THE REMAINING STORAGE AND RATE OF SILTATION OF MAIRUWA DAM IN FUNTUA, NORTH CENTRAL NIGERIA

BY

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DEDICATION

I dedicate this thesis work to God Almighty and to my late father Mallam Salawu Onukaba.

DECLARATION

I declare that the thesis titled THE REMAINING STORAGE AND RATE OF SILTATION OF MAIRUWA DAM IN FUNTUA, NORTH CENTRAL NIGERIA: has been written by me, SALAWU OZOMARI ABDULAZEEZ in the Department of Geology under the supervision of Prof. K. Schoeneich and Prof P.M. Zaborski. The information derived from this literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented partly or wholly for another degree or diploma at any university.

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CERTIFICATION

This Thesis entitled **THE REMAINING STORAGE RATE OF SILTATION OF MAIRUWA DAM, FUNTUA, NORTH CENTRAL NIGERIA** by SALAWU OZOMARI ABDULAZEEZ Meets the regulations governing the award of the degree of Masters of Science in Hydrogeology of Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

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ABSTRACT

Mairuwa Dam is located at the outskirt of Funtua town in north western Nigeria. It was constructed in 1970 with a storage capacity of 5.5 million cubic metres for irrigation and water supply to Funtua and its environ. After 41 years of siltation since impoundment, it is not known how much water is left in the reservoir or how much sediment is being deposited annually. To determine the volume of water available in the reservoir, the author embarked on measurement of the remaining storage of the reservoir. The measurement was done using boat, measuring tape,, satellite navigator (GPS) and a heavy object to measure depth and edge of water table during the rainy season when the spillway is flowing. From the result of these measurements, a bathymetric map of the impounding reservoir was produced. The area bounded by the water was then determined by the least square method. The area calculated which is enclosed by successive isobaths was multiplied by the average depth obtained to get the volume.

The results obtained from the measurements shows that the remaining storage capacity for the present year 2011 is 3,905,929 m^3. Average depth from spillway is 2.60 m. The rate of siltation between 1970 and 2011 was calculated to be 38,880 m^3/a. this represents storage loss of 0.70% per annum. At this rate, the dam will be silted up in the year 2111.the rate of erosion in the drainage basin of 102 km^2 was calculated to be 0.45 mm/a. This is 511% higher than the world average of 0.088 mm/a.

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CHAPTER 1

INTRODUCTION

1.1 Preamble

Mairuwa dam was constructed for water supply to Funtua town and its environs and it is the major source of water supply to Funtua town for domestic and irrigation purposes. However the water supply has been grossly inadequate. The amount of water pumped is insufficient to meet the increasing water demand. The residents of Funtua town rely mostly on hand dug wells, boreholes and rain harvesting. Yields from irrigated farms are often poor as a result of inadequate water supply.

Mairuwa dam which was constructed in 1970 had at inception a storage capacity of 5.5 million cubic metres. It has a catchment area of 120 km^2, crest length of 457 m and maximum height of 12 m. Since the construction of the dam in 1970, no study has been done aimed at appraising its design storage capacity in view of the widespread poor land use practices over the impounding reservoir's drainage basin which accelerates soil erosion. It is therefore possible that the initial storage capacity of the impounding reservoir may no longer be obtainable at present due to siltation.

The study focuses on the measurement of the remaining storage in Mairuwa impounding reservoir, rate of siltation in the reservoir and rate of erosion in its drainage basin

1.3 Location and Accessibility

The geographical coordinate of the studied area are latitude 7^0 13' to 7^0 21'E and longitude 11^0 30' to 11^0 38'N (Figure 1). The drainage basin lies on part of Funtua Sheet 78SW and SE. of the first edition of 1:50,000 topographic maps of 1967. The study area is accessible

through a Trunk A road from Zaria through Funtua to Gusau. The dam is about 10 km north-west of Funtua.

1.4 People and Land Use

The study area is populated by the Hausa- Fulani as it is the case in most of north-western Nigeria. They are mostly farmers and nomads. Other noticeable tribes here are the Ibo and Yoruba. Most of the land in this area is used for farming and grazing of cattle. A handful of the populace engages in fishing in the reservoir. Some of the villages within the study area are Mairuwa, Dikke, Garduwawa, Kadrawa, Ungwar Maje, Ungwar Dahiru, Ungwar Ishiaku, Fadi, Tafoki and part of Funtua town.

1.5 Vegetation and Climate

The study area belongs to the Sudan savannah which is characterized by short grasses and scattered, drought resistant trees such as the Baobab, Tamarind and Acacia. There are two seasons; the rainy season and the dry season. The rainy season starts from April to October The annual rainfall is averagely 1000 mm.

Dry season is from October to April. Its first half till end of January is called “harmattan period”. During the day it is hot and cool at nights, both characterized often by poor visibility owing to dust haze of harmattan, north- easterly.easterly, and northerly wind. Rainfall is almost nil and the sky is cloudless during harmattan season. Relative humidity is low, about 40%, often as low as 25%. The second half of the dry season, “hot period” season, from early Februaly till end of April and is characterized by hot days and night and a good visibility (Schoeneich and Garba, 2010).

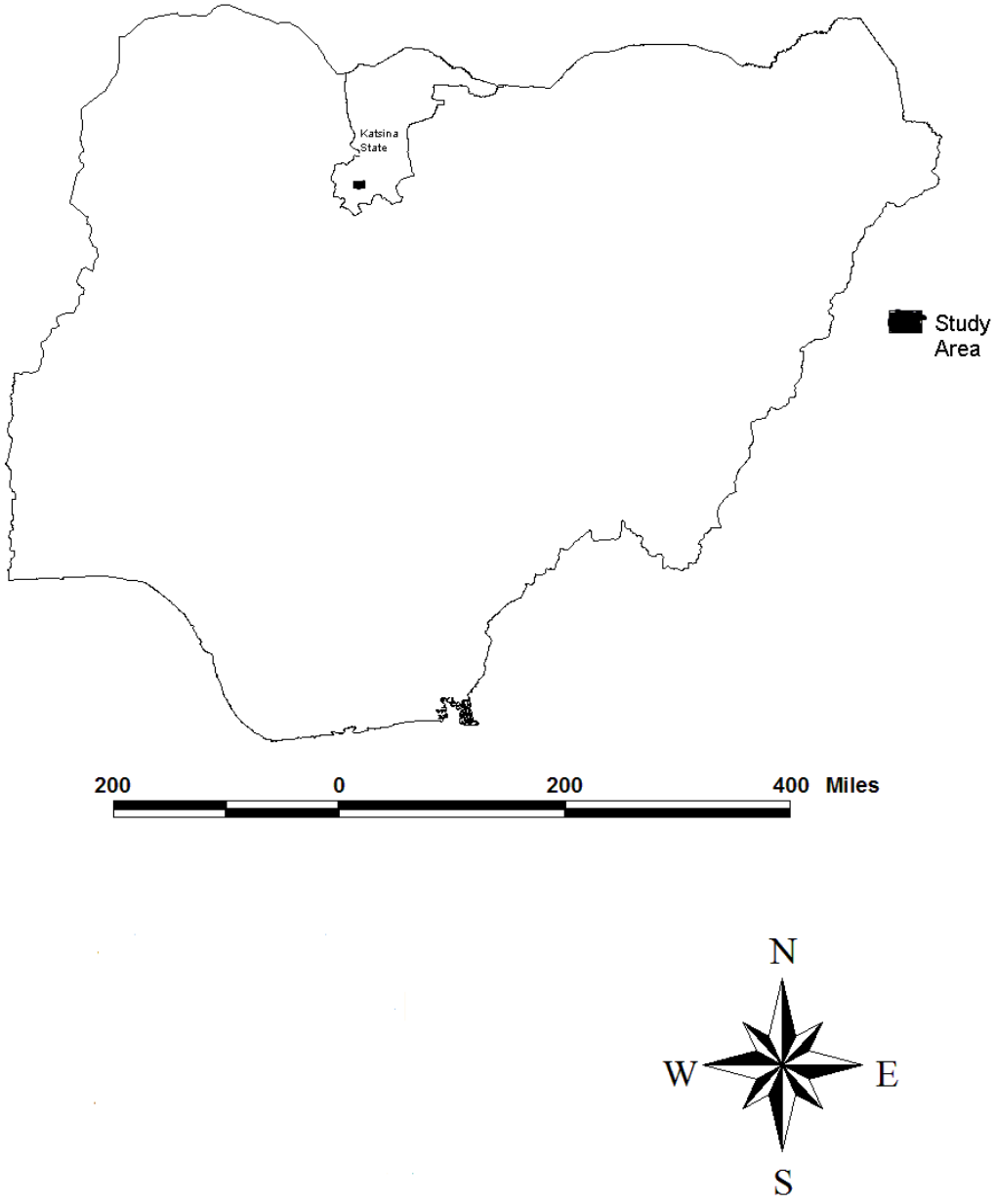


Figure 1. Sketch Map of Nigeria showing location of the study area

The climate sustains fewer trees and shorter grasses than the Guinea Savannah. It is by far the most densely populated zone of northern Nigeria. Thus, the vegetation has undergone severe destruction in the process of clearing land for the cultivation of crops such as cotton, millet, maize and wheat. This is in addition to devastation due to animal husbandry, especially cattle rearing. This greatly favoured in the belt because the area is located northwards beyond the extent of the tse-tse fly zone.

CHAPTER 2

LITERATURE REVIEW

2.1 Review of the Geology of the Area

The study area is located on the crystalline Basement Complex of northern Nigeria. The Basement Complex rocks are;

1. The migmatite-gneiss complex
2. The metasediments (consisting of quartzites and schists)
3. The Older Granites.

2.1.1 Migmatite-gneiss complex

The migmatite-gneiss complex is the commonest rock type in the Nigerian Basement Complex (McCurry, 1976). It makes up about 60% of the surface area of the Nigeria basement. (Rahaman and Ocan, 1978). It comprises two main types of gneisses: the biotite gneiss and the banded gneiss. Very widespread, the biotite gneiss is normally fine to medium-grained to coarse porphyroblastic with strong foliation caused by the parallel arrangement of alternating dark and light minerals. The banded gneiss show alternating light-coloured and dark bands and exhibit intricate folding of their bands and sometimes have variable joint directions with quartz mineralization. The migmatite-gneiss is composed essentially of feldspar, quartz and biotite. The migmatite-gneiss complex is the oldest, dated Birrimian (about 2500 m.y) and is believed to be of sedimentary origin but was later profoundly altered into metamorphic and granitic conditions (McCurry, 1970, 1976).

2.1.2 Metasediments

The Older Metasediments were also among the earliest rocks to form on the Nigerian Basement Complex. Initially of sedimentary origin, with a more extensive distribution, the

Older Metasediments underwent prolonged, repeated metamorphism; and now occur as quartzites (ancient sandstones) which mostly occur as ridges, marbles (ancient limestone), and other calcareous and relics of highly altered clayey sediments and igneous rocks. Most of the Basement Complex terrains are underlain by belts of roughly north-south trending, slightly metamorphosed ancient Precambrian sedimentary and volcanic rocks. The metasediments constitute the schist belts of Nigeria (McCurry, 1976). The schist belts are believed to be Upper Proterozoic relics of a supra crustal cover which was folded into the migmatite-gneiss complex (Russ, 1957: McCurry, 1973). Examples of schist belts of north western Nigeeria include: Zuru, Anka, Maru, Wonaka, Malumfashi, Kushaka, Birnin Gwari, and Kazaure schist belt.

2.1.3 Older Granite

The Older Granites are the magmatic products of the Pan African Orogeny. They are widespread throughout the Basement Complex and occur as large circular masses within the schist and older migmatite gneiss complexes (McCurry, 1976; Ajibade and Fitches, 1988). They are composed of quartz, feldspar and biotite and weakly foliated and massive. These Pan- African granitoids are called the Older Granites in Nigeria to distinguish them from the Mesozoic, tin bearing granite complexes of Central Nigeria which are referred to as the Younger Granites (Ajibade *et al.*, 1989).

2.2 Review of the Hydrogeology of the Area

Crystalline rocks weather more easily and deeply under more humid conditions, and more water is available for storage under rainy conditions. But in arid and semi arid conditions, the extent of weathering, fracturing and erosion is generally limited (Offodile, 2002). Despite this limitation, the prolonged weathering under tropical conditions has produced a lithologic sequence of unconsolidated materials whose thicknesses and lateral extents vary extensively. The localization of groundwater within the lithologic zones is controlled by a number of factors such as type of parent rock, depth, extent and pattern of weathering, thickness of the weathered material, the sand/clay ratio and the degree of fracturing, fissuring and jointing (Amadi and Teme, 1987). Groundwater in the basement complex is unpredictable because potential good aquifers are localized and not widespread; Furthermore, physical make-up of the rock vis-a-vis development of structures development of structures is generally not favourable for storage and transmission of economic supply of water (Dunama, 2000). Groundwater occurs under water table conditions in weathered and fractured zones of the basement rocks and in overlying alluvium (Bankole, 1983).

There are two types of aquifers in the study area: The “soft overburden aquifer” and the “fractured crystalline aquifer”. Groundwater occurs in the two major aquifers which include the fractured crystalline aquifers and the soft overburden aquifers. These aquifers are interconnected and form one hydraulic system with an unconfined water table (Figure 2)

Fractured crystalline aquifers contain water in amounts on which open blasted wells and boreholes can be based but only in tectonically fractured zones (Schoeneich and Aku, 1998). These major tectonically fractured zones extend under the cover of the soft overburden and may be located by geophysical techniques.

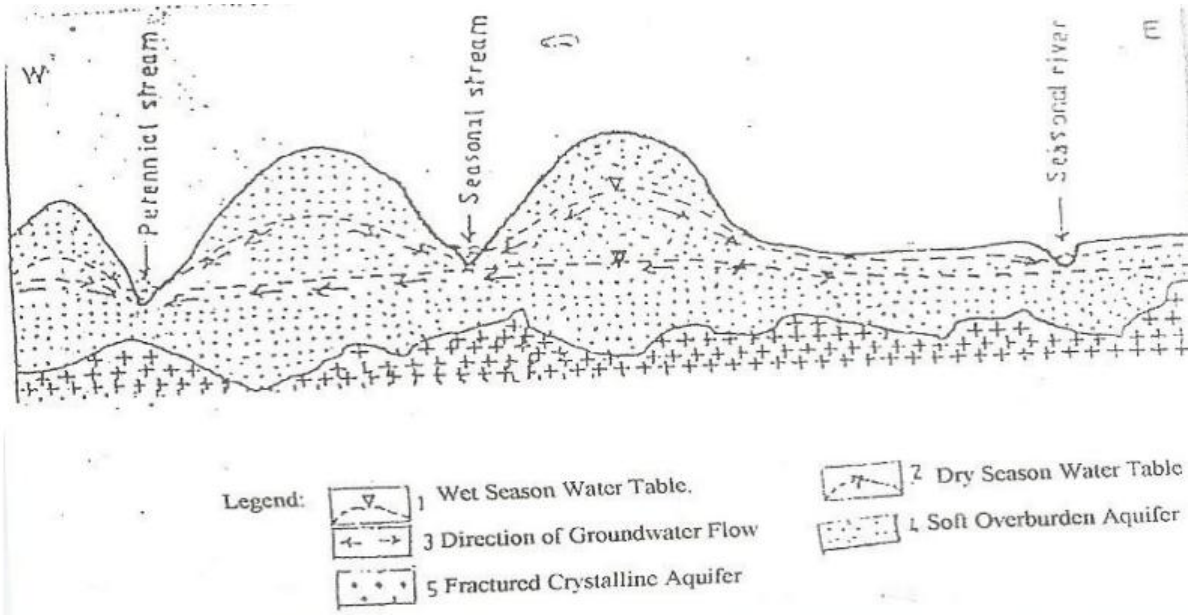


Figure 2: Schematic section showing relationship between soft overburden aquifer and fractured crystalline aquifer (Schoeneich, 1999).

