MEASUREMENT OF THE REMAINING STORAGE AND RATE OF SILTATION IN TAGWAI IMPOUNDING RESERVOIR, NIGER STATE

by

Vulegbo Adamu ALIYU
M. Sc/SCI/10371/2008-2009

DEPARTMENT OF GEOLOGY
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NIGERIA

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Vulegbo Adamu ALIYU. B. Sc (A.B.U. 2005)
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DECLARATION

I declare that the work in the thesis entitled "MEASUREMENT OF THE REMAINING STORAGE AND RATE OF SILTATION IN TAGWAI IMPOUNDING RESERVOIR, NIGER STATE" has been done by me in the Department of Geology Ahmadu Bello University under the supervision of Prof. K. Schoeneich and Dr. S.A. Alagbe.

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 at any university or institution.

Vulegbo Adamu ALIYU	_____	_____
Name of student	**Signature**	**Date**

CERTIFICATION

This thesis entitled "MEASUREMENT OF THE REMAINING STORAGE AND RATE OF SILTATION IN TAGWAI IMPOUNDING RESERVOIR, NIGER STATE" meets the regulations governing the award of the degree of Master of Science (Geology) of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

_____ **Date** _____

Chairman, Supervisory Committee
Professor Krzysztof Schoeneich

_____ **Date** _____

Member, Supervisory Committee
Doctor Solomon Ayo Alagbe

Date _____

_____

Head of Department
Professor Umar Adamu Danbatta

_____ **Date** _____

Dean, Postgraduate School
Professor Adebayo A. Joshua

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ABSTRACT

An attempt was made to measure the remaining storage of Tagwai Impounding Reservoir using bathymetric mapping and remotely sensed surface area data. A field study on Tagwai reservoir was carried out in Tagwai drainage basin, Niger State, Nigeria. The depths of water accompanied with their corresponding coordinates were measured from which area and storage were calculated based on data acquired from the field and that from satellite images. The remaining storage was at the time of measurement, in year 2010, the same as the total storage of the reservoir presently because the dead storage has been already silted up. Remaining storage was in year 2010, 21,650,648 m^3 i.e. 76.5 % of the original storage. Thus, rate at which the storage shrunk from 1978 and 2010 is 207,792 m^3/ year. Losses to siltation are 6,649,352 m^3 during a period of 32 years. This corresponds to the average annual loss to siltation of 0.73 %. The reservoir will be completely silted up in 136 years from the date of its impoundment i.e. in the year 2114, if the rate of siltation is not reduced by upgrading the environment in the drainage basin.

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ABBREVIATIONS

ABU	**Ahmadu Bello University**
DGPS	**Differential Global Positioning System**
ESA	**European Space Agency**
GIS	**Geographic Information System**
GNSS	**Global Navigation Satellite System**
GPS	**Global Positioning System**
ICOD	**International Commission on Large Dams**
MWSS	**Minna Water Supply Scheme**
NIMET	**Nigerian Meteorological Agency**
NSWB	**Niger State Water Board**
NE	**Northeast**
NW	**Northwest**
OWRB	**Oklahoma Water Resources Board**
SE	**Southeast**
SW	**Southwest**
USA	**United State of America**
USACE	**United State Army Corps of Engineers**
USGS	**United State Geological Survey**
USWP	**Utah State Water Plan**

CHAPTER 1

INTRODUCTION

1.1 Concept of the Remaining Storage

Water resources planning and management is a major challenge to most developing nation, in their struggle to secure water. However, this depends on the availability of water, which is increasingly becoming a scarce resource. All the sources of water need to be considered in its management. In this study, reservoir is the focus.

Reservoirs are water storage structures created by construction of dams across rivers to store and capture runoff water for the purposes of water supply, hydro power generation, irrigation, flood control, tourism, aquaculture etc. Environmental impact and long term morphological changes of the natural water course and drainage basin due to human activities are inevitable. Many river basins experience severe and uncontrolled environmental degradation. This results into enhanced soil erosion in the drainage basin and excessive reservoir siltation which are considered as threat.

The term "siltation" means the increased deposition and accumulation of sediments in reservoirs. These sediments originating from erosion processes in the drainage basin are propagated along with the river flow. When the flow of a river is stored in a reservoir, the sediments settle in the reservoirs and reduce their storage capacity. It is the major problem which affects and threatens the performance and sustainability of reservoirs apart from structural stability. Reduction in the storage capacity of a reservoir beyond a limit hampers the purpose for which it is designed i.e. the gradual loss of storage capacity reduces the effective life of reservoirs and diminishes benefits for its intended uses. For example the

Kubanni Impounding Reservoir in Ahmadu Bello University (A.B.U), Main Campus Zaria is being silted up. A.B.U. Committee on Protection of the Kubanni Dam Drainage Basin (2008) said that "Kubanni impounding reservoir, the major source of water for the Ahmadu Bello University, A.B.U Main Campus, is shrinking. In year 2008, it still has more than enough water to meet water demand from the Campus, but from year 2022 onwards water will be rationed. From year 2059 onwards water rationing will stop because there will be no water in the Kubanni impounding reservoir. Kubanni impounding reservoir will be then completely silted up. Excessive siltation of the reservoir is caused by the over exploitation of biological environment in its drainage basin".

The consequences of siltation can be economically serious. Storage capacity losses in reservoirs mean financial losses due to the shortening of their useful lifetime. Thus from management point of view, the existence of reservoirs as well as their distribution and storage capacities must be known. The lack of adequate knowledge on reservoirs remaining storage capacities has been a constraint in decision making processes regarding planning and management of existing water resources. Mugabe *et al*, (2004) cited that 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 resources management. This justifies the need to establish the current storage capacities of reservoirs.

1.2 Background to the Study

Tagwai Reservoir is located on River Tagwayi, (NSWB, 1982). Tagwayi River is a tributary to River Chanchaga in Niger State. The reservoir is currently used as water supply source, to augment the source of raw water for the Chanchaga treatment plant (Minna Water

Supply Scheme, 1992). The dam was commissioned on 1st November, 1978. The dam is classified as a large dam (Nigeria Register of Dams, 1995). The large dam classification means that it satisfies the International Commission on Large Dams (ICOD) definition (Nigeria Register of Dams, 1995). i.e.

(1) All dams with heights of 15 m or more, measured from the lowest portion of the general foundation area to the crest.

(2) Dams between 10 m and 15 m can be included if desired, provided they comply with at least one of the following conditions: (i) the length of crest not less than 500 m (ii) the capacity of the reservoir formed by the dam not less than 1 million m^3 (iii) the maximum flood discharge dealt with by spillway not less than 2000 m^3/sec (iv) the dam has special foundation problems (v) the dam is of unusual design.

The existing water supply scheme in Minna, Niger State capital, is far from adequate, water is being rationed and no one area receives a 24 hour supply except to institutions and households with internal storage facilities. Some areas, like Maitumbi, receive pipe-borne water only a few hours, twice or thrice in a week (Minna Water Supply Scheme, 1992).

