DETERMINATION OF THE REMAINING STORAGE IN THE ZARIA IMPOUNDING RESERVOIR USING BATHYMETRIC METHODS.

BY

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DEPARTMENT OF GEOLOGY
AHMADU BELLO UNIVERSITY
ZARIA-NIGERIA

NOVEMBER, 2012

Title Page

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DEPARTMENT OF GEOLOGY
AHMADU BELLO UNIVERSITY, ZARIA
NIGERIA

NOVEMBER, 2012

DECLARATION

I declare that the work in this thesis entitled '**Determination of the remaining storage in the Zaria Impounding Reservoir using bathymetric methods**' has been performed by me in the Department of Geology under the supervision of Prof. K. Schoeneich and Dr M.L. Garba.

All the information derived from literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at any other tertiary learning institution.

Ebenezer Agayina Kudamnya	……	……
Name of student	Signature	Date

CERTIFICATION

This Thesis entitled "**DETERMINATION OF THE REMAINING STORAGE IN THE ZARIA IMPOUNDING RESERVOIR USING BATHYMETRIC METHODS**" by Kudamnya, Ebenezer Agayina meets the regulations governing the award of the degree of Master of Science of Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

I dedicate this work to God Almighty for making it possible for me to complete this programme and also to my family for their love, encouragement, understanding, prayers and patience.

ACKNOWLEDGEMENT

I want to use this opportunity to give thanks to God Almighty for his faithfulness. This work could never have been done without His grace and mercy on my life. Thank you Lord.

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ABSTRACT

Zaria impounding reservoir for now remains the only source of piped borne water supply to Zaria and its environs since its impoundment in 1974 to date. However, its useful life is constantly been threatened by continuous siltation with sediments originating from within its drainage basin – the Galma drainage basin.

Owing to the great importance of the reservoir in the supply of potable water to Zaria and environs, an attempt was made to determine the remaining storage. Two methods employed are direct field method and indirect method using remotely sensed data. The direct field method was carried out using a boat, measuring tape, satellite navigator (GPS) and a heavy object to measure depth and edge of the open water table at the time the spillway is overflowing. While the indirect method employed the use of ETM+ landsat images using softwares; ILWIS 3.7 to geo-reference and process the satellite images, and GLOBAL MAPPER 11 to determine the reservoir's surface area and also generate the digital elevation models (DEM) of the study area.

The storage volume determined from the indirect method for 1990, 2000 and 2010 were on the high side. However, processed ETM+ landsat images for the respective years show a decrease in surface area of the of the Zaria Impounding Reservoir with time as expected, owing to its siltation. Results obtained from the direct field measurement shows that at present in year 2010, average weighted depth is 2.82 m. Also, the remaining storage capacity was estimated at 21,129,242 m^3, corresponding to about 46% of the original volume. Therefore, the rate of siltation between years 1974 to 2010 was calculated to be 685,299 m^3/year. This corresponds to an annual loss to bed load siltation of about 1.5% per year. Results from the study further show that only the active storage is left remaining. The dead storage had completely been silted up about 23 years after the impoundment or 13 years ago. Active storage volume has

been reduced by about 8,670,758 m^3 by the year 2010. Erosion within the entire drainage basin, which consists of the volume of dissolved sediment, suspended sediment and deposited bottom bed load, was summed to an amount of 1,039,118 m^3/year. Therefore rate of erosion within the reservoir's drainage basin occurs at an average depth of 0.0003 m/year or 0.3 mm/year.

By year 2041 the reservoir will be completely silted up, if necessary measures are not taken. If no action is taken, water rationing in Zaria, caused by progressive siltation of the Zaria impounding reservoir, will start in the dry season of year 2031. Gradually, it will develop to no water in dry season starting from year 2033, and to a complete siltation of the reservoir in year 2042. Siltation of the reservoir can be reduced by taking measures such as afforestation and other forms of environmental upgrading within its entire drainage basin. Also, plans to dredge the reservoir should be put in place.

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CHAPTER ONE

1. INTRODUCTION.

1.1. GLOBAL WATER PROBLEM

Despite the Earth's abundant water resources sufficient to support its population, water is becoming scarce in a growing number of locations. Unequal distribution of rainfall and land degradation contributes to this (Spencer, 1998). Over one billion people today lack access to enough clean water and over 1.2 billion people lack access to basic sanitation. It is estimated that about 2.7 billion people will face water shortage by 2025, (Obrecht, 2003). In 2010, UNDP reports that access to clean water is lowest in Africa, while Asia has the largest number of people with no access to basic sanitation.

While total amount of freshwater remains relatively constant across the Earth, the demand doesn't. Thus countries around the world with increase in its population constantly face water problems in the form of water stress and water scarcity (Fig. 1).

A UN report however attributes water crisis to result from profound failures in water governance (UNDP, 2010). In order to manage water effectively, records of its abstraction from surface water and groundwater deposits are important. But nobody has this information in many countries especially in developing countries (UN-Water, 2008).

The unit of water resources management is the drainage basin, though amidst other units such as geological unit, topographical unit and administrative unit (Offodile, 2000). The idea that the drainage basin is the unit of Earth's surface, that which concentrates run-off to produce river flow is derived from the work of Perrault in the 17th century on the basin of Seine in France (Gregory and Walling, 1973). This also provides a basis for regional cooperation and development of water resources. Pidwirny (2006) defines a "drainage basin", as an area or a topographic region from which a stream or river

receives runoff, through flow, and groundwater flow. According to Gregory and Wallling (1973), it is a unit that integrates the atmosphere, the geosphere and the hydrosphere and thus its input and output can be computed.

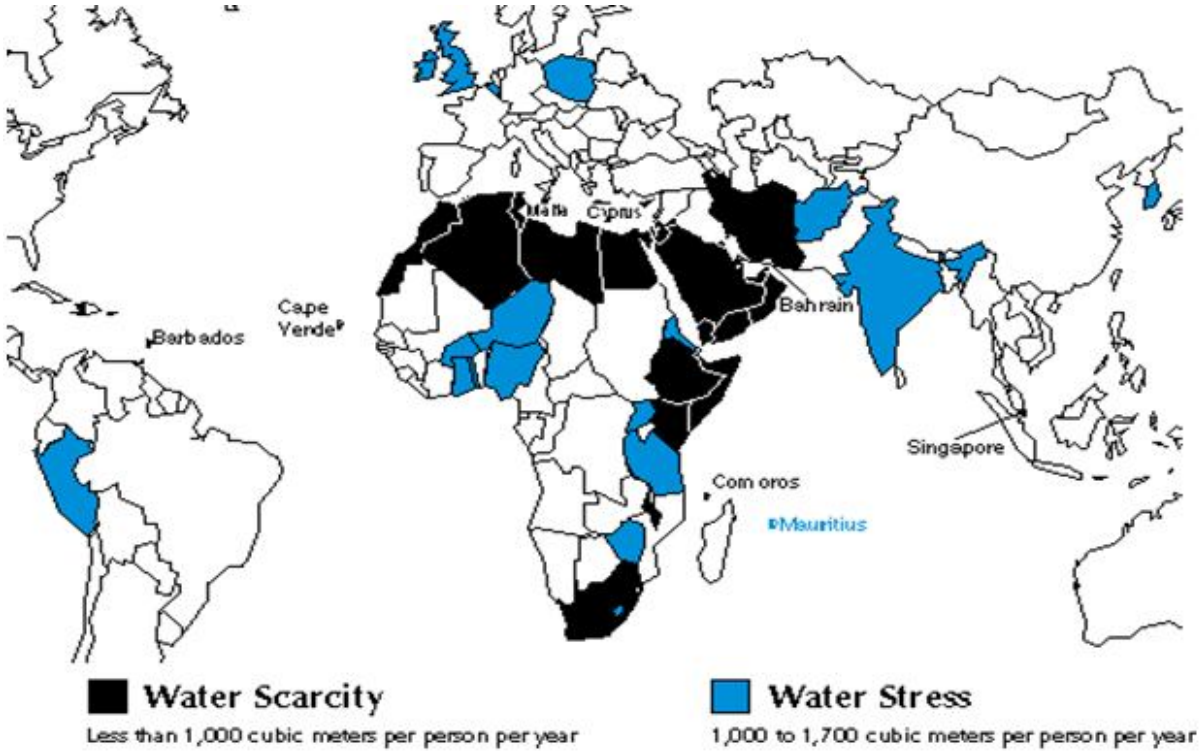


Figure 1: Countries experiencing problems of water-scarcity and water-stress. Source: UNECA, 1999.

Surface water may seem to be abundant on the earth, but its increasing demand by the growing population creates pressure on available impounded water storage in many parts of the world. Gregory and Walling (1973) further stated that in order to effectively harness the water resources within a drainage basin for efficient water supply, impounding reservoir are constructed along major stream channels within the catchment area. Inputs to these systems include precipitation and sediments. Activities within the drainage basin can affect the hydrological cycle and the way in which the drainage basin

operates particularly the amount of, and the rate at which water and sediments are conveyed through the drainage basin.

Terrestrial ecosystems in the upstream area of a basin are important for rainwater infiltration, groundwater recharge and river flow regimes. Adkins (2007), stressed that clearance of natural vegetation for agriculture, overgrazing, over pumping and overuse of river water for agriculture has changed the ecosystem and recharge mechanisms, and can introduce new sources of salinity and pollution.

Population Action International, based upon the UN medium population projections of 1998, states that more than 2.8 billion people in 48 countries will face water stress or water scarcity conditions by 2025 (UNECA, 1999). According to the authors, an area is experiencing water stress when annual water supplies drop below 1700 m^3 per person while water scarcity means that the annual water supply is below 1000 m^3 per person. The writer of this thesis disagrees with UNECA, 1999. He observes that 1000 m^3/annum or 2740 litres/person/day is much more than per capita water demand in the developed countries which is only about 200 litres/person/day. Thus, the basis for 1000 m^3/person/annum and 1700 m^3/person/annum as the base-line for water scarce or water stress conditions respectively is not justified. Nobody knows whether the authors arrived at these values using the earth's dynamic water resources or static water resources. In Nigeria for example, total available (in the water deposit) dynamic water resources are about 10 m^3/person/day or 3587 m^3/person/annum while total available (in water deposit) static fresh water resources are about 228 m^3/person/day or 83,240 m^3/person/annum (Schoeneich, 2007). Thus, Nigeria is not among the water stress region of the world as represented in Fig 1 above. .

As the world's population continues to grow, a higher proportion of the population will be affected by water stress and water scarcity according to UNECA (1999), see Fig. 2. But population is not sufficient reason for the inadequte water supply. There is enough water in the earth according to Shiklomanov, 1993, but the problem is the in ability to manage effectively these water resources. That is to say that water is not made availavble from the source to the water consumers. Problems of water scarcity of course are not limited to few countries, according to UN-Water (2008).

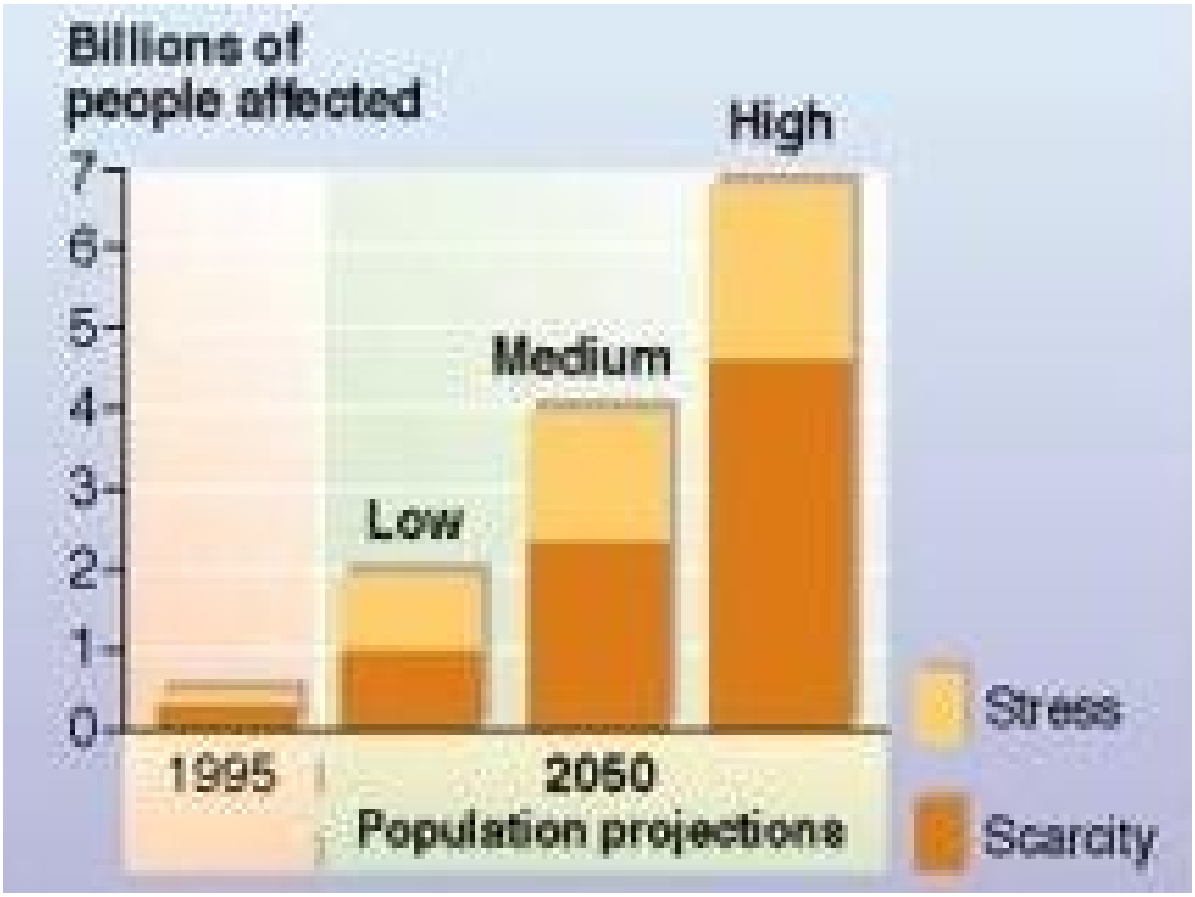


Figure 2: Population estimate in water-scarce and water-stressed countries between years 1995-2050. Source: UNECA, 1999.

Countries with limited renewable water resources include those of the Middle East, North Africa, and Central Asia and sub Saharan Africa which has the fastest growing population.

Elsewhere, water scarcity may be less of a problem at the national level but it is nevertheless severe in many areas such as in northern China and Southern India, western South America, Australia and large parts of Pakistan and Mexico. This of course resulted from an uncoordinated development of water resources that stems from lack of national water policy and an adequate institutional framework for managing these resources in many countries, World Bank (1993).

Nigeria is one of the signatories to the United Nations International Drinking Water Supply and Sanitation Decade whose objective was to supply water to all citizens of the country between 1981 and 1990. In spite of the efforts of various Governments at all levels, the water supply coverage in the country appears to be decreasing and deteriorating. One of the reasons for this deterioration is the enormous socioeconomic rate of development which far outstrips the level of water supply development. Other reasons include low investment level in operation and maintenance which accounts for frequent breakdown of the production facilities and lack of proper management of the nation's water resources, Federal Ministry of Water Resources (2000).

1.2 BACKGROUND TO THE STUDY

Water is as important to life as air and food. It is vital that every human being should have access to safe water for drinking, proper sanitation, and for other domestic purposes. However, there is not enough of piped water running in taps within Zaria. This is evident by the teeming population of the "water vendors" who patronize bore-holes

owned by private individuals and in turn sell at profit to the residents. Also when supplied, taps flow only few hours daily at low pressure and elevated areas are permanently dry. It is obvious that the need for water is constantly increasing because of high rate of population growth and urbanization. This has not been accompanied with corresponding growth in water producing sectors. Communities and sub-settlements served by the Zaria Water Works had to go through periods of complete no tap water for days and weeks. Therefore, searching for drinking, bathing, washing and cooking water has become part of the daily routine for both children and married women. Where the supply is made, it does not exceed 2 hours in some areas. (Lukman *et al.,* 2009)

Then the big question, "Why is there not adequate water supply in Zaria?" Answer to this question depends on who has been asked. Accusing fingers are pointing at various directions. One of the hypotheses is that there is not enough water at source in the Zaria impounding reservoir due to its siltation. Reason attributed to why taps in Zaria are dry may be true, but where is the evidence? It is important to investigate whether there is enough water at source or not.

The main source of water supply to Zaria residents and its environs is the Zaria impounding reservoir (colloquially called the Zaria dam) and its raw water supply is made available from the River Galma, shown in Figure 3. From the Nigeria Register of Dams, Zaria impounding reservoir was constructed in 1974 (FMWRRD, 1995), at the same time with the new Zaria Water Works, with an initial design capacity of 25,000 m^3/day. It was later upgraded to 50,000 m^3/day in other to complement an already existing old water work earlier constructed in 1939 with a designed capacity of 4,500 m^3/day and whose draw-off system had been giving problem, (WAPDECO, 1990). It is categorized as a large dam (FMWRRD, 1995)



Plate I: Zaria Impounding Reservoir – The source of piped treated drinking water for Zaria and its environs. It is threatened by continuous siltation as a result of erosion since the date of its impoundment. One then wonders how many more years ahead can it still serve its purpose?

The old Water Works was located in Zaria City on the bank of the River Galma and raw water is abstracted directly from the river at a point downstream of the old Dutsen-Wai road bridge. At impoundment in 1974, the dead storage was 16,000,000 m^3 , while the active storage was 29,800,000 m^3, according Nigeria Register of Dams (FMWRRD, 1995). Since the construction of the impounding reservoir in 1974, there has not been any study aimed at appraising its designed storage capacity in view of the widespread poor land use practices over the dam's catchment area which accelerates soil erosion. Therefore it is possible that the initial storage capacity of the impounding reservoir may not longer be obtainable at the present, probably due to its siltation. According to Mugabe *et al.* (2004),

the sustainable use of the limited water resources is constrained by insufficient knowledge of the resources, in terms of quantity, and lack of proper water resource management. This justifies the need to establish the capacities of reservoirs regularly for adequate management and planning.

This study focuses on measurement of remaining storage in Zaria impounding reservoir, determination of the rate of siltation within the Lake and rate of erosion in its drainage basin. Sediment accumulation is a major consideration in storage reservoir design and operation (Parkman Nig. Ltd, 2002). Thus, sediments originating from erosion processes in the catchment area of the Galma River are transported by overland flow and stream flow into the reservoir (Maniyunda, 2005). When flow of a river is stored in a reservoir, the sediments settles in the reservoir and thus reduces its capacity (Dada, 2009). Chanson (1998); Liebe *et al.* (2005); and Sawunyama *et al.* (2006) all cited in their work that overall sedimentation problems were experienced mostly with small to medium size reservoirs. Thus, the storage capacity of a reservoir below a threshold limit, hampers the purpose for which it was designed (Dada, 2009).

1.3 STATEMENT OF THE PROBLEM.

Most of the over 300 dams existing in Nigeria were constructed during the 1970's. Since then, part of their original storage has been lost to siltation. Nobody knows what this part is. It probably varies from a dam to a dam. Sooner or later, original storage will be so reduced that water supply schemes using these dams will start rationing the water. It is important to know how many years in advance this will happen. The Zaria impounding reservoir is one of such dams! This dam was constructed across the Galma River with the aim of supplying Zaria community with potable water to meet its demand.

When a dam is constructed across a river it receives water and sediment from its catchment area through a network of rivers. These sediments are continuously deposited at the bottom of lakes and over time become a serious problem as they tend to increase in thickness especially if the dam is not designed to flush out such sediments. Thus, the volume of water the reservoir can hold is hampered. For this, knowledge of the rate of siltation is important. Rate of siltation is calculated by differencing the remaining storage from the original storage, and then divide this difference by the number of years since its impoundment to the present date. The researcher decided to measure remaining storage in the Zaria Impounding Reservoir to calculate rate of siltation within the Lake, rate of erosion in the drainage and most probable date of disappearance of the Zaria Impounding Reservoir from the map, if measures aimed at reducing erosion are not taken.

1.4 WORKING HYPOTHESIS.

Taps in Zaria are dry and water supply is erratic to none at all. The reason attributed to this by water producers is that due to siltation there is not enough water at the Zaria impounding reservoir to meet demand. Whether this assertion is true, is not known unless the present storage of the impounding reservoir is determined. The working hypothesis is that dry taps in Zaria are not caused by siltation of the impounding reservoir but inability of the water producer to transfer the water from reservoir to taps of the consumer.

1.5 OBJECTIVE OF THE RESEARCH.

The research is aimed at adding to the current level of knowledge of;

1. **Present storage of the impounding reservoir, in other to ascertain whether this can meet the current water demand of Zaria.**
2. **Rate of siltation in the impounding reservoir.**
3. **Rate of erosion in its drainage basin.**

1.6 LOCATION, DRAINAGE, VEGETATION AND REGIONAL GEOLOGY.

1.6.1 Location, Extent and Accessibility.

Zaria Impounding Reservoir is located on the Crystalline Hydro-geological Province of northern Nigeria, within the Guinea Savannah belt. It is located on the Federal Surveys 1:50,000 Series Topographical Sheet 102 Zaria SW, on 11^0 08' N, 7^0 45□ E, covering a total area of about 126.9 km^2, Fig. 3 below.

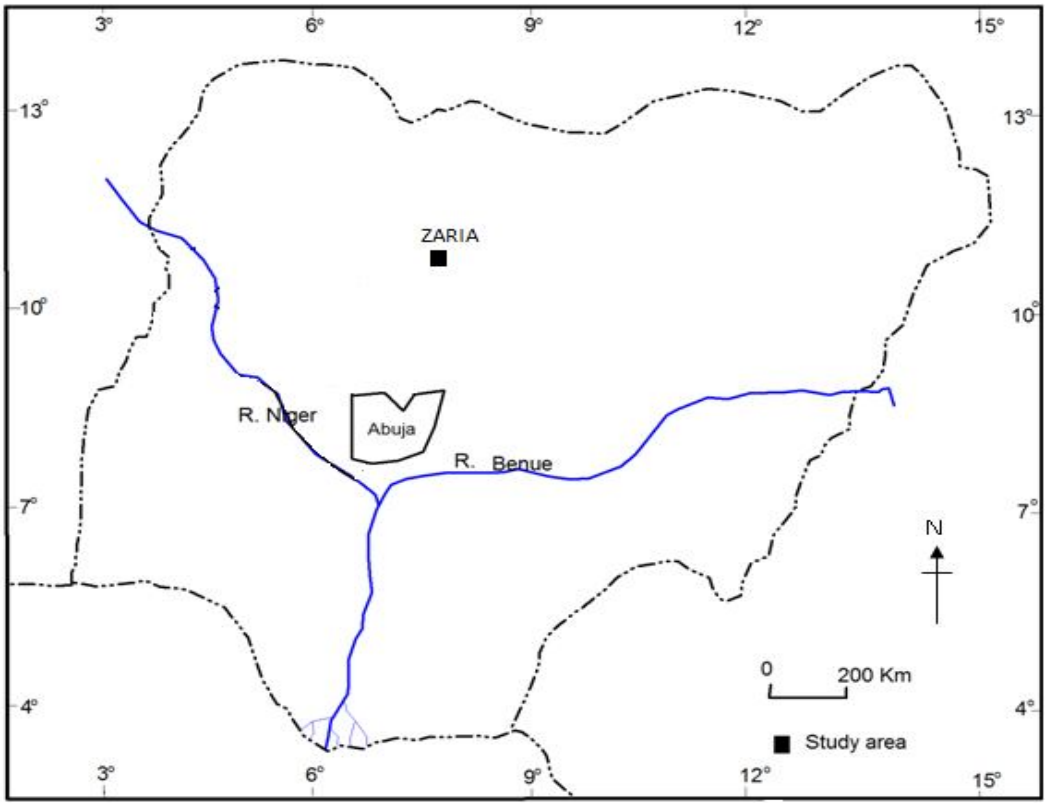


Figure 3: Map of Nigeria showing the location of the study area.

The topography of the area is generally low. Easy accessibility in the study area was possible by the road linking Zaria to Kano in the northwest, also similar roads in the south and river channels and footpaths that link the villages with the major town. The area is accessible through a major road and several footpaths interconnecting the entire study area. Within the study area, there are numerous footpaths that link settlements. More so, the major Zaria - Kano road runs from Ungwan Mijin Goggo to Ungwan Mijin Iya on the north-western portion of the study area enhances accessibility. The scanty nature of vegetation in the area makes the area accessible too. However most of the settlements are not accessible in terms of motorable roads.

