet are attached to the water meter.

(4) Surrounding facilities

Generator house

According to the experience of this construction, it is advisable to procure almost all of the materials and equipment from foreign contractors in terms of quality of materials and the time necessary for the completion, although some of the materials can be procured from local firm.

9. Water Supply Plan for Middle- and Large-Scale Villages

Based on the groundwater resource evaluation and development plans, a water supply plan was prepared for middle- and large-scale villages with populations of 3,000-20,000.

9.1 Basic Plan

(1) Candidate villages for water supply

The water supply plan focuses on 21 candidate villages studied in a detailed survey. Among these villages, at Horo Birni in the sedimentary rock area, construction of a model was executed, making the total number of candidate villages 20 (Figure 12).

(2) Served population

The population in the area planned for water supply is according to the number understood from verbal survey in the villages at the time of the study. The served population, for the year 2000, was estimated based on a constant growth rate of 2.5% of the present population. The served population for the 20 villages is 147,700.

(3) Planned water consumption

Based on the scale of the villages, the present water usage situation and the hydrogeological conditions, the water consumption was determined within a range of 15~30 ℓ/c/d.

(4) Water quality

The water quality of groundwater presents potential use as potable water. The value of concentration is below the maximum permissible limit of the WHO standards.

9.2 Facility Planning

(1) Facility design

Three types of water supply facilities were designed based on the scale, the water usage situation and the hydrogeological conditions of the candidate villages in Sokoto State(Figure 14).

1) Hand-pump system (Type A)

This system is applicable for villages where the specific capacity is presumed to be less than $10m^3$/day/m and the pumping rate less than 50 ℓ/min. The number of people suppliable per hand-pump borehole is determined based on water consumption and pump efficiency, which totals in general about 500 people, if the water consumption is determined at 15 ℓ/c/d.

2) Pipe-supply system (Type B and Type C)

The Type B system is composed of one submersible pump borehole and elevated reservoir tank and distribution pipe and communal faucet. The Type C system is composed of many boreholes connecting to an elevated reservoir tank. This system is applicable to villages where the specific capacity is expected to be 20~$50m^3$/day/m and the pumping rate more than 80 ℓ/min.

9.3 Project Costs

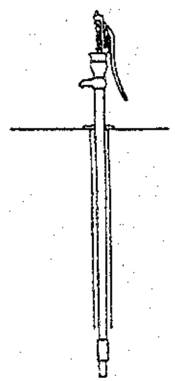
The construction costs necessary for the plan were estimated based on the models set up in Horo Birni (sedimentary rock area) and in Ruwan Bore (basement rock area) (Table 3). This result formed the basis for the estimation for the other 19 candidate villages. The project costs are as shown in the following.

(1) Estimation conditions

1) Estimation period	January 1990
2) Foreign exchange rate	1 US$ = 140 Yen 1 US$ = 7.4 Naira
3) Construction period	30 months