Adanu (1987) stressed that in the basement region, groundwater usually occurs at depths of less than 50 m below the ground surface. In many areas shallow groundwater occurs at depths of less than 15 m in weathered mantle and in alluvium, both of which overlie the fractured bedrock.

The soft overburden aquifers consist of predominantly clayey material of alluvial, eluvial and deluvial origin, as well as in-situ chemical weathering of crystalline rocks namely granites and metamorphic rocks. The soft overburden aquifers can provide adequate yields that can sustain boreholes (Schoeneich and Aku, 1998). These yields depend on the thickness of the regolith that covers the fractured granite (Adamu, 2004).

The "volcanic aquifer" rests mainly on the soft overburden aquifer. It consists mainly of basalt interbedded with volcanic ash which allows it to be tapped jointly with the soft overburden aquifer (Schoeneich and Aku, 1998)

2.3 Development of Dams in Nigeria

During the past three decades, Nigeria has witnessed an upsurge in dam construction. Between 1970 and 1995, 246 dams were constructed in the country (Federal Ministry of Water Resources and Rural Development's Register of Dams 1995). The effect of the Sahelian drought of 1972-1975 aggravated the already stressed food situation in the country, prompting the various levels of government to embark on a rigorous policy to increase food production. To achieve this, the impoundment of rivers was seen as necessary to provide sufficient water for year-round irrigation which led to the construction of over 246 dams (Imervbore *et al*, 1986).

According to Ofoezie (2002), a total of 323 dams have been constructed and many more are under construction. Of the 323 dams 106 are large dams (dams with walls higher than 15m, or 10-15 m high with crest lengths of over 500 m, or having a reservoir capacity of 1million m^3); 27 are medium-sized dams (with walls 8-10 m high); and 192 are small dams (walls less than 8 m) Figure 3.

The Nigeria Register of Dam published by the Federal Ministry of Water Resources and Rural Development in 1995 has a record of 145 dams among which is Mairuwa Dam. (Table I)

In the Compendium of Nigerian Dams, 2007 there are 201 dams listed in alphabetical order indicating type, uses, location and other relevant statistics with visuals of the dam. Mairuwa Dam is one of these dams (Table 2)

The volume of water contained in all Nigerian dams was calculated by Schoeneich, (2003) to be 40.3 km^3. However, the capacity of all dams in Nigeria is estimated to be 44.2 km^3 (FAO, 2008).

Table 1: Mairuwa dam statistics (Nigeria Register of Dams, 1995)

Name	MAIRUWA
Hydrological Area	1
Owner	KATSINA SW. B
Longitude	7^0 15’
Latitude	11^0 30’
River	SOKOTO
Nearest town	FUNTUA
State	KATSINA
Type of Dam	EARTHFILL
Purpose	WS, IR
Engineering	KIRK GRUNDY
Construction by	DELBATO
Year of Completion	1970
Crest Length (m)	457
Maximum Height (m)	12
Catchment Area (km^2)	120
Reservoir Storage Capacity (mcm)	5.5
Dead Storage Capacity (mcm)	0.2
Active Storage Capacity (mcm)	5.3
Spillway Type	OGEE

2.4 Problems and Constraints of Consruction and Management of Dams in Nigeria

Akanmu *et al.,* (2007) recognized the following as part of the problems of reservoir water operation in Nigeria:

2.4.1 Excessive reservoir capacity against river flow

This is applicable in the northern region of Nigeria and has been the result of insufficient feasibility studies including hydrological analysis and project planning.

2.4.2 Large evaporation loss from reservoir surface

In the north region where the rather flat topography created the extensive reservoir areas, the evaporation amounts to 20 to 30 percent of the active reservoir capacity, and this may hamper the effective utilization of the limited scarce resources

Table 2: Mairuwa dam statistics (Department of Dams and Reservoir Operation, 2007)

NAME:	MAIRUWA DAM
CATEGORY:	LARGE
HYDROLOGICAL ZONE:	1
RIVER:	SOKOTO
STATE:	KATSINA
LGA :	FUNTUA
LONGITUDE:	7^0 15’
LATITUDE:	11^0 30’
HEIGHT ABOVE SEA LEVEL:	654M
DAM OWNER :	KT. S.W.B.
TYPE OF DAM:	EARTHFILL
HEIGHT OF DAM :	12M
CREST LENGTH:	457M
RESERVOIR AREA :	
RESERVOIR CAPACITY:	5.5MCM
SPILLWAY TYPE:	OGEE
SPILLWAY DESIGN FLOOD :	
INSTRUMENTATION:	
PURPOSE:	WS & IR
DIRECTN USER	
YEAR OF COMPLETION	1970
AVERAGE MONTHLY SPILL PERIOD	
CONSULTING ENGINEER	KIRKRUNDY
CONTRACTOR	DALBERTO

.2.4.3 Downstream release of reservoir water

It appears that there is the lack of consideration on the reservoir water operation to satisfy the downstream requirements other than the government public schemes. A critical example is the Hadejia-Nguru wetland which requires the artificial flood release from the upstream dams in the wet season to maintain various water uses of the indigenous activities.

2.4.4 Water availability of existing reservoir

The Japanese International Cooperation Agency (JICA) Team in 1995 attempted to evaluate this factor on a preliminary basis taking into account the carry-over for dry year, excessive evaporation loss and downstream water demand. In particular a preliminary analysis of the reservoir operation for 11 representative cases in the north and central-east region was

conducted to estimate the after availability of, on the basis of which the following have been compiled. Nigeria is divided into six hydrological areas.(Table 3 and T able 4)

Table 3: Hydrological Areas (HA) of Nigeria (JICA, 1995)

No	Regions	Hydrological Areas (HA)	States
1	North West	HA I (Niger-North)	Kebbi, Sokoto, Katsina (3)
2	North East	HA-VII (Lake Chad)	Kano, Jigawa, Yobe, Borno, Bauchi (5)
3	Central West	HA- II (Niger-Central)	Niger, Kwara, Kaduna, Kogi, Abuja FCT (5)
4	Central East	HAs-III & IV Upper Benue and Lower Benue.	Adamawa, Taraba, Plateau, Benue (4)
5	South West	HA-VI (Western Littoral)	Oyo, Ogun, Osun, Lagos, Ondo, Edo, Delta (7)
6	South East	Has-V & VII (Niger South & Eastern Littoral)	Anambra, Imo, River, Enugu, Abia, Akwa Ibom, Cross River.

Table 4: Utilization of reservoir water (Akanmu *et al*., (2007)

Unit: 10^5cu.m							
	NW HA1	NE HA-VII	CW HA-II	CE HA-III/IV	SW HA-VI	SE HA-V/VII	TOTAL
Active reservoir capacity	1,750	5,940	940	2,340	1,030	50	12,050
Possible Water use	980	2,120	790	1,620	890	60	6,460
Irrigation	580	1,120	380	1,160	490	30	3,760
Water supply	130	270	330	200	350	30	1,310
Downstream Environment	270	730	80	260	50	0	1,390
Water Use Rate: 2/1 (%)	56	36	84	69	86	120	54

2.4.5 Slow utilization of reservoir water

Most reservoirs in Nigeria are underutilized. Reservoirs are built without proper feasibility studies and as such there is always a considerable gap between the contructon and the actual water use in the downsteam service areas which may imply unfavourable return from huge investment for the dam.

2.4.6 Dam safety

There are technical defects with many existing dams including seepage through dam foundation works, shortage of spillage flood capacity, decrease of effective storage due to excessive sediment inflow, damage of gates and valves due to reckless operations, vegetation growth, severe erosion on dam slopes and extensive aquatic weed development over the reservoir area. When nothing is done to rectify these problems, dams may constitute a significant potential hazard to the downstream people and societies.

2.4.7 Operation and maientenance

Operation and maintenance while for large dams is being carried out to a certain extent, many of the small and medium-scale dams are facing difficulties due to the lack of technical data, equipment and access roads.

In addition, Okoye and Achakpa (2007) identified the following as part of the problems of dam operations in Nigeria:

2.4.8 Failure of environmental impact assessment (EIA)

Environmental Impact Assessment (EIA) frequently fails to influence decision making. EIA consists mostly of measures to compensate for or mitigate the planned impacts and render them acceptable when the decision to proceed has already been taken. Most dam proponents see EIA as an administrative hurdle to be cleared or a requirement to secure funding. Often large political, technical and financial investment has been made before the EIA is even launched.

2.4.9 Lack of participation and transparency

The World Commission on Dams (2000) found out that there has been a general failure to include and recognize affected people and empower them to participate in decision making. Insufficient time, resources and information have been made available for public consultations. Opportunities for participation, when provided, often occur late in the process and are limited in scope. This has magnified the negative impacts of such projects and alienated communities, leading not only to serious social impact but also schedule delays, cost overruns and poor financial and economic performance.

2.4.10 lack of compliance with guidelines/commitments

Poor outcomes and mistrust stem from the failure of dam proponents and financing agencies to fulfill commitments and abide by internal guidelines. Conflicts remain largely unresolved and past impacts largely unmitigated.

2.5 Sedimentation of Reservoirs

Sediment is composed of eroded materials of different shapes and sizes carried by streams or rivers. Sediment load can be classified into three categories: bedload, solute (dissolved) load and suspended load (Ritter, 2006). The sediment generated within a catchment area of the river is subsequently moved from a drainage basin to be deposited in flood plains; in storage reservoirs or carried off to the sea. Sediment is deposited when water velocity decreases to such an extent that particle movement is impossible (Oyegun, 1980). Erosion of land surface yields sediments which are transported by rivers. According to the most comprehensive study, the global erosion rate is 0.088 mm/year (White, 2000).

Ousmane (2008) observed that the rate of erosion is very variable and depends on complex interaction of the following factors:

- Climate: precipitation and run-off, temperature, wind speed and direction.

- Geotechnics: geology, volcanic and tectonic activity
- Topography: slope, catchment orientation, drainage basin area and drainage density.
- Vegetative cover.
- Land use and human impact.

The rate of which a reservoir silts up depends on the amount of silt carried by the river which feeds it and that in turn depends on the rate of erosion in the river's catchment area. Where that catchment area is forested, the soil is not easily eroded due to the network of roots which underlies the forest floor, and is also protected from the effect of wind and rain erosion by the forest canopy above (Goldsmith and Hildyard, 1984). In those areas where forest cover has been depleted, however, the rate of erosion increases drastically, the organically poor soils of the tropics are particularly vulnerable to erosion.

The life time of a reservoir depends on several natural factors among which climatic parameters and geologic-geographic factors are the most important. As a matter of fact these factors also determine the sediment production.

The World Commission on Dams (2000) estimated that 0.5 to 1% of world reservoir volume is lost due to sedimentation annually. Sedimentation can affect a project's physical and economic performance and eventually affect project's life by filling the reservoir storage area.

At the United Nations Environment Programmes's International Conference on Fresh Water (UNEP, 2001), it was reported that many of the world's reservoirs upon which billions of people depend for drinking water and food production, are suffering significant reductions in storage capacity as a result of sedimentation. The current storage capacity of reservoirs worldwide was estimated at just less than 7,000 cubic kilometres. Unless urgent action is

taken, a fifth of this or some 1,500 cubic kilometres will be gradually lost over the coming decade. Experts feared that the loss could be even higher and faster if the scientific forecasts on climate change prove sound and the rate of deforestation in the developing world is not checked.

Sudden loss of the world reservoir capacity would be a catastrophe of unprecedented magnitude, yet their gradual loss due to sedimentation receives little attention or corrective action especially in Nigeria.

Existing reservoirs generally occupy the best available locations with respect to water availability, site geology and proximity to demand areas. These sites offer geologic and hydrologic conditions suitable for dam construction and are located appropriately for the intended users. Sedimented reservoirs therefore, cannot be replaced by new dams at new sites, and many of today's reservoirs are irreplaceable because of unique site characteristics.

Iguisi (1997) carried out an assessment of the current level of sedimentation of the Kubanni Dam. He found out that the lake had lost a substantial part of its depth to sedimentation process caused by high rate of erosion over the catchment area. In about 24 years the lake was constructed, it has lost about 3.3 m depth representing about 30% storage loss. He concluded that if this present rate of siltation continues, the lake can become completely silted up and turned into weed-infested marshes in another 30 years.

In 2008, the A.B.U committee on protection of the Kubanni Dam Drainage Basin came out with a report titled Result of Measurement of Remaining Storage and the Rate of Siltation in A.B.U. Kubanni Reservoir. According to this report, 'if action is not taken, water rationing in the campus, caused by progressive siltation of the Kubanni impounding reservoir, will start in dry season of 2022. Gradually it will develop to no water in dry season starting from 2039, and complete siltation of the reservoir in year 2059'' (Table 5).

There is significant difference between Iguisi (1997) result and that of the the A.B.U committee on protection of the Kubanni Dam Drainage Basin (2008) because Iguisi (1997) measurement was done when the spillway was not flowing, i.e. depth measurements of the reservoir are not referenced to the level of the spillway.

Table 5. Important dates in the life of Kubanni impounding reservoir (A.B.U. Committee on Protection of the Kubanni Dam Drainage Basin, (2008)

YEAR	DRY SEASON	WET SEASON
2059	No water for the Campus	No water for the Campus
2039	No water for the Campus	Rationing of water starts
2022	Rationing of water starts	Still more water than enough
2008	More water than enough	More water than enough

The committee's recommendations included:

- Afforestation of the Kubanni Drainage Basin,
- Construction of five weirs-acting as sediment traps on five tributaries of the dam and
- Manual excavation of the sediment from the dam..

Baba *et al.*, (2009) carried out the measurement and rate of siltation of the Ahmadu Bello University Farm Lake at Zaria. The University Farm Lake is an abandoned impounding reservoir constructed around 1966 with original storage capacity of 636,300m^3. They measured the remaining storage capacity of the reservoir as 349,911m^3 and calculated rate of siltation between year 1966 and 2009 as 6,600m^3/y, and the rate of erosion in the drainage basin in the same period as 0.559mm/m^2/y. The safe yield during 176 days of dry season as non existing because after deduction of 272700 m^3 of environmental reserve – minimum necessary to preserve aquatic life, there is no active storage left.

Vulegbo (2012) measured the remaining storage and the rate of siltation of Tagwai dam in Niger state North Central Nigeria and found the remaining storage of the reservoir to be 21,650,648m^3 as against the original volume of 28 x 10^3 in 1978 when the dam was constructed.This corresponds to annual siltation of 207,792.25m^3/year. Tagwai impounding reservoir if unchecked and allow to continue at the present rate of 0.73% of the original volume/year will result in the disappearance of the reservoir in the year 2114. The rate of shrinkage of the surface area of the reservoir is 1% of the original surface area per year i.e. the open surface of the reservoir will cease to exist in the year 2079. However, long before it ceases to exist, due to siltation, the reservoir will stop to serve its purpose.