The current estimate of total reservoir storage worldwide is around 7000 km^3 (ICOLD, 1997). This storage is used for residential water supply, irrigation, hydropower generation and flood control. Concern about loss of reservoir storage capacity due to siltation was raised by Mahmood (1987) and has recently been expressed in many fora and publications (Palmieri, *et al.,* 2003). It is estimated that between 0.5 % and 1.0 % of global water storage volume is lost annually as a result siltation (White, 2001). The annual loss of storage in reservoir is roughly 1%, corresponding to about 50 km^3 worldwide (Mahmood, 1987). For example, annual loss of storage in the Kubanni reservoir in Ahmadu Bello University,

Zaria, Nigeria is 1.16 % (A.B.U Committee on Protection of the Kubanni Dam Drainage Basin, 2008). Some reservoirs have a much higher storage losses that may exceed 1.7 % annually (Patrick, 1996). Using an intermediate rate, this loss in storage is approximately 45 km^3 per year for the world (Palmieri, *et al.,* 2003). If it is further assumed that the average reservoir volume is 150 million m^3, 300 large dams should be built annually just to maintain current total worldwide storage (Palmieri, *et al.,* 2003). The lack of knowledge of the current storage capacity of many reservoirs around the world has limited the uses for which they are intended, hence the need for bathymetric mapping of such reservoirs i.e. the measurement of underwater depth. To be able to assess the siltation rate or to determine sustainable water withdrawal rates, the water level-volume lake area or stage curve relationship provides invaluable information. However, 40 % of the world's largest lakes (impounding reservoirs) have not been studied and their volumes are therefore approximated (Shiklomanov and Rodda, 2003). About 82% of Nigeria dry season surface water is in man-made impounding reservoirs (Schoeneich, 2003), Most of these dams belong to the category of small and middle size dams. Consequently they are even more endangered by siltation.

Bathymetry is mapping depth of the bottom of a body of water i.e. the measurement of underwater depth. It is the underwater equivalent to hypsometry – elevation of land surface. A bathymetric map usually shows floor relief or terrain as contour lines called depth contours or isobaths. The purpose of the bathymetry is to provide accurate determinations of current storage capacities of reservoirs. Obtaining accurate storage volumes is an integral tool used in the management of water supply. For many reservoirs, the only available storage volumes are those that were estimated when the dam was first

constructed. Because of sediment deposition that occurs in reservoirs, the volume can be grossly reduced over time. By conducting a reservoir bathymetric mapping, the managing authority of a reservoir can be better equipped to handle critical water management issues because of the invaluable information generated.

1.3 Statement of the Problem

Growing water demand creates need for a very sound water resources management, based on reliable data within the context of resource sustainability. To improve the management of water resources many rivers have been dammed; siltation of their reservoirs is a significant problem on which little information is available. Systematic plans and policies are needed to reduce the adverse impacts of siltation and prolong the useful life of reservoirs. Water resources managers routinely need bathymetric maps of inland water bodies to be able to respond effectively to the challenges.

1.4 Aim of the Research

The determination of the Remaining Storage of Tagwai Impounding Reservoir in comparison with the design capacity in order to calculate the rate of siltation in the reservoir and rate of erosion in the drainage basin.

This aim will be achieved through:

- **Review of literatures relevant to Tagwai Reservoir and Reservoir Siltation Studies**
- **Measurement of the remaining surface area of Tagwai Reservoir**
- **Measurement of the remaining depths of Tagwai Reservoir**

1.5 Scope of the study

The scope of this study includes:

- **Delineation of the drainage area of the reservoir;**
- **Collection of available relevant information of the drainage basin;**
- **Geological mapping of the drainage area;**
- **Mapping of the water edges of the reservoir;**
- **Bathymetric mapping of the reservoir;**
- **Calculation of the volume of water in the reservoir;**
- **Calculation of the rate of siltation in the reservoir;**
- **Calculation of the rate of erosion in the drainage basin.**

1.6 Justification of the study

In Nigeria, over 323 dams and reservoirs have been constructed and many more are under construction in different parts of the country (Etiosa, 2006). The Tagwai impounded reservoir is one of them and it is the major source of piped-borne water supply to Minna and its environs. The reservoir at impoundment in 1978, had dead storage of 1.8×10^6 m^3, while the active storage was 26.5×10^6 m^3. Since its impoundment in 1978 part of the original storage has been lost to siltation because of environmental degradation within the drainage basin. This part is still unknown? This study sought to determine the remaining storage, rate of siltation in the reservoir, and rate of erosion in the drainage basin.

1.7 The Study Area

1.7.1 Location

The study area is the drainage basin of Tagwayi River upstream of the Tagwai Reservoir embankment. It lies in the southeastern part of Minna, Niger State capital (Figure 1).

The drainage basin lies on part of sheet 164 Minna, SW and SE of the first edition of 1:50,000 topographic maps of 1967, within latitudes 9^o 33' 0" N to 9^o 41' 0" N and longitudes 6^o 31' 30" E to 6^o 50' 0" E (Figure 2a and 2b).

The dam is built across River Tagwayi which is a tributary of River Chanchaga in Niger State. The dam is an earth filled dam, initiated by the Niger State Government in 1976 and completed in 1978 to augment the source of raw water supply for the Chanchaga treatment plant.

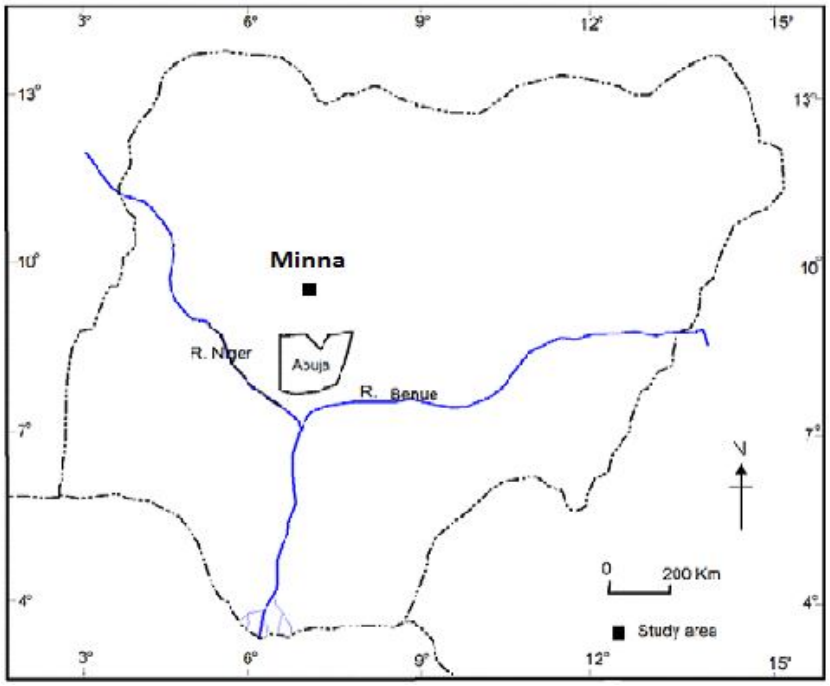


Figure 1. Map of Nigeria showing study area.

1.7.2 Climate and Vegetation

The climatic feature of the study area is a product of its location in the tropical region of West Africa and falls within the Guinea Savanna vegetation zone in Nigeria, marked by distinct wet and dry seasons. The wet season starts, on long term average, on 9th April and ends on 25th October, lasting 200 days (Table 2). The dry season starts on 26th October and ends on 8th April, lasting 165 days.

The most heavy rains that fall at the beginning of wet season are usually short lived. The last stages of the rainy season are marked by light showers and thunderstorms.

TABLE 1. TAGWAI DAM PROJECT DATA. (NSWB, 1982)

1.	Average annual precipitation	1270 mm
2.	Catchment area	110 km^2
3.	Average annual run off	25 x 10^6 m^3
4.	Type of Dam	Zone earth fill
5.	Crest length	1770 m
6.	Crest level	259 m O.D
7.	Free Board	3 m
8.	Maximum flood level	257.5 m O.D
9.	Full supply level	256 m O.D
10.	Crest width	10 m
11.	Maximum structural height	25 m O.G.L
12.	Hydraulic height	21 m
13.	Maximum width of base	150 m
14.	Total storage capacity	28.3 x 10^6 m^3
15.	Active storage capacity	26.5 x 10^6 m^3
16.	Dead storage capacity	1.8 x 10^6 m^3
17.	Dead storage level	245.5 m
18.	Surface area of lake	5.50 x 10^6 m^2
19.	Total volume of Earthwork	870,000 m^3
20.	Service spillway	110 m long with crest elevation 258.3 m
21.	Emergency spillway	170 m long with crest elevation 258.3 m
22.	Intake tower	2 (24'') diameter of steel pipe penstocks with guan and control valve.
23.	Date of commencement	20th September, 1977
24.	Date of completion	1st November, 1978
25.	Cost	₦ 6,960,000

O.D – Ordnance datum, Ordnance ground level.