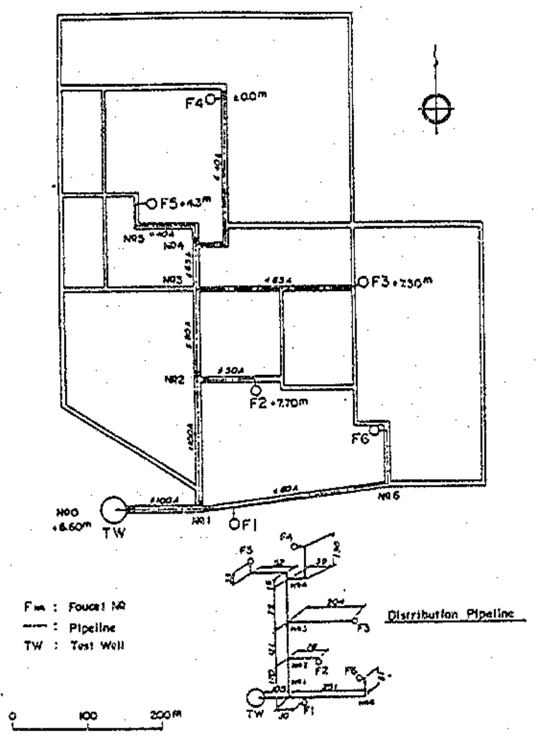
Fig. 14 Water Supply System Design

Hand Pump System

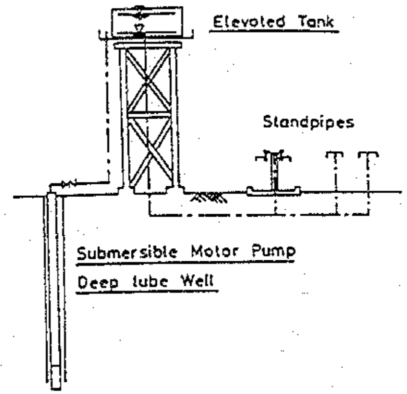


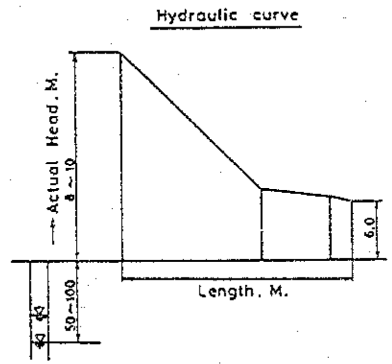
Piped Water System for Rural Area

Distribution Pipeline

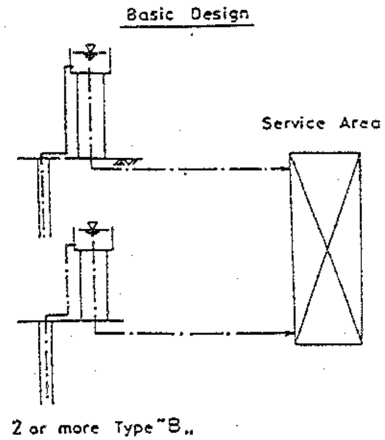


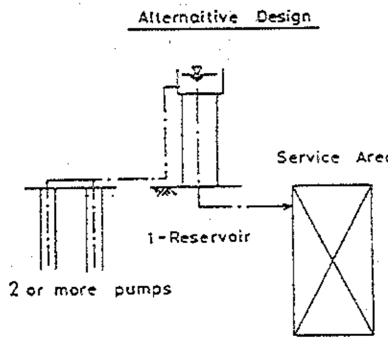
Case Study for Village





Pipe Water System for Semi Urban





Type "A"	Type "B"	Type "C"
(1) Facilities One or more handpumps (2) Classification A-B Handpumps for Basement Area A-S Handpumps for Sedimentary Area	(1) Facilities 1) Deep tube well, 2) Subme sible Motor Pump, 3) Elevated Tank 4) Distribution pipe 5) Standpipes. (2) Classification B-B Piped Water for Rural Basement Area B-S Piped Water for Rural Sedimentary Area	(1) Facilities Type"C" consists of two or more of Type"B" (2) Classification C-B Piped Water for Semi Urban Basement Area C-S Piped Water for Semi Urban Sedimentary Area