Kudamniya, 2012 carried out the determination of the remaining storage in the Zaria Impounding Reservoir in 2010. The remaining storage was found to be 21,129,242m^3 since construction in 1974 representing 54% of the initial storage volume. The siltation rate was estimated at 685,299m^3/year and if the present rate of siltation continues, the reservoir can become completely silted up and turned into weed infested marshes by 2042. Volume of eroded material within the catchment area of the Zaria Impounding Reservoir was 919,742m^3/year. This is equivalent to an average depth of erosion of 0.3mm/year.

CHAPTER 3

MATERIALS AND METHODOLOGY

3.1 Field Work of the Study Area

The study was done in stages which include fieldwork and interpretation of results. The fieldwork lasted for a period of one year during which data were obtained. Data were collected through the following activities:

- Measurement of the remaining storage of the impounding reservoir
- Delineation from the land, edge of the open watertable at the time of spillway flowing
- Measurement of the rate of erosion in the impounding reservoir's drainage basin
- Measurement of depth to watertable in hand dug wells located within the study area
- Geological mapping of the study area.

3.2 Measurement of the Remaining Storage of Mairuwa Reservoir

The measurement was done on the 16th and 17th of July 2011, with the spillway flowing (Plate 1). Depth, in metres to watertable, was measured from a fishing boat (Plate 2) with metric tape having a weight tied to its end. Points of measurement were located with a Garmin Oregon 550T satellite navigator with horizontal accuracy of three metres. The boat was not anchored for the time of depth reading, but immobilized with paddles. The measuring tape is released from the boat and lowered down until the heavy object touches the bottom of the reservoir. The calibration on the tape at the point of interception between the tape and the reservoir's water surface is read and recorded. This is the remaining depth measured in metres at that particular station point. The same procedure was repeated for all sampling points within the extent of the reservoir. The result of depth measurements are shown in Table 7 and are located on the map of remaining storage (Bathymetric Map) in Figure 3.

3.2.1 Delineation of the open watertable

The edge of the water table was located with the same satellite navigator on the 18th and the 19th of July 2011 still with the spillway flowing. Results of water edge location are presented in (Appendix I) and in (Figure 3). The edge of the water table was not always easily accessible, often separated from dry land by a few meters swampy belt from where ground water was seeping to the lake. In order to determine the area of the open water table, points indicating boundaries of the edge of water were mapped by taking the coordinates of selected station points one after the other along station points. This is repeated for several points round the impounding reservoir. These coordinates were plotted to indicate the boundaries of the reservoir on the bathymetric map on Figure 3. The outline of the edge of water table obtained from the field was compared with the open water table from European Space Agency (ESA) Google Earth Satellite Image downloaded from the internet on 15th November, 2012 .(Plate 3)

3.2.2: Preparation of bathymetric map

Results of water depth measurements from Appendix 1 and result of location of edge of water table shown in Appendix II, (with Google Earth image in Plate 1 added to help in demarcation of surface water from dry land), were used to plot the map of remaining storage shown in Figure 3.

3.2.3: Determination of Surface Area of open watertable.

The area bounded by water body was measured by least square method using graph paper. A graph paper was superimposed on the bathymetric map. The number of square boxes bounded by two succeeding isobaths is counted. Correction is done for both the area of one

small square box by taking measurement of any chosen length along both the vertical and



Plate 1: Spillway flowing at time the of measurement (16th July, 2011)



Plate I1: Measurement of the Remaining Storage of Mairuwa Dam on the 16 of July, 2011.



Plate III: Satellite image showing Mairuwa Impoounding Reservoir (Source: Google Earth)

horizontal axis of the graph paper. The length corresponding to a chosen number of small boxes is measured and recorded along the vertical and horizontal axis respectively. This is the corrected length on each axis on paper. The area of one small box, obtained by multiplying the lengths along each axis together is the area on ground using the scale of bathymetric map prepared already. Finally, the number of small boxes counted between successive isobaths is multiplied by the surface area of equivalent to one square box on the ground in order to determine the surface area. The procedure is repeated for all successive isobaths within the entire surface area of the reservoir (Table 6).

3.2.4 Calculating the volume of the remaining storage

Average depth of each interval is determined. The area which is enclosed between successive isobaths was calculated and then multiplied by the average depth obtained. This gives the volume for that particular depth interval. Sum of the individual volume calculated for each

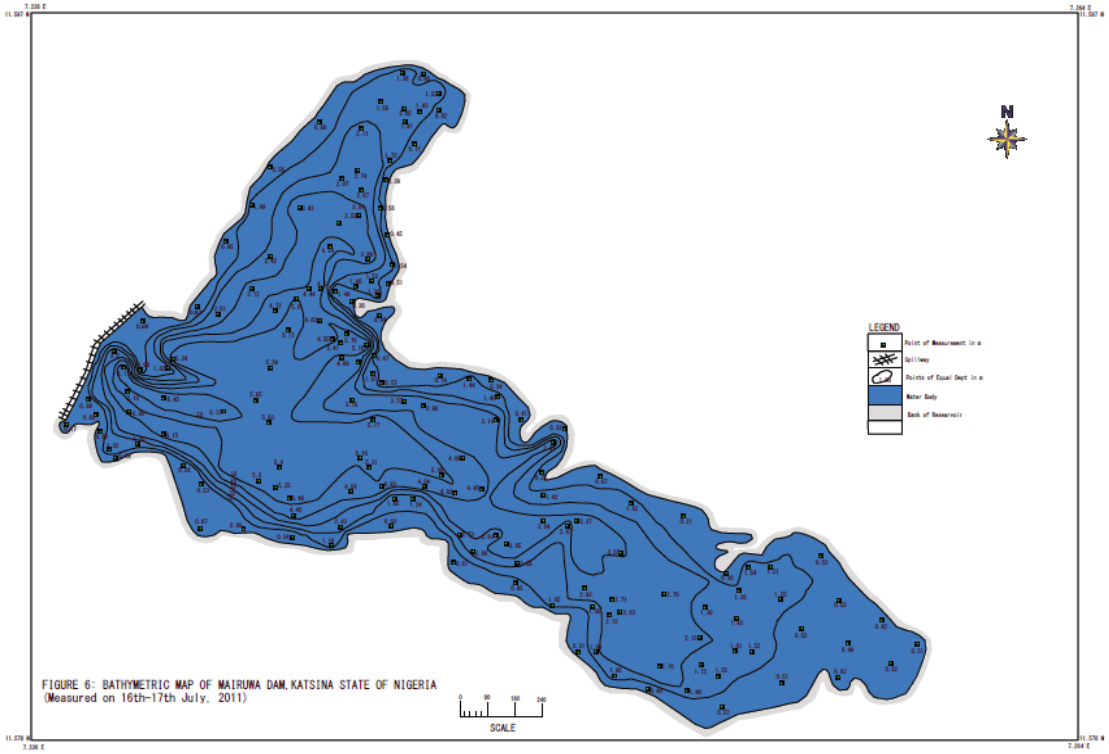


Figure 3: Bathymetric Map of Mairuwa Impounding Reservoir

successive isobaths was determined (Table 7). This is the volume of the remaining storage for Mairuwa impounding reservoir.

3.3 Determination of the Rate of Erosion in the Drainage Basin

In order to determine the rate of erosion within the reservoir drainage basin, the area of the drainage basin was demarcated from the base map of scale 1:57, 5000. A graph paper was thereby imposed and the extent of the drainage basin was drawn. The numbers of the small and the big squares were counted. From the scale of the map, 1mm on paper represents 57,500m on ground. The area of the drainage basin was calculated

3.3.1 Calculation of the area of drainage basin:

Scale of the map on which calculation is done is 1:57,500.

$1mm^2$ on scale 1: 57,500 is 57.5 m x 57.5 m = 3,306.25 m^2

Graph paper was used, there are 9,546 small boxes covering the drainage basin.

Area of one small box = 1.8 mm x 1.8 mm = 3.24 mm^2

Therefore the area of drainage basin on graph paper is 9,564 x $3.24m^2$ = 30,929 mm^2.

The same area of the drainage basin expressed in square metre on the ground is

30,929 mm^2 x 3,306.25 m^2/mm^2 = 102,259,006 m^2

Area of drainage basin = **102,259,006 m^2**

3.3.2 Volume of rainfall in the drainage basin:

Given that the depth of rainfall for Funtua area is 1000mm/a (Figure 4)

Therefore the volume of rainfall in the drainage basin will be

Area of the drainage basin x depth of rainfall in the drainage basin

102,259,006 m^2 x 1.0 m = **102,259,006 m^3**

3.3.3 Volume of total runoff:

Given that the run-off coefficient for the area is equal to 0.23 (Figure 5)

Therefore 1.0 m/a x 0.23 = 0.23 m/a = Depth of Total Runoff.

Volume of total run-off is Area of drainage basin multiplied by depth of total run-of is

102,259,006 m^2 x 0.23 m/a = 23,519,571 m^3

23,519,571 m^3 = Volume of total runoff.

3.3.4 Volume of suspended solids removed from the drainage basin:

Turbidity of the water in Mairuwa impounding reservoir is 0.5kg/m^3 of suspended solid.

Assuming that density of silty and clay particle eroded from the drainage basin is 2g/cm^3

= 2000kg/m^3

Through the reservoir flows, 23,519,571 m^3/a total run-off from the drainage basin

Therefore through the spillway flows

23,519,571m/a x 0.5kg/m^3 =11,759,785.5kg/a

Then the volume of suspended solid washed out from the drainage basin =

11,759,785.5kg/a: 2000kg/m^3: = **5,880m^3/a**

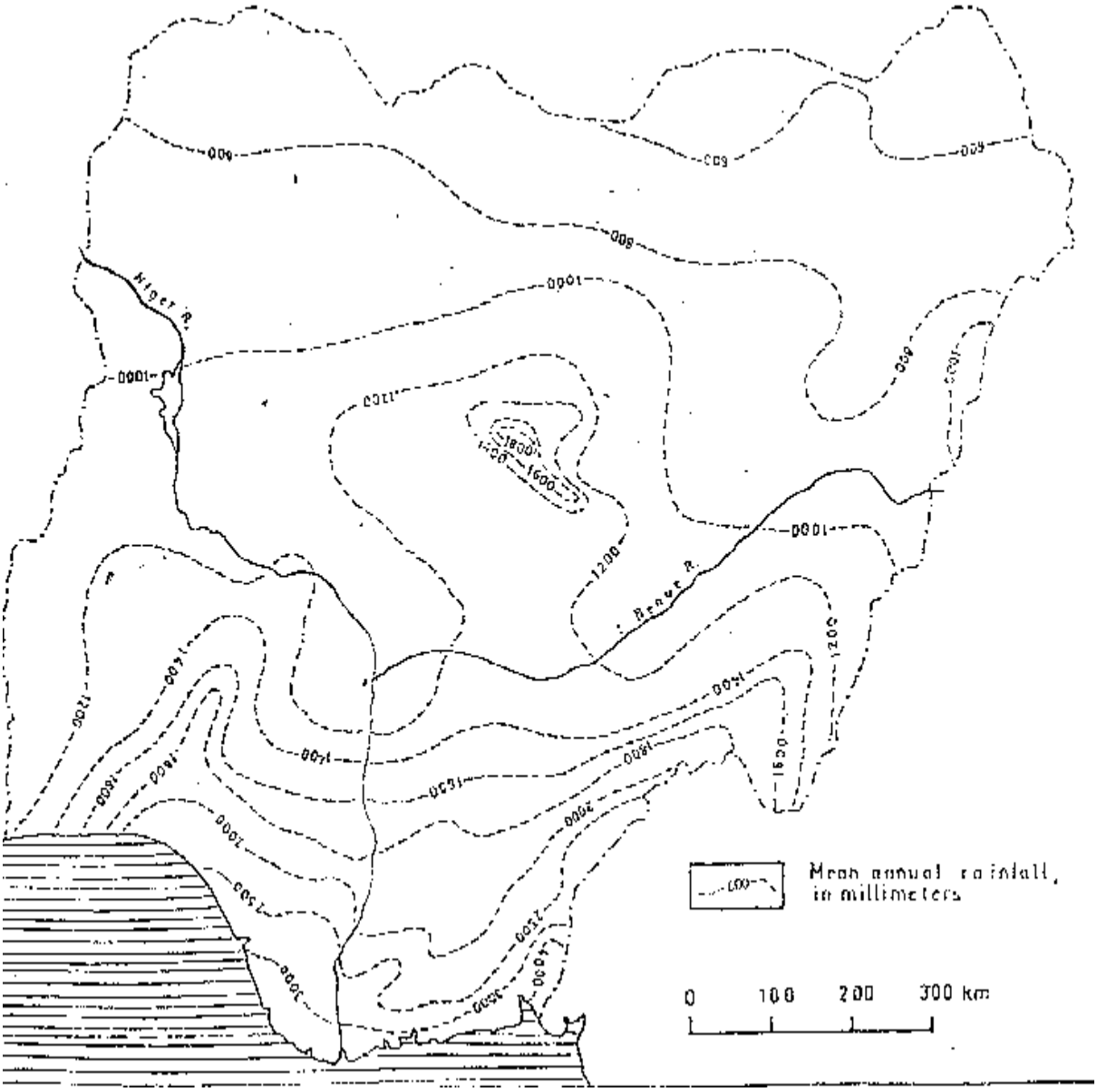


Figure 4: Regional distribution of mean annual rainfall in Nigeria (Schoeneich and Garba, 2010)

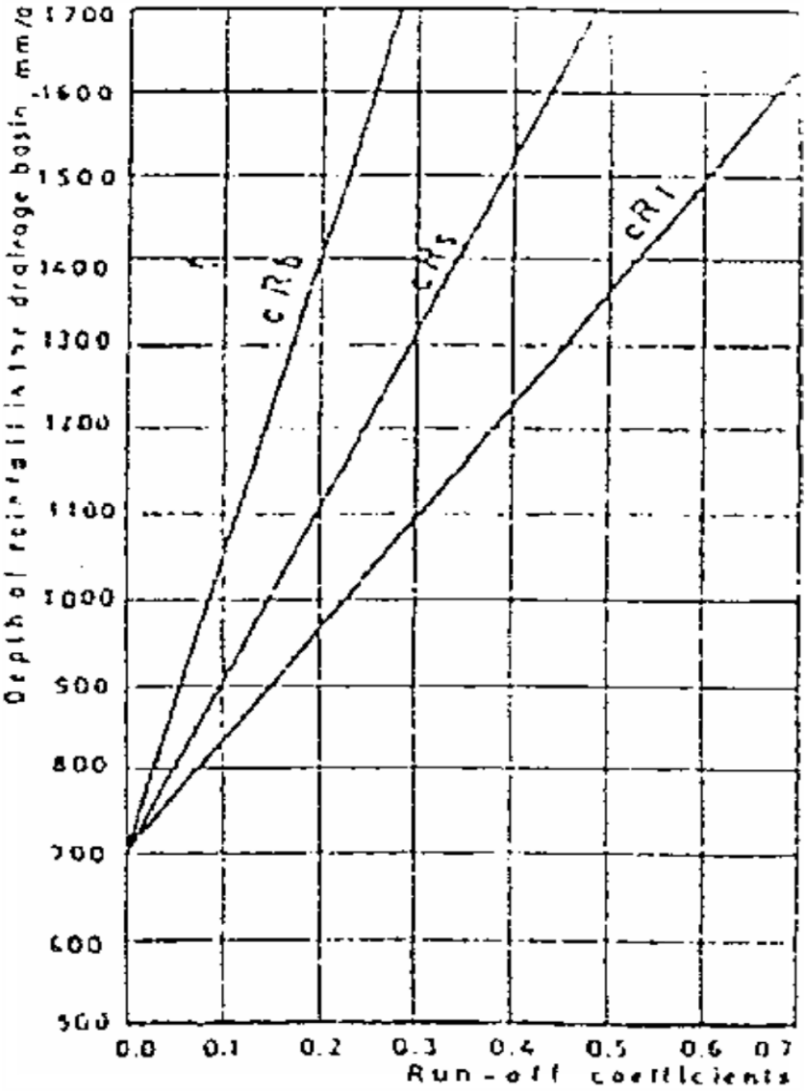


Figure 5: Correlation between Depth of Rainfall and Runoff Coefficient in Drainage Basins.Legend: cRt = total runoff coefficient; cRs = surface runoff coefficient; cRb = base flow coefficient, which is almost the same as infiltration coefficient. Note that rainfall 700 mm/a and less does not produce runoff. (Schoeneich and Garba, 2010).