TABLE 2. MONTHLY TOTAL RAINFALL, MINNA (mm). (NIGERIAN METEOROLOGICAL AGENCY, NIMET, 2006).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	0	0	0	3.6	135.9	231	208.8	308.5	303	153.4	0	0
2001	0	0	0	93.9	139	331.7	244.6	230.2	298.8	25.7	0	0
2002	0	0	5.7	98.8	42.6	201	143.2	226.5	260.6	180.3	0.3	0
2003	0	5.7	0	17.4	114.6	203	123	191.6	188.2	192.4	2.3	0
2004	0	0	0	32.2	151.9	194.9	210.3	211.4	241.5	77.6	0	0
2005	0	0	7.5	49.1		173.9	294.2	127.8	226.4	94.8	0	0
2006	11.2	0	0	29.9	195	107.7	229.7	317.1	360.5	172.1	0	0

The mean annual depth of rainfall recorded by Minna Hydrometeorological Station from year 2000 until year 2006 was 1270 mm. This is in agreement with datum read from Figure 3 below, 1250 mm/a.

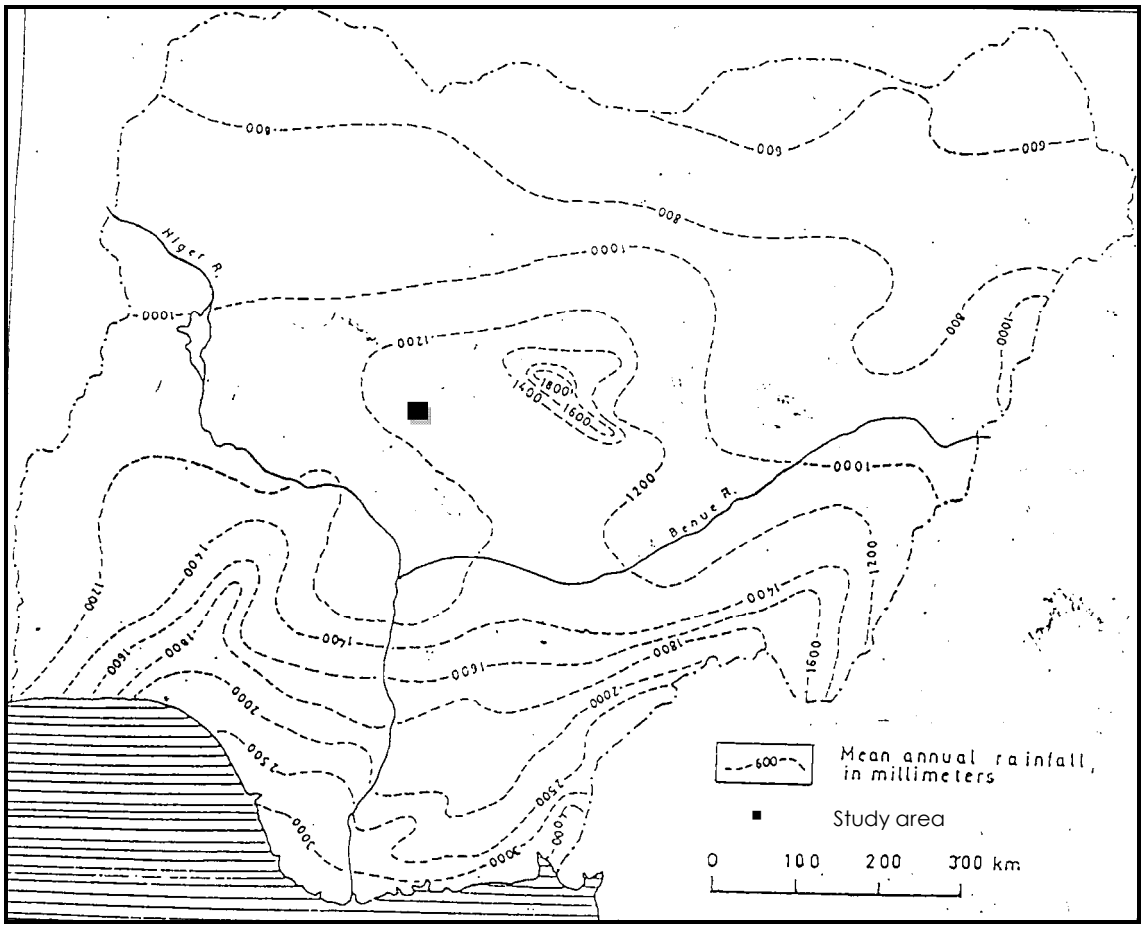


Figure 3. Map of mean annual depth of rainfall in Nigeria (Schoeneich, 2003)

The dry season is characterized by the prevalence of the dry continental northeasterly harmattan wind from the Sahara desert and across the study area.

The vegetation of the study area consist of scattered trees and shrubs. Main trees are *Vitellaria paradoxa* (shear butter), *Parkia biglobosa* (locust bean), *Magnifera indica* (mango).

The study area has mean annual Stevenson Screen temperature of 27.2 ^{o}C according to Schoeneich and Garba (2010). The mean maximum monthly temperatures for Minna are presented in Table 3.

TABLE 3. MEAN MONTHLY MAXIMUM TEMPERATURE (^{O}C) at MINNA. (NIGRTIAN METEOROLOGICAL AGENCY, NIMET, 2006).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	35.7	34.8	38.1	37.3	35.1	30.6	29.2	28.9	30.2	31.5	35.4	34.8
2001	34.8	36.1	38.9	36.3	33.7	30.9	29.1	28.3	29.5	33	36	36.4
2002	33.5	37	38.6	35.8	35.7	32	29.9	29.4	29.2	31.3	34.7	34.9
2003	35.3	38.2	39	36.6	34.7	31.2	29.8	28.8	29.8	31.8	35.5	35.2
2004	34.8	36.7	37.6	37.6	33.5	31	29.2	29	29.9	30	34.8	34.8
2005	33.7	38.3	39.4	37.6	33.7	31.4	29.4	28.8	30.5	31.5	35.1	34.6
2006	35.7	37.5	38.4	31.9	31.5	30.1	28.5	30.1	31.3	30	34.7	34.6

1.7.3 Relief and Drainage

The study area is generally gently undulating; sloping gently from the high lands in the northern part of the area, with highest point as 410m to the southern part of the area, with lowest point as 250m. The drainage pattern is dendritic. The area is drained by the river Tagwayi and its tributaries.

1.7.4 Geology and Hydrogeology

The study area is located within the Crystalline Hydrogeological Province of Nigeria. The rocks of the area are mostly crystalline rocks consisting of granites and metasedimentary schist. The granitic outcrops are highly jointed, fractured and in some places appear as boulders (Plate 1) (Adeniyi, 1985). In addition to these two major rock types, there are other rock types in form of minor intrusive such as quartz veins. They are closely associated with the granitic rocks.



Plate 1. An outcrop of granite, in form of ruware inselberg, at north - east edge of the reservoir.

The flow regime of the rivers in the study area is a function of the rainfall pattern and lithology over which the rivers are flowing. Generally, rivers on the basement tend to be ephemeral or flashy and with very low dry season flow.