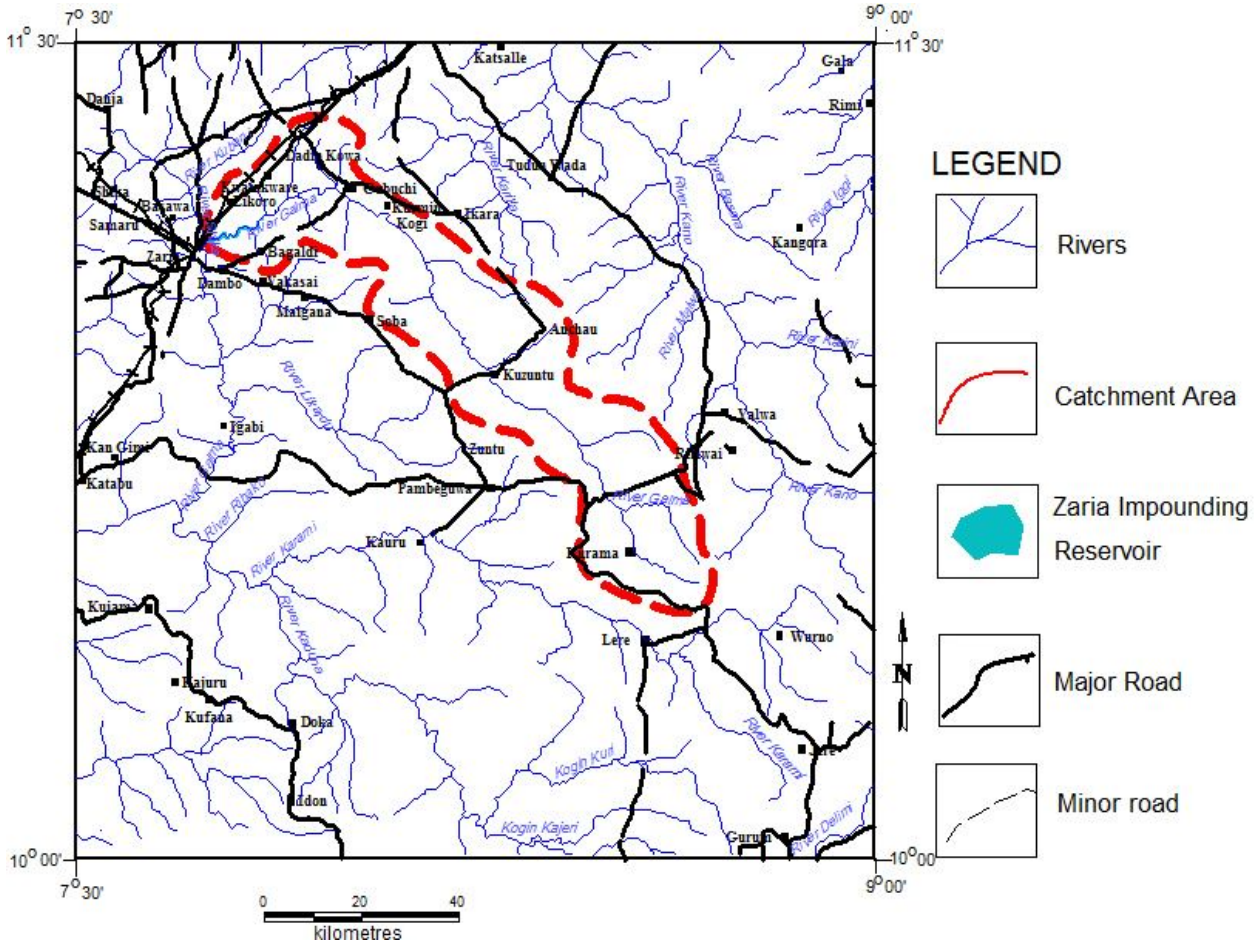


Figure 4: Drainage basin of the Zaria Impounding Reservoir.

Galma River takes it source east of the foothills of Jos Plateau. The source is about 10 km north of Saminaka town on the Jos-Kaduna road. It flows northwest through Gubuchi before flowing southwest through Zaria where it is joined by River Shika. It then flows southwards to its confluence with the River Kaduna near the town of Igabi. Likarbu River flowing westward also joins the Galma River.

According to Maniyunda (2005), the average density of rivers in this drainage sub basin is about 1.0 km/km^2, which means that within one square kilometre there is one-kilometre length of rivers. Apart from the streams that drain the steep hillsides in straight valleys, Galma River and its major tributaries have developed extensive fadama (floodplains) over which they meander therefore increasing the contact length of the rivers with the land surface and improving the total water storage of the soils.

1.6.2 Climate and vegetation.

Zaria belongs to the humid, wet - dry tropics with very distinct wet and dry seasons which are typical of Nigeria. Wet season begins in 20th April and ends by 10th October while the dry season in which there is no rain occurs from October to march. Rainy months are associated with the northwards movement of the Inter-Tropical Discontinuity (ITD), while the southward migration of the Inter-tropical Discontinuity (ITD) is associated with the dry and dusty seasons. The Inter-tropical Discontinuity separates dry continental air masses in the north from moist maritime monsoon air masses in the south of Nigeria (Schoeneich, 2010).

The first half of the dry season is called harmattan period. It is normally dominated by dusty wind, while the second half is a purely hot period (without wind but instead very sunny). The total mean annual rainfall from 1996- 2005 is 1053.4 mm/a according to data

obtained by the Meteorological Data Station of Institute of Agricultural research, Ahmadu Bello University, Zaria (Baba, 2007). Rainfall reaches its peak in mid August to early September. Mean monthly temperatures within Zaria and its environs vary throughout the year. From the records of temperature data for Zaria between 1971 to 2006, according to the Nigerian Meteorological Agency (NIMET), mean monthly temperature varies from 28.1°C in December to a maximum of 41 5°C in April.

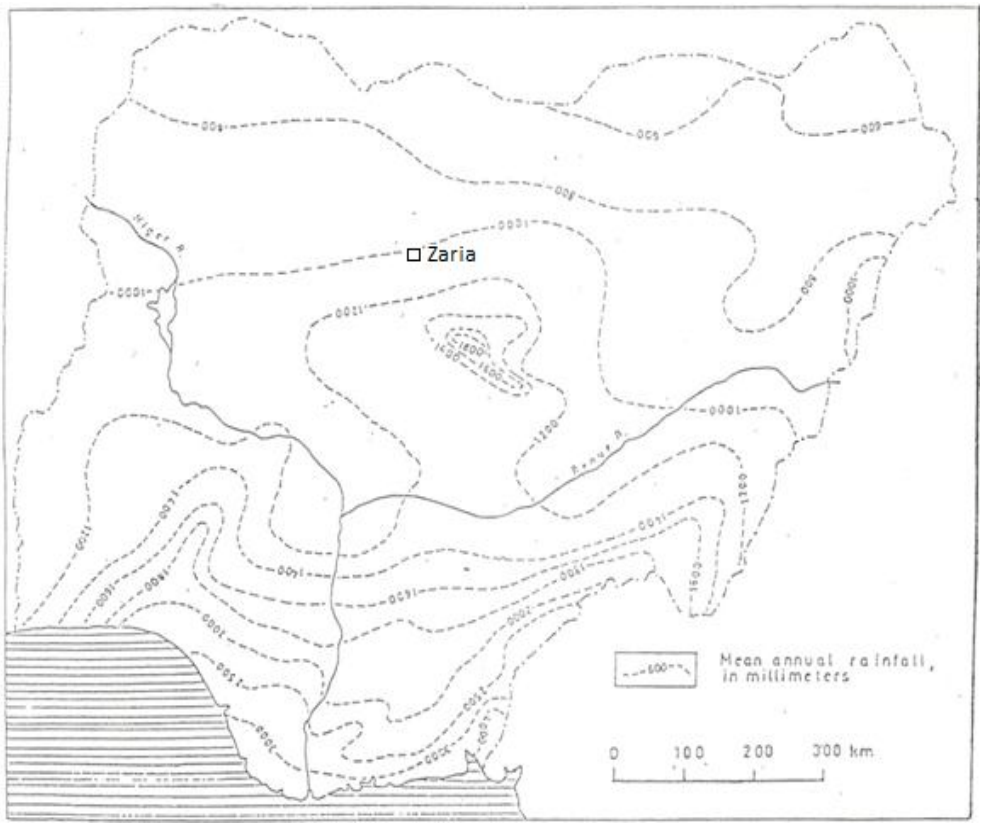


Figure 5: Mean annual distribution of rainfall in Nigeria. Source: Schoeneich and Garba, 2010.

There are two prevalent wind directions. The dry, north-easterly wind known as "harmattan" does occur in November to February period. It usually carries along with it considerable quantities of dust in the atmosphere. Also, the moist south-westerly wind is

associated with the rainy season. It precedes storms and is generally strong but short lived.

The study area lies within the northern Guinea Savannah belt of Nigeria, characterised by open, broad-leaved savannah woodland vegetation with short to medium grasses. However, cultivation, bush burning and grazing activities have greatly modified the natural vegetation cover. Generally, the vegetation has been greatly disturbed by poor land use practice that include bush burning, overgrazing, tree felling for firewood and cultivation. Rain fed agriculture and irrigation are the two major forms of agriculture that are being practiced intensively within the study area. Common tree species in the area include; locust bean (*Ceratonias siliqua*), baobab (*Adansonia digitata*) and mango (*Mangifera indica*). The area surrounding the impounding reservoir is well cultivated with different crops like maize (*Zea mays*), guinea corn (*Sorghum spp*), beans (*Vigna unguiculata*.), sugar cane (*Saccaharum officinarum*) and vegetables such as onion (*Allium cepa*), tomato (*Lycopersicum esculentum*), lettuce (*Lactuca sativa*), and pepper (*Capsicum annum*).

1.7 GENERAL GEOLOGY OF THE AREA WITHIN AND AROUND ZARIA.

The area is underlain in part by Pre-Cambrian rocks which lie in the mobile zone between the West African and Congo cratons. These Pre-Cambrian rocks consist of migmatites, gneisses and north-south trending metasedimentary rocks, intruded by a series of granitic and mafic-ultra-mafic rocks of late Pre-Cambrian to early Palaeozoic age as McCurry (1973) reports. Evidence of complex structural patterns such as joints and faults, forms largely by invading granitic plutons in the basement belonging to the widely distributed Pan-African magmatic suite present. According to Ajibade (1971),

studies have dated the final imprint of the Pan-African orogeny as (600 ± 150) Ma. It is in the light of this that McCurry (1971, 1973) and Ajibade (1971), in agreement with Oyawoye (1964) concluded that there had been at least two orogenic cycles in Nigeria. Ajakaiye *et al.* (1989), reports that the oldest rocks are metesediments, which have been transformed to gneisses and migmatites during these two tectono-metamorphic cycles.

The first orogenic cycle characterized a period of deformation and folding during the epiorogenic uplift, McCurry (1971). The age suggested for this was the Eburnean, (1850 ± 250) Ma by syntectonic metamorphism of probably siltstones and mudstones. The second orogeny occurred after the Pan- African (650 ± 150) Ma, as a result of contact metamorphism due to thermal effect of the Granitic intrusion during the Eburnean Orogeny according to McCurry (1973). This marked the end of the Pan-African event in Nigeria.

Further, McCurry (1973) identified the Basement Complex rocks of Nigeria as underlying the geology of sheet 102 Zaria, where portion of it forms the study area lies. Rock types of the northern Nigeria Basement Complex are classified into three (3) namely the migmatite-gneiss complex, Younger Metasediment and the Older Granites.

Zaria belongs to the Nigeria Basement Complex, which according to McCurry (1973) consists of four distinct rock types namely; the Basement Gneiss, Metasediments ranging from quartzite to schist, the Older Granite suites and diorite. However, there are two distinct lithology within the study area. This comprises of the granite gneiss and medium to coarse grained granite (Fig. 6).

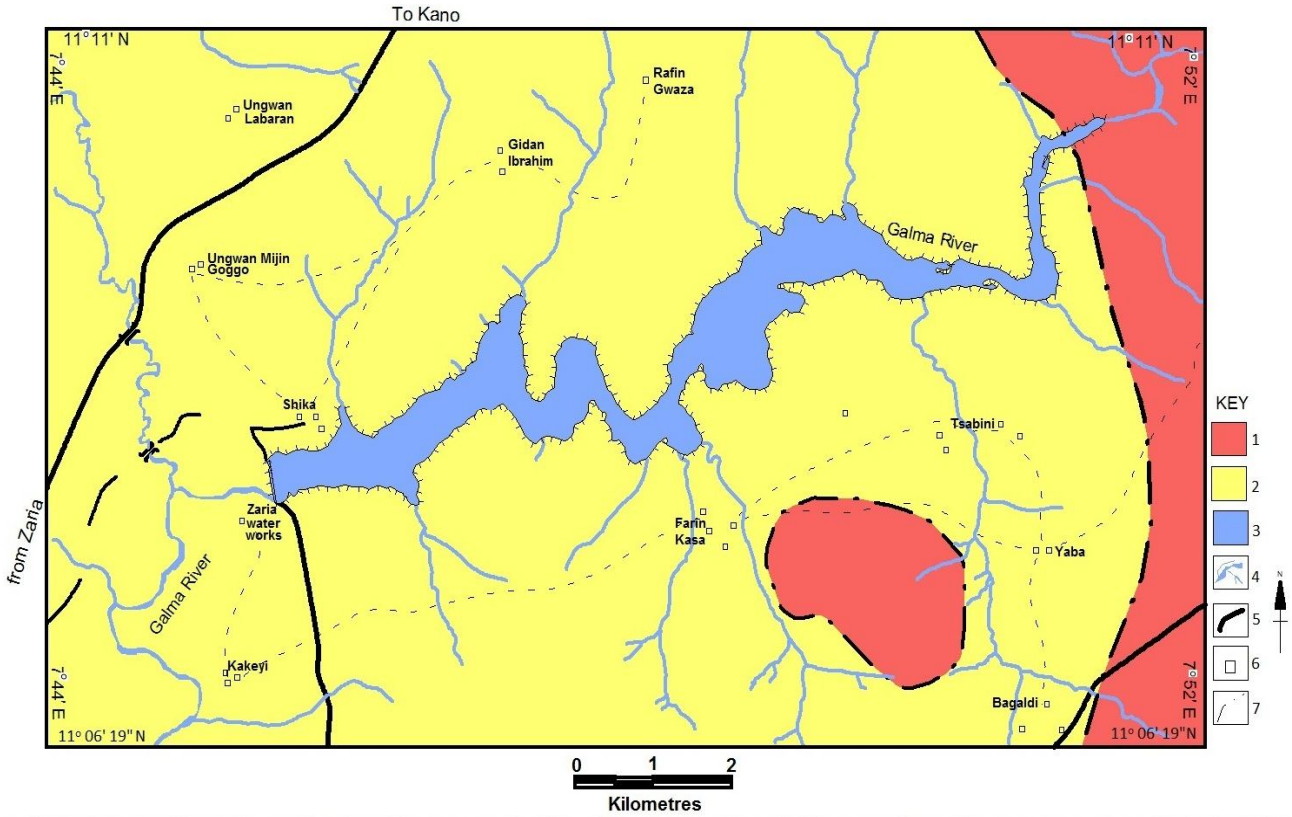


Figure 6: Geological map of the study area. LEGEND: 0 – Study area, 1 – medium to coarse grained granite, 2 – granite gneiss, 3 –Zaria Impounding Reservoir, 4 – Rivers and stream channels, 5 – Major road, 6 – settlements, 7 – Geologic boundaries.

CHAPTER TWO

2. PREVIOUS WORK

2.1 AN OVERVIEW OF RESERVOIR SILTATION.

Impounding reservoirs are sometimes called "man-made lakes" because they are artificial lakes created by man for particular purposes. These artificial lakes can be described as a volume of water impounded that contains various life forms, according to Straškraba and Tundsi (1999). Reservoirs usually fill a river valley that has been impounded by a wall called a dam. However, there is so much mix up about these terminologies – dam or impounding reservoir. Most times the impounded water is often referred to colloquially as the dam. *Senso stricto,* the dam is the barrier or wall built across the river channel in other to hold or store water.

Multi-objective reservoir systems often perform more poorly than anticipated, due to the complexity of operating such systems with conflicting purposes (World Commission on Dams, 2000). Reservoirs are vital to the world's economy for their role in electricity generation, flood control, water supply, and recreation, which are all dependent on water storage capacity.

Reservoir storage capacity comprises of the active (or live) storage and dead storage, Fig. 7. The active storage according to a report by Halcrow Water (2001) is the 'useful' life of a reservoir which depends on the magnitude and nature of incoming sediments, and any physical or operational measures that are in place to reduce the rate at which the remaining storage is depleted.

All dams have a profound effect on fluvial transport and downstream river morphology, and the rate of sediment infilling is crucial to their long-term utility. To optimize the effectiveness of each reservoir, managers of water resources must be able to predict the

rate of reservoir sedimentation processes, especially reservoir-sediment trap efficiency (Heinemann, 1984). They added further that reservoir-sediment trap efficiency is the fraction of the sediment transported into a reservoir that is deposited in that reservoir, usually expressed as a percentage.

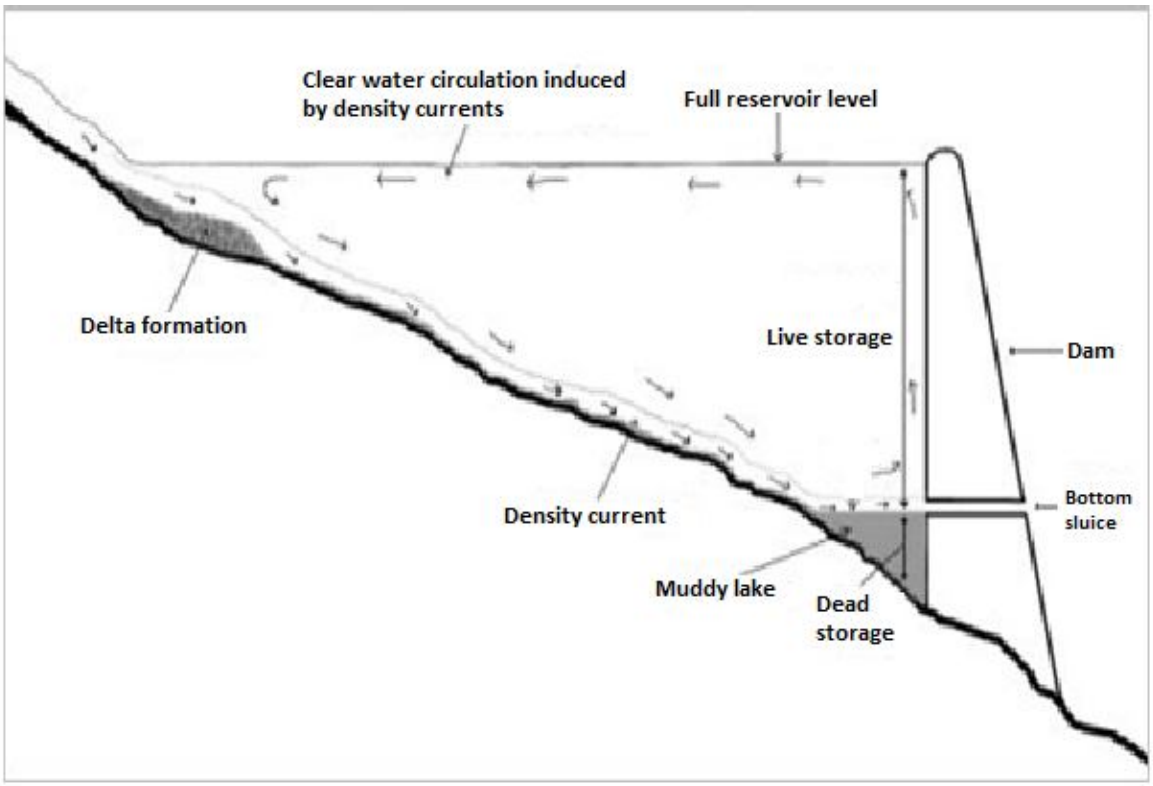


Figure 7: Components of total storage – Active/Live storage and Dead storage, in an impounding reservoir. (Source: Himanshu, and Swarup (2006

Ambers (2001); Dadson *et al.* (2003); and Verstraeten *et al.* (2003) have used the sediment deposited behind dams to understand transport and erosion rates at the watershed or regional scale. Continuous reservoir siltation not only affects water quality, but also reservoir morphology, thus reducing water yield for a given reliability level. Results from studies involving four impoundments in Ceará, where long term (on average seven decades) sedimentation rates were determined, indicates that basin management rather than reservoir management is necessary to avoid substantial reductions in water yield

reliability due to regional reservoir siltation. Therefore, amount of sediment accumulated within an impounding reservoir over time, therefore needs to be quantified.

Different approaches exist to estimate catchment erosion and sediment delivery processes. Volumetric accumulation of material in reservoirs can be estimated by differencing bathymetric surveys taken at different times (Morris and Fan, 1998). This simple method is an effective means of quantifying infilling rates, particularly in reservoirs where detailed maps of the pre-dam river topography are available (Snyder *et al.*, 2004). Reservoirs where bathymetric surveys have been repeated over their history present a particularly exciting opportunity to investigate the evolution of a reservoir deposit (Smith *et al.,* 1960; Morris and Fan, 1998; Dunbar *et al.,* 1999). Childs et al (2003); Ahmadu Bello University Committee on Protection of Kubanni Dam Drainage Basin, (2008); and Baba *et al.,* (2009) prepared an isobath map and produced remaining storage volume estimates of reservoirs. Comparing this with the reservoir's initial storage capacity, the average rate of siltation was determined. Other workers such as Ambers, 2001; Dadson *et al.,* 2003; Verstraeten *et al.,* 2003 have used the sediment deposited behind dams to understand transport and erosion rates at the watershed. Pilotti and Bacchi, (1997) further argued that a more reliable assessment of watershed sediment yield is obtained when a hydraulic approach is augmented by information on the mechanisms that feed sediments to the channelled flow, other authors have used bathymetric method to estimate the volume of sediments infilling impounding reservoirs. These recent investigations demonstrate the importance of collecting quality data documenting the rates, physical properties, and morphology of sediment accumulation behind dams (Smith *et al.,* 1960; and Ambers, 2001), although relatively few detailed studies have been published.

Morphometric characteristics (area, slope, shape, length), relates to the hydrogeology of an area and also control the velocity of the run-off through the catchment (Offodile, 2000; and Ajibade *et al.,* 2010). Thus, a typical granitic basin with high run-off is expected to develop greater drainage density than a basin with thick soil or sedimentary cover which shows low drainage density. Within a river catchment area, hill slopes control sediment generation as they are means by which water, solutes and sediments are supplied to the fluvial system through processes that include precipitation, surface water flow and disintegration of the earth's crust by physical and chemical processes also called mass wasting. These disintegrated earth materials, provide by erosion much of the material that may become fluvial sediment by erosion (either as sheet or channel erosion). According to Newson (1986) stream bank erosion is a significant source of sediment load carried by streams, supplying over 50 percent of the total input in many instances. Studies carried out by the U.S. Department of Agriculture-Soil Conservation Service (1992), reveals that erosion processes are generally slow. However, the annual volumes of sediment load involved are huge. This can prevent a reservoir from impounding water to be used for its different purposes. Over time, such erosion-induced drainage basin changes affect river discharges (Mulder and syvitski, 1996).

The flow of a river within its drainage basin, carries along with it sediments and is eventually stored in a reservoir. These sediments settle and thus, reduce its storage capacity (Fig. 8) below. Heinemann (1984) reports that when storm run-off enters a reservoir from its adjoining catchment area at point A, the inflow together with sediment particles is spread over a large river channel/reservoir cross-section and its velocity is quickly reduced.

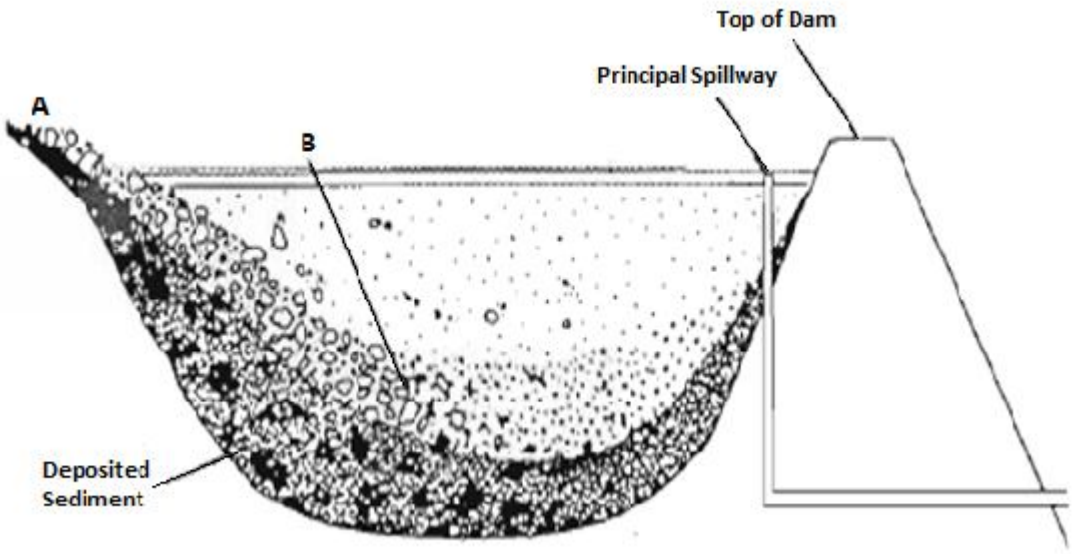


Figure 8: Run-off moving into and in a reservoir. Source: Heinemann, 1984.