3.3.5 Volume of dissolved solid removed from the drainage basin:

The average mineralization of water in the "Crystalline Hydrological Province of Nigeria". according to Schoeneich and Garba (2010), is 60 mg/l = 0.06 mg/cm^3.

Therefore weight of dissolved substance in 1 m^3 of water is 60 g.

Assuming that density of the dissolved solids in dry state is 1.5 g/cm^3,

Then 60 g/m^3:1.5 g/cm^3 = 40 cm^3/m^3.

40 cm^3/m^3 of dried dissolved solid = 0.00004 m^3/m^3.

Therefore total volume of the dissolved solid washed out from the drainage basin is

23,579,571 m^3 x 0.00004 = **943 m^3/a** .

The total load from the drainage basin was divided by the area of the drainage basin The bottom load, suspended load and the dissolved load were added to get the total load eroded to get the rate of erosion in the drainage basin (Table 10).

3.4 Preparation of the Watertable Configuration Map

Measurement of the watertable at the peak of wet season was done from 20th to 23th of July, 2011, while the measurement of the watertable in dry season was done on the 23th of April, 2012 (Plate IV). Most of the hand dug wells in the area are shallow. The coordinates of the wells were taken using the satellite navigators and care was taken to make sure the accuracy of the satellite navigator was not more than 3 metres, elevation of the wells in metres above sea level (asl) was taken. Depth to watertable was measured and subtracted from the elevation of the well to obtain the elevation to water table for each of the wells (Appendix III). Using the base map on a scale of 1:57,500; elevation to watertable for each of the wells for dry season was plotted. The water table configuration map showing the direction of groundwater flow was obtained (Figure 6)



Plate IV: Measurement of depth to water table in well

3.5 Geology of the Study Area

. Geological mapping was done using the Satellite Navigator and the following was achieved: (A) collection of samples using hammer (B) Measurement of structural trends using a geological compass. From the mapping exercise, a geological maps of the study area was produced in which the various lithological boundaries were delineated (Figure 7) and a geological cross section was produced from the geological map to show the thicknesses of the various lithologies in the study area.(Figure 8)

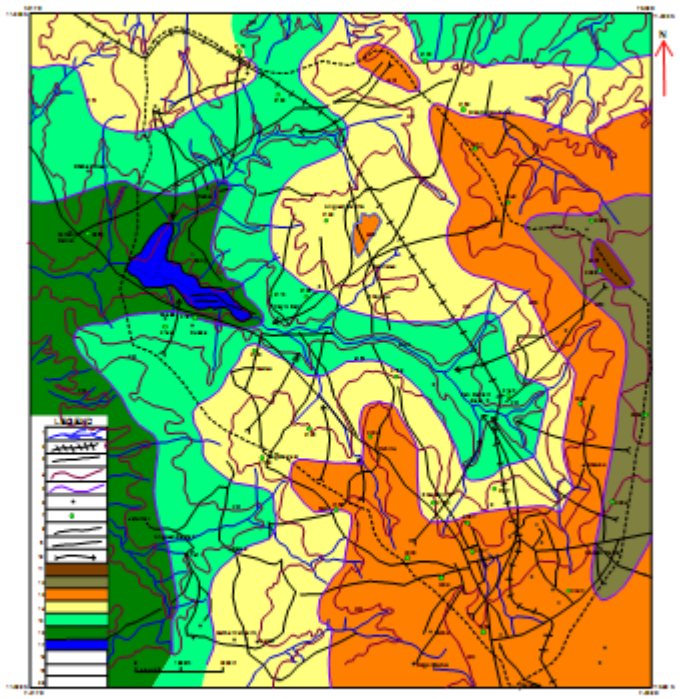


FIGURE 6: HYDROGEOLOGICAL MAP OF MAIRUWA DAMDRAINAGE BASIN DURINGDRY SEASON

CHAPTER 4

RESULTS

4.1 Result of Measurement of Depth of Storage of Mairuwa Impounding Reservoir

Results of water depth measurements from Appendix I and the results of location of edge of water table shown in Appendix II, (with Google Earth image in Plate1 added to help in demarcation of surface water from dry land), They were used to plot the map of remaining storage as shown in Figure 3. The area of the reservoir was calculated (Table 6). Table 7 shows that the remaining storage on the 17th of July 2011.

Table 6: Determination of reservoir area by least square method using graph paper.

INTERVALS (m)	0-1	1-2	2-3	3-4	4-5	5-6	>6
No of small boxes counted	1,401	847	874	710	546	708	58
Area (m^2)	409,764	247,731	255,628	207,661	159,694	207,076	16,964

Area of one small box = 2.0988 x 2.1795 = 4.5743 mm^2 = 4.57 mm^2

From the Bathymetric map of scale 1: 8,000

1 mm on paper represents 8 m on the ground

Therefore 1mm^2 = 64 m^2 on ground

Hence area of 1 small square box = 4.57 mm^2 on paper = 4.57 x 64 m^2/ 1 m^2 on ground

1 small square box = 292.48 m^2 on ground

Table 7: Calculation for the remaining storage of Mairuwa impounding reservoir

INTERVAL (m)	AREA (m^2)	AVERAGE DEPTH (m)	VOLUME (m^3)
0-1	409,764	0.50	204,882
1-2	249,931	1.50	371,597
2-3	255,628	2.50	639,070
3-4	207,661	3.50	726,814
4-5	159,694	4.50	718.623
5-6	207,076	5.50	1,138,914
>6	16,964	6.25	106,025
TOTAL	**1,504,518**	**2.60**	**3,905,929**

The current calculated storage of the Mairuwa Dam is **3,905,929 m^3**

4.2 Calculating the Rate of Siltation of Mairuwa Impounding Reservoir

Loss in volume due to siltation from the date of impoundment =

Original storage – present calculated storage = 5.5 x 10^6 – 3,905,929 = 1,594,071 m^3

Given that the year of impoundment of Mairuwa dam is 1970,

Year of impoundment to 2011 = 41 years

Therefore rate of siltation = 1,594,071/41 = **38,880 m^3/year**

4.3: Calculating the Rate of Erosion in the Drainage Basin

Table 8: Total volume of material eroded from the drainage basin:

Material	Volume (m^3/a)
Bottom load	38,880
Suspended load	5,880
Dissolved load	943
TOTAL	45,703

From Table 10, Total volume load eroded from the drainage basin is **45,703 m^3/a.**

Then rate of erosion in the drainage basin is 45,703 m^3/a**:** 102,259,006 m^2 =

0.00045 m^3/a = 0.45 mm^3.

The rate of erosion in the drainage basin is **0.45 mm/a**

The rate of erosion of 0.45mm/a in Mairuwa drainage basin is comparable with the thickness of bottom load deposited at the bottom of the reservoir, plus suspended load and dissolved load (Table 8) carried away through the spillway all added together, spread uniformly on the surface of the drainage basin.

4.4 Geology of the Study Area

The study area is underlain by the Precambrian basement rocks. These rocks are the migmatite-gneisses, schist and granites.

4.4.1 Migmatite-gneisses

The migmatite-gneisses are the major rock types found within the study area (Figure 7) and (Plate V). They comprise two main types, the biotite gneisses and the banded gneisses. The biotite gneisses are normally fine to medium grained to coarse porphyloblastic with strong foliation caused by the parallel arrangement of alternating dark and light minerals. The banded gneisses shows alternating light-colored and dark bands and exhibit intricate folding of their bands and sometimes have variable joint direction with quartz mineralization. They are composed essentially of feldspars, quartz and biotite. The migmatite-gneiss complex is the oldest basement rock dated as Birrimian in age (about 2500 m.y), and is believed to be of sedimentary origin but was later profoundly altered into metamorphic and granitic conditions (McCurry, 1970).

4.4.2 Schist

The schist was found well exposed in a borrow pit around Angwan Dahiru. It is not as widespread in the study area as the migmatite-gneiss (Figure 8). The schist belongs to the metasediments. It is the earliest rocks to form on the Nigerian basement complex. Initially of sedimentary origin, it underwent prolonged, repeated metamorphism (McCurry, 1970).

. The schist here is part of the Malumfashi schist belt..

4.4.3 Older granites

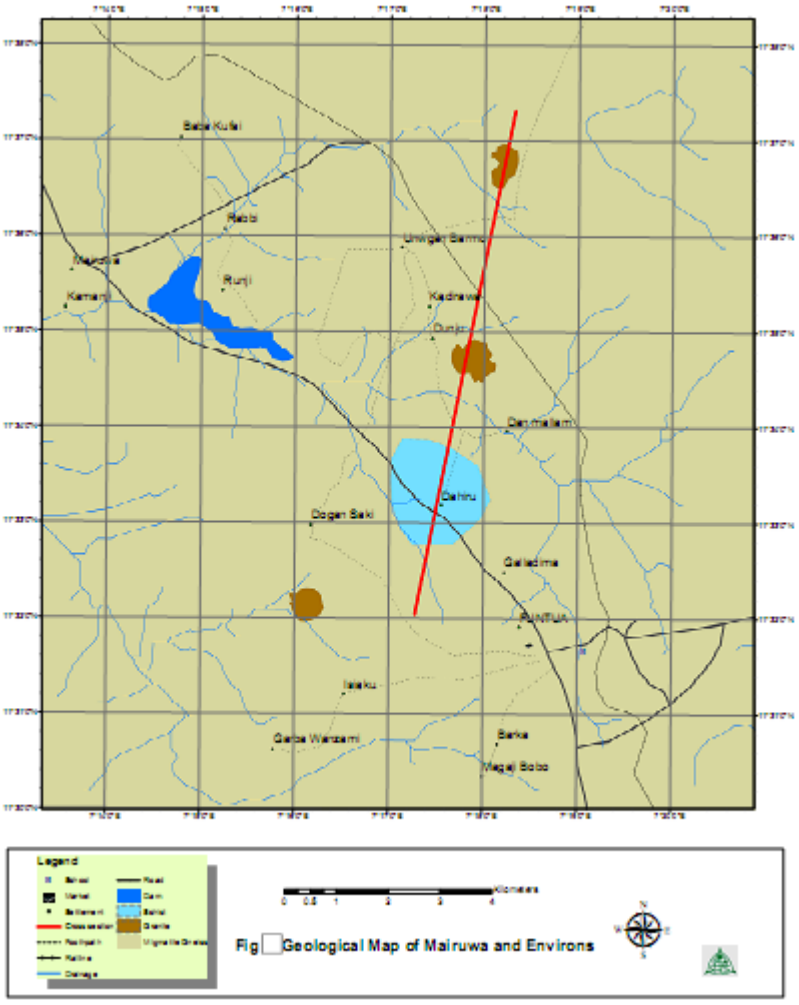
Granites are found in the study area scattered in some few areas. Older Granites are the magmatic products of the Pan African Orogeny. They are widespread throughout the Basement Complex and occur as large circular masses within the schist and the older migmatite-gneiss complexes (McCurry, 1973). The Older Granites varies extensively in

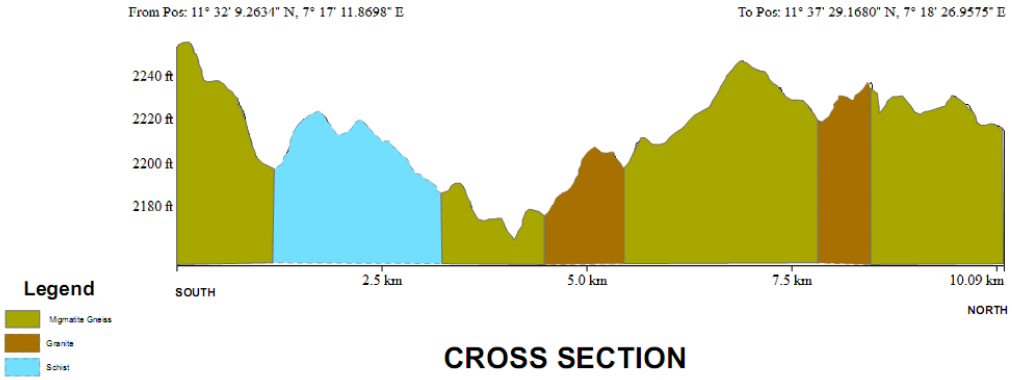


Plate V: Outcrop of migmatite



Plate VI: An outcrop of highly weathered schist at ($N11^{O}$ 33' 26.1'' $E07^{0}$ 17' 31.0'')


Legend
Kilometers
Fig Geological Map of Mairuwa and Environs



CROSS SECTION

composition. They are composed of quartz, feldspars and biotite and are weakly foliated and massive. When fresh, they are grayish-blue due to the presence of biotite, and when weathered, they exhibit brownish coloration.

4.5 Records of Water Production from Mairuwa Dam

The record of monthly water production from Mairuwa Dam for the year 2010 and 2011 was collected from the Funtua District office of the Katsina State Water Board. Tables of water production was made for the year 2010 and 2011, (Appendix V and Appendix VI respectively),. Charts indicating Raw water, Treated Water and Water Pumped to Service Tank was produced for 2010 and 2011; (Figure 9 and Figure 10) respectively. Also produced is a chart for the Monthly Total Operating Time for 2010 and 2011; (Figure 11 and Figure 12 respectively).

From study of this record, the following observations were made:

The difference between the treated water produced and the water pumped to the service tank is as a result of leakages in the pipes and the quantity of water used locally within the waterworks.

From Table 9, it can be seen that there is significant reduction in the amount of water pumped in year 2010 compared to year 2011 (by 38%). The total operating time in 2011 fell short of that of 2010 by 8%.