Minna area is made up of only the Crystalline Hydrogeological Province, as there is complete absence of sedimentary rocks in the study area (Mohammed *et al.,* 2008). This Crystalline Hydrogeological Province is made up of two interconnected aquifers: the soft overburden aquifer within the mostly allochtonous products of chemical weathering, and the Fractured Crystalline Aquifer within the weak zone and the partially weathered / fractured basement. The depth to the water table lies on the average between 3 m and 15 m below the ground surface in the Crystalline Basement Complex (Offodile, 2002). The average yield of borehole in these aquifers is between 0.75 and 1.80 l / sec. In Minna, existing borehole data indicate that the weathered mantle is on the average thin. Areas of rugged topography subjected to high rate of erosion have a thin weathered zone. The water in the weathered zone aquifer is unconfined and shallow, but follows the topography in a suppressed manner.

CHAPTER 2

LITERATURE REVIEW

2.1 Regional Geology

To understand the geology of the study area, knowledge of the regional geology is necessary. The study area is part of sheet 164 Minna SW and SE, which is an integral part of the Northern Nigerian Basement Complex.

The study area is underlain by rocks of Northern Nigeria Basement Complex and consists of rocks that are of Precambrian to Palaeozoic in age (Ajibade, 1972). The Nigerian basement is believed by most workers to have been affected by at least two cycles of orogenesis (Russ, 1957; Oyawoye, 1964; Grant, 1969; 1970; 1978; McCurry, 1970; 1971; Ajibade, 1972; and Turner, 1983) except for Truswell and Cope (1963), who suggested one orogenic cycle.

Both orogenic cycles led to wide spread sedimentation, metamorphism, folding, faulting and remobilization of pre-existing Basement Complex rocks to produce suites of granitoids. The earlier orogeny is characterized by intense deformation and folding about E-W axes which are accompanied by regional metamorphism (McCurry, 1970). The later orogeny is the Pan African, being more intense and nearly erasing all the signs of the earlier orogeny resulting in N-S structural trend of fold axes (McCurry, 1970). This fact is supported by the synclinorial belts of metasediments in large areas of northwestern Nigeria including the Kushaka, the Kusheriki and Zungeru Formations in Niger State.

It was concluded by Oyawoye (1964), McCurry (1971, 1973) and Ajibade (1972), that there are at least two orogenic cycles in Nigerian Basement, one in which the gneisses were

emplaced, the other leading to the emplacement of the schist and Older Granites. The close contact between the contrasting metamorphic grade type, migmatites and the Younger metasedimentary schist accented. Ajibade (1982) interpreted this close contact relationship as a result of the emplacement of a sufficiently large amount of Older Granite that engulfs most of the metasedimentary schist. Different migmatitic structures were formed due to varying degree of assimilation of the schist.

The Northern Nigerian Basement Complex is part of the Pan African Mobile Belt that separates the West African Craton to the west and the Congo Craton to the east. The evolution of the Basement Complex was suggested to be during the late Proterozoic. This is related to the activities occurring at the plate margins. The deposition of rocks of schist belt was subsequent effect of initial crustal extension and continental rifting at the West African Craton margin at about 1000 m.a.

Grant (1969), Betrand and Caby (1978) suggested that the above view supports a well defined geodynamics model for the western margin of the Pan African mobile belt. The deformation of sediments, reactivation of the pre – existing rocks and emplacement of the Pan African granites was due to closure of the ocean at the cratonic margin about 600 M.a. and crustal thickening in the Dahomay (Ajibade *et al.,* 1987). Burke *et al.,* (1976) and Ajibade *et al.,* (1987) suggested that the relics of older rocks exist which may have escaped the effect of the Pan African Orogeny during the emplacement of the granite and associated metamorphic rocks.

Three broad lithological groups are usually distinguished within the Northern Nigerian Basement Complex (Russ, 1957; Truswell and Cope, 1963; Grant, 1969; McCurry, 1970).

1. A polymetamorphic migmatite – gneiss complex which is composed largely of migmatites and gneisses of various compositions and amphibolites. Relict metasedimentary rocks represented by medium to high grade calcareous, pelitic and quartzitic rocks occur within the migmatites and gneisses, and they have been described as ancient "metasediments" (Oyawoye, 1972). Ajibade (1982) differentiated the migmatites into migmatites with no relics of schists or gneisses and migmatites with relics of alternating light bands formed by tonalite and dark band of schist. The complex structures within the migmatite may be due to differential stresses arising from multi layering of adjacent competent and less competent beds so that buckling and differential movement results (McCurry, 1970).

2. Low grade Metasediment dominated schists which form narrow belts have been described as "Newer Metasediments" (Oyawoye, 1972) and "Younger Metasediments" (McCurry, 1976). The schist belts are believed to be relicts of a supracrustal cover which was infolded into the migmatite – gneiss complex (Russ, 1957; McCurry, 1973). They are linear belts of generally green schist facies metamorphism. They are chiefly pelitic and semi – pelitic rocks with inter bedded orthoquartzites and micaceous psammites (Ajibade, 1976). They are believed to be upper Proterozoic (McCurry, 1970; Grant, 1978) and were believed to have been deposited on the granitized basement. The different lithological associations occurring in different belts have led to the suggestion that each belt developed in a separate basin (Truswell and Cope, 1963; Grant, 1978).

3. The granitiods are syntectonic to late tectonic cutting both the migmatite – gneiss complex and the schist belts. The granitoids include rocks varying in composition from granite to tonalite and charnockite with smaller bodies of syenite and gabbro. These Pan African granitoids are called Older Granites in Nigeria to distinguish them from the

Mesozoic tin bearing granite complexes of central Nigeria which are referred to as the Younger Granites. Both the migmatite – gneiss complex and the rocks of the schist belts have parallel N – S structures and have conformable field relations.

2.2 Reservoir Siltation

Hill as well as Visentini (1936) and Brown (1943) were among the first authors having described the importance and the means to control reservoir siltation. Methods and techniques for achieving the sustainable use of reservoirs are described in several books and papers, 15 of which are the most comprehensive ones all date from the eighties and nineties (Annandale, 1987; Mahmood, 1987; ICOLD, 1989; Morris and Fan, 1998, Palmieri *et al.,* 2003). Some other observations and measurements before 1990 are reported in Tadjikistan (Pyrkin *et al.,* 1978), USA (Ford and Johnson, 1981), Canada (Weirich, 1984, 1986), Ecuador (Jervez, 1985), and Japan (Chikita, 1989).

A daily measurement of stage is usually sufficient in lakes and reservoirs for the purpose of calculating changes in storage (Vuglinskiy *et al.,* 2009). Estimation of the amount of sediment stored in reservoirs is the product of complex bathymetry, uncertain knowledge of prereservoir topography, and uncertain estimates of the density of the stored sediments (Graf *et al.,* 2010). Progress in surveying and mapping methods and in instrumentation has been rather pronounced in recent decades. Electronic distance meters such as microwaves, lasers and infra red light devices are widely used. Aerial surveys together with underwater depth sounding are also commonly used. The Global Positioning System (GPS) or the Global Navigation Satellite System (GNSS) positions the soundings with respect to the

surface of the earth. The Global Positioning System (GPS) and Geographic Information System (GIS) have caused a revolution in this field (Zhide and Yuqian, 2003).

Each reservoir independent of its use can have its storage capacity reduced as a result of deposition over the years (Althaus and De Cesare, 2006). A dam causes reduction in flow velocity and consequently in turbulence, which causes the settling process of the materials carried by the river (Frenette and Julien, 1996; Campos, 2001; Chella *et al.,* 2003; Abood *et al*., 2009). Due to flow deceleration, when a river approaches a reservoir, the sediment transport capacity decreases and some of the incoming sediment is trapped and deposited in the reservoir (Raghunath, 1986; Frenette and Julien, 1996). The coarser materials deposit first forming delta at the head of the reservoir, and then finer material settles forming the bottom sediment, spreading throughout the reservoir (Abood *et al*., 2009; Tigrek *et al*., 2009). As the water continues to flow into the reservoir, the delta continues to grow in the direction of the dam, until it eventually fills the entire reservoir volume (Figure 4).