This in turn reduces the transport energy and causes the large sediment particles and aggregates to settle at the bottom, while remainder of the inflow moves along the bottom of the reservoir towards the dam until it reaches an elevation in the reservoir where the density of the inflow equals the density of the reservoir water. This is because as the inflow velocity is further reduced, the larger particles left in the remaining flow will settle to the bottom, decreasing the inflow's density. Some of the flow may move horizontally in to the reservoir before the bulk of the remaining flow. When the flow reaches this point of equal intensity, say point B, it flows horizontally into the reservoir somewhat like a wedge between the lighter and denser water, and raises the water in the reservoir above it. In a full reservoir equipped with a surface discharge principal spill-way, the upper level of water would be discharged. Reservoirs tend to trap both coarse and fine sediment particles.

Chanson and James (1998) stressed that sediment transport is the general term used for the transport of material, for example silt, sand, gravel, boulder in rivers and streams. The transported material is called the 'sediment load'. Sediment load is defined as debris eroded from an area drained by a stream, delivered to and transported by the stream itself Schuum (2009). Sediment load also referred to as sediment yield, and according to other authors it is the amount of sediment transport comprising both bed-load component and a suspended sediment component (Heinemann, 1984; Chanson and James, 1998; and Halcrow Water, 2008).

When particles are eroded and transported by wind, water, or ice, they become part of the transport medium's sediment load. There are three categories of load that may be transported by agents of erosion - dissolved load, suspended load, and bed load:

i. **Dissolved load: Are earth material or sediment load that has been dissolved into ions and transported in solution. The dissolved load in water and ice is not visible. To be deposited, it must be chemically precipitated. During low flow rate, solute concentrations of sediments are relatively high as runoff water flows gradually and aided by groundwater flow, thus prolong the it retention time. Eventually, soluble constituent of the sediments become dissolved and flow along with water in rivers.**

ii. **Suspended or wash load: This is what makes stream water look dirty after a rainstorm and is generally made up of lighter-weight, finer-grained particles such as silt and clay that is maintained in suspension by turbulence. Such sediment is not continuously in contact with the river bed and so is suspended within the medium of transport. It does not contribute greatly to stream erosion, since it is not in frictional contact with the stream bed. They are the finest grained fraction**

of the total sediment load and most important in reservoir sedimentation survey (Walling and Webb, 1987).

iii. **Bed load: These are coarse-grained earth material that travels along the bottom of the stream that is only sporadically transported. Bed load remains in almost continuous contact with the bottom, and moves by rolling, skipping, or sliding along the bottom. Sometimes, turbulent or eddy currents can temporarily lift these larger grains into the overlying flow of water by saltation. Thus, the grains advance by short jumps or skips until the surge diminishes and then fall back to the bottom because of their greater weight. Wind, water, and ice can all transport bed load; however, the size of sediment in the bed load varies greatly among these three transport agents.**

The total sediment discharge into a stream is the total volume of sediment particles in motion per unit time. It includes the sediment transport by bed load motion and by suspension as well as the wash load. This is shown in Fig. 9 below. The sediment load of rivers can exert an important control on the use of a river for water supply, transport and related purposes (Walling, 2008). High sediment load also can result to major problems for water resource development, through reservoir sedimentation, and the siltation of water diversion and irrigation schemes, as well increasing the cost of treating water abstracted from a river. The sediment load of a river also provides an important measure of its morpho-dynamics, the hydrology of its drainage basin and the erosion and sediment delivery processes operating within that basin.

According to Walling (2008), changes in the sediment load of a river can give rise to numerous problems. Increased sediment loads can, for example, result in accelerated rates of sedimentation in reservoirs, river channels and water conveyance systems,

causing problems for water resource development, as well as in adverse impacts on aquatic habitats and ecosystems. Conversely, reduced sediment loads can result in the scouring of river channels and erosion of delta shorelines as well as reduced nutrient inputs to aquatic and riparian ecosystems, particularly lakes, deltas and coastal seas.

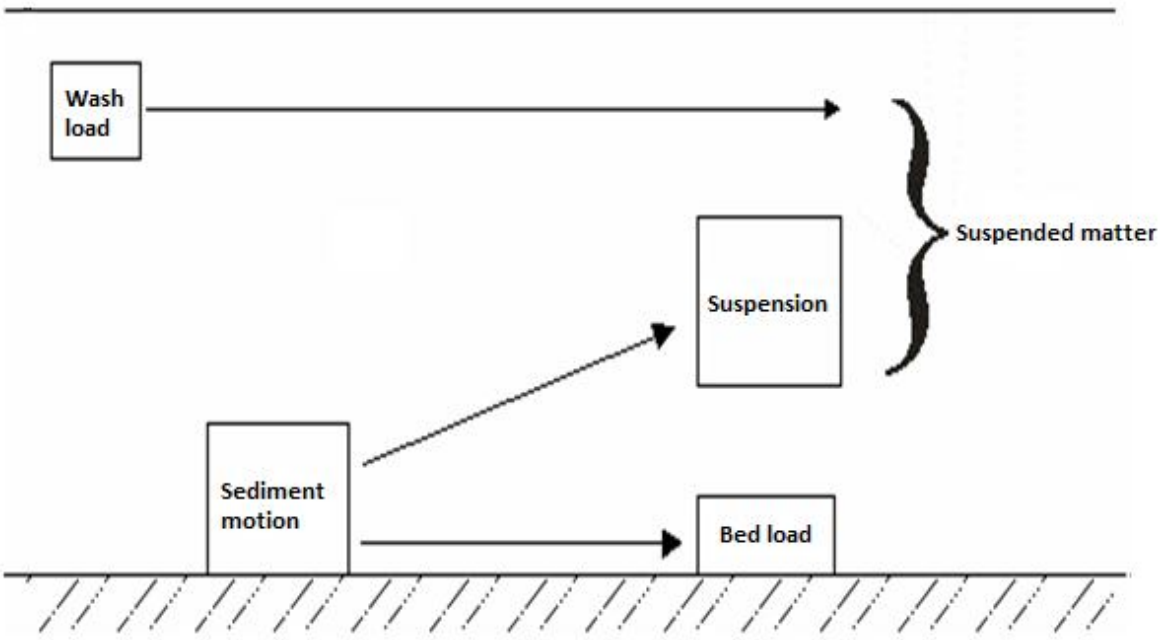


Figure 9: Classification of transported sediments, after Chanson and James (1998).

Impounding reservoirs are effective trap of sediments, and its capacity is reduced as deltas prograde into reservoirs. Mahmood (1987), reports that the global average for the useful life of a reservoir is less than 25 years but in most cases it is usually longer. This is in agreement with James and Chanson (1999), who observes that extreme reservoir siltation, reduced the life of a number of dams to less than 25 years in Australia. Chanson (1998) compared the sedimentation rate as a function of the study period (period between consecutive observations). These data are compared with large sedimentation rates observed in Australia and in Central Europe. The result shown in Fig. 10 below indicates

that the siltation rates at Moore Creek and Quipolly were important and similar to other extreme situations. However the authors added that most reservoirs included in the study plot, were not fully-silted in less than 25 years.

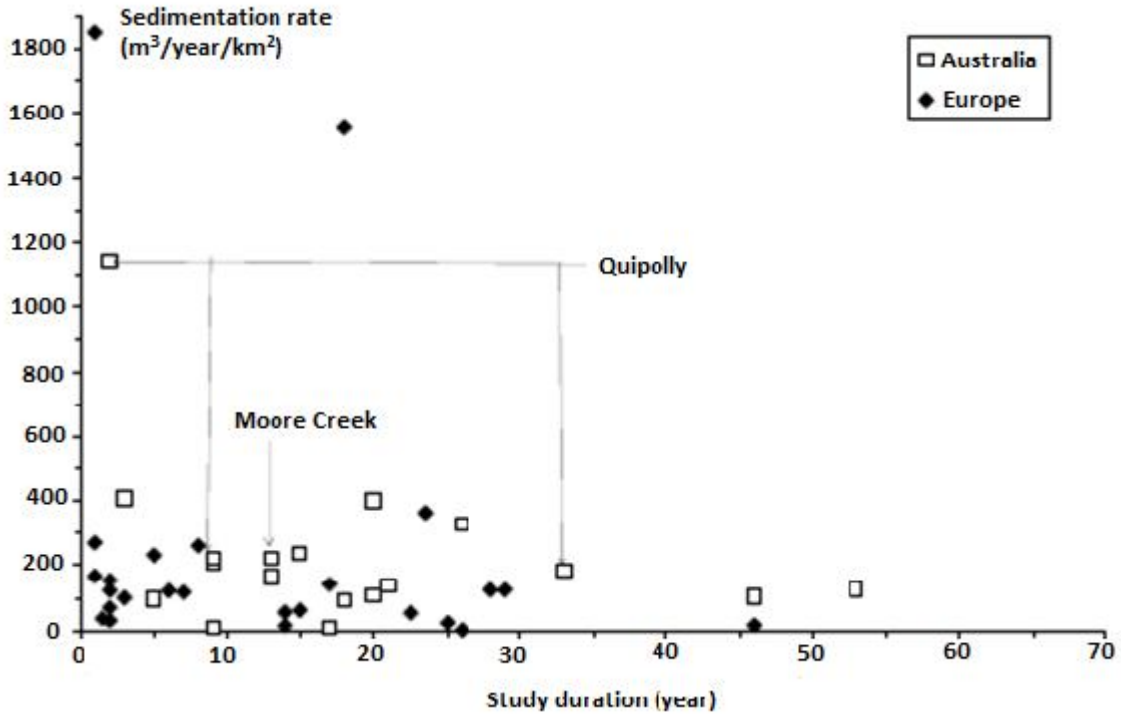


Figure 10: Sedimentation rates over different study period in Australia and Europe, after Chanson and James (1998).

Further, Kondwani *et al.* (2011) reports that many river systems in the tropical regions of Africa continue to experience severe and uncontrolled environmental degradation which have resulted into enhanced soil erosion in the catchments, thereby causing a range of problems from considerable loss of soil fertility and eventual desertification to accelerated river, canal and reservoir sedimentation.

2.2 HYDROGEOLOGY AND DRAINAGE OF THE AREA

Groundwater in the study area is located within the two aquifers: most of it in the Soft Overburden Aquifer, less in the fractures and fissures of the crystalline rocks forming Fractured Crystalline Aquifer. The flow of groundwater extends from wet season until the end of the dry season and augments volume in storage of the impounding reservoir during the both seasons. According to Yunusa (2002) and Garba (2008), there are three types of aquifers system in the study area – the Alluvial Aquifer, the Soft Overburden Aquifer and the Fractured Crystalline Aquifer. However according to observations by the present Author, the impounded valley is erosional and area of the Alluvial Aquifer is very limited. The Alluvial and Soft Overburden aquifers lie directly under the impounded reservoir. They vary in thickness from less than 10 m to 50 m according to Wright and McCurry (1972) and Robinson (1986). Schoeneich (1999) reports that the Soft Overburden Aquifer is about 30 metres thick on the average on metamorphic rocks and less than 10 m thick on the granites, and consists of gritty clays with effective voidity of about 2.8%. The Soft Overburden Aquifer is a readily accessible source of water to the local population through hand dug wells, although Adanu (1987) stated that borehole yields are low, between 0.3 l/s to 0.5 l/s due to its clayey nature. Below it is the Fractured Crystalline Aquifer, extending up to the maximum depth of 70 metres below the ground surface, which can only be exploited through bore-holes.

The Zaria Impounding Reservoir was constructed along the Galma River near Shika village, within the upper Galma River Sub-Basin. Galma Basin is one of the sub-basins of the Kaduna River Basin, itself being a sub-basin of the River Niger. It is at the northern boundary of the main Kaduna River Basin. There are three major rivers, which

together drain the basin. They are the main Galma River, Rivers Shika and River Likarbu.

2.3 QUANTITATIVE MEASUREMENTS IN IMPOUNDING RESERVOIRS.

According to Ajibade *et al.* (2010), measurement and quantitative expression within drainage basins began with the work of James Hutton in 1775. Reservoir storage volume (or capacity) can be estimated through direct and indirect techniques (Dada, 2009). The direct method involves obtaining field measurements directly using metric tape, a heavy weight and a slow moving boat, or even echo sounder using a large boat. On the other-hand, indirect methods analyses satellite images using remote sensing softwares.

Iguisi (1997) determined the depth of the Kubanni impounding reservoir; while Ahmadu Bello University Committee on Protection of Kubanni Dam Drainage Basin (2008) and Baba (2009) all used the direct method to estimate the remaining storage capacities in the Kubanni and University Farm Lake respectively and hitherto calculated the rate of siltation in the reservoirs. Elsewhere, studies by Goel *et al*., (2002); Liebe *et al.,* (2005); Mukherjee *et al.,* (2007); Zola and Bengtsson (2007) and Oklahoma Water Resources Board, Final Report (2009) have shown the viability of the indirect method by employing remote sensing with direct field method.

Iguisi (1997) assessed the current level of sediments in Kubanni using survey technique. He concludes that the lake had lost its depth, about 3.3 metres, representing about 30% storage loss through sedimentation process caused by high rate of erosion over the catchment area. However, the amount of sediments accumulated over the years since its impoundment was not quantified.

However, Parkman (2002) carried-out a preliminary survey of the Zaria impounding reservoir. They employed the NASA 'TARGET' ECHO SOUNDER to sound the reservoir's depth and also a GARMIN etrex - VISTA GPS to accurately establish the coordinates of the location of depths. In addition, they analysed landsat image of Zaria impounding reservoir when the reservoir water level was approximately at the spillway crest level in order to determine Area – Capacity values at various designed elevation. They concluded that the gross capacity of the Zaria dam reservoir based on the measured field data established at the spillway crest level was 20,900,000 m^3.

More recently, Liebe *et al.* (2005) developed a formula to estimate and monitor reservoir storage volumes of impounding reservoirs on the basis of their surface areas. They employed the direct field method and in combination with satellite imagery of large numbers of small reservoirs in Upper East Region of Ghana, situated in the Volta Basin. The use of satellite imagery allows us to measure the reservoir surface areas. Using this method, the authors compared reservoir storage volume as a function of surface area using a theoretically derived relation. The derivation of this relation starts with a square based, top down pyramid that is diagonally cut in half, shown in Fig 11 below.

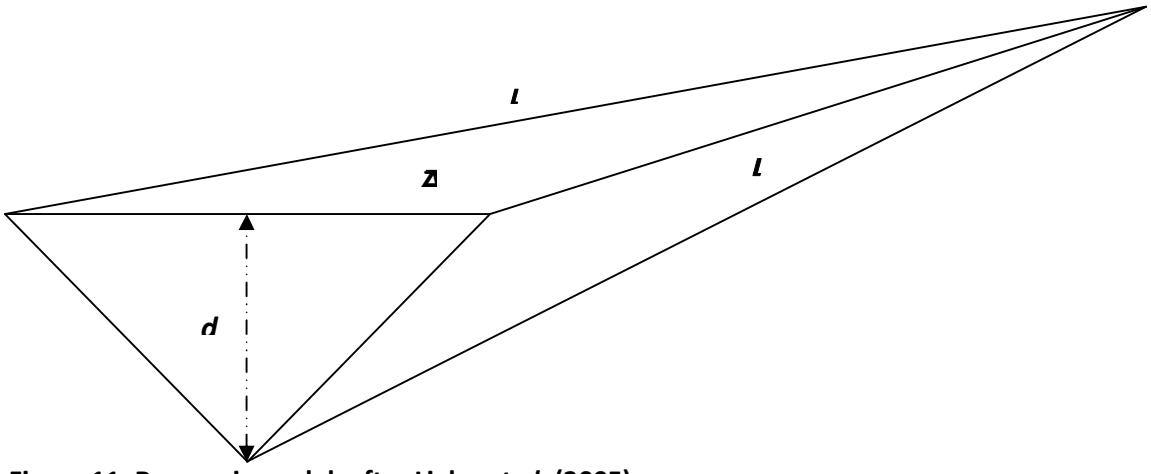


Figure 11: Reservoir model, after Liebe *et al.* (2005)

The volume of such a body is given by;

$$V_{half\ pyramid} = \frac{1}{6} * A * d \text{..... (1)}$$

Where,

V **is volume,**

A is the area defined by the square of its characteristic side length *l*.

Depth, *d* can be expressed as a fraction 1/*f* of a side length *l*, thus;

$$depth, d = \frac{1}{f} * l \text{..... (2)}$$

Equation (1) can also be written as;

$$V_{half\ pyramid} = \frac{1}{6} l^2 * \frac{1}{f} l = \frac{1}{6*f} l^3 \text{..... (3)}$$

Substituting $A = l^2$ **yields**

$$V_{half\ pyramid} = \frac{1}{6*f} * A^{3/2} \text{..... (4)}$$

Taking logarithm of both sides gives;

$$logV_{half\ pyramid} = log\frac{1}{6} + log\frac{1}{f} + \frac{3}{2} logA \text{..... (5)}$$

Equation (5) is the relation for the expected area-volume on a log-log plot. The outline of each reservoir was mapped using GPS. GPS readings of depth measurements were taken at sampling points. Bathymetric maps were compiled on the basis of GPS-referenced depth measurements, taken with a telescopic stadia rod from a boat.

The first term of equation (5) indicates that half a pyramid has 1/6 (one-sixth) of the volume of a cube that has the same characteristic length *l* as the pyramid, while the last two terms represent the general volume definition consisting of area A and depth *d* expressed as a fraction 1/*f* of the characteristic length *l*.

To verify that the volumes of reservoirs can be predicted by a formula of this form, field data were obtained and used in collaboration with remote sensing. Depth measurement were taken using a telescopic stadia rods, GPS from a slow moving boat, while the surface area was obtained by analysing satellite images` using Landsat ETM bands 3, 4 and 5.

Based on these measurements, the reservoirs' volumes can be described with the regression equation:

$$logV_{reservoir} = -2.067 + 1.4367 * logA \text{..... (6)}$$

This linear trend resembles the theoretically derived area-volume relation in equation (5) above. This according to the authors is remarkable given the fact that the surface shapes of the reservoirs are not similar at all and display a large variety of length/ width ratios., Comparing equations (5) and (6), the term $1.4367 * logA$ **was found to be close to the expected** $\frac{3}{2} logA$ **and -2.067=**$log\frac{1}{6} + log\frac{1}{f}$**. Despite the variety of shapes, the derived equation is highly consistent. Thus, the sizes of the measured reservoir are finally summarised in the equation:**

$$Volume = 0.00857 * Area^{1.4367} [m^3] \text{..... (7)}$$

This relates reservoir areas to storage volumes with high precision. With this relation, the total storage capacity of all the reservoirs within their study area was estimated at 185 × 10^6 m^3. However, no attempt was made to determine the siltation rates for each of these impounding reservoirs.

Later, Zola and Bengtsson (2007) compared three techniques in order to determine the area-depth relationship of Lake Poopó in Bolivia. Results from their measurement using the direct field technique from a slow moving boat was used to plot depth against elevation of the lake bottom along two cross-sections. Satellite images were used to

determine the water surface area of the Lake at different water stages with GIS (geographic information system) software. Also they carried out water balance computations based on knowledge of water inflows to, and outflows from the Lake; precipitation directly onto the lake surface; evaporation from the lake surface; and the lake surface area from satellite images, the change in storage can be determined. Results from the studies according to the authors revealed that information about the depth of Lake Poopó is best obtained by performing measurements from a slowly moving boat using a rod, although cumbersome.

Ahmadu Bello University Committee on Protection of Kubanni Dam Drainage Basin (2008) measured the remaining depth in the Kubanni impounding reservoir by direct field technique using a slow moving boat, satellite navigator (GPS), a heavy weight and metric tape. The result of their study in Table 1, showed the calculated remaining storage of 1,568725 m^3 or 60% of the dam original year 1973 storage. They determined the rate of siltation in the impounding reservoir at 30,331 m^3/a.

Table 1: Results of the remaining depth measured at Kubanni Impounding Reservoir by Ahmadu Bello University Committee on Protection of Kubanni Dam Drainage Basin, 2008.

Depth Interval be-low circular spill-way (m)	0 – 1	1 – 2	2 – 3	3 – 4	4 – 5	5 – 6	> 6	Total
Area of depth interval (m^2)	152,900	82,300	93,600	105,000	105,500	49,900	2,900	592,100
Average depth of water (m)	0.5	1.5	2.5	3.5	4.5	5.5	6.25	2.65
Volume of water (m^3)	76,450	123,450	234,000	367,500	474,750	274,450	18,125	1,568,725

Their conclusion was that with the water consumption of 1,211,800 m^3/a in the campus, and at the established rate of siltation of the impounding reservoir, by year 2023 rationing of water will start in Ahmadu Bello University Campus, first during the dry season. From 2039, water will flow only in the wet season. This is because the volume of water will be insufficient to meet water demand. It was proposed that the dam should be dredged if adequate water supply must be sustained on the campus.

Dada, (2009) studied the level of sedimentation in the Galma reservoir by carrying out depth measurement within an area about 640 m away from the embankment using land surveying technique (this is also a direct field technique) to fix survey points grid squares over the study area during dry season of 2007. Grid lines were drawn from the south bank to the north bank and from the embankment to the upstream (Table 2). Eight grid lines labelled P_1-P_8 were drawn between the two banks at 80 m intervals.

Table 2: Zaria Lake depth at each sampling point in metres. Source: Dada, 2009.

	Embankment								
Traverses	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
P_1	**0.7**	**1.0**	**1.4**	**2.6**	**2.6**	**2.7**	**1.2**	**1.4**	**2.1**
P_2	**0.9**	**1.2**	**2.9**	**3.5**	**3.1**	**4.1**	**3.1**	**3.2**	**3.2**
P_3	**1.2**	**1.8**	**7.2**	**7.1**	**7.3**	**6.4**	**3.9**	**3.7**	**3.6**
P_4	**1.5**	**5.2**	**6.5**	**6.9**	**5.2**	**5.9**	**3.8**	**3.7**	**1.6**
P_5	**4.3**	**4.5**	**4.3**	**3.6**	**3.1**	**4.0**	**3.1**	**2.4**	**2.7**
P_6	**1.3**	**3.2**	**3.2**	**3.0**	**3.1**	**3.0**	**2.7**	**2.5**	**2.0**
P_7	**1.5**	**1.7**	**3.1**	**3.8**	**3.1**	**1.6**	**2.0**	**2.1**	**1.8**
P_8	**1.8**	**1.9**	**2.0**	**3.1**	**3.6**	**1.4**	**1.7**	**1.8**	**1.6**

Upstream

Nine grid lines labelled 1-9 were selected from the embankment towards the upstream at 20 m intervals. Similar grid lines were also taken from one bank of the reservoir to the other, each at an interval of 20 m. The intersection between these two sets of grid lines were designated sampling point and using the theodolite, a canoe was guided. Measurement of the lake depth was taken for 72 sampling points over the lake area using a rope, with a medium weight plumb tied to its end. It is worth noting that in Dada, 2009, the study did not survey the entire dam. Only the portion of the dam extending up to about 160 metres away from the dam crest was surveyed in order to determine the remaining depth of the impounding reservoir. In this writer's opinion, the depth obtained will not be a good representation of the entire dam. Also, the level of sedimentation in terms of volume was not quantified. The previous author's conclusion was that the reservoir has lost 7.6 m depth to sedimentation, indicating 51% loss in installed initial storage capacity and also determined the catchment area to be 3241.36 km^2 from landsat images.

However, in an attempt to determine whether the abandoned University Farm Lake, Shika, can still be used to as the main source of water supply for the Ahmadu Bello University Teaching Hospital, Shika, Baba *et al.* (2009) did a study to measure the remaining storage of the lake using a fishing boat, metric tape and a satellite navigator (GPS). The authors proposed to use this reservoir as the main source of water for Shika Hospital because with water demand at 154 m^3/day and 547 beds, the hospital suffers from inadequate and irregular water supply. After 43 years of siltation the remaining storage of the reservoir was found to be 349,911 m^3. The rate of siltation between 1966 (date of dam construction) 2009 was calculated as 6,600 m^3/year, rate of erosion in the

drainage basin during the same period as 0.559 mm/year and safe yield as non existing because there is no active storage. It was found that after deduction of losses to evaporation calculated as 194,560 m^3/y and deduction of 272,700 m^3 of environmental reserve (minimum necessary to preserve aquatic), there was no active storage left meaning that there is also no safe yield. The authors concluded that the University Farm Lake cannot serve as a source of water for the Ahmadu Bello University Teaching Hospital Shika, unless it is dredged to its original storage capacity. In years to come there will be little or no more water in it because it will be completely silted up until there will be no more trace of it seen on the map.

CHAPTER THREE

3. METHODOLOGY.

3.1 TYPES OF DATA COLLECTED.

The study was carried out in order to achieve its aim by a thorough desk review of relevant literatures (like maps, textbooks, journals, papers, etc). Also, data on the depth of the Zaria impounding reservoir during its impoundment and other characteristics of the dam were collected from the Nigeria registry of dams (FMWRRD, 1995). Data of raw water pumped from the impounding reservoir was generously supplied by the Zaria Water Works.