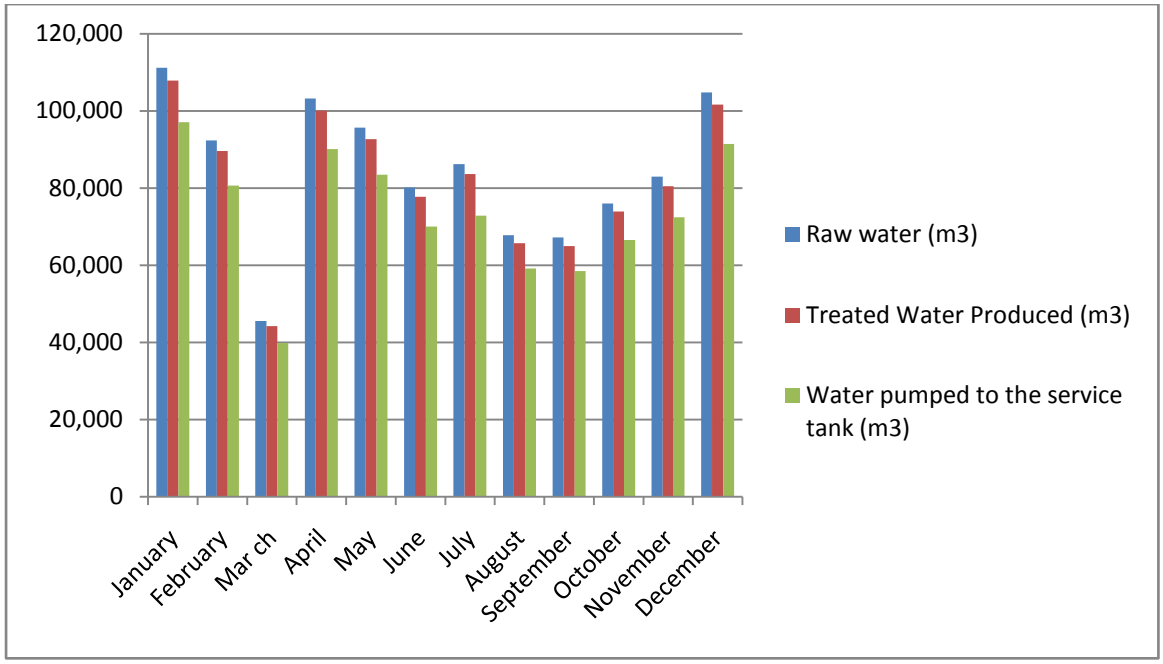


Figure 9: Monthly raw water, treated water and water pumped to the service tank from Mairuwa dam for year 2010

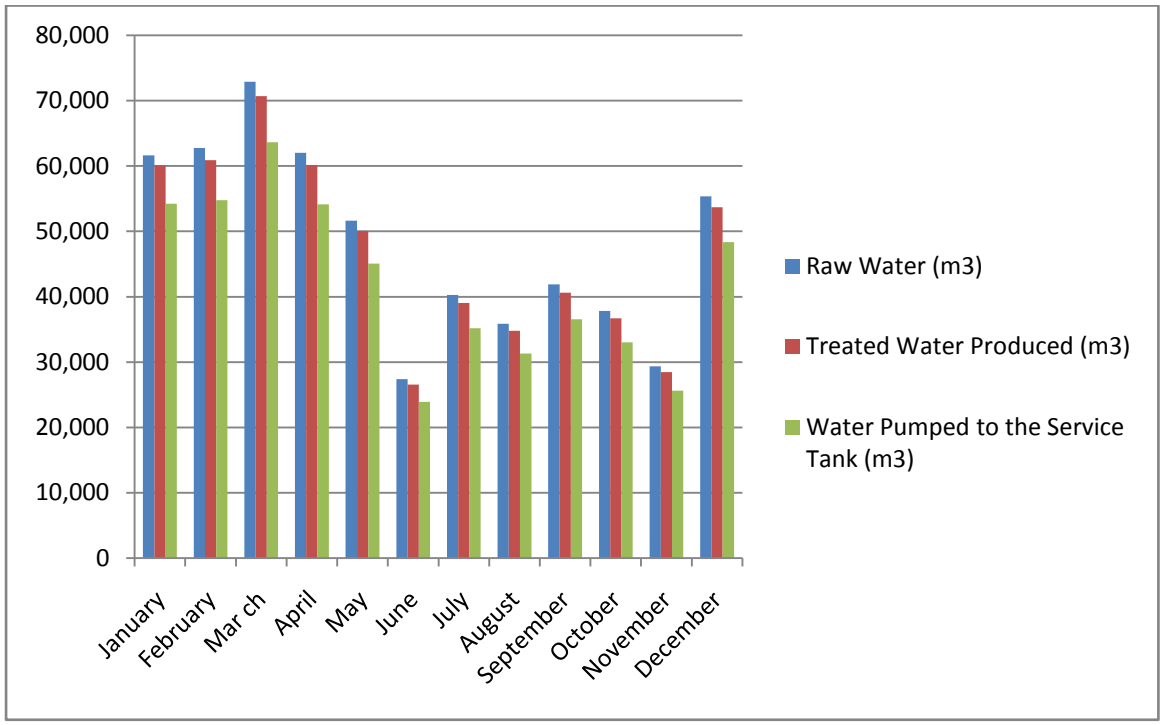


Figure 10: Monthly raw water, treated water and water pumped to the service tank from Mairuwa dam for year 2011

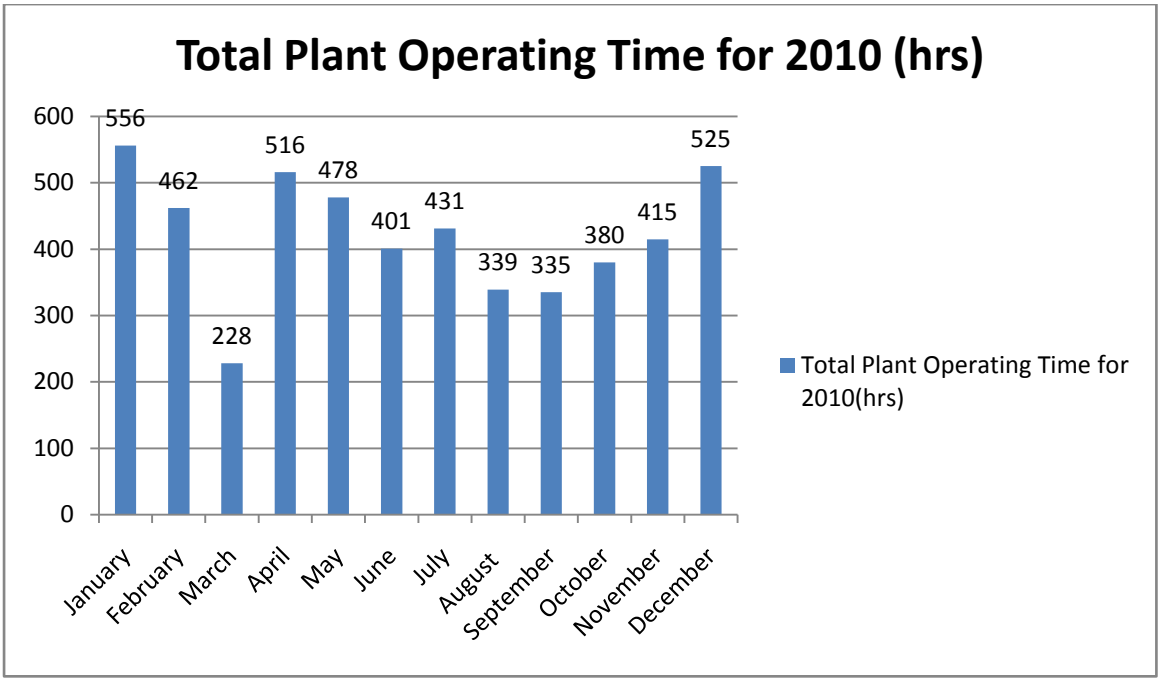


Figure 11: Monthly total operating time of mairuwa dam for year 2010.

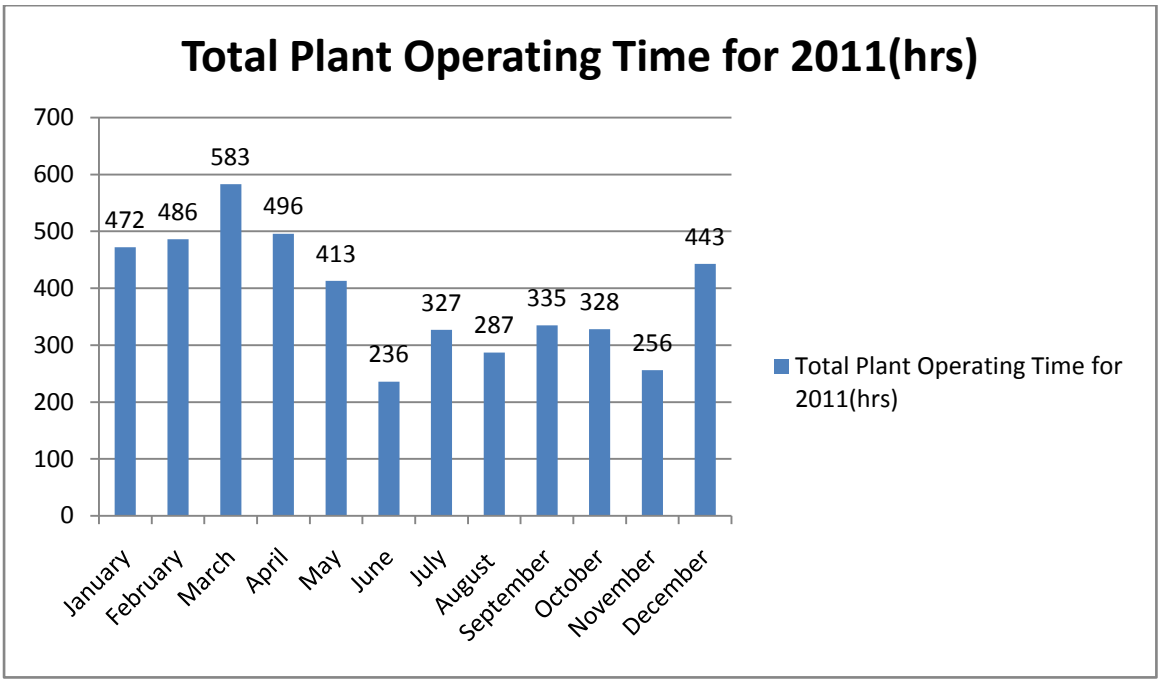


Figure 12: Monthly total operating time of mairuwa dam for year 2011.

Table 9: Comparison of record of water production for the years 2010 and 2011 for Mairuwa dam

Observations	2010	2011
Total Raw Water Produced (m^3)	935,680	578,937
Total Plant Operating Time (hrs)	5066	4662
Average Water Pumped per Hour (m^3/hr)	184.6	124.18

CHAPTER 5

DISCUSSION

5.1 Siltation of Mairuwa Impounding Reservoir

From the result of the calculation of the remaining storage in Table VI, the remaining storage of the dam is 3,905,929 m^3 as against the initial storage of 5,500,000 m^3 in 1970. The average siltation of the dam is 38,880 $m^{3/}$/a. This also shows that the dam has lost about 29% of its total storage after 41 years since its construction which translates to 0.70% loss in storage per annum. The dam will be silted up totally in the next 100 years if no action is taken to stop or reduce the rate of siltation of the dam. Long before this time, there will be not enough water to be pumped from the dam.

Mairuwa dam occupies the best available location with respect to water availability, site geology and proximity to demand areas. The site offers geologic and hydrologic conditions suitable for dam construction and is located appropriately for the intended users. If completely silted, it cannot easily be replaced by a new dam, or by shifting the dam upstream or downstream of the Sokoto River. Actions need to be taken to check the rate of siltation in the dam.

The situation of sedimentation in Mairuwa impounding reservoir is the same with all the reservoirs in Nigeria but, little or nothing is being done about the sedimentation problems of reservoirs in Nigeria

Ousamane, (2008), observed that some reservoirs experience problems of sedimentation ten years after construction, Sedimentation becomes a serious problem 50 more years after construction of a dam. In 2006, 21% of total global storage capacity was filled with sediment,

this is expected to increase to 42% by the year 2050.The number and size of dams have been increased after the Second World War (Figure 13). Most of the existing reservoirs in the world will be completely silted up in 200 to 300 years from now.

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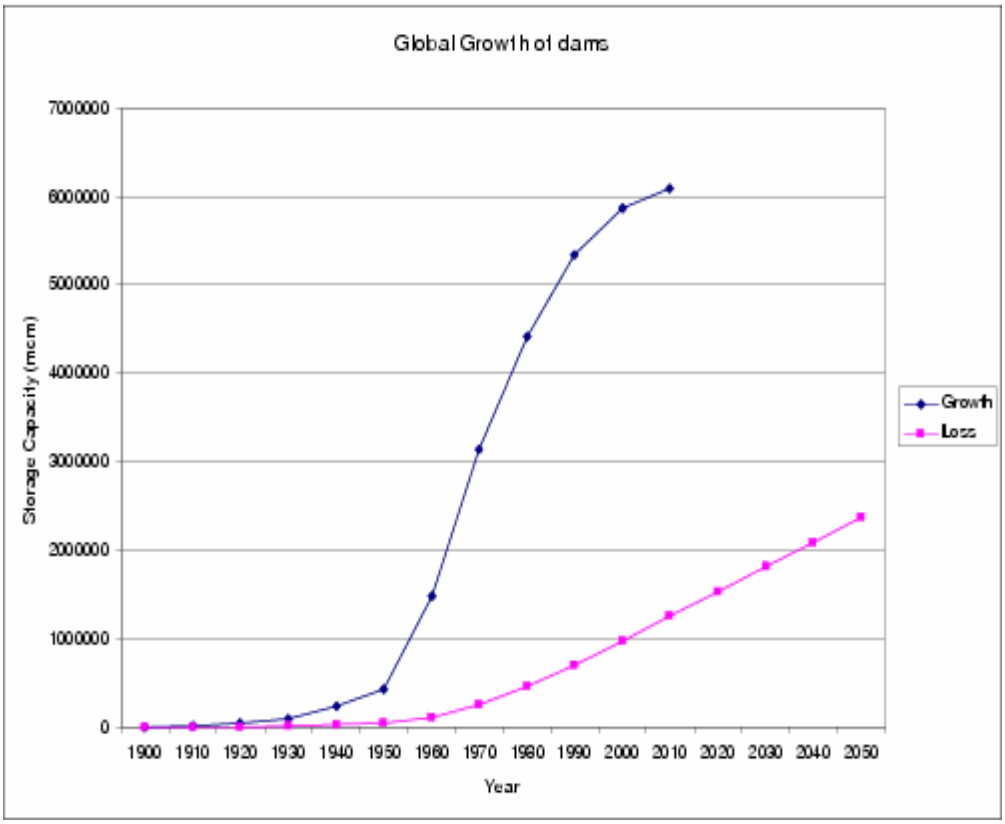


Figure 13: Global growth of reservoir storage capacity and reservoir sedimentation (After Bason and Roseboom, 2007)