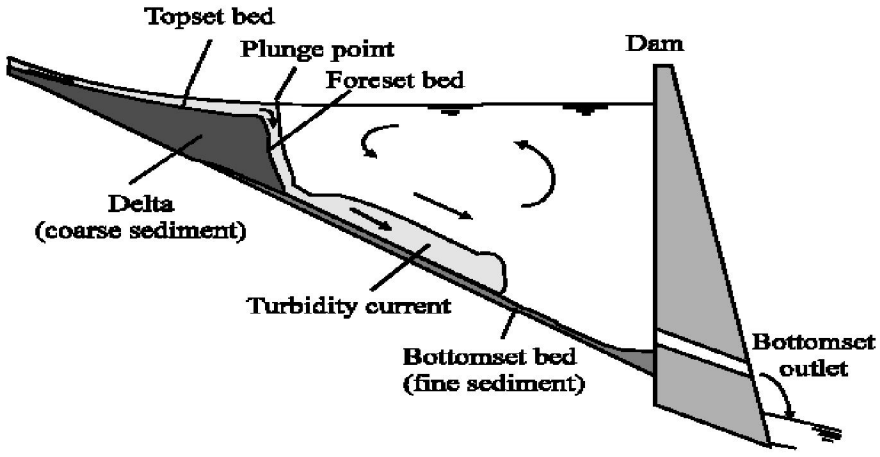


Figure 4. Schematic presentation of siltation mechanism in reservoirs (Sloff, 1997)

Sediment deposition in reservoirs causes loss of water storage capacity (Graf, 1984; Fan and Morris, 1992; Yoon, 1992; Cobo *et al.,* 1997; Avendano *et al.,* 1997; Sloff, 1997; Carvalho, 1998; White, 2000; Goel *et al.,* 2002; and Jain *et al.,* 2002). Both catchment and impoundment characteristics control the rate and pattern of sediment deposition within a reservoir (Molino *et al*., 2001). Hydrology, geology and land use determine the sediment yield, and the properties of sediment delivered to the reservoir (Jain and Kothyari 2000; Small *et al.,* 2003; Lee 2004; Jain *et al.,* 2005). The rate at which a watershed contributes sediment to its streams is affected by both natural and human factors; the primary natural factors include rainfall amounts and intensity, soil type, bed rock outcrop, topography, groundcover and vegetation (Fried *et al.,* 2000; Abood *et al*., 2009; USWP, 2010). Human activities can alter most of these natural factors and consequently can have a strong impact upon the resulting erosion and siltation rates.

The current estimate of total reservoir storage worldwide is around 7000 km^3 (ICOLD, 1997). Mahmood (1987) raised concerns about loss of reservoir storage capacity due to sedimentation. It is estimated that more than 0.5 % of the total reservoir storage volume in the world is lost annually as a result of sedimentation (White, 2001). However, Jacobsen (1999) states that there are no accurate data on the rates of reservoir sedimentation worldwide, but it is commonly accepted that about 1 – 2 % of the worldwide capacity is lost annually. The introductions of sediment management measures in some older dams, were appropriate, and in the design of new ones could help to reduce sedimentation problem (Palmieri *et al.,* 2003). There have been a few case studies conducted on sustainable management of water resources, e.g., by Arntzen (1995), Bobba and Singh (1997), Carroll and Turpin (1997), Charlton (1997), Nguyen (2000). These studies strongly call for

incorporating the sustainability criteria in early stages of planning. A balance must be struck between current and future water requirements on the one hand and maintenance of a minimum water level, on the other. As many of the reservoirs end up holding much of the sediment load themselves (Chakela, 1980; Iguisi, 1997; Verstraeten and Poesen, 2000; Haregeweyn *et al.,* 2006; Tamene *et al.,* 2006; Schumm, 2009).

Sediment load is defined as debris eroded from an area drained by a stream, delivered to and transported by the stream itself (Schumm, 2009). The sediment yields of various drainage basins are expected to be high because of the observed poor environmental practices (Turner *et al.*, 1990; IGBP-BAHC 1997). The current pace of environmental change prompted partly by degradation continues at an alarming proportion (Eswaran *et al.,* 2001; Weller 2005 in Nwilo and Adeleke, 2008). Reservoirs whose drainage basins are rapidly undergoing urbanization, continuous cultivation, logging, mining and perennial bush burning are usually more vulnerable to siltation (Iguisi, 1997; A.B.U. Committee on protection of the Kubanni dam drainage basin, 2008; Jain and Das, 2010). Many reservoirs are losing storage capacity at alarming rate due to environmental degradation within the drainage basin (A.B.U. Committee on protection of the Kubanni dam drainage basin, 2008). Sediment movement into water channels by flood and storm water occur as a result of soil erosion in the drainage basin. Erosion processes are generally slow; however, the annual volumes of sediment load involved are huge (U.S. Department of Agriculture-Soil Conservation Service, 1992). According to an estimate, the global production of sediment is about 2×10^{10} t / year (Alam, 2001).

Due to continuous deposition and encroachment of the live storage by sediment, siltation study is gaining much attention (Garde, 1995; Morris and Fan, 1997; Varshney, 1997). The

approach adopted to study a particular reservoir depends upon the size of the reservoir in relation to its inflows, the sediment regime in the river and the purpose of the reservoir. There are several guidelines which one can use to decide how critical siltation is likely to be in a particular reservoir; Churchill (1948); Brown (1950) and Brune (1953) produce trap efficiency of reservoir which is defined as the percentage of total inflowing sediment that is retained in the reservoir.

Gottschalk (1951); USACE (1989); Zhide and Yuqian (2003), outlined methods of conducting reservoir siltation studies. The volume of sediment accumulated in a reservoir is computed as the difference between the present water capacity of the reservoir and a known water capacity of some prior date usually the original capacity. Heinemann and Rausch (1971) stated that the sediment deposits may change because of compaction between successive studies. USACE (1989) and Zhide and Yuqian, (2003) outline that three methods are most commonly used to measure erosion and deposition in reservoirs and river reaches, namely the Contour area (topographic survey) methods, Cross-section area (range-line) methods and the composite method (combination cross-section contour Area methods). However, Utah State Water Plan, (USWP) (2010) outline two ways to measure the present reservoir volume, a range survey and a contour survey. A range survey uses a sonar device to measure water depth along preset range lines that cross the reservoir at regular intervals. The contour survey (or bathymetric survey) also uses a sonar device to measure water depth, and incorporates a Global Positioning System (GPS) to determine the boat location. An approximate grid pattern is followed across the entire reservoir surface. The overall sedimentation rate is determined using the original reservoir volume, the present volume, and the number of years since the reservoir began storing water.

Selecting a method depends mainly on the topography of the studied area and the accuracy desired (Zhide and Yuqian, 2003). The contour area methods are based upon the assumption that the area encompassed by a contour line and the contour interval can adequately represent the volume between any successive contour elevations. There are four contour area methods: Stage-area, Modified prismoidal, Average contour area, and Simpson's rule.

a. Stage-Area Method: This method requires an accurate stage-area curve. The stage-area curve is developed by planimetering the area inside a contour line and plotting it against the contour elevation. Reservoir volume is calculated by integrating the area between this "contour area curves".

b. Modified Prismoidal Method: This method is based upon an averaging of the areas of two successive contour lines and a geometric mean area all multiplied by the contour interval to obtain the volume between the contour elevations. It is expressed mathematical as the frustum cone formula: $V = 1/3\ (A + B + (AB)^{1/2})\ L$.