Both the direct and indirect methods were employed in the determination of the present storage in the Zaria Impounding Reservoir. Direct method was employed using field techniques by the use of a slow moving boat, metric tape tied to a heavy object and a satellite navigator to determine the remaining depth, delineate the open water table at the time the spillway is still overflowing by comparing with Google Earth image of the study area and surface area of the impounding reservoir.

The indirect method analysed surface area of the impounding reservoir from remotely sensed data of ETM+ landsat images for October of years 1990, 2000, 2010 in order to calculate the volume. Software such as ILWIS 3.7 and GLOBAL MAPPER 11 were used to analyze and process the land satellite images. Maps of the study area were manually prepared and then later digitized. Digitization of the maps was done using MAP INFO 7.5 and AUTOCADD. The rest of the data were collected through the following activities;

a) **Reconnaissance survey.**
b) **Direct field method.**

i. **Measurement of remaining depth of the impounding reservoir.**

ii. **Delineation with satellite navigator, from the land, edge of the open water table at the time of spillway flowing.**

iii. **Determination of surface area of open water table at the time spillway is still flowing.**

c) **Indirect method.**

d) **Measurement of depth to water-table in hand dug wells located within the study area.**

e) **Determination of the rate of erosion in the impounding reservoir's drainage basin.**

3.2 RECONNAISSANCE SURVEY.

First, a reconnaissance survey of the study area was undertaken. This was done to get the researcher acquainted with terrain and delineate the area of study. Also, this was to ensure that management of the Zaria water works were informed of the researcher's intension to carry out a study within and around the Zaria impounding reservoir which constitutes the study area. The methodology employed in this study is fully described in the sections that follow.

3.3 DIRECT FIELD METHOD.

3.3.1 Measurement of remaining depth in the impounding reservoir.

The traverse method employed for this work is random and systematic, extending across region of shallow to very deep lake bed within the impounding reservoir. This was done in such a way that the traverse extends across from shore to shore. Sampling stations were designated points where the depth, in metres, below the water-table was measured.

This was done from a fishing boat using a measuring tape having a heavy weight tied to its end, see Plate 2. The boat is made to be stationary by the paddler at the time depth measurements are taken. Then the measuring tape is released from the boat and lowered down until the heavy object tied to it just touches the bottom of the reservoir. Gently, the rope is then drawn up until it is taut due to the heavy weight tied at its bottom. The calibration on the tape at the point of intersection 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.

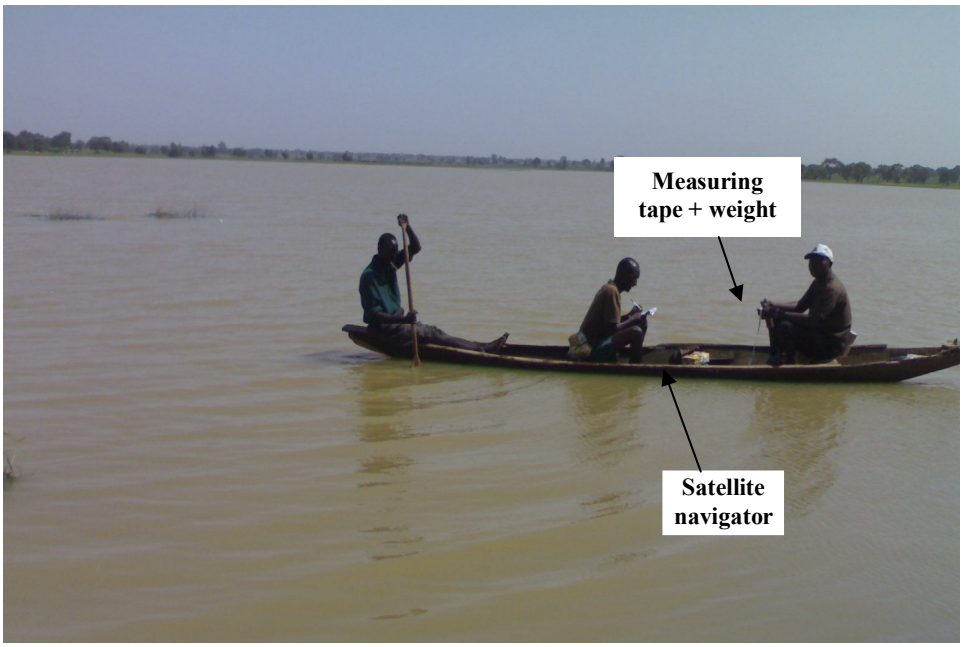


Plate II: Field method for the depth to bottom of lake measurement.

The same procedure was repeated for all sampling points within the extent of the reservoir surface to determine the depth of the lake at each respective point. Points of measurement for each sampling station were located using a satellite navigator with horizontal accuracy of ± 8 m. Summary of depth measurements obtained during the

field work is documented in Appendix IV. Also, the points where depth measurements were taken are located on the map. Interpolation between any two neighbouring depth measurements was done in order to obtain isobaths, (Fig. 13a and 13b).

3.3.2 <u>Delineation of the open water-table</u>.

In order to determine the area of the open water table, points indicating boundaries of the edge of water were mapped by marking the coordinates of selected station points one after the other along edge of water with a satellite navigator. This was in turn, repeated for several points round the impounding reservoir. The positions of these coordinates acquired were taken and then plotted to indicate the boundaries of the reservoir on the bathymetric map in Fig. 13. The outline of the edge of open water-table obtained from field measurement was then compared with the open water-table taken from European Space Agency (ESA), Google Earth satellite image, made available on the internet and obtained on 27th November, 2010 shown in Fig. 12.

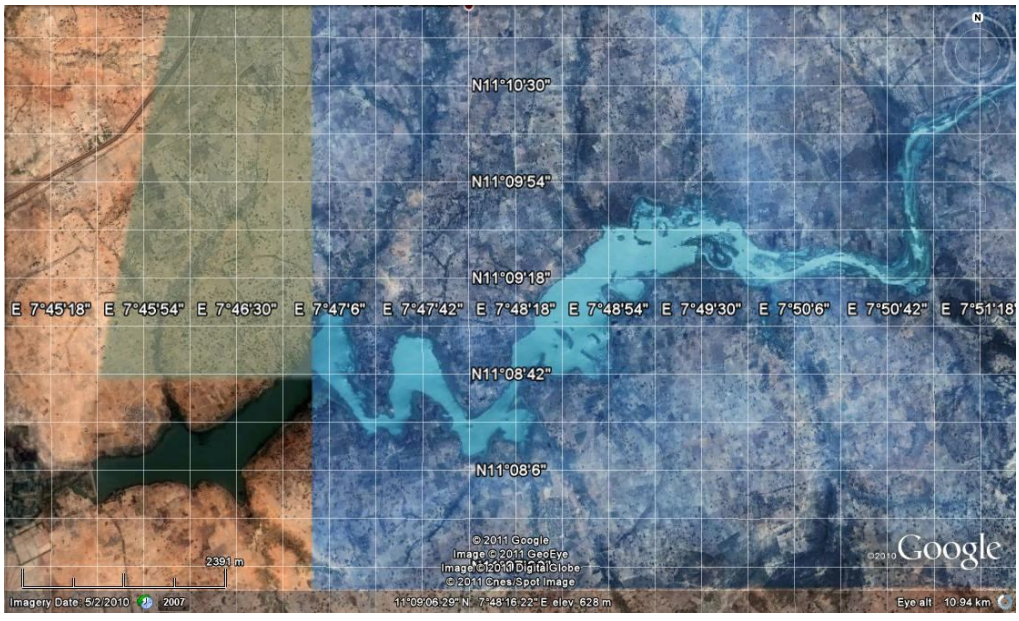


Figure 12: Open water table of the Zaria impounding reservoir from Google Earth satellite image.

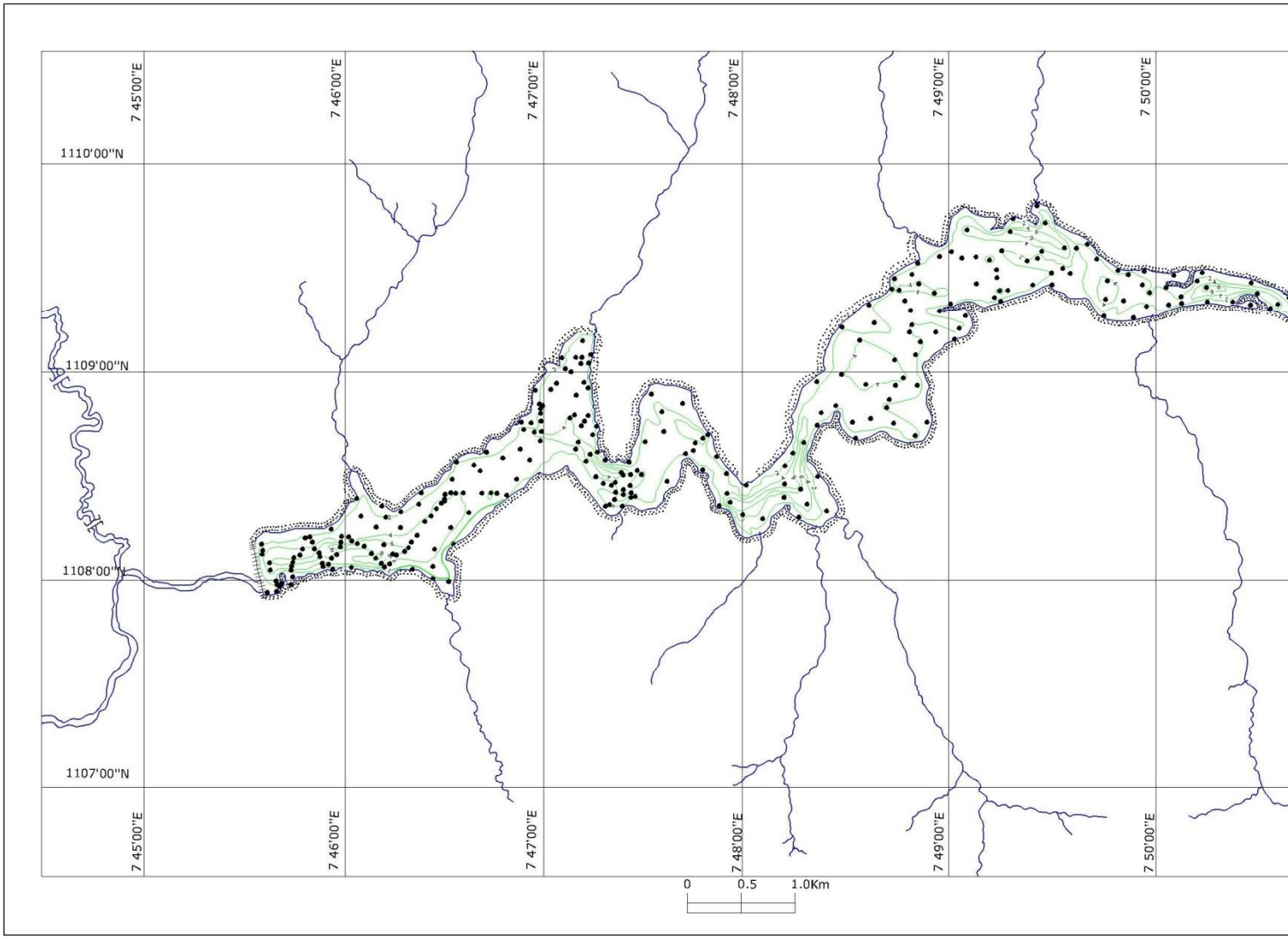


Figure 13a: Bathymetric map of Zaria Impounding Reservoir showing station points and isobaths. Explanation: 1- Point of depth measurement below the level of the spillway, 2 – River and tributaries, 3 – Bridge, 4 – Boundary of the impounding reservoir, 5 – Isobath in metres below the level of the spillway, 6 – Dam body.

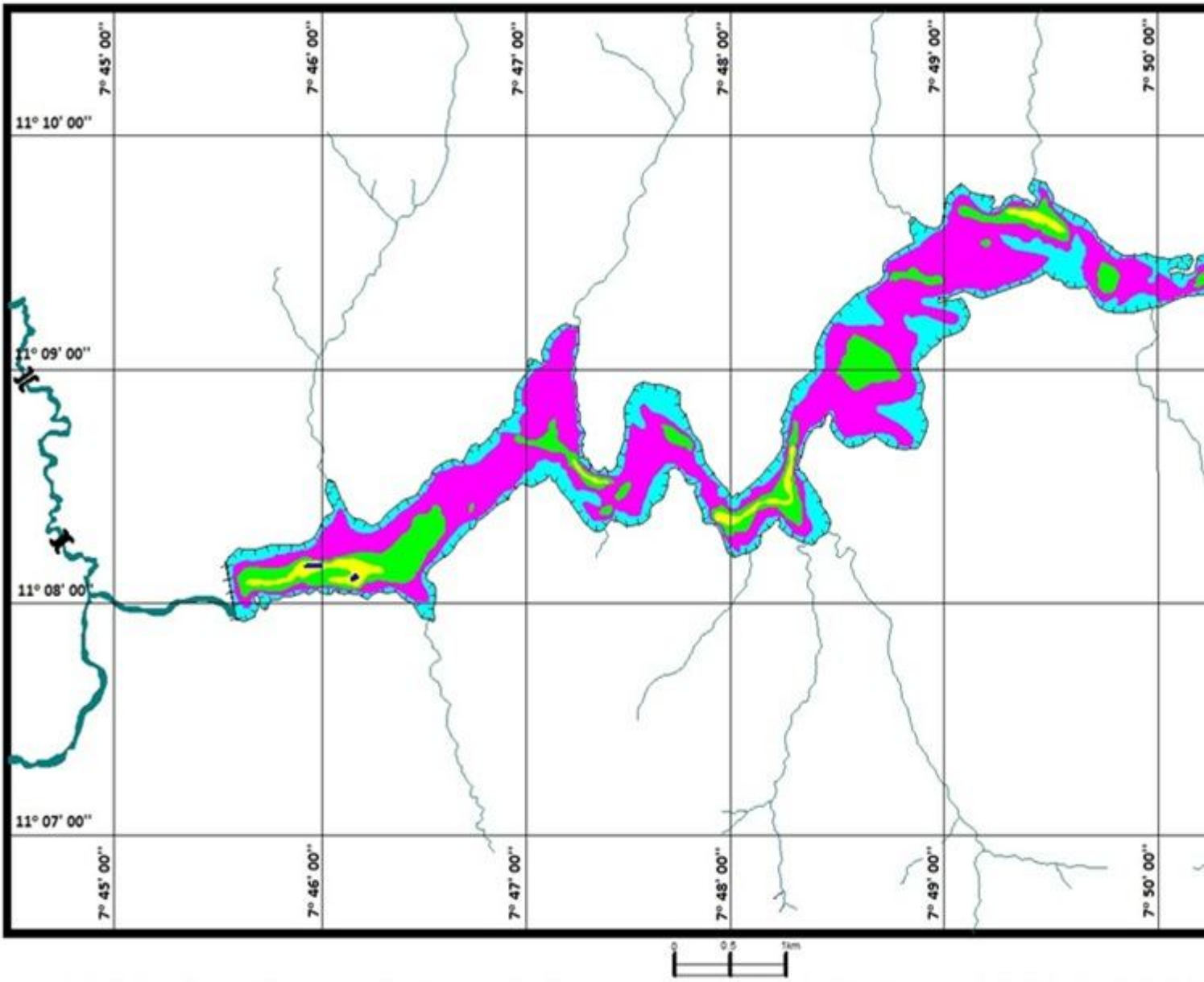


Figure 13b: Bathymetric map of Zaria Impounding Reservoir when the spillway is flowing. Explanation: 1 - River and tributaries. 2 - Brigde. 3 - B
impounding reservoir. 4 - Dam body.

3.3.3 Determination of surface area of open water table.

The area bounded by the water body was then measured by the least square method. The number of small square boxes bounded by two succeeding isobaths is counted. Correction is done for the area of one small square box by taking measurement of any chosen length along both the vertical and horizontal axes of the graph paper. This is so because paper contracts during the dry season and expands during the wet season, and so in order to avoid this, correction for the graph paper must be done. The length corresponding to a chosen number of small boxes is measured and recorded along the vertical and horizontal axes respectively. For each axis, the length corresponding to one small box can thus be determined. This is the corrected length along each axis on paper. The area of one small box, obtained by multiplying the lengths along each axis together is then converted to its equivalent surface area on ground using the scale of the bathymetric map already prepared. Finally, the number of small boxes counted between successive isobaths is then multiplied by the surface area equivalent to one small 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.

3.4 INDIRECT METHOD.

Landsat ETM+ imageries for the month of October of the study area, bands 1, 2, 3 for years 1990, 2000 and 2010 was obtained from the Centre for Remote Sensing, Jos - Plateau State. The images were geo-referenced using recognizable points on the image whose corresponding coordinate on the ground is known. This process relates the position of the imageries to their true ground position. Next, the images were processed by combining bands 1, 2, 3 in the colour combination blue, green, red respectively, to

obtain true colour composites using ILWIS 3.7. At this point, the image is ready to be analysed. The choice of bands combined was because the blue-green water of the impounding reservoir in the composite image has moderate reflection in bands 1 and 2 (blue and green) and a small amount of reflection in band 3 (red). Thus, surface of the impounding reservoir have a reflectance that contrast sharply with that of the surrounding vegetation. Surface area of the water body was determined from the imagery using Global Mapper 11. With this software, a "measure" tool is used to outline the boundary of the water body since the blue-green colour distinguishing the surface of water can be clearly demarcated and at the same time calculate the surface area enclosed. Thus, the surface area of the Zaria Impounding Reservoir was calculated and using the equation below the storage volume is calculated.

$$Volume = 0.00857 * Area^{1.4367} [m^3]$$

3.5 DEPTH TO GROUNDWATER TABLE IN HAND DUG WELLS.

Groundwater in the study area is tapped via hand dug wells located within and around the settlements. Elevation and coordinates of wells were measured with a satellite navigator. While the depth to the surface of water is measured using a metric tape. The static water level in the wells (Appendix VI) is obtained by subtracting depth between the ground surface and water level in the wells from the elevation of the wells. These measurements were used for construction of the groundwater flow direction indicated on the map in Fig. 14, which is showing configuration of groundwater table and routes of groundwater flow.

3.6 DETERMINATION OF THE RATE OF EROSION WITHIN THE RESERVOIR'S DRAINAGE BASIN.

In other to determine the average rate of erosion within the reservoir's drainage basin, total recharge into this basin must first be determined. The Zaria impounding reservoir's drainage basin including its open water – table was determined by Global Mapper 11 from a Federal Survey topographic map on a scale 1:50,000. Rainfall data from the Meteorological Data Station of Institute of Agricultural Research, Zaria (Appendix I) show that the average depth of rainfall recorded is 1,053.4 mm/year according to Baba (2007), while for Jos-Plateau area of the drainage basin records average depth of 1258.9 mm/year (NIMET). The mean between these values 1156.2 mm/year, is taken as representative of the reservoirs' drainage basin for the purpose of the study. Then total recharge within the catchment of the Zaria impounding reservoir is calculated from the relation:

$$\mathbf{V}olume = \text{Area} \times depth$$

Volume of total run-off is divided into its component surface run-off and base flow (or underground flow). This is made possible using run-off coefficients in the drainage basin obtained from Fig. 15 below as:

Coefficient of surface run-off, $_cR_s = 0.21$

Coefficient of base flow, $_cR_b = 0.12$

Coefficient of total run-off, $cR_t = 0.33$

Thus, the volume of surface run-off, base flow and total run-off can be calculated as follows:

$$_cR_t = \frac{\text{volume of total run-off from a drainage basin}}{\text{volume of rainfall on the drainage basin in a period of time}}$$

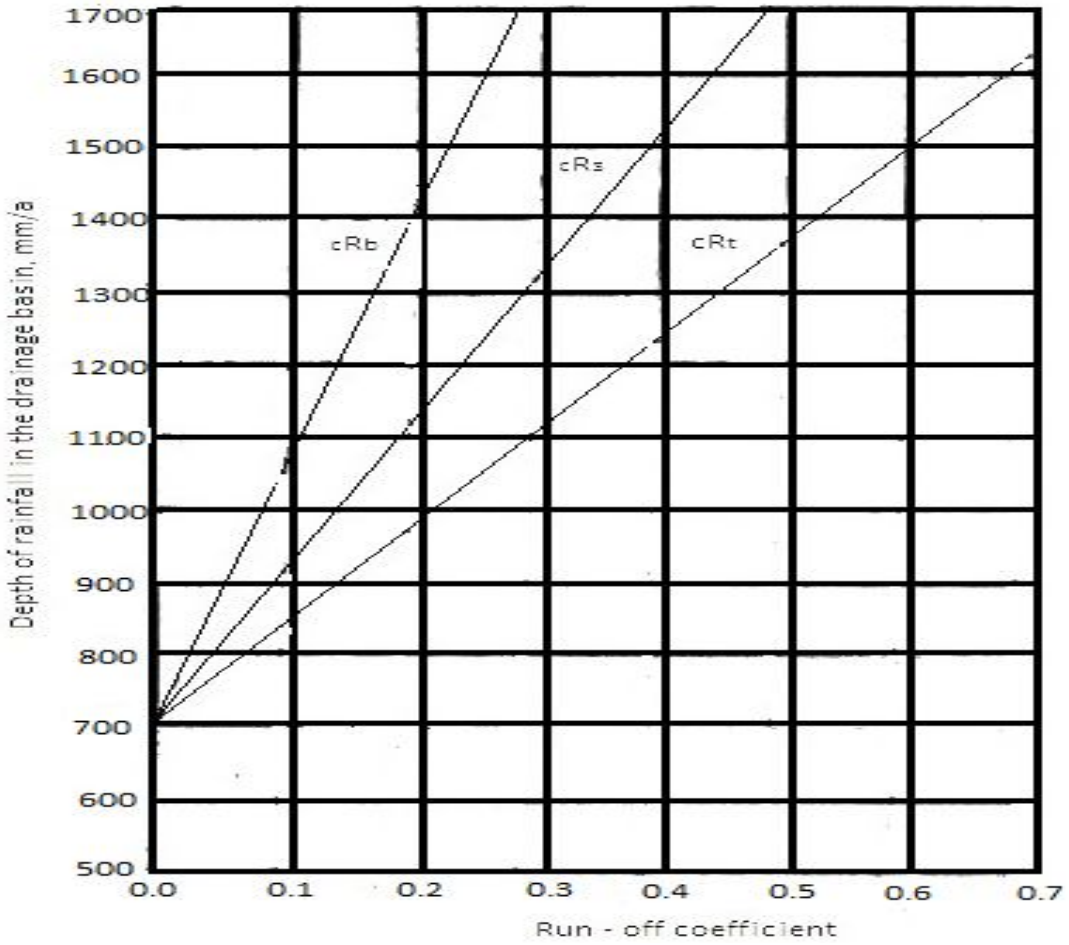


Figure 15: Correlation between depth of rainfall and run-off coefficient in drainage basins. Source: Schoeneich and Garba, 2010. Legend: $_cR_t$ = total run-off coefficient; $_cR_s$ = surface run-off coefficient; $_cR_b$ = base flow coefficient.

The amount of eroded sediment which settles at the bottom of the reservoir referred to as bed load was determined by comparing the difference between the volume of storage at impoundment and the remaining storage at the time of measurement. The difference is divided by the number of years that have elapsed since the construction of the reservoir. While the total dissolved solid and suspended solid was calculated using the total run off volume in the reservoir's drainage basin. Sum of the bed load sediment, total dissolved sediment and total suspended sediment is the volume of erosion in the drainage basin. Assumptions made are that:

i. **Average density of clay, ρ_{clay} is 2.0 gcm^{-3} while that of dissolved salt, ρ_{salt} is 2.22 gcm^{-3} (Telford *et al.*, 1990).**

ii. **Average wet season total suspended solid (TSS) for crystalline basement is 500 mgl^{-1} (Schoeneich, 1999).**

iii. **Total dissolved solid (TDS) for the crystalline basement is 80 mgl^{-1} (Schoeneich, 1999).**

The key equation used to determine their volume is;

$$\text{density} = \text{mass} \div \text{volume}.$$

Where density in kgm^{-3}, mass in kg and volume in m^3.

CHAPTER FOUR

4. RESULTS AND ANALYSIS.

4.1 PRESENT STORAGE AND RATE OF SILTATION IN THE ZARIA IMPOUNDING RESERVOIR.

Using the least square method, area of one small square is 1.9941 mm × 1.9859 mm = 3.9601 mm^2. However, scale of the map is 1:22,024 then;

=> Area of one small square = $\frac{3.96\ mm^2 \times 485.06\ m^2}{1\ mm^2}$ **=1920.84 m^2 on the ground.**

Thus, the area on the ground corresponding to one small square box, 1920.84 m^2 is then multiplied by the number of small square boxes counted between successive isobaths. This gives the area enclosed by the successive isobaths.