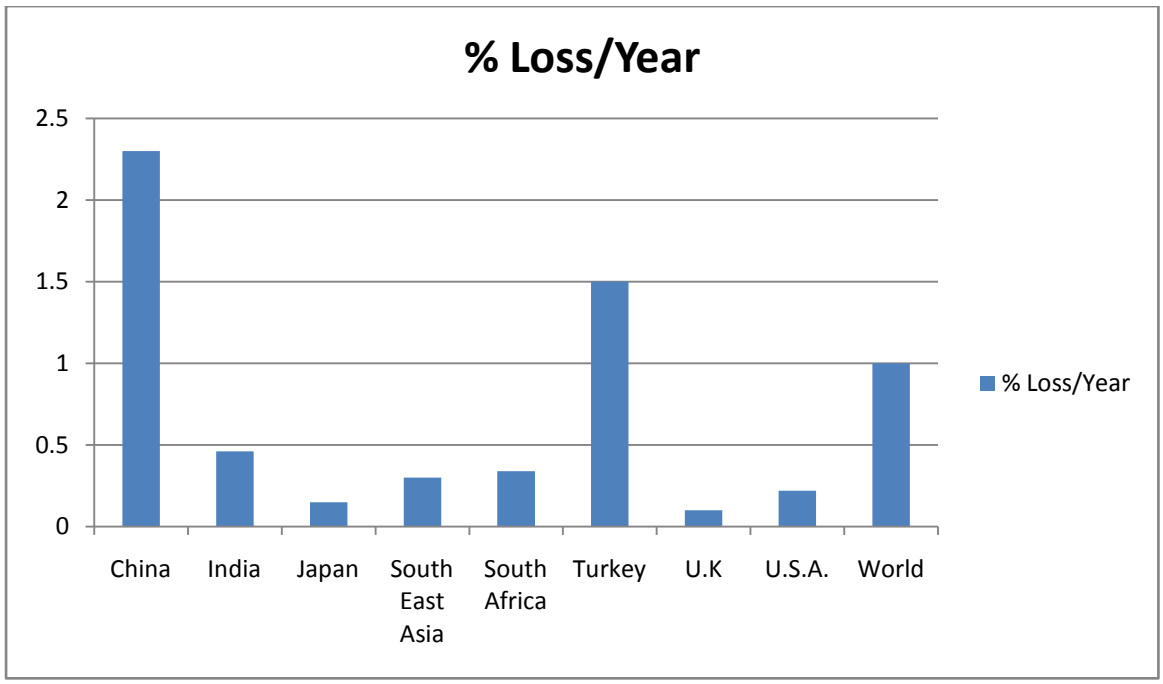


Figure 14: Reservoir sedimentation rates in various countries (After Ousmane, 2008)

The global distribution of the rate of loss of storage varies considerably (Figure 14). China and India are losing 2.3% and 0.5% respectively of storage capacity annually because of the low forest cover and high erosion, but the annual loss rates in Japan and Southeast Asia are only 0.15% and 0.3% respectively due to high forest cover and relatively low sediment yield (White, 2001)

5.2 Rate of Erosion in Mairuwa Impounding Reservoir Drainage Basin

The rate of erosion in the Mairuwa drainage basin was calculated to be 0.46 mm/a. Baba *et al*, (2009) calculated the rate of erosion in the Ahmadu Bello Unversity Farm Dam drainage basin to be 0.559 mm/year. Kudamnya (2012) on the other hand calculated the average depth of erosion in the Zaria Impounding Reservoir drainage basin to be 0.3 mm/year. All these values of rate of erosion in Nigeria especially in the guinea savanna are very high.

According to the most comprehensive study, the global erosion rate is 0.088mm/year (corresponding to 132t/km2/year) (White, 2000). It could be seen that the rate of erosion in the Mairuwa drainage basin is far more than the world average. This is a result of the human

activities such as farming, building and construction of roads in the drainage basin. Protection of the drainage basin is therefore a necessity to slow down the processes of erosion in the drainage basin.

The rate of erosion is very variable and depends on a complex interaction of the following factors:

• Climate: precipitation and run-off, temperature, wind speed and direction.

• Geotechnics: geology, volcanic and tectonic activity soils.

• Topography: slope, catchment orientation, drainage, basin area, drainage density.

• Vegetation cover.

• Land use and human impact.

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Mairuwa Dam constructed in 1970 for water supply and irrigation with storage capacity of 5,500,000m^3 has been reduced to 3,905,929 m^3 after 41 years since construction. The rate of siltation in the impounding reservoir is 38,880m^3/a. This represents storage loss of 0.70% per annum. At this rate, the dam will be silted up completely in the year 2111 if nothing is done to reduce the rate at which sediment is deposited in the reservoir.

The rate of erosion in the drainage basin is 0.45 mm/a, which is 511% higher than the world average of 0.088 mm/a. The most feasible sediment management strategy is the construction of sediment traps upstream of the reservoir which will trap most of the 38,880 m^3 of sediment and prevent it from entering the reservoir. These sediment traps should be excavated every dry season.

Plans for the Mairuwa dam drainage basin management should be taken seriously in order to protect the quantity and quality of the reservoir. With the rate of pollutants flowing into the reservoir from farms, and settlements within the drainage, the water quality of Mairuwa impounding reservoir need to be investigated, to check if it is still within the limit of World Health Organization and Nigerian Standard for Drinking Water.

There is lack of adequate data on sedimentation in most reservoirs in Nigeria. The rate of sedimentation in these reservoirs is not monitored. This may lead to the reservoirs being filled up with sediments before the estimated reservoir life is reached leading to sudden end of its benefits.

6.2 Recommendations

There are several actions that could be taken to reduce the rate of siltation of the Mairuwa dam thereby prolonging its lifespan. Such actions include:

- Construction sediment traps or weirs upstream of the dam will help in trapping of sediment and also serve as sources of water for cattle and for irrigation. The sediment traps will intercept much of the 38,880m^3 of sediment being deposited yearly into Mairuwa Impounding Reservoir. This sediment captured in these weirs will be excavated annually.
- Elevating the level of the dam body will increase the storage capacity of the dam from the present 3,905,929 m^3 depending on the increased height. This will definitely prolong the life span of the dam but will not stop the 38,880 m^3 of sediment from entering the dam every year
- Dredging of the reservoir during the dry season if possible will elongate the life span of the dam.
- Hydraulic flushing can be an effective mechanism for removing sediments, empting the reservoir through low level outlets and allowing natural flows to scour out deposits of sediment during the rainy season.
- The afforestation of the drainage basin will definitely reduce the volume of sediment coming into the dam.
- Controlled farming methods within the reservoir drainage basin should be practiced.
- Bush burning and deforestation should be stopped within the drainage basin.
- There is urgent need to commence sedimentation and general reservoir management studies in all reservoirs in Nigeria to save them from rapid siltation and loss of benefits.

CONTRIBUTION TO KNOWLEDGE

This study contributed the following to knowledge:

- The bathymetric map of Mairuwa impounding reservoir on a scale of 1:8.000 was produced.
- The determination of the remaining storage of Mairuwa impounding reservoir and its rate of siltation per year was made possible using bathymetric method.
- The hydrogeological map of the drainage basin showing ground water flow direction was produced. Also, the geological map of the study area was updated.
- The rate of erosion in the Mairuwa impounding reservoir drainage basin was calculated.

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APPENDICES

Appendix I: Results of Measurement of Remaining Storage (Instruments used are Satellite Navigator, Metric Tape and Paddle Canoe) measured by the Author on 17 and 18 July, 2011.

LOCATION	LATITUDE	LONGITUDE	DEPTH (m) BELOW THE LEVEL OF SPILLWAY	ELEVATION (m asl)	ACCURACY (m) of navigator
01	11^0 35' 10.7''	07^0 14' 13.5''	0.17	640	3
02	11^0 35' 12.8''	07^0 14' 15.4''	0.69	640	3
03	11^o 35' 11.2''	07^0 14' 16.2''	0.83	641	3
04	11^0 35' 09.8''	07^0 14' 16.5''	0.68	640	3
05	11^0 35' 08.0''	07^0 14' 17.6''	1.32	641	3
06	11^0 35' 07.3''	07^0 14' 18.0''	0.89	642	3
07	11^0 35' 08.5''	07^0 14' 20.0''	1.36	641	3
08	11^0 35' 11.3''	07^0 14' 19.5''	4.80	640	3
09	11^0 35' 13.8''	07^0 14' 19.2''	5.10	639	3
10	11^0 35' 15.8''	07^0 14' 19.1''	6.17	640	3
11	11^0 35' 17.6''	07^0 14' 18.1''	3.50	640	3
12	11^0 35' 15.5''	07^0 14' 20.1''	0.98	641	3
13	11^0 35' 15.8''	07^0 14' 22.9''	1.62	641	3
14	11^0 35' 16.4''	07^0 14' 23.4''	5.34	642	3
15	11^0 35' 13.0''	07^0 14' 22.5''	6.45	641	3
16	11^0 35' 09.4''	07^0 14' 24.4''	4.15	641	3
17	11^0 35' 06.3''	07^0 14' 24.4''	0.56	640	3
18	11^0 35' 04.6''	07^0 14' 25.2''	0.53	642	3
19	11^0 35' 01.2''	07^0 14' 26.2''	0.87	642	3
20	11^0 35' 01.3''	07^0 14' 30.2''	0.89	641	3
21	11^0 35' 05.0''	07^0 14' 31.7''	5.50	640	3
22	11^0 35' 06.4''	07^0 14' 33.6''	5.40	640	3
23	11^0 35' 10.9''	07^0 14' 28.2''	6.12	641	3
24	11^0 35' 10.6''	07^0 14' 32.3''	5.93	642	3
25	11^0 35' 12.7''	07^0 14' 31.2''	5.85	641	3
26	11^0 35' 15.8''	07^0 14' 32.7''	5.39	639	3
27	11^0 35' 18.4''	07^0 14' 29.5''	5.41	640	3
28	11^0 35' 20.5''	07^0 14' 27.6''	4.83	641	3

29	11^0 35’ 20.5’’	07^0 14’ 20.4’’	0.68	641	3
30	11^0 35’ 23.4’’	07^0 14’ 26.3’’	4.44	642	3
31	11^0 35’ 22.0’’	07^0 14’ 25.5’’	0.83	641	3
32	11^0 35’ 23.2’’	07^0 14’ 29.0’’	3.66	641	3
33	11^0 35’ 21.4’’	07^0 14’ 27.6’’	2.51	641	3
34	11^0 35’ 23.9’’	07^0 14’ 30.9’’	3.12	641	3
35	11^0 35’ 27.0’’	11^0 14’ 32.8’’	2.42	642	3
36	11^0 35’ 23.1’’	07^0 14’ 31.5’’	4.72	641	3
37	11^0 35’ 27.1’’	07^0 14’ 28.4’’	0.93	641	3
38	11^0 35’ 31.6’’	07^0 14’ 31.0’’	1.49	641	3
39	11^0 35’ 31.3’’	07^0 14’ 35.4’’	3,43	640	3
40	11^0 35’ 39.4’’	07^0 35’ 37.4’’	0.68	641	3
41	11^0 35’ 38.9’’	07^0 14’ 41.5’’	2.11	642	3
42	11^0 35’ 41.4’’	07^0 14’ 43.3’’	1.59	639	3
43	11^0 35’ 40.8’’	07^0 14’ 45.4’’	2.05	641	3
44	11^0 35’ 44.5’’	07^0 14’ 45.3’’	1.36	641	3
45	11^0 35’ 44.4’’	07^0 14’ 47.4’’	0.88	639	3
46	11^0 35’ 42.3’’	07^0 14’ 49.0’’	1.53	640	3
47	11^0 35’ 40.9’’	07^0 14’ 49.0’’	0.62	640	3
48	11^0 35’ 40.5’’	07^0 14’ 47.1’’	1,92	642	3
49	11^0 35’ 39.7’’	07^0 14’ 45.8’’	1.91	641	3
50	11^0 35’ 37.4’’	07^0 14’ 37.4’’	0.71	640	3
51	11^0 35’ 34.4’’	07^0 14’ 46.8’’	0.39	641	3
52	11^0 35’ 35.5’’	07^0 14’ 32.5’’	0.56	640	3
53	11^0 35’ 35.9’’	07^0 14’ 44.4’’	1.72	640	3
54	11^0 35’ 35.0’’	07^0 14’ 41.0’’	2.74	641	3
55	11^0 35’ 34.1’’	07^0 14’ 39.8’’	2.87	641	3
56	11^0 35’ 33.1’’	07^0 14’ 41.4’’	2.87	640	3
57	11^0 35’ 31.2’’	07^0 14’ 43.1’’	1.56	640	3
58	11^0 35’ 30.6’’	07^0 14’ 41.2’’	3.53	640	3
59	11^0 35’ 29.8’’	07^0 14’ 39.3’’	3.81	641	3
60	11^0 35’ 27.6’’	07^0 14’ 38.7’’	4.14	642	3
61	11^0 35’ 29.0’’	07^0 14’43.9’’	0.45	641	3
62	11^0 35’ 26.7’’	07^0 14’ 42.0’’	3.88	640	3
63	11^0 35’ 25.9’’	07^0 14’ 44.3’’	1.54	640	3
64	11^0 35’ 24.3’’	07^0 14’ 42.0’’	1.53	643	3
65	11^0 35’ 23.0’’	07^0 14’ 42.9’’	1.36	642	3

66	11^0 35’ 23.8’’	07^0 14’ 40.9’’	1.46	640	3
67	11^0 35’ 21.4’’	07^0 14’ 43.0 ‘’	0.44	640	3
68	11^0 35’ 22.6’’	07^0 14’ 40.4’’	0.30	641	3
69	11^0 35’ 24.5’’	07^0 14’ 43.9’’	0.51	641	3
70	11^0 35’ 23.4’’	07^0 14’ 37.5’’	4.50	640	3
71	11^0 35’ 22.5 ‘’	07^0 14’ 35.1’’	5.00	639	3
72	11^0 35’ 19.5’’	07^0 14’ 34.7’’	5.17	639	3
73	11^0 35’ 18.8’’	07^0 14’ 38.8’’	4.55	639	3
74	11^0 35’ 17.0’’	07^0 14’ 42.0’’	0.47	640	3
75	11^0 35’ 15.3’’	07^0 14’ 42.4’’	1.67	640	3
76	11^0 35’ 13.0’’	07^0 14’ 40.6’’	3.16	639	3
77	11^0 35’ 09.2’’	07^0 14’ 40.0’’	5.76	639	3
78	11^0 35’ 07.0’’	07^0 14’ 39.7’’	4.99	640	3
79	11^0 35’ 06.6’’	07^0 14’ 41.2’’	5.18	641	3
80	11^0 35’ 08.1’’	07^0 14’ 42.0’’	5.16	640	3
81	11^0 35’ 11.0’’	07^0 14’ 42.6’’	5.17	641	3
82	11^0 35’ 14.6’’	07^0 14’ 43.3’’	0.17	640	3
83	11^0 35’ 12.9’’	07^0 14’ 45.6’’	3.57	640	3
84	11^0 35’ 12.3’’	07^0 14’ 47.4’’	3.98	640	3
85	11^0 35’ 15.5’’	07^0 14’ 49.2’’	0.74	639	3
86	11^0 35’ 15.1’’	07^0 14’ 51.8’’	1.44	639	3
87	11^0 35’ 13.3’’	07^0 14’ 54.7’’	1.45	640	3
88	11^0 35’ 15.1’’	07^0 14’ 54.0’’	0.33	640	3
89	11^0 35’ 11.3’’	07^0 14’ 56.7’’	0.25	640	3
90	11^0 35’ 11.2’’	07^0 14’ 54.3’’	3.19	642	3
91	11^0 35’ 07.3’’	07^0 14’ 51.4’’	4.09	641	3
92	11^0 35’ 04.4’’	07^0 14’ 53.0’’	4.45	641	3
93	11^0 35’ 04.0’’	07^0 14’ 59.0’’	1.43	643	3
94	11^0 35’ 06.3’’	07^0 14’ 59.0’’	0.36	641	3
95	11^0 35’ 01.4’’	07^0 14’ 59.7’’	3.64	642	3
96	11^0 34’ 59.0’’	07^0 15’ 00.0’’	3.61	642	3
97	11^0 35’ 01.6’’	07^0 15’ 02.1’’	3.37	641	3
98	11^0 35’ 06.0’’	07^0 15’ 04.6’’	0.67	640	3
99	11^0 35’ 10.7’’	07^0 15’ 00.9’’	0.21	641	3
100	11^0 35’ 03.3’’	07^0 15’ 07.5’’	1.62	641	3
102	11^0 35’ 02.3’’	07^0 15’ 12.1’’	0.53	642	3
103	11^0 35’ 01.2’’	07^0 15’ 01.3’’	2.87	640	3