Where V = Volume between two contour elevations, L = Contour interval, A = Area of lower contour, B = Area of upper contour.

c. Average Contour Area Method: This method uses the averaging of two contour areas multiplied by the contour interval. It is expressed mathematical as $V = (L/2) \times (A+ B)$, variables are same as above.

d. Simpson's Rule: This method requires the contour interval to be constant if using contour-area data. If cross section area data is used, the cross sections must be parallel and evenly spaced, both requiring even number of segments.

The development of current collection systems has made the contour method the preferred method for data collection and analysis. Manual sounding poles, sounding weights and echo sounders are commonly used for depth measurements (Zhide and Yuqian, 2003). A bell shaped sounding weight or a sounding pole may be used to take soundings where an echo sounder is not available (Soil Conservation Service, 1973). The accuracy of a sedimentation survey, needless to say, relies on the accurate positioning of measuring points, particularly in places where the sediment deposition is not appreciable (Zhide and Yuqian, 2003). The use of Differential Global Positioning System (DGPS) made possible positioning accuracies of 1 to 2 m, which is acceptable in a hydrographic survey (Ferrari and Dorough, 1998). Ferrari and Dorough (1996) used two approaches in computing the reservoir capacity from topographic survey data: the point elevation-area method and the conventional contour-area method. A computer program is used for efficient and economically feasible data evaluation. In the point elevation-area method, the surveyed area is large and has a high data density. With the development of electronic measuring and computerized collection and analysis systems, the contour method of creating new reservoir topographic maps has become the preferred method for reservoir sedimentation surveys. The ARC/INFO package is used to develop reservoir topography from the collected data. ARC/INFO is a software package for using the GIS. Contours for the reservoir area at selected elevation intervals are computed from the compiled data using the TIN (triangular irregular network) modelling package within ARC/INFO. The Area-Capacity Computation Program is used to generate elevation versus capacity and / or surface area for the reservoir area. The amount of deposition or erosion is the difference of capacities under the specified elevation computed for two surveys (Ferrari and Dorough,

1996). Obviously, at points where no deposition or erosion takes place, the elevation of the bed surface should coincide with that measured in a previous study. This is a good check of the accuracy and reliability of the siltation measurement method. Heinemann and Dvorak (1965) determined reservoir capacity of several small reservoirs using stage-area, modified prismoidal, Eakin's range formula, Simpson's Rule (range cross-sectional area method), average contour area, and cross-sectional area versus distance from dam methods. They found all these methods to be fairly accurate. Contour methods are generally used for original volume computation because of availability of contour maps or the relative ease of obtaining more accurate contour maps by aerial photometric procedures.

Methods used to collect information necessary for water storage capacities and sediment accumulation investigations in reservoirs have changed over the decades. Changes in the methodologies substantially affect the ability to quantitatively compare results between studies and temporal changes in sediment accumulation; however, it improves the quality of results obtained. Natural Resources Conservation Service (NRCS) used the range method, which utilized a number of transects to determine the cross-sectional area of reservoirs at different locations (EA Engineering, Science and Technology, Inc., 1989). The OWRB (2006) conducted hydrographic survey of Okemah lake adhering to US Army Corps of Engineer (USACE) standards (USACE, 2002) using a combination of Echo sounder and GPS, the depths are then checked manually with a weighted measuring tape to ensure that the echo sounder is properly calibrated and operating correctly. It has been standard practices to estimate a lake stage curve from its bathymetry since the 1930's using sounding lines and since the 1950's using fathometers (Dost and Mannaerts, 2004). With the introduction of Global positioning system (GPS) satellite navigator in the 1990's the

positioning of the depth recordings improved (Dunbar *et al.,* 1999). In recent years radar altimetry proves to be an efficient alternative to monitor periodic variations in large water bodies and has potential to measure inland water surfaces as well. It is derived from the topography within its footprint resulting in an area aggregation and not a point measurement such as obtained using traditional gauges (Dost and Mannaerts, 2004).

By the use of remote sensing in conjunction with geographic information system (GIS), the temporal change in water-spread area can by analyzed to evaluate the sediment disposition (Goel *et al.,* 2002). With the availability of high-resolution satellite data, capacity surveys of reservoirs by remote sensing technique are gaining recognition and acceptance. A number of studies using this approach have been carried out (Solomonson, 1973; Bartoluci *et al.,* 1977; Holeyer, 1978; Khoram, 1981; Manvalan *et al.,* 1991; Goel and Jain, 1996; 1998; Gupta, 1999; Goel *et al.,* 2002; Jain *et al.,* 2002; Liebe *et al.,* 2005; Adediji, 2005; Sawunyama *et al.,* 2006; Pillco and Bengtsson, 2007; Adediji and Ajibade, 2008). Smith *et al.,* (1980) determined siltation in the Aswan High Dam Reservoir by comparing reflectance values in the green and red portions of the spectrum. The surface area of the entire reservoir was determined by totalling all pixels classified as water. Rao *et al.,* (1985) used a visual interpretation technique on large scale imagery of Landsat-MSS to estimate the water-spread area at different levels. They used these water-spread estimates to evaluate the capacity of the reservoir and concluded that the results are comparable with hydrographic survey observations. Mohanty *et al.,* (1986) computed water spread of Hirakud Reservoir from multi-date Landsat-MSS imagery and reported that the area capacity curves derived using remote sensing data, were almost similar to the curves obtained from the conventional methods. Vibulsresth *et al.,* (1988) employed digital

techniques in which density slicing of Landsat-MSS near-infrared (IR) data was performed for extracting the water-spread area of Ubolratana Reservoir in Thailand. They correlated computed surface areas with the water levels and calculated the reservoir capacity based on the surface area obtained using cone formulae. Goel and Jain (1996) carried out a reservoir sedimentation study using the density-slicing approach for water-spread area extraction. They used IRS-1 A (LISS II) data to evaluate reservoir sedimentation in Dharoi Reservoir, India.

Bathymetric studies can be accomplished using many different techniques; the simplest approach is to measure depth using a weighted line or an echo sounding device (Moreno and Garcia, 1989; Linhart and Lund, 2008). Ortt *et al.,* (2000, 2007) collected bathymetry data for the following reservoirs in USA, Loch Raven and pretty boy, liberty, Triadelphia and Rocky Gorge respectively using differential global positioning system (DGPS) techniques and digital echo sounding equipment. Some recent studies employed the use of satellite technology such as interfrometric synthetic aperture radar (INSAR) to measure lake depth (Jeffries and Morris, 2000). The most common method for sample location is the recording of GPS coordinates, depths and location can then be imported into a GIS to generate bathymetric maps or three dimensional models and calculate lake area and volume (Leonard and Coughlan, 1997; Guay *et al.,* 1999; Mueller, 2009). Pillco and Bengtsson (2007) determine the hypsographic curve for Lake Poopo in Bolivia by combining manual measurements using rod, analysis of satellite images, and water balance computations. They state that the bathymetry of a lake is usually determined rather easily by traversing the lake in a fast boat, using echo sounding and GPS. The existing techniques for estimating reservoir capacity include direct methods (reservoir surveys) and indirect

methods (use of topographical maps) (Sawunyama *et al.,* 2006). Sawunyama *et al.,* (2006) estimate small reservoir capacities using remotely sensed surface areas, in conjunction with depths of water accompanied with their coordinates acquired from the field. Liebe *et al.,* (2005) mapped the outline of reservoirs using GPS and the reservoir surface using GPS referenced depth measurements with a telescopic stadia rod from a boat.