Table 3 Cost Estimate of the Model Construction

No.	Village Name	Design System	Facilities		Intake: Deep Well	Intake: Pump & Generator	Intake: Pump House and Fitting	Intake: Total ①	Elevated Water Tank: Reservoir Tank (GRP)	Elevated Water Tank: Tower (Steel)	Elevated Water Tank: Total ②	Pipeline: Pipe & valve Faucet	Pipeline: Total ③	Grand Total: ¥×1000	Grand Total: $
4	RUWAN BORE Basement Area Service Population P=8,000 Water Daily Maximum Q=230m^3/d	(B)−B	Specification		Dia. 6" Depth 90m Quantity 160 ℓ/min	50∮ 5.5 kw 17.5 kVA	Brook Concrete 3.0×8.0×3.0		98 m^3 7.0×7.0×2.0H	392 m^3 7.0×7.0×8.0H		80A 120m 50A 240 40A 240 25A 60			
			Number		1	2 (1-spare)	1		1	1		Total 660m			
			Cost ¥ ×1000	Material	—	6,600		6,600	5,782	6,272	12,054	2,300	2,300	20,954	149.6
				Installation	5,400	—	3,000	8,400	1,862		1,862	1,978	1,978	12,240	87.4
				Administration	2,160	—	1,200	3,360	744		744	791	791	4,895	35.0
				Total	7,560	6,600	4,200	18,360	14,660		14,660	5,069	5,069	38,089	272.00
			%	①~③/④				48%			39%		13%	100%	
23	HORO BIRNI Sediment Area Service Population P=8,000 Water Daily Maximum Q=345 m^3/d	(B)−S	Specification		∮ 6" D 110m Q 300 ℓ/min	60∮ 7.5 kw 17.5 kVA	3.0×8.0×3.0		128 m^3 8.0×8.0×2.0H	480 m^3 8.0×8.0×7.5H		100A 330m 80A 540 65A 340 40A 350			
			Number		1	2	1		1	1		25A 90 Total 1745m			
			Cost ¥ ×1000	Material	—	8,281		8,281	7,540	7,710	15,250	3,360	3,360	26,891	192.1
				Installation	6,600	—	3,085	9,685	2,403		2,403	2,897	2,897	14,985	107.0
				Administration	2,640	—	1,234	3,874	961		961	1,158	1,158	5,993	42.8
				Total	9,240	8,281	4,319	21,840	18,614		18,614	7,415	7,415	47,869	341.9
			%	①~③/④				46%			39%		15%	100%	

Note: RUWAN BORE (B)−B Unit cost 38,089,000 ¥/230 m^3/d = 165,600 ¥/m^3/d = 1,180 $/$m^3$/d

HORO BIRNI (B)−S Unit cost 47,869,000 ¥/345m^3/d = 138,000 ¥/m^3/d = 1,000 $/$m^3$/d

Facilities unit cost:
- Deep well 60,000 ¥/m depth
- Reservoir Tank 54,000 ¥/volume m^3
- Tower 16,000 ¥/Air volume m^3
- Pipeline & Faucet 10,000 ¥/m^3/d

Hand pump 25,000 ¥/1 unit

Borehole pump & Generater 600,000 ¥/pump kw

Table 4 Cost Estimation for W/Supply System (1/3)

No.	Village Name (Local Gov.)	Population (Service population)	Hydro-geological Feature	Water Consumption ℓ/c/d	Water Demand m³/d: Average (ℓ/min)	Water Demand m³/d: Daily Maximum (ℓ/min)	Result of Test Drilling	System Design: System	System Design: Preminary Design	Estimate Construction Cost 1000 ¥: Intake	Elevated Tank	Distribution Pipeline	Total: 1000 ¥	Total: $	Estimate Operation & Maintenance Cost N/Month (N/p/Month)
1	Tunga Ardo (Anka)	30,000 (3,000)	Basement	15	54 (90)	65 (108)	T/W 80 m 17 ℓ/min	A	6 Deep Well 50 m, 18 ℓ/min 6 Hand Pumps	27,300	–	–	27,300	195,000	1,300 (0.43)
2	Bullake (Anka)	10,500 (5,000)	Basement	15	90 (150)	108 (180)		A	10 Deep Well 50 m, 18 ℓ/min 10 Hand Pumps	45,500	–	–	45,500	325,000	2,160 (0.43)
4	Ruwan Bore (Gusau)	11,500 (8,000)	Basement	20	192 (133)	230 (160)	T/D 84 m 49 ℓ/min T/W 90 m 84 - 168 ℓ/min	B	1 Deep Well (90 m) 160 ℓ/min 1 Unit Water Supply System	18,360	14,660	5,069	38,089	272,064	1,500 (0.18)
5	Dokau (Gusau)	10,000 (10,000)	Basement	20	240 (166)	288 (200)		C	2 Deep Well 90 m, 100 ℓ/min 2 Unit Water Supply System	36,720	14,960	6,346	58,026	414,471	2,250 (0.22)
6	Bamamu (Gusau)	10,000 (4,000)	Basement	15	72 (120)	86 (144)		A	8 Deep Well 50 m, 18 ℓ/min 8 Hand Pump	36,400	–	–	36,400	260,000	1,728 (0.43)
7	Dauran (Kaura Namoda)	23,500 (23,500)	Basement	20	564 (391)	676 (470)	T/W 84 m 110 ℓ/min~ 210 ℓ/min	C	3 Deep Well 90 m, 160 ℓ/min 3 Unit Water Supply System	47,520	43,982	14,898	106,400	760,000	3,579 (0.15)
8	Yambuki (Kaura Namoda)	25,000 (12,000)	Basement	20	288 (200)	345 (200)	T/D 80 m 50 ℓ/min T/W 100 m 80 ℓ/min	C	3 Deep Well 100 m, 80 ℓ/min 3 Unit Water Supply System	49,200	22,440	9,884	81,524	582,314	3,579 (0.29)