105	11^0 34’ 58.4’’	07^0 15’ 06.6’’	3.07	641	3
106	11^0 34’ 54.8’’	07^0 15’ 10.6’’	2.70	641	3
107	11^0 34’ 53.7’’	07^0 15’ 14.4’’	1.38	640	3
108	11^0 34’ 50.3’’	07^0 15’ 14.0’’	2.15	639	3
109	11^0 34’ 49.8’’	07^0 15’ 16.9’’	2.15	640	3
110	11^0 34’ 52.3’’	07^0 15’ 17.6’’	1.93	641	3
111	11^0 34’ 55.1’’	07^0 15’ 17.6’’	1.93	641	3
112	11^0 34’ 57.4’’	07^0 15’ 18.8’’	1,54	640	3
113	11^0 34’ 57.6’’	07^0 15’ 20.6’’	1.51	640	3
114	11^0 34’ 54.3’’	07^0 15’ 21.7’’	1.55	641	3
115	11^0 34’ 51.9’’	07^0 15’ 23.8’’	0.52	642	3
116	11^0 34’ 49.3’’	07^0 15’ 19.1’’	1.52	641	3
117	11^0 34’ 46.4’’	07^0 15’ 21.8 ’’	05.1	641	3
118	11^0 34’ 47.0’’	07^0 15’ 27.1’’	0.66	640	3
119	11^0 34’ 50.2’’	07^0 15’ 31.2’’	0.49	640	3
120	11^0 34’ 48.5’’	07^0 15’ 32.0’’	0.62	639	3
121	11^0 34’ 54.5’’	07^0 15’ 27.1’’	0.53	639	3
122	11^0 34’ 52.5’’	07^0 15’ 31.2’’	0.51	640	3
123	11^0 34’ 58.8’’	07^0 15’ 25.4’’	0.53	640	3
124	11^0 34’ 57.0’’	07^0 15’ 16.5’’	0.51	641	3
125	11^0 34’ 49.1’’	07^0 15’ 17.4’’	1.81	641	3
126	11^0 34’ 46.6’’	07^0 15’ 15.9’’	1.55	641	3
127	11^0 34’ 44.1’’	07^0 15’ 16.1’’	0.57	642	3
126	11^0 34’ 47.7’’	07^0 15’ 14.2’’	1.72	641	3
127	11^0 34’ 45.4’’	07^0 15’ 12.9’’	1.90	640	3
128	11^0 34’ 45.6’’	07^0 15’ 09.0 ’’	0.40	640	3
129	11^0 34’ 47.7’’	07^0 15’ 10.1’’	2.16	639	3
130	11^0 34’ 46.8’’	07^0 15’ 06.2’’	1.85	639	3
131	11^0 34’ 49.0’’	07^0 15’ 04.5’’	1.99	641	3
132	11^0 34’ 49.2’’	07^0 15’ 02.2’’	0.31	641	3
133	11^0 34’ 52.0’’	07^0 15’ 05.3’’	2.12	642	3
134	11^0 34’ 52.9’’	07^0 15’ 06.4’’	2.63	642	3
135	11^0 34’ 54.1’’	07^0 15’ 05.7’’	2.71	641	3
136	11^0 34’ 53.7’’	07^0 15’ 03.9’’	1.08	641	3
137	11^0 34’ 52.2’’	07^0 15’ 03.0’’	2.93	642	3
138	11^0 34’ 53.6’’	07^0 15’ 00.0’’	1.05	641	3
139	11^0 34’ 55.7’’	07^0 14’ 56.6’’	0.95	642	3

140	11^0 34’ 57.4’’	07^0 14’ 56.4’’	2.68	642	3
141	11^0 34’ 59.4’’	07^0 14’ 55.4’’	3.65	640	3
142	11^0 35’ 00.0’’	07^0 14’ 54.3’’	2.93	640	3
143	11^0 34’ 58.7’’	07^0 14’ 52.2’’	2.60	642	3
144	11^0 34’ 57.5’’	07^0 14’ 50.3’’	0.61	640	3
145	11^0 35’ 00.0’’	07^0 14’ 51.1’’	2.73	641	3
146	11^0 35’ 04.1’’	07^0 14’ 50.5’’	4.82	641	3
147	11^0 35’ 05.8’’	07^0 14’ 49.4’’	5.08	642	3
148	11^0 35’ 04.6’’	07^0 14’ 47.6’’	4.04	642	3
149	11^0 35’ 03.5’’	07^0 14’ 46.4’’	1.24	641	3
150	11^0 35’ 03.5’’	07^0 14’ 44.8’’	1.65	640	3
151	11^0 35’ 05.0’’	07^0 14’ 44.3’’	0.63	643	3
152	11^0 35’ 04.7’’	07^0 14’ 43.5’’	4.93	642	3
153	11^0 35’ 06.6’’	07^0 14’ 42.1’’	5.31	641	3
154	11^0 35’ 07.3’’	07^0 14’ 41.2’’	5.10	640	3
155	11^0 35’ 04.2’’	07^0 14’ 40.3’’	4.54	641	3
156	11^0 35’ 00.4’’	07^0 14’ 39.7’’	2.43	641	3
157	11^0 34’ 59.0’’	07^0 14’ 38.8’’	1.19	642	3
158	11^0 34’ 59.6’’	07^0 14’ 34.9’’	0.86	641	3
159	11^0 34’ 59.6’’	07^0 14’ 35.0’’	0.34	641	3
160	11^0 35’ 01.4’’	07^0 14’ 34.8’’	4.40	642	3
161	11^0 35’ 03.5’’	07^0 14’ 34.3’’	5.49	642	3
162	11^0 35’ 04.4’’	07^0 14’ 32.9’’	5.25	642	3

Appendix II: Results of Location of Water Table Boundary of Mairuwa Dam. Instruments used are Satellite Navigator (Measured by the Author)

S/NO	DATE OF MEASUREMENT	CORDINATES IN SATELLITE NAVIGATOR			ACCURACY (m) of navigator
		LATITUDE	LONGITUDE	ELEVATION (m asl)	
1	18/07/2011	11^0 35’ 13.1”N	07^0 14’ 14.7”E	671	3
2	18/07/2011	11^0 35’ 14.5”N	07^0 14’ 15.2”E	668	3
3	18/07/2011	11^0 35’ 18.0”N	07^0 14’ 16.7”E	651	3
4	18/07/2011	11^0 35’ 21.8”N	07^0 14’ 20.3”E	668	3
5	18/07/2011	11^0 35’ 21.1”N	07^0 14’ 20.7”E	666	3
6	18/07/2011	11^0 35’ 20.5”N	07^0 14’ 22.7”E	666	3
7	18/07/2011	11^0 35’ 20.22N	07^0 14’ 24.2”E	667	3
8	18/07/2011	11^0 35’ 21.2”N	07^0 14’ 24.9”E	668	3
9	18/07/2011	11^0 35’ 24.4”N	07^0 14’ 27.4”E	669	3
10	18/07/2011	11^0 35’ 26.0”N	07^0 14’ 27.3”E	664	3
11	18/07/2011	11^0 35’ 28.8”N	07^0 14’ 28.4”E	665	3
12	18/07/2011	11^0 35’ 20.8”N	07^0 14’ 30.4”E	663	3
13	18/07/2011	11^0 35’ 32.4”N	07^0 14’ 30.4”E	658	3
14	18/07/2011	11^0 35’ 34.8”N	07^0 14’ 34.8”E	660	3
15	18/07/2011	11^0 35’ 39.8”N	07^0 14’ 37.4”E	662	3
16	18/07/2011	11^0 35’ 42.8”N	07^0 14’ 38.9”E	661	3
17	18/07/2011	11^0 35’ 43.6”N	07^0 14’ 40.9”E	664	3
18	18/07/2011	11^0 35’ 43.1”N	07^0 14’ 42.8”E	666	3
19	18/07/2011	11^0 35’ 44.5”N	07^0 14’ 42.4”E	667	3
20	18/07/2011	11^0 35’ 42.3”N	07^0 14’ 51.4”E	666	3
21	18/07/2011	11^0 35’ 41.5”N	07^0 14’ 44.5”E	668	3
22	18/07/2011	11^0 35’ 39.2”N	07^0 14’ 50.4”E	670	3
23	18/07/2011	11^0 35’ 38.0”N	07^0 14’ 44.3”E	659	3
24	18/07/2011	11^0 35’ 36.6”N	07^0 14’ 46.3”E	664	3
25	18/07/2011	11^0 35’ 35.2”N	07^0 14’ 45.0”E	669	3
26	18/07/2011	11^0 35’ 34.0”N	07^0 14’ 44.0”E	668	3

27	18/07/2011	11^0 35’ 32.2”N	07^0 14’ 43.6”E	664	3
28	18/07/2011	11^0 35’ 30.6”N	07^0 14’ 43.7”E	667	3
29	18/07/2011	11^0 35’ 27.2”N	07^0 14’ 44.5”E	664	3
30	18/07/2011	11^0 35’ 23.7”N	07^0 14’ 43.1”E	666	3
31	18/07/2011	11^0 35’ 24.4”N	07^0 14’ 44.3”E	655	3
32	18/07/2011	11^0 35’ 22.1”N	07^0 14’ 22.1”E	658	3
33	18/07/2011	11^0 35’ 22.9”N	07^0 14’ 40.9”E	659	3
34	18/07/2011	11^0 35’ 20.7”N	07^0 14’ 41.1”E	666	3
35	18/07/2011	11^0 35’ 21.4”N	07^0 14’ 41.9”E	668	3
36	18/07/2011	11^0 35’ 22.0”N	07^0 14’ 43.7”E	669	3
37	18/07/2011	11^0 35’ 21.5”N	07^0 14’ 44.7”E	664	3
38	18/07/2011	11^0 35’ 20.3”N	07^0 14’ 43.7”E	663	3
39	18/07/2011	11^0 35’ 18.7”N	07^0 14’ 43.1”E	662	3
40	18/07/2011	11^0 35’ 17.0”N	07^0 14’ 44.3”E	667	3
41	18/07/2011	11^0 35’ 16.0”N	07^0 14’ 46.1”E	668	3
42	18/07/2011	11^0 35’ 16.2”N	07^0 14’ 49.0”E	665	3
43	18/07/2011	11^0 35’ 15.4”N	07^0 14’ 53.0”E	666	3
44	18/07/2011	11^0 35’ 14.9”N	07^0 14’ 54.9”E	665	3
45	18/07/2011	11^0 35’ 12.0”N	07^0 14’ 57.8”E	669	3
46	18/07/2011	11^0 35’ 09.1”N	07^0 14’ 57.4”E	670	3
47	18/07/2011	11^0 35’ 05.3”N	07^0 14’ 59.2”E	664	3
48	18/07/2011	11^0 35’ 06.5”N	07^0 15’ 02.1”E	665	3
49	18/07/2011	11^0 35’ 06.7”N	07^0 15’ 06.7”E	666	3
50	18/07/2011	11^0 35’ 03.9”N	07^0 15’ 09.5”E	667	3
51	18/07/2011	11^0 35’ 02.9”N	07^0 15’ 14.0”E	661	3
52	18/07/2011	11^0 35’ 00.8”N	07^0 15’ 15.1“E	662	3
53	18/07/2011	11^0 35’ 00.0”N	07^0 15’ 19.1”E	664	3
54	18/07/2011	11^0 34’ 59.0”N	07^0 15’ 18.7”E	668	3
55	18/07/2011	11^0 34’ 58.8”N	07^0 15’ 16.7”E	666	3
56	18/07/2011	11^0 34’ 58.2”N	07^0 15’ 15.3”E	665	3
57	18/07/2011	11^0 34’ 56.8”N	07^0 15’ 15.8”E	667	3

58	18/07/2011	11^0 34’ 58.5”N	07^0 15’ 17.7”E	668	3
59	18/07/2011	11^0 34’ 58.5”N	07^0 15’ 20.0”E	669	3
60	18/07/2011	11^0 34’ 59.9”N	07^0 15’ 20.0”E	665	3
61	18/07/2011	11^0 35’ 00.4”N	07^0 15’ 23.0”E	667	3
62	18/07/2011	11^0 34’ 59.9”N	07^0 15’ 25.7”E	665	3
63	18/07/2011	11^0 34’ 54.3”N	07^0 15’ 30.4”E	666	3
64	18/07/2011	11^0 34’ 51.8”N	07^0 15’ 37.1”E	669	3
65	18/07/2011	11^0 34’ 50.7”N	07^0 15’ 35.3”E	665	3
66	18/07/2011	11^0 35’ 10.5”N	07^0 14’ 13.2”E	668	3
67	18/07/2011	11^0 35’ 10.3”N	07^0 14’ 14.0”E	667	3
68	19/07/2011	11^0 35’ 10.3”N	07^0 14’ 15.9”E	664	3
69	19/07/2011	11^0 35’ 10.5”N	07^0 14’ 16.5”E	665	3
70	19/07/2011	11^0 35’ 09.8”N	07^0 14’ 16.6”E	668	3
71	19/07/2011	11^0 35’ 08.1”N	07^0 14’ 16.4”E	669	3
72	19/07/2011	11^0 35’ 06.8”N	07^0 14’ 16.9”E	664	3
73	19/07/2011	11^0 35’ 05.8”N	07^0 14’ 17.5”E	665	3
74	19/07/2011	11^0 35’ 05.0”N	07^0 14’ 17.9”E	667	3
75	19/07/2011	11^0 35’ 00.6”N	07^0 14’ 25.7”E	664	3
76	19/07/2011	11^0 35’ 00.6”N	07^0 14’ 26.3”E	665	3
77	19/07/2011	11^0 35’ 00.2”N	07^0 14’ 27.7”E	667	3
78	19/07/2011	11^0 35’ 00.6”N	07^0 14’ 29.0”E	665	3
79	19/07/2011	11^0 35’ 00.4”N	07^0 14’ 31.3”E	666	3
80	19/07/2011	11^0 35’ 00.1”N	07^0 14’ 31.4”E	668	3
81	19/07/2011	11^0 34’ 59.4”N	07^0 14’ 34.2”E	663	3
82	19/07/2011	11^0 34’ 59.2”N	07^0 14’ 34.4”E	662	3
83	19/07/2011	11^0 34’ 58.2”N	07^0 14’ 34.9”E	665	3
84	19/07/2011	11^0 34’ 57.5”N	07^0 14’ 35.8”E	663	3
85	19/07/2011	11^0 34’ 58.1”N	07^0 14’ 36.5”E	668	3
86	19/07/2011	$11\ ^0$34’ 58.2”N	07^0 14’ 37.6”E	664	3
87	19/07/2011	$11^0$34 ‘57.7”N	07^0 14’ 39.6”E	663	3
88	19/07/2011	11^0 34’ 57.4”N	07^0 14’ 40.3”E	660	3