Yoon, (1992) states that approximately 1 % of the storage volume of worlds reservoir is lost annually due to sediment deposition. The 'useful' life of a reservoir is often defined as the time taken for 90 % of the live storage to be depleted (Halcrow Water, 2001). The operational life of a reservoir is normally determined by the point in time at which sediment accumulations reduce the reservoir yield below supply requirements. Mahmood (1987) give the global average total sediment yield as 190 t/km^2/yr. Walling (1988), Dearing and Foster (1993) give 50 t/km^2/yr as typical value of suspended sediment yield for Britain and cites site specific yield measurements between 1 and 488t/km^2/yr. In Britain, the rate at which reservoir capacity is lost by sedimentation is low by global standards (Halcrow Water, 2001). It is reported that the global average for the useful life of a reservoir is less than 25 years (Mahmood, 1987) whereas the average for British reservoirs is considerably longer and in a number of cases already exceeds 100 years (Halcrow Water, 2001). In China; in 1989, 232 large and medium size reservoirs had a total loss of 11.5 billion m^3 accounting for 14.3 % of the total capacity of 80.4 billion m^3 (Qian, 1994). In India, measurements of reservoir sedimentation indicate that the average annual loss in storage capacity of nine important reservoirs is between 0.34 and 1.79 percent (Zhide and Yuqian, 2003). The analysis of the reservoir sediment deposit data for South African dams showed that almost 25 % of the total numbers of reservoirs have lost between 10 to 30 % of their

original storage (Msadala, 2009). Analysis of the results showed that the average annual storage loss due to sedimentation in South African reservoirs is approximately 0.3 %. This scenario adversely affects the long term sustainability of the reservoirs (Msadala, 2009). Rooseboom (1978) estimated that the total sediment delivery from South Africa, Lesotho and Swaziland amounts to between 100 and 150 Million t/a. Sediment yields vary from less than 1000 t/km^2/a in specific catchments. The Welbedacht reservoir in South Africa, completed in 1973 with a 152.2 million m^3 storage capacity, lost most of its storage capacity (66%) within the first 13 years of its existence (Rooseboom, 1992). In Brazil, many reservoirs have been subjected to increasing losses of their storage capacities (Carvalho, 1998). Wiebe and Brennan (1973) noted that the John Martin reservoir (Colorado, USA) lost 7.5 % of its capacity in its first 15 years but that half of this loss was the product of two extreme storms. The Habra reservoir in Algeria lost 58 % in 22 years, and the Wuchieh reservoir in Taiwan lost 98.7 % in 35 years (Zhide and Yuqian, 2003). In arid and semi-arid regions, reservoir sedimentation problems become most acute where the loss of storage capacity by reservoir sedimentation is above 1 to 2 percent per year and the lifetime of most reservoirs is only 20 to 30 years (Zhide and Yuqian, 2003).

The rates of sedimentation calculated are dependent upon the accuracy not only of a recent study but also of the original survey at the time of dam construction and on comparability between the two (White *et al.,* 1996; Halcrow Water, 2001). Duck and McManus (1994); Foster and Lees (1999) carried out measurements of reservoir sediment to estimate the rate of infilling since construction. Foster and Lees (1999) used dated reservoir bottom sediment to provide long term measures of sediment yield, relying on the sediment within the reservoir being relatively undisturbed. The interaction between catchment characteristics,

climate and population pressure, determines the sediment yield from drainage basins (Dooge, 1984). Rooseboom (1978) delineated areas with similar sediment yield potentials on the basis of soil type, geomorphology and geology. Rapp *et al.,* (1972) monitored sedimentation in four reservoirs in Tanzania by periodic relevelling and concluded that some of them would have a total life of only 30 years. Bruk (1985) summarized the views of an international panel of expert contributors and concluded that, in the long run, watershed management is the best way to reduce the yield of sediment and its entry into the reservoir. Kennedy *et al.,* (1985) state that reservoirs are greatly influenced by tributary inflows and their water conditions reflect geographic, climatic and watershed characteristics. White *et al.,* (1996) state that the nature of the vegetation and land use in a catchment will have some impact on the sediment yield of rivers draining it. Bassoon and Rooseboom (1999) also commented upon the complex nature of the relationship between erosion and sediment yield. Butcher *et al.,* (1992) highlighted the need to consider the importance of changing management practices such as the introduction and abandonment of catchwater systems that influence sediment transfer. Mahmood (1987) stated that, intuitively, the first method of reducing reservoir siltation would be to reduce sediment yield from the basin upstream by watershed (catchment) management. However, Hufschmidt, (1986) has shown that intensive conservation efforts spanning several decades may be needed to reduce sediment yields by 10–20 percent for catchments that exceed 1000 km^2. The rate of siltation in a reservoir decreases with time as the storage capacity is reduced, until a residual river channel remains in the reservoir. The difference between the original total storage capacity and the remaining storage is called the storage of siltation. It

is important to estimate the process of siltation in order to estimate the benefit of a reservoir.

CHAPTER 3

MATERIALS AND METHODS

The following are the list of materials and data used in this study.

- **Boat, GPS, metric tape and weight (weighted line), graph paper and notebook.**
- **Topographic map of Minna, sheet 164 SW and SE on a scale of 1:50,000.**
- **Google image of Tagwai Reservoir on a scale of 1:10,000 and a paper coordinator.**
- **Digitized Topographic Map of Tagwai Dam Drainage Area on a scale of 1:50,000.**
- **Landsat images of Tagwai Reservoir**
- **Global mapper and Google earth softwares**

3.1 Study approach

The collection of coordinates along the edges of the reservoir to delineate edge of the open water surface with satellite navigator (GPS). Measurement of the remaining depth is carried out in a slow moving boat, using a weighted line and a hand held GPS. Depth in meters below the open water surface is measured from a boat (plate 2) with a weighted line. Northeasterly wind caused waves which reduce vertical accuracy of measurements. Also, due to this wind, the water surface is not horizontal but sloped slightly from the northeast to the southwest.

Points of measurement are located with a Global Positioning System (GPS). It is read twice (just before and after measurement) and the boat is immobilized with paddles at the time of depth readings, to minimize error of location due to drift at every measurement point.



Plate 2. MEASUREMENT OF THE REMAINING DEPTH IN THE TAGWAI IMPOUNDING RESERVOIR ON 15TH DECEMBER, 2010. The tools used are boat, satellite navigator, and metric tape and weight (Weighted line).

Measurements of depth are adjusted to the level of the spillway (Plate 3) located on the map in Figure 5. Outline of the open water surface in Figure 5 is gotten from the perimeter coordinates measured using GPS on 13th and 14th December, 2010 Table 4 in appendix 1, and reconciled with the Google image of the reservoir gotten from the internet website "Google-Earth". It represents the extent of water spread area of the reservoir in the year 2010.

Measurements were carried out at the time when the reservoir has a maximum storage capacity, at the end of rainy season.

For the depth measurement, irregular network of points was used. This was done from a boat using a measuring tape with a weight tied to its end. This is the remaining depth,

measured in metres at that particular point. The same procedure was repeated for all sampling points randomly selected but closely spaced, within the extent of the reservoir surface area in order to determine the depth at each respective point.



Plate 3. Spillway with open water surface 0.35 m below level of the spillway.

Depth measurements already taken from points are then located on an already prepared map from coordinates collected from edge of open water surface to a scale 1:10,000 using a paper coordinator. Isobaths were interpolated between the depth points.

The area bounded by the water body was then measured by the least square method (graph paper method). The area calculated, which is enclosed between successive isobaths is then multiplied by the average depth obtained to get the volume.

3.2 Bathymetric Data Collection

3.2.1 Bathymetric Mapping

Track lines running perpendicular to the river channels were established; these track lines were spaced approximately 5 m close to the dam and 10m upstream and extended shoreline to shoreline. Additionally, the track lines were run along the perimeter of the reservoir to assist in the surface modeling. The track lines are evident in Figure 5. The bathymetric mapping was conducted in December, 2010.