From result obtained by field procedure explained in the previous chapter, the sum of the surface area between successive isobaths equal to the year 2010 total surface area 7,489,356 m^2 enclosed by the water body for the Zaria impounding reservoir. The Table 3 below is a summary of the results obtained for area enclosed by successive isobaths to obtain the total surface area for the study area.

Table 3: Summary of the area enclosed between successive isobaths.

Depth interval (m)	0-2	2-4	4-6	6-8	> 8	Total
Number of small square boxes.	1,252	1,953	487	203	4	3,897
Area in square metres (m^2)	2,404,892	3,751,401	935,449	389,931	7,683	7,489,356

Average depth for each interval is determined. The area which is enclosed between successive isobath 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 successive isobath was determined. This volume quantifies the present remaining storage for the Zaria impounding reservoir, using direct field method and similar to the approach used by Ahmadu Bello University Committee on Protection of Kubanni Dam Drainage Basin (2008) and Baba *et al.* (2009).

On the basis of the equation, year 2010 remaining storage volume for the Zaria impounding reservoir is calculated to be 21,129,242 m^3. This volume is then divided by the total area enclosed for the impounding reservoir in other to obtain the average depth of the Zaria impounding reservoir as shown in Table 4.

Table 4: Results from bathymetric measurements of the remaining depth using the direct field method (prepared on paper by least square method in Fig. 13).

Depth interval be-low spill-way in metres, (m).	Area of depth interval in square metres, (m^2).	Average depth of water in metres, (m).	Volume of water in cubic metres, (m^3).
0 – 2	2,404,892	1.0	2,404,892
2 – 4	3,751,401	3.0	11,254,203
4 – 6	935,449	5.0	4,677,245
6 – 8	389,931	7.0	2,729,517
> 8	7,683	> 8.25	63,385
Total	7,489,356	2.82	21,129,242

Average depth of Zaria impounding reservoir is given by;

$$\frac{total\ volume\ of\ the\ impounding\ reservoir}{area\ enclosed\ by\ the\ impounding\ reservoir}$$

$$= \frac{21{,}130{,}008\ m^3}{7{,}489{,}355\ m^2}$$

$= 2.82\ m$

Summary of the present year 2010 surface area, average depth and remaining storage volume for the Zaria impounding reservoir in which measurements were carried out between periods from 20 October, 2010 to 6 November, 2010, presented below are derived from the map in Fig. 13 and shown in Table 4.

Also the indirect method using remotely sensed ETM+ land satellite images of years 1990, 2000 and 2010 was applied in order to determine the surface area and storage capacity of the Zaria Impounding Reservoir for the respective years, shown in Table 5. GLOBAL MAPPER 11 was used to determine the surface area of the impounding reservoir for the each land satellite image available. The area obtained was then inputted into the model equation according to Liebe *et al.,* (2005) shown below to calculate the storage capacity of the Zaria Impounding Reservoir.

$$Volume = 0.00857 * Area^{1.4367}[m^3]$$

Table 5: Results of storage capacity using indirect method by analysing remotely sensed land satellite image of October acquired for years 1990, 2000 and 2010.

Year	Surface area of open water table (m^2)	Storage volume (m^3)
1990	6,720,000	55,190,237
2000	5,660,000	43,127,292
2010	4,510,000	31,119,761

This result was then compared with a derived equation by Liebe *et al.* (2005) for determining storage of a reservoir. Results from this method were extremely high. For

example, the storage capacity calculated for the year 1990 of 55,190,237 m^3 is much greater than its original storage capacity at impoundment in 1974. This is not possible. So the model equation by Liebe *et al.*, (2005) could not apply in determining the storage volume of the Zaria Impounding reservoir.

However, the indirect method was useful in showing a continuous shrinkage in surface area of the Zaria Impounding Reservoir from year 1990 to 2010 as a result of its siltation. This is represented Fig.16 below.

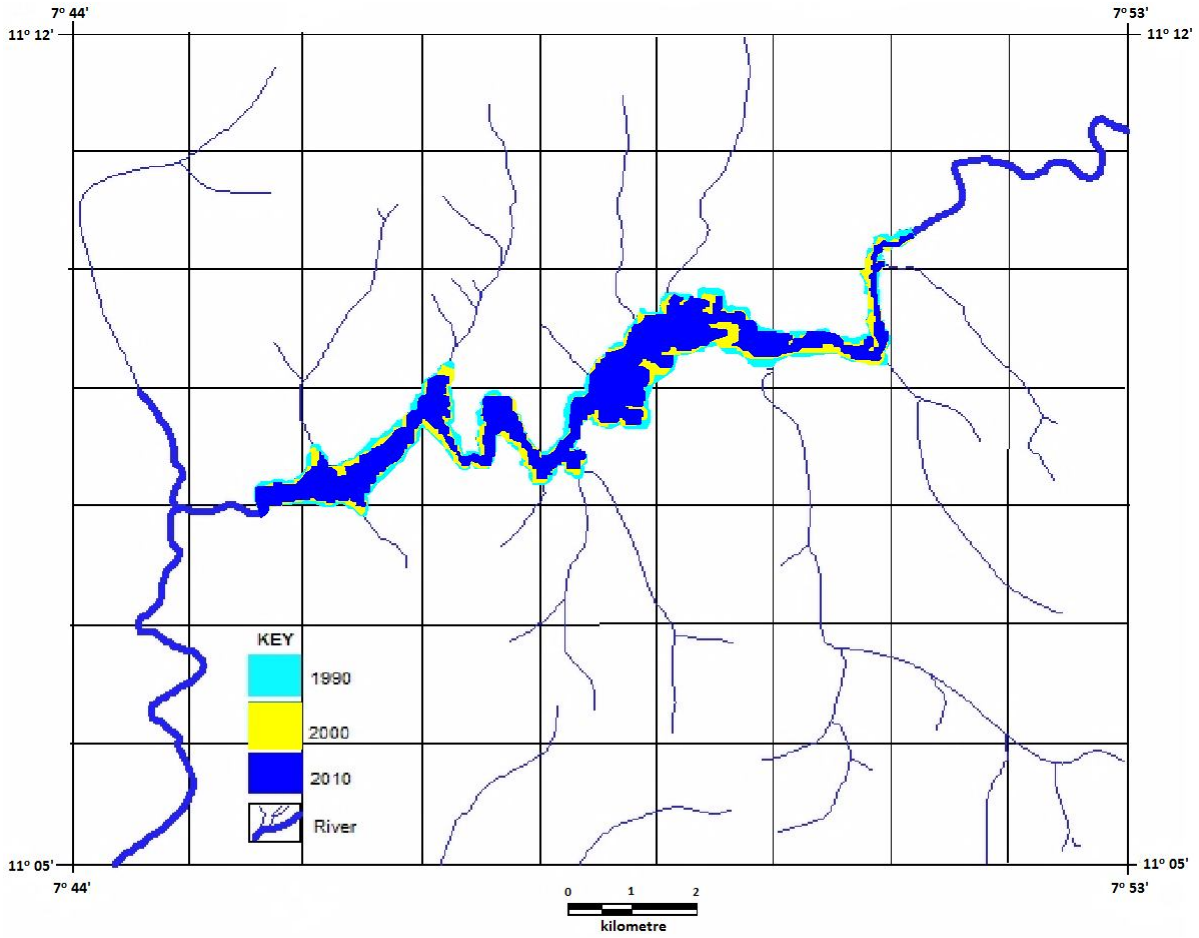


Figure 16: Shrinkage in the surface area of the Zaria Impounding Reservoir for 1990, 2000 and 2010.

Digital Elevation Model (DEM) of the study area was downloaded using GLOBAL MAPPER 11. The map prepared from the direct field method when drape on the DEM

show conformity between them in three dimension (3-D) perspective view. This is shown in Fig. 17 below.

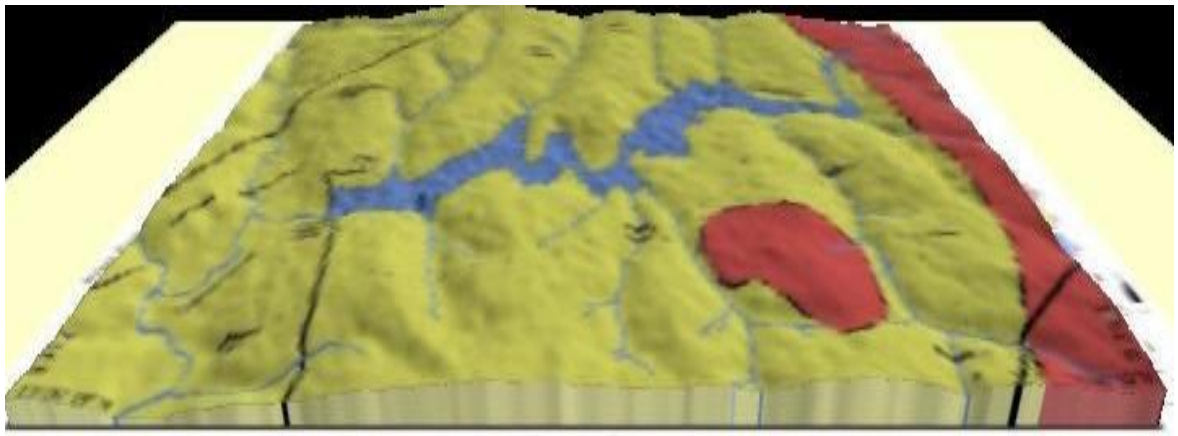


Figure 17: 3-D perspective view of the study area draped on the digital elevation model. Vertical Exaggeration = 7.5

The result of the storage capacity (Table 5) from the indirect method is high when compared with original storage for the Zaria Impounding Reservoir. Therefore for the purpose of analysis the more reliable result from the direct field method is used. The remaining storage for the Zaria impounding reservoir using field technique at the time the spillway is flowing was determined as 21,129,242 m^3 .Assumption is made here, that the correct original total storage is 45,800,000 m^3 because it was observed that there was an error in summation of active storage and dead storage in the Nigeria Register of Dams (FMWRRD, 1995). Dam total storage comprises the sum of both active storage and the dead storage. This error in summation by the author of Nigeria Register of Dams may have occurred during compilation of the dam records. This value is the correct total when dead storage and active storage are summed up going by the records of the Nigeria register of dams (FMWRRD, 1995) which show that active storage is estimated to be 29,800,000 m^3 and dead storage is 16,000,000 m^3 for the Zaria impounding reservoir.

Therefore, the amount of bed load sediments which have been deposited so far into the Zaria impounding reservoir can be obtained when the present year 2010 remaining storage of the impounding reservoir is subtracted from the original storage volume since its impoundment, that is, 45,800,000, m^3 □ 21,129,242 m^3 = 24,670,758 m^3 . It therefore mean that 24,670,758 m^3 of sediment have continuously been eroded and deposited into the impounding reservoir from its surrounding drainage basin during its 36 years of existence since year 1974. The average rate of siltation which is the same as rate of sediment deposition for the Zaria impounding reservoir since its impoundment is 24,670,758 m^3 ÷ 36 years = 685,299 m^3/year. This corresponds to a percentage annual loss to siltation of (685,299 m^3/year ÷ 45,800,000 m^3) × 100% = 1.5% per year. It thus mean that at estimated rate of siltation, dead storage is completely lost and part of the active storage had been lost up to about 29,800,000 m^3 - 21,129,242 m^3 = 8,670,758 m^3. Probably, siltation of the active storage had already begun by 8,670,758 m^3 ÷ 685,299 m^3/year = 13 years ago, about year 1997. With the present siltation rate of 685,299 m^3/year, the Zaria impounding reservoir will be completely silted up in 45,800,000 m^3 ÷ 685,299 m^3/year = 67 years from the date of impoundment. This will occur by year 1974 + 67 years = year 2041 or 21,129,242 m^3 ÷ 685,299 m^3/year = 31 years from year 2010 (year 2010 + 31years = year 2041).

4.2 LOSSES ON STORAGE

Records of date for the cessation of spillway flow are not known because readings of the gauge on the intake tower for many years have not been taken. Because of this, the undersigned researcher closely monitored the spillway flowing in year 2010 up to the

date it ceases to flow on 2 January, 2011. On the 8 April, 2011, it was observed that the water table dropped by 0.97 metres below the level of spillway. This makes a total of 96 days between these respective dates. Decrease in the volume of water from the level where the spillway overflows between these dates is 0.97 m × 7,489,356 m^2 = 7,264,675 m^3. Out of these, Zaria water works pumps water at an average pumping rate of 24,057 m^3/day from Zaria Impounding Reservoir. Therefore the total volume of water pumped out of the reservoir by the water works during the period from 2 January to 8 April is an estimated, 24,057 m^3/day × 96 days = 2,309,472 m^3, to be treated and supplied to water consumers throughout Zaria and its environs. The remaining volume referred to as the losses on storage, 7,264,675 m^3 □ 2,309,472 m^3 = 4,955,203 m^3 were lost during 96 days (between 2 January and 8 April) to seepage under the dam and evaporation from the open water table. Therefore daily rate of water loss to evaporation from the open water table and seepage is estimated at 4,955,203 m^3 ÷ 96 days = 51,617 m^3/day.

Also, date when the spillway starts to overflow once again was observed on 29 April, 2011, making a total of 117 days for the hydrological dry season. During the study, mean annual duration of the hydrological dry season is the period between cessation of spillway flow to time when the spillway begins to flow again. For Zaria Impounding Reservoir, the hydrological dry season for year 2010 to 2011 was observed as 117 days. Then loss of water to evaporation and seepage during the hydrological dry season are 51,617 m^3/day × 117 days = 6,039,189 m^3 per dry season. With pumping rate of 24,057 m^3/day, the total volume of water pumped out of the reservoir by the water works during the whole hydrological dry season will be 24,057 m^3/day × 117 days = 2,814,669 m^3. Thus, total withdrawal from the impounding reservoir during the hydrological dry season is 6,039,189 m^3 + 2,814,669 m^3 = 8,853,858 m^3

Observation has shown that there is no visible seepage under the dam's embankment especially during the dry season. During the wet season, portion of the embankment within the old river channel appears swampy but dries up early in the dry season. So it is assumed here that since seepage under the dam is not visible, the volume of water lost under the dam due to seepage is negligible. Therefore, 6,039,189 m^3 per dry season is lost from the impounding reservoir through evaporation. The depth of evaporation therefore is 6,039,189 m^3/dry season ÷ 7,489,356 m^2 = 0.81 metre per dry season.

4.3 SAFE YIELD IN DRY SEASON

Safe yield calculated during the period of measurements between 20 October, 2010 to 6 December, 2010 was (21,129,242 m^3 □ 6,039,189 m^3) ÷ 117 days = 128,975 m^3/day. However, storage capacity of the Zaria Impounding Reservoir is reduced by its siltation at a rate of 685,299 m^3/year and the volume of water 8,853,858 m^3 is lost during the dry season. Unit water demand for Zaria is 50 litres/person/day or 0.05 m^3/person/day according to Amana (2005) In: Ahmadu Bello University Committee on Protection of Kubanni Dam Drainage Basin, 2008). Hence water demand for Zaria with a population of 408,196 persons will be 20,410 m^3/day. Therefore, it will take (21,129,242 m^3 □ 8,853,858 m^3) ÷ 685,299 m^3/year = 18 years to reduce safe yield from 128,975 m^3/day to 20,410 m^3/day, the daily water demand.

This implies that until the year 2010 + 18 = 2028, there will be enough water in the Zaria impounding reservoir to meet water demand from Zaria and its environs. Safe yield will reduce finally to zero after (21,129,242 m^3 □ 6,039,189 m^3) ÷ 685,299 m^3/year = 22 years. This will happen in year 2010 + 22 = 2032. The dates in Table 7 establish when Zaria and

its environs will begin to experience water scarcity due to gradual silting up of the impounding reservoir.

Table 6: Important dates in the life of Zaria Impounding Reservoir. It is presumed that the rate of siltation between the periods 1974 to 2010 will continue, while water demand from the Zaria and its environs will remain at its year 2010 level.

YEAR	DRY SEASON	WET SEASON
2041	No water for Zaria and its environs from the Impounding Reservoir	No water for Zaria and its environs from the Impounding Reservoir.
2032	No water for Zaria and its environs from the Impounding Reservoir	Rationing of water starts
2028	Rationing of water starts	Still more water than enough in the Zaria Impounding Reservoir
2010	There is more than enough water from the Impounding Reservoir	There is more than enough water from the Impounding Reservoir

4.4 QUANTITY OF EROSION IN THE DRAINAGE BASIN

4.4.1 Recharge in the drainage basin.

In other to effectively estimate the rate of erosion and subsequently its depth within the Galma Drainage Basin where the Zaria Impounding Reservoir is located, knowledge of the volume of annual recharge within the entire basin is of eminent importance. That is to say, how much rain water falls on the drainage basin? For this, the total surface area of the drainage basin must be determined. The area enclosing the drainage basin of the Zaria Impounding Reservoir was determined using Global Mapper 11 software from a Federal Survey topographic map on a scale 1:1,000,000 (Fig. 4). The total area of the

catchment for the Zaria Impounding Reservoir was found approximately to be 3,242 km^2. This is close to the 3,241.36 km^2 earlier obtained by Dada (2009) also using remote sensing.

The mean depth of rainfall for the entire drainage basin within the area of study is 1,156.2 mm/year, and then total recharge within the catchment of the Zaria Impounding Reservoir is obtained as follows:

Volume of recharge = 3,242,000,000 m^2 × 1.1562 m/year

= 3,748,400,400 m^3/year.

For a given annual rainfall depth of 1,156.2 mm, run-off coefficients in the drainage basin is as follows:

Coefficient of surface run-off, $_cR_s$ = 0.21

Coefficient of base flow (or underground flow), $_cR_b$ = 0.12

Coefficient of total run-off, cR_t = 0.33

But $_cR_s = \dfrac{\text{volume of surface run-off}}{\text{volume of rainfall on the drainage basin in a periodof time}}$

∴ Volume of surface run-off = 0.21 × 3,748,400,400 m^3/year

= 787,164,084 m^3/year

Similarly, $_cR_b = \dfrac{\text{volume of base (underground) flow}}{\text{volume of rainfall on the drainage basin in a period of time}}$ **,**

∴ Volume of base (underground) flow = 0.12 × 3,748,400,400 m^3/year

= 449,808,048 m^3/year

and, $_cR_t = \dfrac{\text{volume of total run-off from a drainage basin}}{\text{volume of rainfall on the drainage basin in a periodof time}}$

∴ Volume of total run-off from a drainage basin = 0.33 × 3,748,400,400 m^3/year

= 1,236,972,132 m^3/year

Therefore, 1,236,972,132 m^3 of water recharges the Zaria Impounding Reservoir from its surrounding drainage basin per year during wet season.

4.4.2 <u>Volume estimation of total suspended solids.</u>

Assumptions:

Average density of clay, ρ_{clay} = 2.0 gcm^{-3} or 2,000 kgm^{-3}

Total suspended solid (TSS), average in the wet season for the crystalline basement = 500 mgl^{-1} or 0.5 kgm^{-3}.

∴ mass of suspended solid (M_{ss}) = Total suspended solid (TSS) × Volume of water flowing through the spillway (V_{sw}) or 0.5 kgm^{-3} × 1,236,972,132 m^3/year = 618,486,066 kg/year.

However, $\rho_{clay} = M_{ss} \div V_{ss}$, then;

Volume of suspended solid (V_{ss}) = mass of suspended solid (M_{ss}) ÷ density of clay (ρ_{clay})

= 618,486,066 kg/year ÷ 2,000 kgm^{-3}

V_{ss} = 309,243 m^3/year.

4.4.3 <u>Volume estimation of total dissolved solids.</u>

Assumptions:

Density of dissolved salt, ρ_{salt} = 2.22 gcm^3 or 2,220 kgm^3

Total dissolved solid (TDS) for the crystalline basement = 80 mgl^{-1} or 0.08 kgm^{-3}

∴ Mass of dissolved solid (M_{Ds}) = Total dissolved solid (TDS) × Volume of water flowing through the spillway (V_{sw}) or 0.08 kgm^{-3} × 1,236,972,132 m^3/year = 98,957,771 kg/year.

However, $\rho_{salt} = M_{Ds} \div V_{Ds}$, then;

Volume of dissolved solid (V_{Ds}) = mass of suspended solid (M_{Ds}) ÷ density of clay (ρ_{clay})

= 98,957,771 kg/year ÷ 2,220 kgm^{-3}

V_{Ds} = 44,576 m^3/year.

4.4.4 Rate of erosion in the drainage basin.

Annual estimates of the three (3) components of erosion – bed load sediments, suspended sediment load and dissolved sediment load, have all been calculated. They amount to the total sediment load generated within the drainage basin. Hence, estimate for the rate of erosion in the impounding reservoir's drainage basin is 685,299 m^3/year + 309,243 m^3/year + 44,576 m^3/year = 1,039,118 m^3/year. This is the average volume of eroded material generated within the reservoir's drainage basin annually.

Since the area 3,242,000,000 m^2 of the drainage basin for the Zaria Impounding Reservoir produces eroded materials to an amount of 1,039,118 m^3/year, then average depth of erosion will be 1,039,118 m^3/year ÷ 3,242,000,000 m^2 = 0.0003 m/year or 0.3 mm/year.

CHAPTER FIVE

5. DISCUSSIONS.

5. 1 DISCUSSION OF RESULTS.

According to WAPDECO (1990) and Nigeria Register of Dams (FMWRRD, 1995), Zaria Impounding Reservoir was constructed mainly to provide adequate water for domestic use and also for the purpose of irrigation during dry season. Knowledge of its remaining depth from the study has proven to be a viable tool in the determination of remaining storage, and subsequently the rate of siltation within Zaria Impounding Reservoir.

Result of the remaining storage obtained showed that there is still about 21,129,242 m^3 of water remaining in the Zaria Impounding Reservoir. Field work using bathymetric technique was employed. This implies that the useful life of the Zaria Impounding Reservoir did not remain as planned over time because it is constantly been threatened by continuous siltation with sediments originating from within the Galma Drainage Basin due to erosion. Over time, the area extent and storage capacity of the impounding reservoir changes as a result of continuous sedimentation taking place since its date of impoundment about 36 years ago. The surface area of the impounded water reduces gradually in size over the years as more sediments, until a time will come when it becomes completely silted. The remaining storage represents about 46% of the original storage volume and this is enough to meet Zaria demand of 20,410 m^3/day at least for now.

About 8,853,858 m^3 is loss on storage during the hydrological dry season. Out of this, 2,814,669 m^3 of raw water is pumped to the new Zaria Water Works and then treated, while 6,039,189 m^3 is lost to evaporation from the open water-table since there is no visible seepage on the dam. Thus, the depth of evaporation within the Zaria Impounding

Reservoir therefore is 0.81 m/dry season. This value is comparable to 0.893 m/dry season obtained for the Kubanni impounding reservoir (Ahmadu Bello University Committee on Protection of Kubanni Dam Drainage Basin, 2008) and also the University Farm Lake (Baba, 2009).

With the present remaining storage of 21,129,242 m^3, the implication is that 8,670,758 m^3 of the active storage is currently being silted up by year 2010. This means that the dead storage (16,000,000 m^3) has completely been lost to siltation by sediments generated within the reservoir's drainage basin in addition to part of the active storage that have already been silted. This makes a total of 24,670,758 m^3, right from the date of impoundment of the dam since in 1974 from the initial records contained in the Nigeria Registry of Dams (FMWRRD, 1995). This amount of sediment is deposited and finally settles at the bottom of the impounding reservoir as a result of gravity is actually the bed load sediments. They originate from within and around the reservoir's drainage basin. Therefore with the average rate of siltation for the 36 years approximately is 685,299 m^3/year. This is the rate at which the bed load sediments are deposited annually.

Siltation rate is generally a function of river discharge, land erosion, tidal current, wind wave, rainfall, water density, and so forth. Then average depth of silt accumulation annually in the impounding reservoir will be 685,299 m^3/year ÷ 7,489,356 m^2 = 0.092 m/year. Thus, the siltation of the active storage probably had already started about 8,670,758 m^3 ÷ 685,299 m^3/year = 13 years ago. This mean that siltation of the active storage began in the year 2010 □ 13 years = year 1997, about 23 years after impoundment of the reservoir. The implication of this is that if measures aimed at reducing erosion within the impounding reservoir drainage basin is not taken, the Zaria impounding reservoir will be completely silted up in 45,800,000 m^3 ÷ 685,299 m^3/year =

67 years from the date of impoundment. This will happen by year 1974 + 67 years = year 2041 or 21,129,242 m^3 ÷ 685,299 m^3/year = 31 years from year 2010. Hence, the predicted date of the final disappearance of the Zaria Impounding Reservoir from the map due to its complete siltation is year 2041, which is 31 years from now.