Table 4 Cost Estimation for W/Supply System (2/3)

No.	Village Name (Local Gov.)	Population (Service population)	Hydro-geological Feature	Water Consumption ℓ/c/d	Water Demand m³/d Average (ℓ/min)	Water Demand m³/d Daily Maximum (ℓ/min)	Result of Test Drilling	System Design: System	System Design: Preminary Design	Estimate Construction Cost 1000¥: Intake	Elevated Tank	Distribution Pipeline	Total 1000¥	Total $	Estimate Operation & Maintenance Cost N/Month (N/p/Month)
10	Maga (Zuru)	4,000 (4,000)	Basement	20	96 (66)	115 (80)	T/D 80 m 5 ℓ/min-20 ℓ/min T/W 130 m 120 ~ 200 ℓ/min	B	1 Deep Well 100 m, 80 ℓ/min 1 Unit	10,800	7,480	2,599	20,879	149,136	1,500 (0.37)
14	Daki Takwas (Gummi)	20,000 (5,000)	Basement	15	90 (150)	108 (180)		A	10 Deep Well 50 m, 18 ℓ/min 10 Hand Pumps	45,500	–	–	45,500	325,000	2160 (0.43)
15	Zugu (Gummi)	4,000 (4,000)	Basement	20	96 (66)	115 (80)		B	1 Deep Well 120 m, 80 ℓ/min 1 Unit	10,800	7,480	2,534	20,814	148,671	1,500 (0.37)
18	Takware (Yauri)	10,000 (10,000)	Sedimentary	30	360 (250)	432 (300)		B	1 Deep Well 90 m, 300 ℓ/min 1 Unit	20,760	24,487	9,521	54,768	391,200	1,500 (0.15)
23	Horo Birni (Yabo)	8,000 (8,000)	Sedimentary	30	288 (200)	345 (240)	T/D 150 m 200 ℓ/min T/W 110 m 380 ℓ/min	B	1 Deep Well 110 m, 240 ℓ/min 1 Unit						
25	Gudale (Argungu)	11,000 (11,000)	Sedimentary	30	396 (275)	475 (330)		B	1 Deep Well 110 m, 330 ℓ/min 1 Unit	26,640	24,487	13,540	64,667	461,907	1,500 (0.13)
26	Chibike (Argungu)	5,000 (5,000)	Sedimentary	30	180 (125)	216 (150)		B	1 Deep Well 60 m, 150 ℓ/min 1 Unit	15,840	14,660	4,790	35,290	252,071	1,500 (0.30)

Table 4 Cost Estimation for W/Supply System (3/3)