89	19/07/2011	11^0 34’ 55.7”N	07^0 14’ 42.1”E	662	3
90	19/07/2011	11^0 34’ 55.1”N	07^0 34’ 42.4”E	666	3
91	19/07/2011	11^0 34’ 54.8”N	07^0 34’ 52.3”E	665	3
92	19/07/2011	11^0 34’ 54.5”N	07^0 34’ 54.9”E	664	3
93	19/07/2011	11^0 34’ 54.5”N	07^0 14’ 56.5”E	668	3
95	19/07/2011	11^0 34’ 53.7”N	07^0 14’ 57.5”E	667	3
96	19/07/2011	11^0 34’ 52.5”N	07^0 14’ 59.2”E	665	3
97	19/07/2011	11^0 34’ 51.0”N	07^0 15’ 01.8”E	659	3
98	19/07/2011	11^0 34’ 49.2”N	07^0 15’ 01.6”E	660	3
99	19/07/2011	11^p 34’ 47.2”N	07^0 15’ 04.3”E	664	3
100	19/07/2011	11^0 34’ 46.7”N	07^0 15’ 04.5”E	668	3
101	19/07/2011	11^0 34’ 45.7”N	07^0 15’ 05.7”E	667	3
102	19/07/2011	11^0 34’ 45.8”N	07^0 15’ 06.2”E	665	3
103	19/07/2011	11^0 34’ 45.6”N	07^0 15’ 08.0”E	667	3
104	19/07/2011	11^0 34’ 45.0”N	07^0 15’ 09.5”E	666	3
105	19/07/2011	11^0 34’ 45.0”N	07^0 15’ 10.0”E	665	3
106	19/07/2011	11^0 34’ 44.7”N	07^0 15’ 10.7”E	669	3
107	19/07/2011	11^0 34’ 44.2”N	07^0 15’ 10.9”E	662	3
108	19/07/2011	11^0 34’ 41.9”N	07^0 15’ 14.9”E	663	3
109	19/07/2011	11^0 34’ 43.2”N	07^0 15’ 17.6”E	665	3
110	19/07/2011	11^0 34’ 44.1”N	07^0 15’ 21.7”E	668	3
111	19/07/2011	11^0 34’ 44.3”N	07^0 15’ 22.9”E	669	3
112	19/07/2011	11^0 34’ 44.3”N	07^0 15’ 23.7”E	670	3
113	19/07/2011	11^0 34’ 04.7”N	07^0 15’ 26.0”E	665	3
114	19/07/2011	11^0 34’ 45.9”N	07^0 15’ 27.1”E	660	3
115	19/07/2011	11^0 34’ 45.9”N	07^0 15’ 28.1”E	667	3
116	19/07/2011	11^0 34’ 46.9”N	07^0 15’ 28.9”E	664	3
117	19/07/2011	11^0 34’ 46.5”N	07^0 15’ 29.8”E	661	3
118	19/07/2011	11^0 34’ 45.2“N	07^0 15’ 30.3”E	667	3

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APPENDIX III: Results of measurements of water table in hand dug in rainy season.

(Instruments used are Satellite Navigator and Metre Tape)

S/NO	DATE OF MEASUREMENT	CORDINATE (SATELLITE NAVIGATOR)			DEPTH TO WATER TABLE (m)	ELEVATION OF WATER TABLE (m asl)	ACCURACY (m)	VILLAGE
		LATITUDE	LONGITUDE	ELEVATION (m asl)				
W1	21/07/11	11^0 34′ 37.4″N	07^0 15′ 06.2″E	653	5.08	647.92	5	Dikke
W2	21/07/11	11^0 34′ 29.1″N	07^0 14′ 45.6″E	655	3.60	651.40	3	Dikke
W3	21/07/11	11^0 35′ 41.5″N	07^0 13′ 41.5″E	645	0.80	644.20	4	Mairuwa
W4	21/07/11	11^0 34′ 12.0″N	07^0 15′ 51.8″E	666	5.10	660.90	3	Gardawa
W5	21/07/11	11^0 34′ 52.6″N	07^0 16′′ 01.5″E	657	4.90	652.10	3	A. Maje
W6	22/07/11	11^0 34′ 48.5″N	07^0 16′ 27.7″E	659	6.78	652.22	3	Kadrawa
W7	22/07/11	11^0 33′ 47.4″N	07^0 17′ 42.8″E	690	5.50	684.50	3	Kwana Guga
W8	22/07/11	11^0 33′ 09.2″N	07^0 17′ 23.6″E	712	5.00	707.00	3	A. Dahiru
W9	22/07/11	11^0 33′ 13.7″N	07^0 16′ 37.4″E	668	4.50	663.50	3	Dogondaji
W10	22/07/11	11^0 32′ 15.3″N	07^0 16′ 58.0″E	681	5.10	675.90	3	Fadi
W11	22/07/11	11^0 30′ 44.0′′N	07^0 18′ 51.5′′E	711	1.70	709.3	3	U.. Wanzami
W12	22/07/11	11^0 31′ 37.9′′N	07^0 18′ 41.3′′E	708	2.50	705.5	3	Layi Magaji
W13	22/07/11	11^0 31′ 56.1′′N	07^0 19′ 07.4′′E	695	3.05	691.95	3	BCGA
W14	22/07/11	11^0 32′ 33.4′′N	07^0 18′ 58.2′′E	685	2.10	682.9	3	Bagari
W15	22/07/11	11^0 32′ 20.8′′N	07^0 20′26.8′′E	708	1.50	706.50	3	Saberia
W16	22/07/11	11^0 33′ 23.0′′N	07^0 20′ 57.1′′E	695	1.00	694.00	3	Ungwan Tsirgi
W17	22/07/11	11^0 33′ 30.0′′N	07^0 20′ 08.9′′E	698	0.60	697.40	3	Doka
W18	22/07/11	11^0 35′ 16.0′′N	07^0 20′ 20.0′′E	710	1.00	709.00	3	Sabon-jida
W19	22/07/11	11^0 35′ 44.5′′N	07^0 20′ 15.9′′E	711	1.10	709.90	3	.Sarkin Baka
W20	22/07/11	11^0 36′ 00.7′′N	07^0 19′ 14.4′′E	700	0.70	689.30	3	Yan Uku
W21	22/07/11	11^0 36′ 44.9′′N	07^0 18′ 44.7′′E	696	9.10	686.90	3	U. Koji
W22	22/07/11	11^0 37′ 12.6′′N	07^0 18′ 39.9′′E	683	5.90	677.10	3	U.Koji
W23	22/07/11	11^0 37′ 43.0′′N	07^0 18′ 06.0′′E	677	10.15	666.85	3	.Sarkin Baka
W24	22/07/11	11^0 37′ 24.9′′N	07^0 16′ 53.0′′	670	7.70	662.30	3	Tafoki
W25	22/07/11	11^0 37′ 58.0′′N	07^0 15′43.8′′E	670	2.00	668.00	3	Shadawa
W26	22/07/11	11^0 31′ 37.5′′N	07^0 17′ 52.6′′E	700	3.50	696.50	3	Dandaji
W27	24/04/12	11^0 33′ 45.3′′N	07^0 18′ 07.0′′E	669	5.40	663.60	3	Dan Mallam
W28	24/04/12	11^0 32′ 58.2′′N	07^0 17′ 18.0′′E	674	4.80	669.20	3	Galadima

W29	24/04/12	11^0 32’ 58.1’’N	07^0 15’ 43.7’’E	680	3.50	676.50	3	Dogon Zaki
W30	24/04/12	11^0 31’ 22.2’’N	07^0 18’ 21.0’’E	703	6.20	696.60	3	Funtua
W31	24/04/12	11^0 35’ 59.5’’N	07^0 16’ 57.5’’E	678	4.70	673.70	3	U.Barmo
W32	24/04/12	11^0 32’ 03.9’’N	07^0 18’ 40.0’’E	694	6.10	687.90	3	Nassarawa

APPENDOX IV: Results of measurements of water table in hand dug wells, in dry season Measured by the Author (Instruments used are Satellite Navigator and Metre Tape)

S/NO	DATE OF MEASUREMENT	CORDINATE (SATELLITE NAVIGATOR)			DEPTH TO WATER TABLE (m)	ELEVATION OF WATER TABLE (m asl)	ACCURACY (m)	VILLAGE
		LATITUDE	LONGITUDE	ELEVATION (m asl)				
W1	23/04/12	11^0 34′ 37.4″N	07^0 15′ 06.2″E	653	8.90	644.10	5	Dikke
W2	23/04/12	11^0 34′ 29.1″N	07^0 14′ 45.6″E	655	7.80	647.20	3	Dikke
W3	23/04/12	11^0 35′ 41.5″N	07^0 13′ 41.5″E	645	6.40	638.60	4	Mairuwa
W4	23/04/12	11^0 34′ 12.0″N	07^0 15′ 51.8″E	666	10.80	655.20	3	Gardawa
W5	23/04/12	11^0 34′ 52.6″N	07^0 16′′ 01.5″E	657	10.20	646.80	3	A. Maje
W6	23/04/12	11^0 34′ 48.5″N	07^0 16′ 27.7″E	659	11.00	648.00	3	Kadrawa
W7	23/04/12	11^0 33′ 47.4″N	07^0 17′ 42.8″E	690	9.80	680.20	3	Kwana Guga
W8	23/04/12	11^0 33′ 09.2″N	07^0 17′ 23.6″E	712	11.10	700.90	3	A. Dahiru
W9	23/04/12	11^0 33′ 13.7″N	07^0 16′ 37.4″E	668	9.60	658.40	3	Dogondaji
W10	23/04/12	11^0 32′ 15.3″N	07^0 16′ 58.0″E	681	10.20	670.80	3	Fadi
W11	24/04/12	11^0 30′ 44.0′′N	07^0 18′ 51.5′′E	711	9.83	701.17	3	U.. Wanzami
W12	24/04/12	11^0 31′ 37.9′′N	07^0 18′ 41.3′′E	708	10.00	698.00	3	Layi Magaji
W13	24/04/12	11^0 31′ 56.1′′N	07^0 19′ 07.4′′E	695	7.53	687.47	3	BCGA
W14	24/04/12	11^0 32′ 33.4′′N	07^0 18′ 58.2′′E	685	7.10	677.90	3	Bagari
W15	24/04/12	11^0 32′ 20.8′′N	07^0 20′26.8′′E	708	7.20	700.80	3	Saberia
W16	24/04/12	11^0 33′ 23.0′′N	07^0 20′ 57.1′′E	695	4.75	690.25	3	U. Tsirgi
W17	24/04/12	11^0 33′ 30.0′′N	07^0 20′ 08.9′′E	698	4.95	693.05	3	Doka
W18	24/04/12	11^0 35′ 16.0′′N	07^0 20′ 20.0′′E	710	6.20	703.80	3	Sabon-jida
W19	24/04/12	11^0 35′ 44.5′′N	07^0 20′ 15.1′′E	711	6.10	704.90	3	.Sarkin Baka
W20	24/04/12	11^0 36′ 00.7′′N	07^0 19′ 14.4′′E	700	6.60	693.40	3	Yan Uku
W21	24/04/12	11^0 36′ 44.9′′N	07^0 18′ 44.7′′E	696	11.80	684.20	3	U. Koji
W22	24/04/12	11^0 37′ 12.6′′N	07^0 18′ 39.9′′E	683	9.70	673.70	3	U.Koji
W23	24/04/12	11^0 37′ 43.0′′N	07^0 18′ 06.0′′E	677	13.75	663.25	3	Sarkin Baka
W24	24/04/12	11^0 37′ 24.9′′N	07^0 16′ 53.0′′	670	12.90	657.10	3	Tafoki
W25	24/04/12	11^0 37′ 58.0′′N	07^0 15′43.8′′E	670	4.60	665.40	3	Shadawa
W26	24/04/12	11^0 31′ 37.5′′N	07^0 17′ 52.6′′E	700	10.50	689.50	3	Dandaji
W27	24/04/12	11^0 33′ 45.3′′N	07^0 18′ 07.0′′E	669	9.30	689.70	3	Dan Mallam
W28	24/04/12	11^0 32′ 58.2′′N	07^0 17′ 18.0′′E	674	10.60	663.40	3	Galadima

W29	24/04/12	11^0 32’ 58.1’’N	07^0 15’ 43.7’’E	680	12.20	667.80	3	Dogon Zaki
W30	24/04/12	11^0 31’ 22.2’’N	07^0 18’ 21.0’’E	703	12.80	690.20	3	Funtua
W31	24/04/12	11^0 35’ 59.5’’N	07^0 16’ 57.5’’E	678	11.30	666.70	3	U.Barmo
W32	24/04/12	11^0 32’ 03.9’’N	07^0 18’ 40.0’’E	694	13.2	680.80	3	Nassarawa

Appendix V: Report on Water Production from Mairuwa Dam 2010

Source: KATSINA STATE WATER BOARD, FUNTUA DISTRICT.

MONTHS	RAW WATER (m^3)	TREATED WATER PRODUCED (m^3)	WATER LOST THROUSH DESLUDGING (m^3)	WATER USED FOR INTERNAL CONSUMPTION AND CLEANING (m^3)	WATER PUMPED TO THE SERVICE TANK (m^3)	TOTAL PLANT OPERATING TIME (hrs)
JANUARY	111,200	107,864	3,336	1,0786	97,078	556
FEBRUARY	92,400	89,628	2,772	8,963	80,665	462
MARCH	45,600	44,232	1,360	4,423	39,809	228
APRIL	103,200	100,104	3,098	10,010	90,094	516
MAY	95,660	92,732	2,868	9,273	83,459	478
JUNE	80,200	77,794	2,406	7,779	70,015	401
JULY	86,200	83,614	2,586	8,361	72,867	431
AUGUST	67,800	65,766	2,034	6,577	59,189	339
SEPTEMBER	67,200	64,950	2,210	6,499	58,491	335
OCTOBER	76,000	73,920	2,080	7,399	66,528	380
NOVEMBER	83,000	80,510	2,490	8,051	72,459	415
DECEMBER	104,800	101,656	3,144	10,166	91,490	525

Appendix VI: Report on Water Production from Mairuwa Dam 2011

Source: KATSINA STATE WATER BOARD, FUNFUA DISTRICT.

MONTH	RAW WATER (m^3)	TREATED WATER PRODUCED (m^3)	WATER LOST THROUSH DESLUDGING (m^3)	WATER USED FOR INTERNAL CONSUMPTION AND CLEANING (m^3)	WATER PUMPED TO THE SERVICE TANK (m^3)	TOTAL PLANT OPERATING TIME (hrs)
JANUARY	61,826	60,120	1,706	5,890	54,230	472
FEBRUARY	62,756	60,873	1,883	6,087	54,786	486
MARCH	72,875	70,689	2,186	7,069	63,620	583
APRIL	62,000	60,140	1,860	6,014	54,126	496
MAY	51,625	50,076	1,549	5,000	45,068	413
JUNE	27,363	26,542	821	265	23,888	236
JULY	40,250	39,043	1,207	3,904	35,199	327
AUGUST	35,875	34,799	1,076	3,480	31,319	287
SEPTEMBER	41,875	40,619	1,256	4,062	36,557	335
OCTOBER	37,814	36,679	1,135	3,666	33,011	328
NOVEMBER	29,325	28,445	830	2,844	25,601	256
DECEMBER	55,375	53,714	1,661	5,371	48,343	443