Safe yield calculated in the year 2010 for the Zaria Impounding Reservoir was 128,975 m^3/day and with continuous siltation this amount will tend towards zero. However, storage capacity of the Zaria Impounding Reservoir is reduced by its siltation at a rate of 685,299 m^3/year and also by evaporation to a volume of water 7,264,675 m^3 during the dry season. Therefore, it will take 18 years to reduce safe yield from 128,975 m^3/day to 20,410 m^3/day the daily water demand. This implies that until the year 2028, there will be enough water in the Zaria Impounding Reservoir to meet water demand from Zaria and its environs. In spite of progressing siltation of the impounding reservoir, there is still, and will be more water in it than is needed. Therefore any shortage, scarcity or rationing of water experienced on or before year 2030 will be largely due to the inability of the Water Works to pump enough water from the reservoir to taps of consumers. However, 22 years from now, safe yield will reduce finally to zero and this will happen in year 2032. Therefore from year 2028 to year 2032, water available for pumping to consumers in Zaria and its environs will gradually reduce to zero towards the end of this period during the dry season. It then implies that there will be very little water flowing from taps of consumers in the dry season, although there will still be enough water during wet season to meet its water demand. From year 2032 to year 2041, Zaria Impounding Reservoir will only exist as a shallow, seasonal water body, drying up completely towards end of the season. During this period there will be water pumped, enough to flow in taps of consumers only in the wet season, just sufficient to meet demand. Therefore during the

wet season, water will be rationed and this progressively deteriorates as less and less water will be pumped from the impounding reservoir to the taps. In the dry season, there will be no water in the Zaria Impounding Reservoir. Again, by year 2041 the Zaria Impounding Reservoir will disappear from maps. These dates calculated above are the most important findings in predicting the remaining useful life and possibly the date of disappearance from map, of the Zaria Impounding Reservoir.

Volume of rainfall over the entire Zaria Impounding Reservoir's drainage basin is 3,748,400,400 m^3/year, out of which 1,236,972,132 m^3/year is total runoff. From this, surface runoff is 787,164,084 m^3/year while base flow was determined as 449,808,048 m^3/year. Measurements of the depth to water level in hand-dug wells show that both the surface run-off and base flow recharges the reservoir (Fig. 14). Sediment generation originates within the reservoir's drainage basin through process of erosion. This assertion was supported by the work of Pidwirny (2006); Snyder *et al*. (2004); James and Chanson (1999); Small et al. (2003), Price *et al.* (2000). Total material eroded within the catchment of Zaria Impounding Reservoir on the average is 1,039,118 m^3/year. About 66% that flows into the impounding reservoir, settle at the bottom constituting the bed load, 30% remain suspended in the water, while 4% are dissolved into the water. It shows that the bulk of materials generated within the reservoir's drainage basin eventually silts up the impounding reservoir, contributing to the loss of its initial storage volume.

Direct and indirect methods were employed. Remaining storage of 21,129,242 m^3 was obtained from the direct field method. This amount is comparable to result from preliminary studies by Parkman (2002) which employed the use of echo sounder. The indirect method of applying remote sensing, determined the reservoir's storage volume

for years 1990, 2000 and 2010 using the model equation developed by Liebe *et al*. (2005). Results obtained with this method for the storage volume of Zaria Impounding Reservoir, was a little on the high side and so was not used for further analysis. For example, storage volume of 31,119,761 m^3 determined from the ETM+ land satellite image of 2010 was much more than the 21,129,242 m^3 obtained using the direct field method. The storage volume calculated using the indirect method was in excess of about 9,990,519 m^2 over the direct field method. This difference is quite large.

However, the indirect method, namely Liebe et al., (2005) formula, employed during this study was found accurate when applied to small reservoirs such as the Kubanni Impounding Reservoir and University Farm Lake, whose remaining storage were earlier determined by Ahmadu Bello University Committee on Protection of Kubanni Dam Drainage Basin (2008) and Baba (2009) respectively using the direct method. Liebe et al., (2005) formula is also accurate for Tagwai Impounding Reservoir which is a large reservoir according to the on-going study by Mr Adamu Vulegbo (verbal information to the present Author). With these reservoirs mentioned above, the results from the direct field method and indirect method were all in agreement. This implies that the indirect method is also a viable approach for the determination of reservoir's storage capacities because it is time- and cost effective, less cumbersome, and accurate.

Limitations of the indirect method during the present study in the determination of storage capacity of Zaria Impounding Reservoir could be attributed to:

i. **The irregular shape of the Zaria Impounding Reservoir, an indication that the region is morphologically and morphometrically unstable.**
ii. **Aquatic vegetation sometimes makes it difficult to demarcate the actual water edge of the impounding reservoir, and so errors could occur.**

5.2 REASONS FOR INADEQUATE POTABLE WATER SUPPLY IN ZARIA.

Unit water demand calculated for Zaria according Ojonugwa (2005) was 50 litres/person/day. With the present population of Zaria and its environs from results of the last census in year 2006 estimated at 408,198 inhabitants (www.wikipedia.org/wiki/Zaria), total water demand is about 20,410 m^3/day. Record of the monthly report from the Zaria Water Board show that water distribution is 24,057 m^3/day (see appendix II). The difference of 3,647 m^3 between total daily water demand and water supply in Zaria is allowed for losses in distribution. Although claims by the Zaria Water Board is that with every given resources available, potable water produced for distribution will be about 50,000 m^3/day.

Result obtained for the remaining storage capacity of the Zaria Impounding Reservoir calculated as 21,129,242 m^3 shows that there is more than enough water at present to meet the demand requirements for now. Thus, there will be no need for an extra raw water source proposed in WAPDECO (1990) report and even the multi-billion naira contract awarded for a new water treatment plant presently under construction of an estimated capacity of 150,000 m^3/day will not be necessary. Instead, for adequate water supply to be achieved and sustained both for present and the future, plans for dredging of the dam proposed should go ahead. This is to prevent water shortage anticipated in 20 years from now, and also ensure to put in place an effective drainage basin management system that works. The inability of the Zaria Water Works to make drinking water available is beginning to exert pressure on groundwater resources in the area as most of the residents who can afford, prefer to drill private boreholes in their compounds.

The present writer therefore suggests that other factors and not inadequate water at source may be responsible for the poor water supply to Zaria and its environs. The

factors may include inadequacy of skill and inadequate power supply, which result in under-utilization of installations at the water treatment plant. As a result of the inherent power shortage supply problem throughout the whole country, the operations of the Zaria Water Works are thus crippled. So the Water Board had to rely on the old generator which can only power for not more than 4 – 6 hours. Sometimes for several days the water treatment plant does not produce potable drinking water for distribution to water consumers. This was observed from the monthly reports of September, October, and November in 2010 up to February, March, and April in 2011 (see Appendix I). Of the six pumps available only two are working properly, used to pump water. These two obviously will not be sufficient to pump the amount of water Zaria needs.

CHAPTER SIX

6. WATER PROTECTION STRATEGY AND ENVIRONMENTAL MANAGEMENT PLAN FOR ZARIA IMPPOUNDING RESERVOIR.

6.1 WATER PROTECTION STRATEGY.

Human activities and certain practices have consequential impacts on the environment and have put great pressure on the agricultural land within the Galma Drainage Basin. Nigerian Industrial Standard (2007) defines an area surrounding a water source where activities that may affect qualities are restricted or prohibited as "protection zone". Therefore, protection of drinking water of the required standard quality should be the source and within its catchment. Also, the impact of the activities within the reservoir's drainage basin could cause pollution of water in the reservoir. This is because groundwater flows towards the direction of the reservoir, shown in Fig. 14. Therefore water protection strategy around the Zaria Impounding Reservoir should include:

- Protection of water quality.
- Protection of water quantity.
- Waste disposal strategy.

6.1.1 <u>Protection of water quality.</u>

Yunusa (2002) writes that the irrigation practices within Galma Drainage Basin have affected the water chemistry in the study area by elevating the concentrations of major ions with the nitrate concentrations elevated above the average background level of 1.15 mg/l, occurring in the range 7.6 – 15.3 mg/l and on the average 11.44 mg/l. The intensive farming activities within and around the Zaria Impounding Reservoir happens to be a major source of chemical pollution of water by use fertilizers and pesticides. Thus protection of the source for pipe-borne water to Zaria against chemical pollution is of great importance. Schoeneich and Aku,

(1998): fide: Schoeneich, (2007), write that this can be achieved by establishing of "blue belts" through legal acts.

6.1.2 Protection of water quantity.

This can be achieved through afforestion of all land not suitable for irrigated farming especially rocky hills, gullies as well as land within the reservoirs' drainage basin. This vegetation slows down surface run-off, thereby reducing erosion of the top soil into the impounding reservoir. Also, it will favour infiltration by increasing the groundwater-table, so that in the dry season there will be enough groundwater recharging the reservoir, (Fig. 14). This will pay off in the conservation of water through reduction of surface run-off and evaporation. Consequently, siltation rate of the Zaria Impounding Reservoir is immensely reduced and much quantity of water impounded by the reservoir will be preserved to serve for a much longer period of time.

6.1.3 Waste disposal strategy.

Nigeria lacks a comprehensive strategy on sanitation as a whole, including excreta disposal, solid waste disposal, wastewater disposal, drainage and treatment of wastewater, Federal Republic of Nigeria, (2000). There is very little sewerage in urban Nigeria and regarding solid waste, the frequency of collection is poor. Storm water drainage system is frequently a disposal point for solid waste. Moreover, disposal, when waste is collected, is by dumping rather than sanitary landfill and is a major cause of water pollution either through the storm water drainage system or seepage into the groundwater. Wastewater disposal pollutes the surface water.

However, possible source of pollutants flowing into the Zaria Impounding Reservoir is through effluent waste from surrounding villages flowing through tributaries, to the main Galma River where the reservoir is located.

Strategies to be adopted here include the use of waste collection bins so that solid waste is not directly disposed into flowing water. Also, a centralized waste disposal unit should be provided within localities bordering the impounded reservoir. .

6.2 ENVIRONMENTAL MANAGEMENT PLAN.

This is an aspect of "Drainage Basin Management" within the broader field of water "Resources Management". Reservoir siltation as a process is a function of both the catchment management and reservoir management. In the view of James and Chanson (1999), sediment supply and delivery factors are; geology, surface cover, topography and rainfall. Until this rock is weathered into transportable fragments, the sediment yield is low. This prompted Schumm (2009) in his publication to point out that evaluation of the drainage's erosion conditions provides a good estimate of the sediment yield. Also it is important to implement necessary practices aimed at reducing rate of siltation in impounding reservoirs so as to prolong the reservoir's useful life, Fig. 16 below.

Within and around the study area, observable land management factors affecting the detachment of surface material includes land clearing, intensive and continuous felling of trees, over grazing and bush burning practices shown in Plate 3 and 4 below. All these practices expose the surrounding land, thereby favours surface run-off over infiltration. Thus, surface run–off is the main driver of erosion. Furthermore, siltation in the impounding reservoir is likely to cause environmental imbalance such as delta erosion, river bed erosion and non-availability of food for aquatic life to survive on.

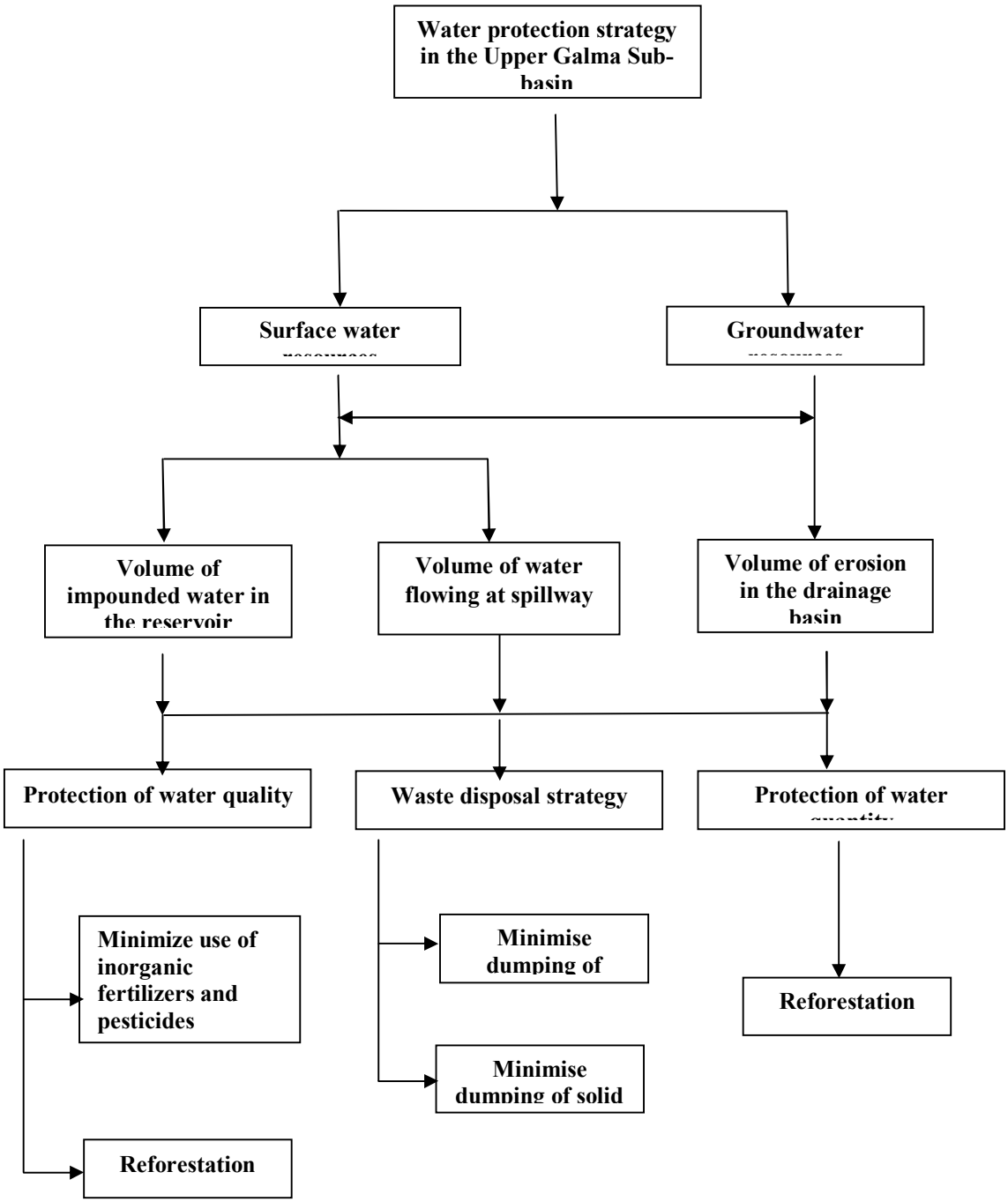


Figure 18: Water protection strategies and environmental management plan in upper Galma Drainage Sub-Basin.



Plate III: Bush burning within and around the Zaria Impounding Reservoir. These activities are common and will eventually deplete the area its vegetation cover. Co-ordinates: 11° 07' 57.1" and 07° 46' 05.0". Photo was taken by Author.



Plate IV: Cutting and felling of trees in area surrounding the Zaria Impounding Reservoir. Co-ordinates: 11° 09' 348.1" and 07° 48' 12.0" Photo was taken by the author.



Plate V: Land surrounding the impounding reservoir intensively cultivated under both rain-fed and dry season irrigation farming. Co-ordinates: 11° 09' 18.2" and 07° 48' 18.4" Photo was taken by the author.



Plate VI: Termite caste favours infiltration to groundwater over surface run-off. Co-ordinates: 11° 09' 26.2" and 07° 48' 37.1" Photo was taken by the author.

7. CONTRIBUTION TO KNOWLEDGE AND CONCLUSION.

7.1 CONTRIBUTION TO KNOWLEDGE.

Determination of the remaining storage and rate of siltation in the Zaria Impounding Reservoir was made possible with the aid of a bathymetric map produced, shown in Fig. 13. It further provides a basis where the rate of evaporation from the open water table, safe yield for the impounding reservoir, and also what year in the future when this will reduce to the volume of water daily pumped from the impounding reservoir, were all calculated. Federal Survey Topographic Sheet 102 SW has been updated by indicating the exact boundary extent of the Zaria Impounding Reservoir. Erosion within the reservoir's catchment was calculated by quantifying its products that consist of the dissolved load, suspended load and bed load. Some important dates in the life of the impounding reservoir were thus predicted.

During the study, it was discovered that active storage and dead storage were summed up incorrectly in the Nigeria Register of Dams (FMWRRD, 1995). Dead storage was recorded to be 16,000,000 m^3 and active storage was 29,800,000 m^3, while the total storage of the dam was recorded as 15,910,000 m^3. This is not possible because a reservoir's total storage comprises the sum of both active storage and the dead storage. Therefore, active storage or dead storage respectively alone cannot be greater than total storage. This error in summation may have occurred during compilation of the dam records. This volume of 15,910,000 m^3 in the researcher's opinion is assumed to be an incorrect summation. The correct total storage of the Zaria Impounding Reservoir, going by the record of Nigeria Register of Dams (FMWRRD, 1995) should be 45,800,000 m^3 actually. This value is the summation of the dead storage and active storage. Therefore FMWRRD (1995) cited this value in error.

Table 7: Summary of results obtained.

Open water-table, 5th November 2010:	**7,489,356 m^2**
Average weighted depth of water below the spillway in wet season:	**2.82 m**
Total active water storage remaining with spillway flowing:	**21,129,242 m^3**
Rate of siltation between years 1974 and 2010:	**685,299 m^3/year**
Depth of siltation in the Zaria Impounding Reservoir:	**0.092 m/year**
Number of days between date spillway ceases to start of spillway flow:	**117 days**
Total water loss from reservoir, year 2010 dry season:	**8,853,858 m^3**
Raw water pumped from dam, year 2010 dry season:	**2,814,669 m^3/dry season**
Total water losses on storage (seepage plus evaporation):	**6,039,189 m^3/dry season**
Depth of evaporation per dry season:	**0.81 m**
Safe yield in dry season of year 2010/2011:	**128,975 m^3/day**
Total recharge in the drainage basin:	**3,748,400,400 m^3**
Catchment area:	**3,242,000,000 m^2**
Total suspended solids (TSS):	**309,243 m^3/year**
Total dissolved solids (TDS):	**44,576 m^3/year**
Total bed load:	**685,299 m^3/year**
Rate of erosion in the drainage basin:	**1,039,118 m^3/year**
Depth of erosion in the drainage basin:	**0.3 mm/year**
Predicted date of safe yield falling to 20,410 m^3/day in dry season:	**Year 2028**
Predicted date of safe yield falling to 20,410 m^3/day in wet season :	**Year 2032**
Predicted date of complete siltation:	**Year 2041**

7.2 CONCLUSION

The result obtained from this study has shown that the Zaria Impounding Reservoir has lost a significant part of its storage volume to siltation, representing 54% of the initial storage volume. After about 37 years, since construction in 1974, the present year 2010

storage capacity of the Zaria Impounding Reservoir is 21,129,242 m^3. Since its impoundment till date, siltation rate is estimated at 685,299 m^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 calculated and quantified to an amount 919,742 m^3/year. This is equivalent to an average depth of erosion, 0.3 mm/year.

Annual water lost from the impounding reservoir as a result of pumping as well as due to evaporation and seepage is 7,264,675 m^3 during the dry season. Safe yield was calculated as 128,975 m^3/day, and with volume of water lost to evaporation estimated at 6,039,189 m^3 per dry season. Depth of evaporation is 0.81 metre per dry season. In view of this, rationing of water is expected to commence by year 2031 and taps will become dry by year 2033 throughout the whole dry season.

At present, the remaining storage is sufficient to meet the demand for water in Zaria and its environs. Hence, the Zaria Impounding Reservoir is adequate and can still satisfactorily serve as source of water supply. In view of these results, siltation in the Zaria Impounding Reservoir is not the reason for the inadequate water supply in Zaria and its environs as there is enough water at present in the reservoir to meet its demand.

The siltation will be further worsened by negative environmental practices like bush burning, felling of trees, intensive and uncontrolled farming activities, dumping of refuse and excavation of soil in areas around the reservoir will impact environmental problems This in-turn may threaten the quality of the source of potable water. Also, because of the very low flow velocities within impounding reservoirs generally, they tend to be very efficient sediment traps. Therefore, when sediment inflow is large relatively to the reservoir storage capacity, then the useful life of impounding reservoirs supplying water

to meet our various needs may become very short. Hence, eventually cannot further serve its purpose.

Therefore if other factor militating against water supply in Zaria is not addressed in view its alarming growing population, then according to the words of Professor Abdullahi Mahadi, the president of 'The Mahadi Foundation', "Even if Zaria dam is being manage properly, for example from the perspective of preventing its siltation, it cannot continue to meet the water need of Zaria and its regions". In other to ensure an efficient drainage basin management, periodic surveys are also necessary to arrive at a realistic siltation index for planning of future reservoir projects in the basin

7.3 RECOMMENDATION

From the result of the studies carried out on the remaining storage and rate of siltation of Zaria Impounding Reservoir and also to effectively manage the water resources to ensure that there is enough water at source, the following are recommended:

1. **All surface water sources within Zaria and its environs should be integrated so that water supply can be effectively enhanced.**
2. **Environmental management of the reservoir's drainage basin should be practiced so that the useful life of the Zaria Impounding Reservoir can be prolonged.**
3. **There should be plans to commence dredging of the Zaria Impounding Reservoir immediately if the reservoir is to continue to serve its purpose as the main source of piped water supply.**
4. **Controlled farming methods surrounding the impounding reservoir should be practiced.**

5. **Frequent, regular and periodic capacity surveys of the Zaria Impounding Reservoir will help in assessing the rate of siltation, eventual reduction in storage capacity and effective management of the reservoir and its water resources.**
6. **Further study should be carried out on a regional scale in other to establish the accuracy between direct field method and indirect method of remote sensing to determine the storage capacity of large impounding reservoirs.**

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Appendix I: Mean monthly rainfall data between the years 1996 – 2005 in milimetres (mm). Source: Meteorological Data Station of Institute of Agricultural research, Ahmadu Bello University. Location: 11° 10□ 56.6□□, 07° 37□ 00.8□□. Source: (Baba, 2007).

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	D
1996	0.0	0.0	0.0	13.4	181.7	118.8	159.3	191.9	100.6	59.5	0.0	
1997	0.0	0.0	0.0	47.6	86.4	155.2	193.5	290.2	182.6	81.4	0.0	
1998	0.0	0.0	0.0	110	69.5	129.6	196.4	473.3	221.0	48.3	8.2	
1999	0.0	0.0	0.0	7.0	23.4	231.8	285.5	154.8	204.2	38.4	0.0	
2000	0.0	0.0	0.0	0.0	149.5	193.4	221.1	245.2	182.1	78.2	0.0	
2001	0.0	0.0	0.0	83.9	160.3	177.7	267.8	360.9	271.7	0.0	0.0	
2002	0.0	0.0	19.9	69.6	10.6	133.1	229	201.4	218.8	125.2	0.0	
2003	0.0	0.0	0.0	31.0	78.4	69.2	243.1	427.1	219.5	67.1	0.0	
2004	0.0	0.0	13.6	7.8	162.8	190.5	242.3	308.3	126.3	20.8	0.0	
2005	0.0	0.0	0.0	63.1	113.1	160.2	152.6	235.5	122.4	16.8	0.0	
SUM	0.0	0.0	33.5	433.4	1035.7	1559.5	2190.6	2888.6	1849.2	538.7	8.2	
MEAN	0.0	0.0	3.0	43.34	103.57	155.95	219.06	288.86	184.92	53.57	0.7	

Appendix II: DAILY MANAGEMENT REPORT FROM THE TREATMENT PLANT.

STATION: Zaria New Water Works. MONTH: September. YEAR: 2010.