No.	Village Name (Local Gov.)	Population (Service population)	Hydro-geological Feature	Water Consumption ℓ/c/d	Water Demand m³/d Average (ℓ/min)	Water Demand m³/d Daily Maximum (ℓ/min)	Result of Test Drilling	System Design: System	System Design: Preminary Design	Estimate Construction Cost 1000¥: Intake	Elevated Tank	Distribution Pipeline	Total 1000¥	Total $	Estimate Operation & Maintenance Cost N/Month (N/p/Month)
32	Gendene (Bagudo)	3,500 (3,500)	Sedimentary	30	126 (87)	151 (105)		B	1 Deep Well 80 m, 105 ℓ/min 1 Unit	14,604	10,771	3,327	28,702	205,014	1,500 (0.42)
34	Soro (Silame)	4,500 (4,500)	Sedimentary	30	162 (112)	194 (135)	T/W 150 m 900 ℓ/min	B	1 Deep Well 60 m, 135 ℓ/min 1 Unit	7,884	10,771	4,275	22,930	163,786	1,500 (0.33)
42	Sambawa (Jega)	8,000 (8,000)	Sedimentary	30	288 (200)	345 (240)		B	1 Deep Well 130 m, 240 ℓ/min 1 Unit	21,720	19,148	7,603	48,471	346,221	1,500 (0.18)
43	Kimba (Jega)	6,200 (6,200)	Sedimentary	30	223 (155)	267 (186)		B	1 Deep Well 80 m, 190 ℓ/min 1 Unit	17,520	14,660	5,884	38,064	271,885	1,500 (0.24)
44	Kuka Kogo (Jega)	3,500 (3,500)	Sedimentary	30	126 (155)	151 (105)	T/W 110 m 800 ℓ/min	B	1 Deep Well 90 m, 105 ℓ/min 1 Unit	5,643	10,896	3,327	19,866	141,900	1,500 (0.42)
46	Mallamawa (Sokoto)	10,000 (5,000)	Sedimentary	15	90 (150)	108 (180)		A	10 Deep Well 50 m, 18 ℓ/min 10 Hand Pump	45,500	–	–	45,500	325,000	2,160 (0.43)
47	Samalu (Sokoto)	4,500 (4,500)	Sedimentary	30	162 (112)	194 (135)		B	1 Deep Well 80 m, 135 ℓ/min 1 Unit	15,360	10,081	4,275	29,716	212,257	1,500 (0.33)
										519,571	250,963	97,872	868,406	6,202,897	

4) Contractor — Foreign well drillers and water supply construction workers

(2) Project cost (20 villages)

	×10³	×10³
Construction Cost	¥ 868,000	($6,200)
Equipment & Material Cost	105,000	(750)
Design & Supervision Cost	97,000	(700)
Total	¥ 1,070,000	($7,650)

9.4 Implementation Plan

(1) Organization for implementation

The principal implementing body for this project is the Sokoto State Water Board (SSWB). The SSWB promotes this project based on the policies related to the Nigerian National Water Supply Plan, and in cooperation with the Federal Department of Water Resources (FDWR) and the Sokoto-Rima River Basin Development Association (SRRBDA).

(2) Implementation plan

This project is a water supply plan by groundwater resources and its content largely depends on the success of the well drilling. Consequently, it is necessary for the work involving the borehole drilling and the pumping tests to be separate from that involving the construction of facilities. This concept is shown in the flow chart in Figure 15. The necessary time for implementation of this project is 30 months (Figure 16).

(3) Operations and maintenance

The daily operations and maintenance of the facilities are handled by a village water association composed of the inhabitants. The water association monthly collect the fee for the fuel, the personal expense and repair of the faucet and the valve etc.

The SSWB is responsible for the instruction and management concerning the water association and the repair of the major facilities and equipment such as the pump and the generator etc.