Date	P1 Hrs	P2 Hrs	RAW WATER					Pre chlorine		Alum		Pre Lime		Settled Water				Filtered Water						P1 HRS	P2 HRS	Final Water mld						Water Lo	
			p2	p3	total	ntu	ph	kg	mg/l	kg	mg/l	kg	mg/l	ph	ntu	BKW	ph	ntu	kg	mg/l	Kg	Mg/l			p1	p2	total	ph	ntu	cl res	ml	
1-Sep-10	0.00	8.21	0.000	7.537	7.537	163	nd	10	1.3	536.20	71	20	2.7	nd	7				20	3.1	40	6.1	5.90	0.00	6.520	0.000	6.520	nd	4	1.00	1.017	13.
2-Sep-10	3.33	0.00	3.057	0.000	3.057	168	nd	5	1.6	264.00	86	10	3.3	nd	6				20	10.3	40	20.7	1.75	0.00	1.934	0.000	1.934	nd	4	1.00	1.123	36
3-Sep-10	5.22	0.00	4.792	0.000	4.792	167	nd	10	2.1	440.00	92	10	2.1	nd	7				20	5.8	40	11.6	3.11	0.00	3.437	0.000	3.437	nd	4	1.50	1.355	28
4-Sep-10	8.45	0.00	7.757	0.000	7.757	165	nd	5	0.6	594.00	77	5	0.6	nd	6				15	2.3	20	3.1	5.93	0.00	6.553	0.000	6.553	nd	3	1.25	1.204	15
5-Sep-10	18.21	0.00	16.717	0.000	16.717	172	nd	5	0.3	898.20	54	5	0.3	nd	7				20	1.6	40	3.2	11.23	0.00	12.409	0.000	12.409	nd	4	1.00	4.308	25
6-Sep-10	9.55	0.00	8.95	0.000	8.959	175		5	0.6	634	72		0.0		7				15	2.4		0.0	5.62	0.00	6.210	0.000	6.210		4	1.25	2.649	29
7-Sep-10	5.37	0.00	4.93	0.000	4.930	180		5	1.0	318	65	10	2.0		7				15	3.7	40.00	9.9	3.67	0.00	4.055	0.000	4.055		3	1.00	0.874	17
8-Sep-10	3.17	0.00	2.910	0.000	2.910	187	nd	5	1.7	175.00	60	5	1.7	nd	8				15	12.9	20	17.2	1.05	0.00	1.160	0.000	1.160	nd	3	1.00	1.750	60
9-Sep-10	6.83	0.00	6.270	0.000	6.270	190	nd	5	0.8	524.00	84		0.0	nd	7			nd	20	4.0		0.0	4.50	0.00	4.973	0.000	4.973	nd	3	1.25	1.297	20
10-Sep-10	9.17	0.00	8.418	0.000	8.418	167		5	0.6	442.20	53	5	0.6		6			nd	15	1.8	20	2.5	7.38	0.00	8.155	0.000	8.155	nd	3	1.00	0.263	3
11-Sep-10	2.72	0.25	2.497	0.230	2.726	180	nd	5	1.8	198.00	73	5	1.8	nd	8			nd	15	9.0	20	12.1	1.50	0.00	1.658	0.000	1.658	nd	3	1.25	1.099	39
12-Sep-10	0.00	4.60	0.000	4.223	4.223	173	nd	5	1.2	290.80	69	5	1.2	nd	8			nd	20	5.6	20	5.6	3.25	0.00	3.591	0.000	3.591	nd	3	1.25	0.632	14
13-Sep-10	4.97	0.00	4.562	0.000	4.562	200	nd	5	1.1	290.40	66	5	1.1	nd	9			nd	20	4.7	40	9.5	3.83	0.00	4.232	0.000	4.232	nd	5	1.50	0.330	7.
14-Sep-10	6.05	2.00	7.390	0.000	7.390	190	nd	5	0.7	299.40	73	5	0.7	nd	7			nd	15	2.3	20	3.0	6.03	0.00	6.663	0.000	6.663	nd	4	1.50	0.727	9.
15-Sep-10	7.50	0.00	6.885	0.000	6.885		nd	5	0.7	541.20	92	5	0.7	nd	7			nd	20	3.4	20	3.4	5.32	0.00	5.879	0.000	5.879	nd			1.006	14
16-Sep-10	12.26	0.00	11.273	0.000	11.273	180	nd	5	0.4	561.20	62	5	0.4	nd	7			nd	10	0.9	20	1.8	10.18	0.00	11.249	0.000	11.249	nd	4	1.25	0.024	0.
17-Sep-10	11.48	0.00	10.539	0.000	10.539	182	nd	5	0.5	704.00	58	5	0.5	nd	7			nd	20	2.1	20	2.1	8.65	0.00	9.558	0.000	9.558	nd	3	1.00	0.980	9.
18-Sep-10	9.83	0.00	9.024	0.000	9.024	180	nd	5	0.6	713.40	72	10	1.1	nd	7			nd	15	1.7	40	4.7	7.77	0.00	8.586	0.000	8.586	nd	4	1.00	0.436	4.
19-Sep-10	4.33	0.00	3.975	0.000	3.975	155	nd	5	1.3	646.40	80	10	2.5	nd	7			nd	20	7.4	40	14.8	2.45	0.00	2.707	0.000	2.707	nd	4	1.50	1.268	31
20-Sep-10	6.67	0.00	6.123	0.000	6.123	185	nd	10	1.6	316.20	46	10	1.63	nd	7			nd	20	3.9	40	7.8	4.65	0.00	5.138	0.000	5.138	nd	4	1.25	0.985	16
21-Sep-10	12.07	0.00	11.080	1.836	12.916	165	nd	5	0.4	284.40	75	10	0.8	nd	7			nd	15	1.5	40	3.9	8.13	1.17	8.984	1.293	10.277	nd	3	1.25	2.640	20
22-Sep-10	10.30	9.98	9.455	9.162	18.617	176	nd	5	0.3	970.80	41	10	0.5	nd	8			nd	20	1.5	40	3.0	4.23	1.72	4.674	8.531	13.205	nd	3	1.25	5.412	29
23-Sep-10	7.65	0.00	7.023	0.000	7.023	170	nd	5	0.7	759.00	62	10	1.4	nd	7			nd	20	3.3	40	6.6	0.35	5.11	0.387	5.647	6.033	nd	3	1.25	0.989	14
24-Sep-10	11.08	0.00	10.171	0.000	10.171	160	nd	5	0.5	574.00	69	5	0.5	nd	7			nd	20	2.0	40	4.0	4.33	4.65	4.785	5.138	9.923	nd	4	1.50	0.249	2.
25-Sep-10	12.28	0.00	11.273	0.000	11.273	139	nd	5	0.4	501.80	31	10	0.9	nd	7			nd	25	2.9	40	4.7	6.28	1.47	6.939	1.624	8.564	nd	4	1.00	2.709	24
26-Sep-10	10.53	0.00	9.758	0.000	9.758	138	nd	5	0.5	241.90	84	10	1.0	nd	8			nd	0	0.0	40	4.5	0.00	8.05	0.000	8.895	8.895	nd	3	1.50	0.863	8.
27-Sep-10	11.00	0.00	10.098	0.000	10.098	141	nd		0.0	916.80	67		0.0	nd	7			nd	20	3.0		0.0	6.08	0.00	6.718	0.000	6.718	nd	4	1.00	3.380	33
28-Sep-10	10.75	0.00	9.869	0.000	9.869	136	nd	5	0.5	678.40	76	10	1.0	nd	7			nd	20	2.6	40	5.2	6.92	0.00	7.647	0.000	7.647	nd	3	1.50	2.222	22
29-Sep-10	11.16	0.00	10.263	0.000	10.263	138	nd	5	0.5	746.40	69	10	1.0	nd	8			nd	0	0.0	40	5.5	2.27	4.27	2.506	4.716	7.227	nd	3	1.25	3.037	29
30-Sep-10	10.23	0.00	9.391	0.000	9.391	136	nd		0.0	706.20	111	5	0.5	nd	7			nd	20	2.4	20	2.4	2.22	5.42	2.453	5.989	8.442	nd	3	0.25	0.949	10
Total	244.40	25.04	224.359	22.987	247.346	5031	0	155	24	16067	3716	215	33	0	200	0	0		122	510	108	880	179	144.58	37.86	159.761	41.835	201.596	0	102	35	46	5
Average	8	1	7	1	8	173		6	1	536	124	8	1		7				4	18	4	33	6	4.82	1.26	5	1	7		4	1	2	

Appendix II Continued – October, 2010.

Date	P1 Hrs	P2 Hrs	RAW WATER					Pre chlorine		Alum		Pre Lime		Settled Water		Filtered Water			Post Chlorine		Post lime		P1 HRS	P2 HRS	Final Water mld						Water
			p2	p3	total	ntu	ph	kg	mg/l	kg	mg/l	kg	mg/l	ph	ntu	BKW	ph	ntu	kg	mg/l	Kg	Mg/l			p1	p2	total	ph	ntu	cl res	ml
1-Oct-10	13.08	5.08	12.007	4.663	16.671	130	6.9	5	0.3	767.20	46	5	0.3	6.7	7		6.4	6	20	1.8	20	1.8	5.03	5.08	5.558	5.613	11.172	6.4	3	1.50	5.499
2-Oct-10	5.17	0.00	4.746	0.000	4.746	137	6.7	5	1.1	389.40	82	10	2.1	6.6	8		6.3	7	15	3.6	40	9.6	3.78		4.177	0.000	4.177	6.4	3	1.50	0.569
3-Oct-10	7.50	0.00	6.885	0.000	6.885	132	6.5	5	0.7	690.80	100	10	1.5	6.5	7		6.4	6	20	3.2	40	6.4	5.62		6.210	0.000	6.210	6.4	4	1.25	0.675
4-Oct-10	5.17	0.00	4.746	0.000	4.746	131	6.7	10	2.1	291.00	61	5	1.1	6.4	6		6.5	7	20	4.5	40	9.0	4.03		4.453	0.000	4.453	6.5	3	1.25	0.293
5-Oct-10	6.58	0.00	6.040	0.000	6.040	133	6.5	5	0.8	369.60	61	10	1.7	6.6	7		6.4	8	20	4.0	40	8.0	4.50		4.973	0.000	4.973	6.4	3	1.50	1.068
6-Oct-10	2.18	0.00	2.001	0.000	2.001	120	6.5	10	5.0	415.80	208	10	5.0	6.8	7		6.4	7	20	16.5	40	32.9	1.10		1.216	0.000	1.216	6.40	4	1.00	0.786
7-Oct-10	1.03	0.00	0.946	0.000	0.946	109	6.6	5	5.3	105.60	112	10	10.6	6.9	7		6.4	7	20	54.8	40	109.7	0.33		0.365	0.000	0.365	6.40	3	1.00	0.581
8-Oct-10	16.00	12.23	14.688	11.227	25.915	100	6.5	15	0.6	1783.20	69	15	0.6	6.6	8		6.5	6	30	1.2	60	2.3	11.07	12.38	12.232	13.680	25.912	6.4	4	1.00	0.003
9-Oct-10	11.17	11.80	10.254	10.832	21.086	100	6.5	15	0.7	1135.40	54	15	0.7	6.6	7		6.4	8	30	1.5	80	4.0	7.33	10.55	8.100	11.658	19.757	6.4	5	1.25	1.329
10-Oct-10	14.62	14.58	13.421	13.384	26.806	95	6.5	15	0.6	1518.60	57	20	0.7	6.6	6		6.4	10	30	1.3	80	3.5	10.45	10.50	11.547	11.603	23.150	6.4	7	1.25	3.656
11-Oct-10	23.97	22.00	22.004	20.196	42.200	88	6.6	15	0.4	1351.30	32	20	0.5	6.6	6		6.6	8	30	0.7	80	1.9	17.28	20.00	19.094	22.100	41.194	6.4	4	1.00	1.006
12-Oct-10	17.32	17.27	15.900	15.854	31.754	90	6.5	15	0.5	2821.20	89	20	0.6	6.7	6		6.5	9	30	1.0	80	2.5	13.72	14.80	15.161	16.354	31.515	6.5	5	1.25	0.239
13-Oct-10	20.55	20.55	18.865	18.865	37.730	90	6.5	10	0.3	1904.60	50	20	0.5	6.7	9		6.5	9	20	0.5	80	2.2	15.77	17.18	17.426	18.984	36.410	6.5	4	1.25	1.320
14-Oct-10	16.10	16.00	14.780	14.688	29.468	89	6.7	15	0.5	1636.80	56	15	0.5	6.7	7		6.5	8	30	1.2	60	2.4	8.80	14.28	9.724	15.779	25.503	6.5	4	1.00	3.964
15-Oct-10	9.58	9.23	8.794	8.473	17.268	91	6.6	15	0.9	868.00	50	15	0.9	67	7		6.7	8	30	1.8	60	3.6	6.67	8.28	7.370	9.149	16.520	6.7	4	1.25	0.748
16-Oct-10	13.87	13.87	12.733	12.733	25.465	89	6.8	5	0.2	590.80	23	5	0.2	6.9	7		6.7	8	10	0.4	40	1.8	6.83	13.50	7.547	14.918	22.465	6.7	4	1.25	3.001
17-Oct-10	24.00	21.75	22.032	19.967	41.999	85	6.7	15	0.4	3027.60	72	15	0.4	6.8	7		6.7	8	30	0.7	60	1.5	15.33	21.87	16.940	24.166	41.106	6.8	3	1.25	0.892
18-Oct-10	23.82	23.83	21.867	21.876	43.743	87	6.4	15	0.3	2453.60	56	20	0.5	6.2	7		6.3	7	30	0.7	80	1.8	17.08	22.25	18.873	24.586	43.460	6.3	4	1.00	0.283
19-Oct-10	23.70	23.70	21.757	21.757	43.513	84	4.4	15	0.3	2249.00	52	20	0.5	6.2	7		6.3	9	30	0.7	80	1.9	18.17	20.70	20.078	22.874	42.951	6.3	4	1.25	0.562
20-Oct-10	23.70	23.70	21.757	21.757	43.513	79	6.6	15	0.3	2489.60	57	20	0.5	6.4	7		5.8	11	30	0.7	80	1.9	20.40	18.42	22.542	20.354	42.896	5.8	5	1.50	0.617
21-Oct-10	14.00	13.97	12.852	12.824	25.676	86	6.6	15	0.6	1322.20	51	20	0.8	6.5	7		5.8	8	30	1.3	80	3.4	13.04	8.50	14.409	9.393	23.802	5.8	5	1.00	1.875
22-Oct-10	5.00	5.00	4.590	4.590	9.180	87	6.5	15	1.6	693.00	75	15	1.6	6.5	6		6.5	10	30	4.5	60	9.0	3.00	3.00	3.315	3.315	6.630	6.3	4	1.25	2.550
23-Oct-10	Power Failure																														
24-Oct-10	4.35	0.00	3.993	0.000	3.993	85	6.5	5	1.3	363.00	91	5	1.3	6.5	7		6.5	7	10	3.2	20	6.5	2.80		3.094	0.000	3.094	6.3	4	1.25	0.899
25-Oct-10	8.85	12.17	8.124	11.172	19.296	78	6.4	5	0.3	376.20	19	10	0.5	6.2	7		6	8	20	2.8	40	5.6	6.50		7.183	0.000	7.183	5.4	5	1.50	12.114
26-Oct-10	5.42	12.17	4.976	11.172	16.148	78	6.5	10	0.6	1221.60	76	10	0.6	6.4	6		6.5	7	20	1.3	40	2.6	3.98	10.05	4.398	11.105	15.503	6	5	1.50	0.644
27-Oct-10		21.52	0.000	19.755	19.755	82	6.5	15	0.8	1661.00	84	20	1.0	6.5	7		6.4	7	30	1.7	80	4.4		16.43	0.000	18.155	18.155	6.3	14	1.25	1.600
28-Oct-10	16.75	0.00	15.377	0.000	15.377	80	6.7	15	1.0	1165.10	76	15	1.0	6.6	7		6.4	16	30	2.2	60	4.5	12.17		13.448	0.000	13.448	6.3	4	1.25	1.929
29-Oct-10	22.25	0.00	20.426	0.000	20.426	85	6.6	15	0.7	1468.60	72	30	1.5	6.6	6		6.2	8	30	1.5	100	5.0	18.00		19.890	0.000	19.890	6.4	4	1.25	0.535
30-Oct-10	18.07		16.588	0.000	16.588	84	6.6	15	0.9	1389.00	84	25	1.5	6.7			6.4	13	30	2.0	100	6.8	13.28		14.674		14.674	6.4	5	1.00	1.914
31-Oct-10	24.00	0.00	22.032	0.000	22.032	84	6.5	15	0.7	1694.00	77	15	0.7	6.5	7		6.4	8	30	1.7	60	3.4	15.88		17.547	0.000	17.547	6.3	5	1.25	4.485
Total	397.80	300.42	365.18	275.79	640.97	2888	195	350	30	38213	2093	445	40	258	200	0	192	249	755	123	1820	260	282	248	312	274	585	190	135	37	56
Average	14	10	12	9	21	96	7	12	1	1274	70	15	1	9	7		6	8	25	4	61	9	10	14	10	9	20	6	5	1	2

Appendix II Continued – November, 2010 .

Date	P1 Hrs	P2 Hrs	RAW WATER					Pre chlorine		Alum		Pre Lime		Settled		Filtered Water			Post Chlorine		Post lime		P1 HRS	P2 HRS	Final Water mld						Wa
			p2	p3	total	ntu	ph	kg	mg/l	kg	mg/l	kg	mg/l	ph	ntu	BKW	ph	ntu	kg	mg/l	Kg	Mg/l			p1	p2	total	ph	ntu	cl res	ml
1-Nov-10	13.13	4.72	12.053	4.333	16.386	82	6.7	30	1.8	1048.60	64	15	0.9	6.4	12		6.2	5	15	1.1	60	4.3	8.62	4.02	9.525	4.442	13.967	6.2	5	1.25	2.41
2-Nov-10	20.21	20.18	18.553	18.525	37.078	80	6.7	30	0.8	2347.40	63	100	2.7	6.5	12		6.2	4	15	0.4	100	2.8	17.37	15.23	19.194	16.829	36.023	6.2	5	1.50	1.05
3-Nov-10	17.50	17.50	16.065	16.065	32.130	84	6.7	30	0.9	773.00	24	50	1.6	6.4	16		6.0	8	15	0.5	100	3.1	14.08	14.68	15.558	16.221	31.780	6.0	9	1.25	0.35
4-Nov-10	22.00	22.00	20.196	20.196	40.392	85	6.7	30	0.7	2452.40	61	20	0.5	6.3	18		6.2	8	15	0.4	100	2.6	17.58	17.60	19.426	19.448	38.874	6.2	7	1.50	1.51
5-Nov-10	24.00	24.00	22.032	22.032	44.064	82	6.5	30	0.7	2183.40	50	25	0.6	6.2	20		6.2	14	15	0.3	100	2.3	19.28	20.25	21.304	22.376	43.681	6.2	13	1.25	0.38
6-Nov-10	19.13	19.13	17.561	17.561	35.123	80	6.5	30	0.9	1575	45	25	0.7	6.5	8		5.9	4	15	0.5	100	3.1	18.43	10.63	20.365	11.746	32.111	5.8	4	1.25	3.01
7-Nov-10	21.80	21.78	20.012	19.994	40.006	84	6.5	30	0.7	1871	47	25	0.6	6.7	7		5.8	3	15	0.4	100	2.5	19.40	16.65	21.437	18.398	39.835	5.8	4	1.25	0.17
8-Nov-10	18.02	20.95	16.542	19.232	35.774	85	6.7	30	0.8	1608.80	45	25	0.7	6.4	10		5.9	5	15	0.4	100	3.0	14.27	16.05	15.768	17.735	33.504	5.5	5	1.25	2.27
9-Nov-10	12.00	16.20	11.016	14.872	25.888	82	6.2	20	0.8	1287.60	50	10	0.4	6.4	8		6.0	4	10	0.4	100	4.0	8.92	13.45	9.857	14.862	24.719	5.5	4	1.25	1.16
10-Nov-10			0.000	0.000	0.000																				0.000	0.000	0.000				0.00
11-Nov-10	8.95	8.80	8.216	8.078	16.295	88	6.2	30	1.8	765.60	47	25	1.5	6.5	13		5.6	6	15	1.0	100	6.8	7.80	5.48	8.619	6.055	14.674	6.2	6	1.25	1.62
12-Nov-10	20.70	20.68	19.003	18.984	37.987	84	6.5	30	0.8	1746.20	46	25	0.7	6.5	8		6.0	6	15	0.4	100	2.9	17.75	13.87	19.614	15.326	34.940	6.3	5	1.00	3.04
13-Nov-10	14.17	14.17	13.008	13.008	26.016	82	6.5	30	1.2	1329.80	51	25	1.0	67	7		6.2	4	15	0.6	100	3.9	10.55	12.87	11.658	14.221	25.879	6.0	4	1.25	0.13
14-Nov-10	14.47	14.47	13.283	13.283	26.567	80	6.5	20	0.8	1017.60	38	25	0.9	6	9		5.4	6	10	0.4	50	2.0	13.10	9.13	14.476	10.089	24.564	5.7	6	1.25	2.00
15-Nov-10	6.35	0.00	5.829	0.000	5.829	81	6.6	10	1.7	408.40	70		0.0	6.5	9		5.6	6	10	2.4	50	11.8	3.85		4.254	0.000	4.254	5.8	5	1.25	1.57
16-Nov-10	5.30	0.00	4.865	0.000	4.865	82	6.6	10	2.1	389.00	80	25	5.1	5.8	9		5.8	4	10	3.1	100	31.2		2.90	0.000	3.205	3.205	5.8	4	1.25	1.66
17-Nov-10	6.63	0.00	6.086	0.000	6.086	82	6.7	10	1.6	323.40	53	25	4.1	5.5	8		5.8	4	15	2.8	25	4.7	4.85		5.359	0.000	5.359	5.7	4	1.25	0.72
18-Nov-10	5.25	0.00	4.820	0.000	4.820	82	6.7	18	3.7	309.00	64	25	5.2	5.5	8		5.5	4	15	4.0	100	26.6	3.40		3.757	0.000	3.757	5.5	4	1.25	1.06
19-Nov-10	4.83	0.00	4.434	0.000	4.434	85	6.5	20	4.5	296.20	67	25	5.6	5.8	10		5.6	5	15	3.5	100	23.0		3.93	0.000	4.343	4.343	5.6	5	1.25	0.09
20-Nov-10		4.93	0.000	4.526	4.526	87	5.7	15	3.3	247.60	55	25	5.5	5.8	8		5.4	3	15	6.1	100	40.6		2.23	0.000	2.464	2.464	5.9	3	1.25	2.06
21-Nov-10		8.28	0.000	7.601	7.601	67	5.7	15	2.0	521.40	69	10	1.3	6	8		6.0	3	15	2.2	50	7.3		6.18	0.000	6.829	6.829	5.7	3	1.50	0.77
22-Nov-10		4.65	0.000	4.269	4.269	63	6.0	20	4.7	323.40	76	25	5.9	5.6	4		6.2	3	15	8.6	50	28.8		1.57	0.000	1.735	1.735	5.6	2	1.25	2.53
23-Nov-10		4.82	0.000	4.425	4.425	67	5.4	15	3.4	323.40	73	25	5.7	5.6	6		6.2	4	15	6.6	50	22.1	2.05		2.265	0.000	2.265	5.7	3	1.25	2.16
24-Nov-10	2.93	2.50	2.690	2.295	4.985	61	6.7	30	6.0	377.80	76	25	5.0	5.6	6		5.9	2	15	3.5	50	11.5	1.67	2.25	1.845	2.486	4.332	6.0	2	1.50	0.65
25-Nov-10	4.63		4.250	0.000	4.250	60	5.6	20	4.7	250.20	59	25	5.9	5.7	4		5.8	3	15	3.8	50	12.7	3.55		3.923	0.000	3.923	6.2	3	1.25	0.32
26-Nov-10	4.00		3.672	0.000	3.672	59	5.7	30	8.2	462.00	126	20	5.4	5.4	4		5.8	2	15	4.6	50	15.4	2.93		3.238	0.000	3.238	6.0	2	1.25	0.43
27-Nov-10	4.98		4.572	0.000	4.572	61	5.8	20	4.4	177.80	39	15	3.3	5.6	5		5.7	3	15	5.6	25	9.3	2.42		2.674	0.000	2.674	5.8	3	1.50	1.89
28-Nov-10	5.82		5.343	0.000	5.343	57	5.7	20	3.7	201.00	38	20	3.7	6.2	6		5.5	4	15	4.1	25	6.9	3.28		3.624	0.000	3.624	5.8	3	1.25	1.71
29-Nov-10	3.75		3.443	0.000	3.443	63	5.6	15	4.4	230.00	67	25	7.3	5.6	6		6.0	3	15	6.0	10	4.0		2.25	0.000	2.486	2.486	6.0	3	1.25	0.95
30-Nov-10	8.25	8.25	7.574	7.574	15.147	61	5.8	30	2.0	267.00	18	50	3.3	6.2	5		6.0	3	15	1.2	20	1.6	8.60	2.97	9.503	3.282	12.785	6.0	4	1.50	2.36
Total	288.80	258.01	265.118	236.853	501.972	2196	182	668	73	25114	1658	760	85	236	254	0	170	133	415	75	2065	301	223.75	194.19	247.244	214.580	461.824	171	130	38	40
Average	12	11	9	8	17	76		23	3	866	57	27	3		9			5	14	3	71	10	9.73	9.25	8	7	15	6	4	1	1

Appendix II Continued – February, 2011.

Date	P1 Hrs of Op	P2 Hrs of Op	RAW WATER p2	p3	total	ntu	ph	Pre chlorine kg	mg/l	Alum kg	mg/l	Pre Lime kg	mg/l	Settled ph	ntu	filtered water ph	ntu	Post Chlorine kg	mg/l	Post lime Kg	Mg/l	P1 HRS	P2 HRS	Final Water mld p1	p2	total	ph	nd	cl res	Water L ml
1-Feb-11	24.00	24.00	22.03	22.03	44.06	40	6.2	20	0.5	1535.85	35	25	0.6	6.1	8	6.0	7	25	0.6	75	1.7	18.36	21.25	20.29	23.48	43.77	6.1	7	1.50	0.295
2-Feb-11	15.73	16.43	14.44	15.08	29.52	44	6.5	20	0.7	1411.90	48	35	1.2	6.2	8	6.1	5	25	0.9	75	2.6	13.88	12.05	15.34	13.32	28.65	6.2	nd	1.00	0.870
3-Feb-11	19.45	17.80	17.86	16.34	34.20	40	6.5	20	0.6	1733.65	51	35	1.0	6.3	10	6.2	9	25	0.7	75	2.2	15.25	15.25	16.85	16.85	33.70	6.0	8	1.50	0.493
4-Feb-11	23.03	23.00	21.14	21.11	42.26	50	6.3	20	0.5	1744.25	41	35	0.8	6.1	11	6.0	9	25	0.6	100	2.4	18.80	19.00	20.77	21.00	41.77	6.0	7	1.25	0.487
5-Feb-11	24.00	24.00	22.03	22.03	44.06	42	6.3	20	0.5	1338.90	30	35	0.8	6.1	8	6.0	6	25	0.6	75	1.7	20.00	19.50	22.10	21.55	43.65	6.1	6	1.50	0.416
6-Feb-11	22.80	22.80	20.93	20.93	41.86	37	6.3	20	0.5	1450.50	35	25	0.6	6.2	10	6.1	8	25	0.6	75	1.8	19.50	18.27	21.55	20.19	41.74	6.5	5	0.50	0.125
7-Feb-11	20.75	20.75	19.05	19.05	38.10	38	6.3	20	0.5	1673.25	44	25	0.7	6.4	11	6.3	8	25	0.7	75	2.2	17.00	14.48	18.79	16.00	34.79	6.2	5	1.25	3.312
8-Feb-11	11.26	11.23	10.34	10.30	20.64	39	6.4	20	1.0	1605.45	78	25	1.2	6.4	7	6.4	5	25	1.3	75	3.8	8.02	9.80	8.86	10.83	19.69	6.2	6	1.50	0.950
9-Feb-11	23.52	23.52	21.59	21.59	43.18	43	6.3	20	0.5	774.30	18	25	0.6	6.3	15	6.0	7	25	0.6	75	1.8	19.25	19.17	21.27	21.18	42.45	6.1	6	1.00	0.729
10-Feb-11	24.00	24.00	22.03	22.03	44.06	46	6.3	20	0.5	1971.25	45	25	0.6	6.1	15	6.0	8	25	0.6	75	1.7	19.00	20.00	21.00	22.10	43.10	6.0	6	1.25	0.989
11-Feb-11	20.60	20.60	18.91	18.91	37.82	40	6.3	20	0.5	1248.55	33	25	0.7	6.2	10	6.1	7	25	0.7	75	2.0	16.50	17.50	18.23	19.34	37.57	6.0	6	1.50	0.252
12-Feb-11	24.00	24.00	22.03	22.03	44.06	45	6.1	20	0.5	1743.55	40	25	0.6	6.1	8	6.2	7	25	0.6	100	2.3	21.27	18.00	23.50	19.89	43.39	6.1	6	1.00	0.671
13-Feb-11	24.00	24.00	22.03	22.03	44.06	48	6.3	20	0.5	1129.75	26	25	0.6	6.2	9	6.1	6	25	0.6	100	2.3	18.65	21.00	20.61	23.21	43.81	6.0	6	1.5	0.251
14-Feb-11	22.97	23.00	21.09	21.11	42.20	44	6.4	20	0.5	2416.75	57	25	0.6	6.0	9	6.3	6	25	0.6	100	2.4	20.00	18.13	22.10	20.03	42.13	6.0	6	1.25	0.067
15-Feb-11	23.65	23.65	21.71	21.71	43.42	40	6.3	20	0.5	1194.60	28	25	0.6	6.2	9	5.9	8	25	0.7	100	2.6	15.18	19.35	16.77	21.38	38.16	6.1	6	1.25	5.266
16-Feb-11	22.97	22.93	21.09	21.05	42.14	38	6.3	20	0.5	1871.75	44	25	0.6	6.2	8	6.0	6	25	0.6	100	2.4	19.00	19.00	21.00	21.00	41.99	6.0	12	1.50	0.146
17-Feb-11	22.00	21.92	20.20	20.12	40.32	48	6.2	20	0.5	1674.25	42	25	0.6	6.1	10	6.0	7	25	0.6	75	1.9	19.12	15.75	21.13	17.40	38.53	6.1	6	1.50	1.787
18-Feb-11	20.58	17.66	18.89	16.21	35.10	65	6.5	20	0.6	1744.55	50	25	0.7	6.1	15	8.0	6	25	0.8	50	1.6	11.75	16.75	12.98	18.51	31.49	5.9	6	1.50	3.612
19-Feb-11	21.83	21.66	20.04	19.88	39.92	59	6.3	30	0.8	1700.00	43	25	0.6	6.2	7	5.9	6	60	1.6	75	1.9	19.00	15.90	21.00	17.57	38.56	6.3	7	1.50	1.359
20-Feb-11	20.83	20.83	19.12	19.12	38.24	58	6.2	20	0.5	1690.10	44	25	0.7	6.0	7	6.0	14	25	0.7	75	2.0	19.97	14.02	22.07	15.49	37.56	6.0	7	1.50	0.685
21-Feb-11	20.78	20.75	19.08	19.05	38.12	55	6.3	20	0.5	1665.35	44	25	0.7	6.1	9	6	6	25	0.7	75	2.0	20.50	14.00	22.65	15.47	38.12	6.0	6	1.50	0.002
22-Feb-11	19.57	19.42	17.97	17.83	35.79	54	6.3	20	0.6	1520.80	42	25	0.7	6	9	8.0	8	25	0.7	75	2.1	17.00	15.10	18.79	16.69	35.47	6.1	6	1.50	0.322
23-Feb-11	20.92	20.90	19.20	19.19	38.39	57	6.2	20	0.5	1756.95	46	25	0.7	6.3	9	5.9	7	25	0.7	100	2.6	19.58	14.62	21.64	16.16	37.79	6.1	6	1.25	0.600
24-Feb-11	20.00	20.00	18.36	18.36	36.72	59	6.2	20	0.5	1543.60	42	25	0.7	6.1	9	6.0	6	25	0.7	100	2.8	18.33	14.50	20.25	16.02	36.28	6.0	6	1.50	0.443
25-Feb-11	23.45	23.45	21.53	21.53	43.05	60	6.2	20	0.5	1829.65	42	50	1.2	6.0	8	6.1	6	25	0.6	75	1.8	20.50	18.00	22.65	19.89	42.54	6.0	6	1.25	0.512
26-Feb-11	24.00	24.00	22.03	22.03	44.06	58	6.3	20	0.5	1759.45	40	25	0.6	6.1	8	7	6	25	0.6	100	2.3	18.47	21.33	20.41	23.57	43.98	59	6	1.50	0.085
27-Feb-11	23.72	23.68	21.77	21.74	43.51	60	6.2	20	0.5	1797.00	41	25	0.6	6.0	9	5.9	7	25	0.6	75	1.8	18.50	20.00	20.44	22.10	42.54	5.9	6	1.50	0.971
28-Feb-11	7.00	7.00	6.43	6.43	12.85	58	6	25	1.9	526.85	41	50	3.9	6.0	9	5.8	7	20	1.8	50	4.5	3.05	7.00	3.37	7.74	11.11	6.0	6	1.50	1.747
Total	591.41	586.98	542.91	538.84	1081.76	1365	176	575	16.2	44052.80	1168	790	23.1	283	265	174	198	730	20.7	2275	63.2	485.43	468.72	536.40	517.94	1054.34	223	172	37.75	27.422
Average	20.39	22.58	18.72	18.58	37.30	47	6.1	20	0.6	1519.06	40	27	0.8	9.8	9.1	6	6.8	25	0.7	78	2.2	16.74	16.16	18.497	17.86	36.36	7.69	5.9	1.302	0.946

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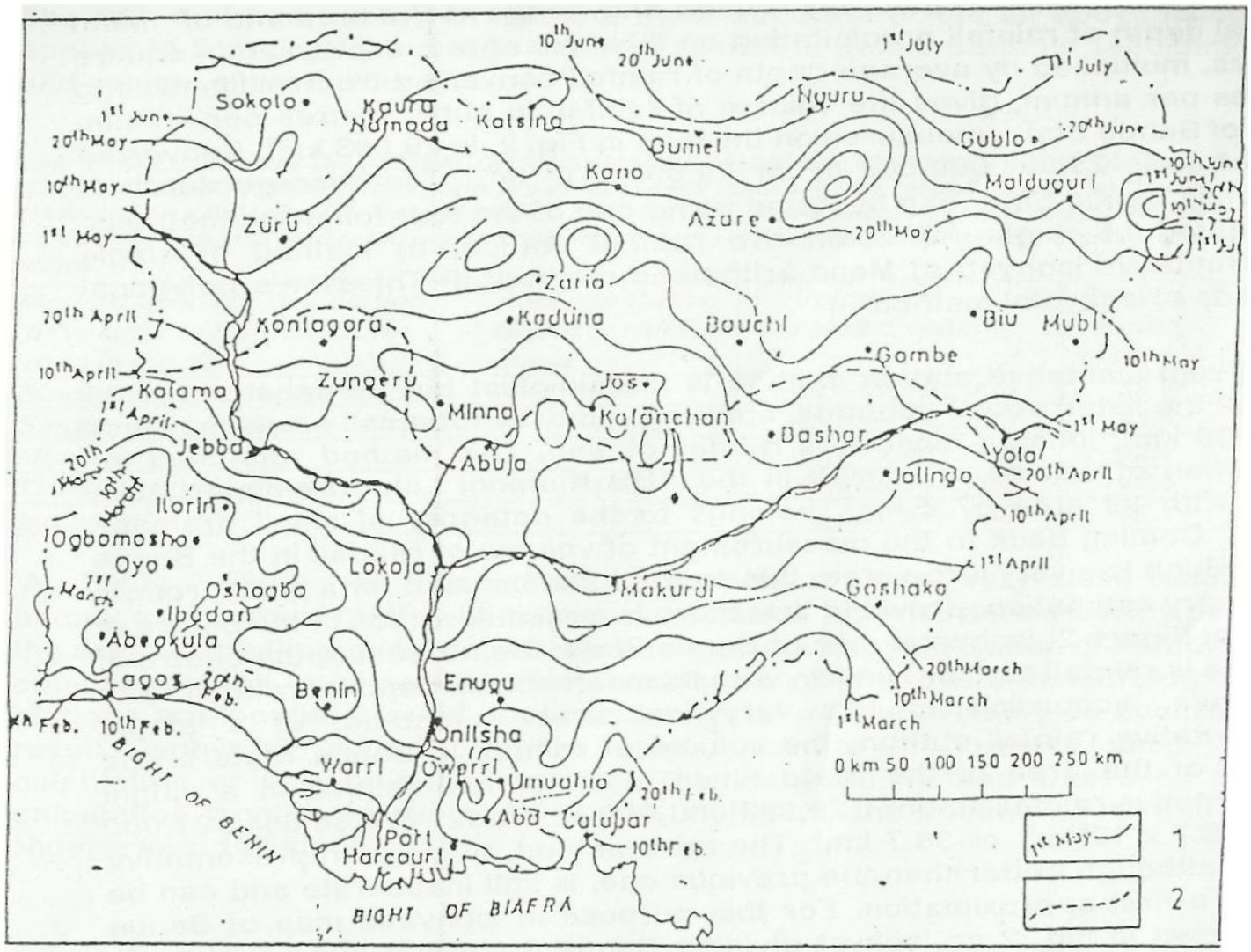
Appendix II Continued March, 2011.

	P1 Hrs of	P2 Hrs of	RAW WATER					Pre chlorine		Alum		Pre Lime		Settled Water				Post Chlorine		Post lime		P1 HRS	P2 HRS	Final Water mld					
Date	Op	Op	p2	p3	total	ntu	ph	kg	mg/l	kg	mg/l	kg	mg/l	ph	ntu	ph	ntu	kg	mg/l	Kg	Mg/l			p1	p2	total	ph	ntu	cl
1-Mar-11	15.42	15.17	14.156	13.93	28.08	62	6.3	20	0.7	1346.40	48	50	1.8	6.1	8	6.0	5	25	0.9	25	0.9	12.97	11.00	14.332	12.155	26.487	6.0	4	
2-Mar-11	19.07	19.00	17.506	17.44	34.95	65	6.1	20	0.6	1274.30	36	75	2.1	5.8	6	5.8	5	25	0.8	25	0.8	13.08	16.67	14.453	18.420	32.874	6.0	4	
3-Mar-11	14.00	24.00	12.852	22.03	34.88	65	6.1	20	0.6	1560.90	45	75	2.1	6.0	7	5.9	6	25	0.7	50	1.4	11.47	20.03	12.674	22.133	34.808	6.1	6	
4-Mar-11	0.00	24.00	0.000	22.03	22.03	58	6.2	20	0.9	1072.25	49	100	4.5	6.1	7	6.0	6	25	1.1	25	1.1	13.18	6.67	14.564	7.370	21.934	6.0	6	
5-Mar-11	0.00	24.00	0.000	22.03	22.03	60	6.3	20	0.9	1096.50	50	75	3.4	6.1	8	6.0	7	25	1.2	25	1.2	18.75	0.00	20.719	0.000	20.719	6.1	6	
6-Mar-11	0.00	21.87	0.000	20.08	20.08	58	6.3	20	1.0	927.30	46	100	5.0	6.1	7	6.0	5	25	1.3	25	1.3	17.75	0.00	19.614	0.000	19.614	6.1	4	
7-Mar-11	0.00	22.17	0.000	20.35	20.35	62	6.3	20	1.0	960.85	47	100	4.9	6.1	8	6.0	7	25	1.4	25	1.4	7.37	8.55	8.144	9.448	17.592	6.1	6	
8-Mar-11	0.00	21.25	0.000	19.51	19.51	60	6.2	20	1.0	809.40	41	100	5.1	6.0	8	5.9	6	25	1.3	25	1.3	0.00	17.45	0.000	19.282	19.282	6.0	5	
9-Mar-11	0.00	15.92	0.000	14.61	14.61	62	6.3	5	0.3	606.95	42	25	1.7	6.1	8	6.0	6	5	0.4	25	1.8	5.93	6.58	6.553	7.271	13.824	6.0	5	
10-Mar-11	0.00	24.00	0.000	22.03	22.03	95	6.4	20	0.9	503.50	23	75	3.4	6.2	13	6.0	8	25	1.2	25	1.2	0.00	19.23	0.000	21.249	21.249	6.1	6	
11-Mar-11	16.75	24.00	15.377	22.03	37.41	95	6.3	20	0.5	2415.70	65	100	2.7	6.3	10	6.0	8	25	0.8	25	0.8	8.92	19.92	9.857	22.012	31.868	6.1	7	
12-Mar-11	6.47	6.47	5.939	5.94	11.88	96	6.1	20	1.7	803.70	68	100	8.4	6.1	10	6.0	6	25	2.2	25	2.2	6.42	3.97	7.094	4.387	11.481	6.0	6	
13-Mar-11	21.40	21.37	19.645	19.62	39.26	95	6.2	20	0.5	2326.75	59	50	1.3	6.1	9	5.6	6	25	0.7	25	0.7	14.00	20.72	15.470	22.896	38.366	5.9	6	
14-Mar-11	17.52	16.42	16.083	15.07	31.16	100	6.4	20	0.6	1177.70	38	75	2.4	5.9	9	5.8	8	25	0.8	25	0.8	15.17	12.55	16.763	13.868	30.631	5.8	7	
15-Mar-11	13.33	13.33	12.237	12.24	24.47	114	nd	10	0.4	2347.25	96	50	2.0	nd	9	nd	7	10	25.0	25	1.0	12.00	10.00	13.260	11.050	24.310	nd	7	
16-Mar-11	23.17	23.17	21.270	21.27	42.54	118	nd	10	0.2	2341.40	55	100	2.4	nd	11	nd	9	10	0.2	25	0.6	21.87	16.05	24.166	17.735	41.902	nd	5	
17-Mar-11	16.67	17.38	17.139	15.95	33.09	130	5.7	20	0.6	1466.85	44	75	2.3	5.6	9	5.6	4	25	0.8	25	0.8	15.67	14.00	17.315	15.470	32.785	5.6	4	
18-Mar-11	22.45	19.47	20.609	17.87	38.48	113	5.7	20	0.5	2259.95	59	100	2.6	5.6	8	5.6	7	25	0.7	50	1.4	15.03	17.68	16.608	19.536	36.145	6.2	5	
19-Mar-11	14.67	21.00	13.467	19.28	32.75	119	6	20	0.6	1539.90	47	100	3.1	5.9	13	5.8	7	25	0.8	25	0.8	17.37	12.17	19.194	13.448	32.642	6.1	6	
20-Mar-11	18.77	21.08	17.231	19.35	36.58	113	6	20	0.5	1434.00	39	75	2.1	5.8	8	5.8	7	25	0.7	25	0.7	17.07	14.08	18.862	15.558	34.421	6.1	6	
21-Mar-11	21.80	21.77	20.012	19.98	40.00	112	6.2	20	0.5	2118.40	53	75	1.9	5.8	11	5.9	7	25	0.6	25	0.6	14.00	21.22	15.470	23.448	38.918	5.9	5	
22-Mar-11	21.13	19.38	19.397	17.79	37.19	115	6.1	20	0.5	1954.00	53	100	2.7	5.8	11	5.6	7	25	0.7	25	0.7	21.95	11.05	24.255	12.210	36.465	5.7	7	
23-Mar-11	20.33	20.97	18.663	19.25	37.91	114	nd	20	0.5	2019.90	53	100	2.6	nd	11	nd	9	25	0.7	25	0.7	21.83	12.00	24.122	13.260	37.382	nd	8	
24-Mar-11	21.08	18.08	19.351	16.60	35.95	120	7.6	20	0.6	1711.45	48	100	2.8	7.0	10	7.2	6	25	0.7	25	0.7	19.87	11.97	21.956	13.227	35.183	7.4	6	
25-Mar-11	23.00	22.92	21.114	21.04	42.15	129	6.1	20	0.5	2166.15	51	50	1.2	5.6	10	5.5	8	25	0.6	25	0.6	19.07	18.65	21.072	20.608	41.681	5.5	7	
26-Mar-11	22.62	14.85	20.765	13.63	34.40	140	6.2	20	0.6	1883.30	55	100	2.9	5.5	9	5.7	8	25	0.7	25	0.7	14.00	16.92	15.470	18.697	34.167	5.7	6	
27-Mar-11	23.47	23.47	21.545	21.55	43.09	137	6.1	20	0.5	2167.20	50	100	2.3	5.7	11	5.6	7	25	0.6	25	0.6	22.92	16.01	25.327	17.691	43.018	6.0	7	
28-Mar-11	22.07	21.75	20.260	19.97	40.23	144	7.6	20	0.5	2221.30	55	75	1.9	7.4	10	7.5	7	30	0.8	50	1.3	22.06	13.05	24.376	14.420	38.797	7.5	7	
29-Mar-11	22.03	23.37	20.224	21.45	41.68	160	7.2	15	0.4	2041.30	49	50	1.2	6.8	10	7.0	8	30	0.7	75	1.9	20.65	15.83	22.818	17.492	40.310	7.2	7	
30-Mar-11	23.47	22.68	21.545	20.82	42.37	151	7.2	15	0.4	2181.10	51	50	1.2	6.8	10	7.0	8	30	0.7	75	1.8	23.75	14.05	26.244	15.525	41.769	7.0	7	
31-Mar-11	24.00	24.00	22.032	22.03	44.06	148	nd	15	0.3	2254.20	51	50	1.1	nd	13	nd	10	30	0.7	75	1.8	19.22	19.33	21.238	21.360	42.598	nd	6	
Total	*466.69*	*628.31*	*428.42*	*576.79*	*1005.21*	*3210*	171.2	*570*	*19.4*	*50991.9*	*1566.1*	*2450*	*85.1*	164	*292*	157.2	*215*	*745*	*50.5*	*1000*	*33.5*	*463.3*	*417.4*	*511.991*	*461.227*	*973.218*	166.2	*184*	
Average	*15.05*	*20.27*	*13.82*	*18.61*	*32.43*	*107*	5.52	*18.4*	*0.6*	*1644.9*	*50.5*	*79.03*	*2.7*	5.29	*9.4*	5.07	*6.9*	*24*	*1.63*	*32.26*	*1.1*	*14.9*	*13.5*	*16.516*	*14.878*	*31.394*	5.36	*5.9*	

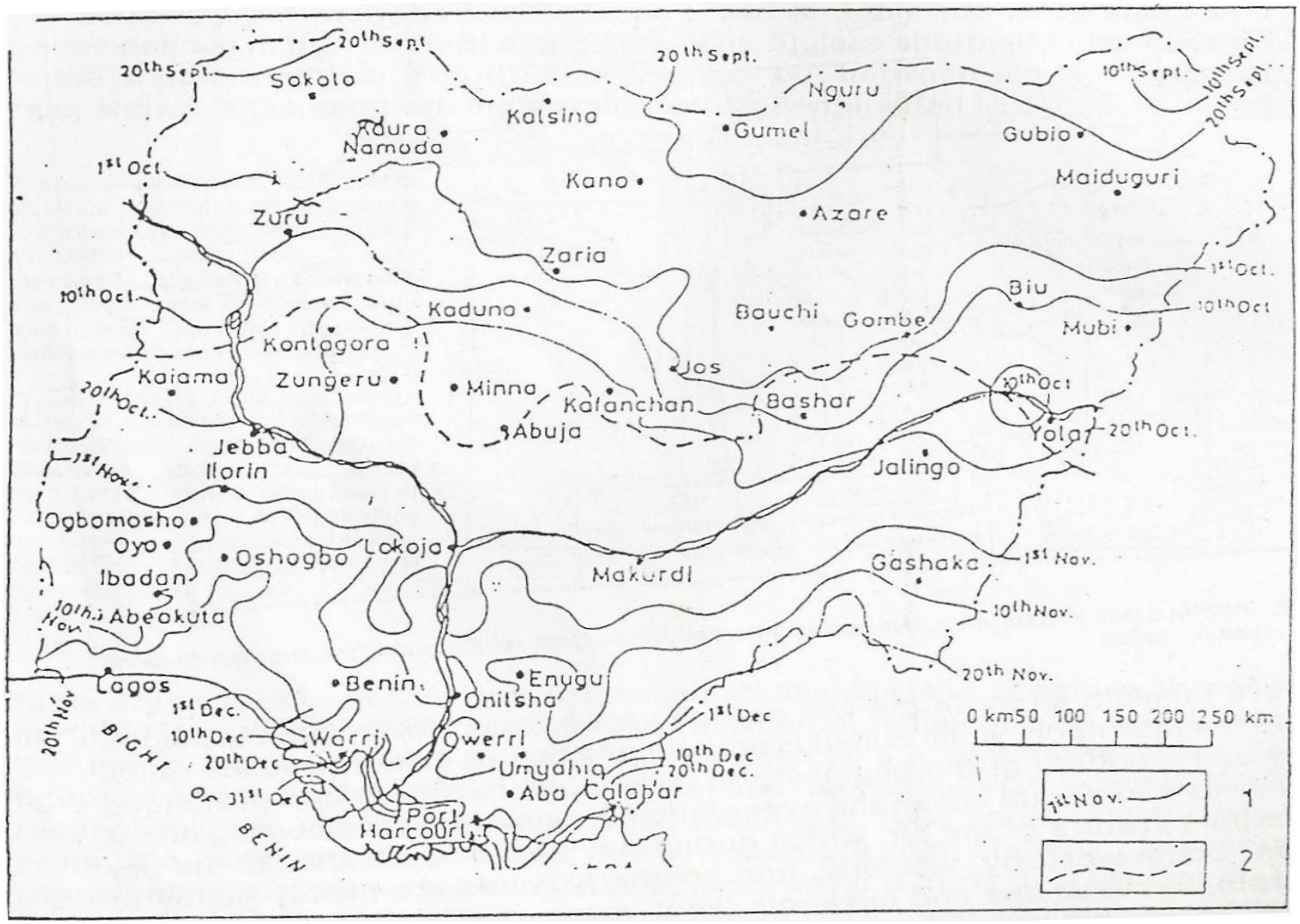
Prepared by: [illegible]

Water Chemist

Appendix III: Dates when the rainy season starts in Nigeria. Legend - 1. Isochrone for the start of the rainy season; 2. Boundary between one- peak rainy season in the north and two peak rainy season in the south. Source: Walter, 1977.



Appendix IV: Dates when the rainy season ends in Nigeria. Legend - 1. Isochrone for the end of the dry season; 2. Boundary between one- peak rainy season in the north and two peak rainy season in the south. Source: Walter, 1977.


20th Sept.
Sokoto
Kalsina
Nguru
Gumel
Gubio
Maiduguri
Kano
Azare
Zaria
Zuru
Kaduna
Bauchi
Gombe
Biu
Mubi
Jos
Kontagora
Kaiama
Zungeru
Minna
Kafanchan
Bashar
Abuja
Yola
Jebba
Ilorin
Jalingo
Ogbomosho
Oyo
Oshogbo
Lokoja
Ibadan
Makurdi
Gashaka
Abeokuta
Lagos
Benin
Enugu
Onitsha
Warri
Owerri
Umuahia
Aba
Calabar
Port Harcourt
BIGHT OF BENIN
0 km 50 100 150 200 250 km
1
2