Fig.15 Summarized Procedure of Construction

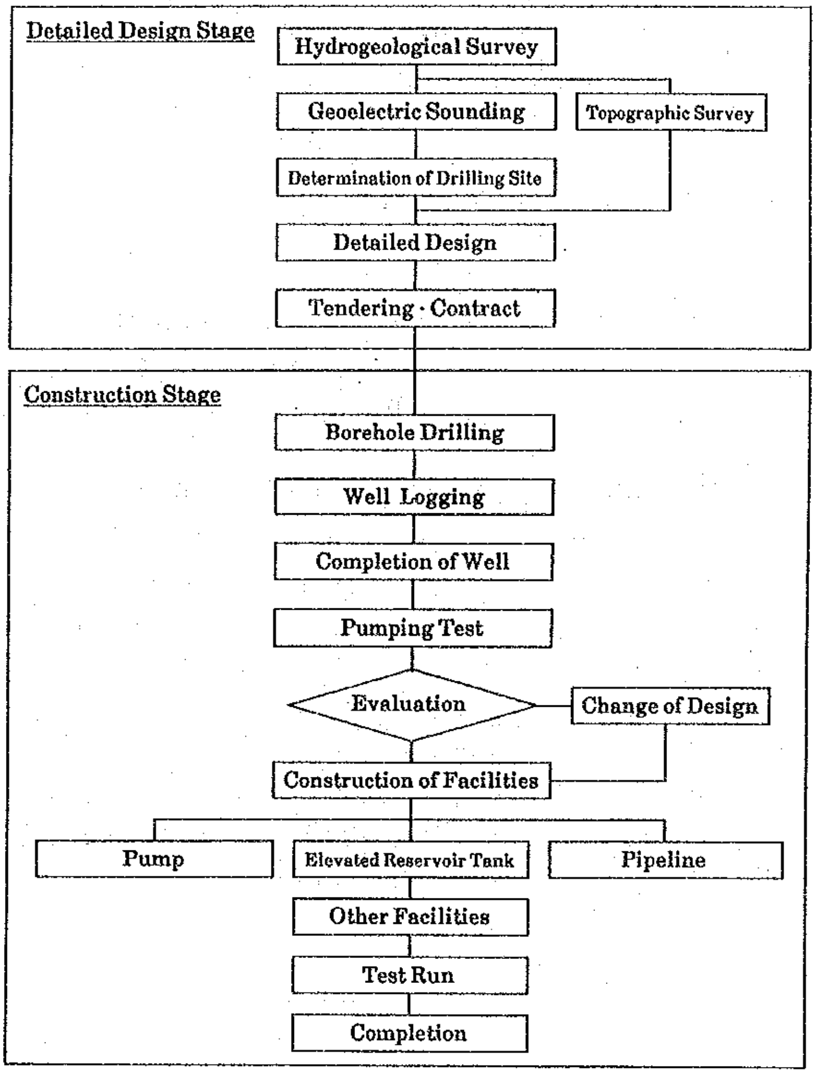
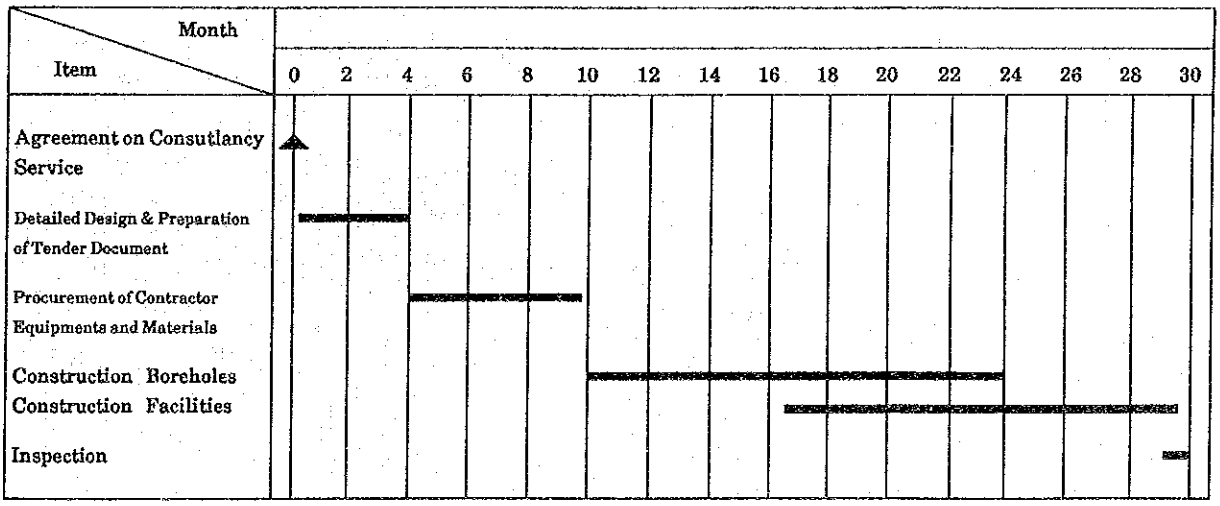


Fig.16 Tentative Inplementation Schedule



In the case of the model water supply system in Horo Birni (B type), the operation and management fee is calculated as follows :

Fuel and parts	511	Naira / month
Personal expenses	725	
Reserve found for repairs	247	
Total	1483	Naira / month

This shows about 1.5 Naira / month / family, when the number of the households is 1,000 in proportion to the population of 8,000 in this village. Judging from the existing conditions, 1.5-4 Naira / month / family is feasible.

The SSWB is supposed to guide the water association and maintain the major facilities such as the pump, the generator and the pipeline. The elevated tower and tank are semipermanently usable. However, the submersible pump and the generator should be repaired every 5-7 years. In order to repair the facilities, a reserve fund must be prepared by the SSWB. This fund is estimated at about 3,700 / Naira / system / year.

Judging from the capability shown in the course of the model construction, the SSWB is able to maintain the facilities in terms of technical ability and organization.

9.5 Project Eveluation

9.5.1 Socio-Economic Evaluation

The benefits of the proposed project are evaluated qualitatively in view of the socio-economy as in follows.

(1) Health improvements of the inhabitants

The percentage of contraction is supposed to be reduced and the status of the health should be improved by the supply of sanitary and abundant water. In Sokoto State, people are suffering from epidemic diseases, such as dysentery and Guinea-Worm disease in several villages. But the project may reduce the risk of such disease. This is considered to a direct effect of the project and may stabilize the agricultural labor force at peak demand leading to an increase in agricultural production.

(2) Time savings

The project can reduce the time spent by people collecting water, by providing it close to their home. In Sokoto State, the inhabitants of the village consume 2-3 hours collecting of river bed-water along the fadama during the dry season, since the existing dug wells are dried up. The time saved can be spent on economically productive activity, such as farming of crops, on care of livestock and so on. This will also lead to an increase in agricultural production.

(3) Activation of rural community

Water is mainly used for drinking. In addition, water is utilized for feeding livestock, irrigation and processing of agricultural products. These acitivities may improve the products and this becomes a basis of the development in the community.

After completion of the model water supply system, the activation of economical exchange between communities through the water supply was observed in Horo Birni. The water supply system might encourage the concentration of scattered settlements into large communities, which are organized into a new economic unit and may activate the rural area.

(4) Effect of project investment

The economic benefit of this project is difficult to evaluate quantitatively. However, a water supply income of 30-40 Naira / month / family is estimated, if expected IRR value of 3% is guaranteed. Then, the difference between this income and the actual paid fees (in this case, the operation and maintenance fees) is seen as representative of the benefit. Based on the calculation results, a benefit of 1.3 times the total construction cost could be earned in the project life.

9.5.2 Evaluation of organization, operation and maintenance

(1) Organization

The SSWB consists of 6 departments : Administration, Account, Design, Hydrology, Rural Water Supply, Operation and Maintenance. Number of employees is about 1,200. The SSWB mainly carried out the construction, operation and maintenance of the urban water supply systems using foreign assistance. As far as observed in the course of the field survey, it is understood that the SSWB has enough capacity to implement the project in terms of the ability of the engineers in the field of groundwater and water supply and their organization.

(2) Operation and maintenance

In this project, daily operation and maintenance is planned to be carried out by the water association composed of the inhabitants of the community. The SSWB is responsible for guidance of the management and repair of the major facilities. The amount of fee of daily operation by the inhabitants is thought to be payable considering the living standard of the village people.

Moreover, the SSWB intends to establish the water supply program in the middle to large scale villages (semi-urban area) throughout this project. Taking this willingness into consideration, this project has a validity in view of operation and maintenance.

9.5.3 Overall evaluation

An increase in agricultural production and the activation of rural communities can be expected by the improvement of the health environment through the provision of sanitary and abundant water after the completion of the water supply system. The project will greatly contribute to Sokto State which is economically undevelopped due to its geographical condition. In addition, this project has a validity in terms of operation and maintenance.

It is judged that the project is highly effective and should be implemented immediately considering the severe natural environment surrounding these project sites.