3.2.2 Mean Pool Level Adjustment

The bathymetric data collected presented measurements based upon the distance between the surface of the water in the reservoir and the top of the water-sediment interface. Due to fluctuations in the reservoirs level, the bathymetric data are adjusted to a known reference level i.e. the level of the spillway. These water levels and adjustments are documented in Table 5 appendix 2.

3.3 Bathymetric Interpretation and Volumetric Calculations

Bathymetric data were interpreted manually by inspection and averaging the values. Development of sounding systems that use global positioning systems technology for horizontal position location enabled whole reservoir coverage. The raw data are processed using a coordinator and least square method. This help to create bottom topography model of the reservoir. A two meter isobaths were drawn by analyzing the depths, from which storage and siltation rates can be calculated by finding the area enclosed by the individual isobaths using the least square method.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 The Bathymetry

The results of this study provided various resource maps and reasonable estimates of the reservoir's volume, surface area, and depth. Figure 5 is the bathymetric map of Tagwai reservoir. It illustrates the relationship of the reservoir's volume, surface area, and depth.

All results of measurements done from 15th to 21st December, 2010, Table 5 in appendix 2 are plotted on map in Figure 5. Results shown in Table 6 are derived from map Figure 5. It is observed that the year 2010 average weighted depth of the reservoir is 5.76 meters below the level of the spillway.

Table 6. Results of the measurements of the remaining storage.

Depth interval Below Spillway (m)	Area of Depth Interval (m^2)	Average Depth of Water (m)	Volume of Water (m^3)
0 – 2	503,999	1	503,999
2 – 4	840,259	3	2,520,777
4 – 6	887,179	5	4,435,895
6 – 8	591,583	7	4,141,081
8 – 10	404,685	9	3,642,165
10 – 12	298,724	11	3,285,964
12 – 14	194,718	13	2,531,334
14 – 16	32,844	15	492,660
>16	5,865	16.5	96,773
TOTAL	3,759,856	5.76	21,650,648

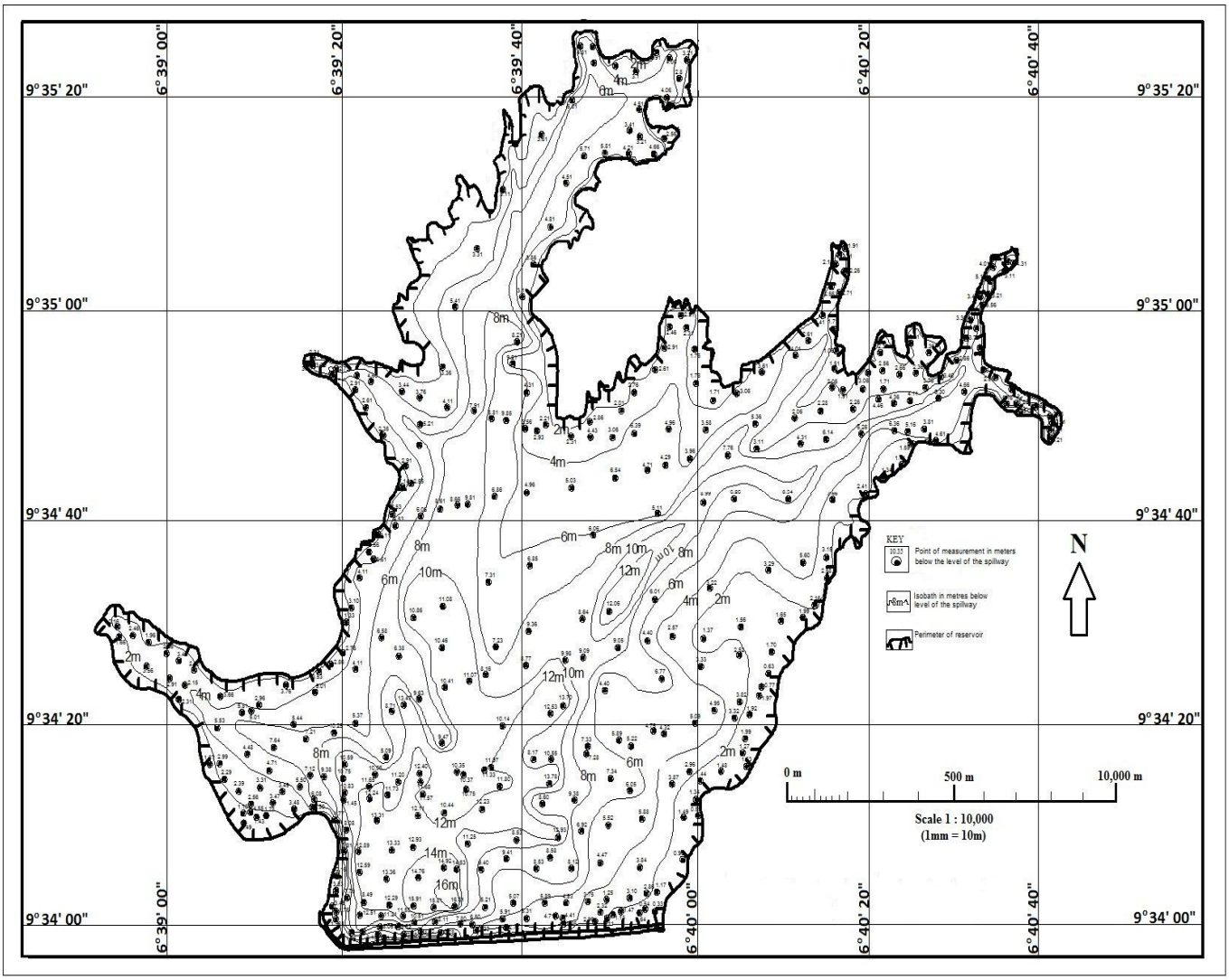


Figure 5. Bathymetric Map of Tagwai Reservoir (Contour Intervals; 2 m).

4.2 Onset and Cessation of the Hydrological Dry Season

Recording of the gauge readings, on the gauges installed by Niger State Water Board upstream from the reservoir, has since long ago stopped. However, meteorological dry season (i.e. from the cessation of the rains to the onset of the rains) starts in Minna, as earlier mentioned, on 26th October and ends on 8th April i.e. 165 days later. For the purpose of this study, it is the Hydrological dry season (i.e. the period between the cessation and the beginning of the spillway flow at Tagwai dam) that is needed and not the meteorological dry season.

The average date of cessation of spillway flow, as observed by the author himself in years 2010 and 2011, is 25th November. The start of the rains in April relieves the pressure on water at about 20th April, which gives a dry period of 146 days.

4.3 Area of the Open Water Surface

Outline of the open water surface in Figure 5 is derived from the perimeter coordinates measured using GPS on 13th and 14th December, 2010 presented in Table 4; appendix 1 and reconciled with the Google image of the reservoir downloaded from the internet website "Google-Earth" of European Space Agency (ESA) satellite image. The image was downloaded on the 13th of December 2010; therefore it represents the extent of water spread area of the reservoir in the hydrological dry season.

Area of open water table measured by least square method (graph paper method) is 3,759,856 m^2. Thus, since impoundment in 1978, the area of open water surface is reduced by (5,500,000 - 3,759,856) = 1,740,144 m^2 to remaining (3,759,856 : 5,500,000) x 100 % = 68 percent of the original area. Thus, rate at which the area shrunk between 1978 and 2010 is

1,740,144 m^2 : 32 years = 54,380 m^2 / year, or 32 % : 32 years = 1 % of the original area per year.

The open water surface of the reservoir will cease to exist in 100 % : 1 % = 100 years from the date of impoundment of the reservoir i.e. in the year 2079. However, long before it ceases to exist, due to siltation, the reservoir will stop to serve its purpose.

4.4 Position of the outlet Pipes Relative to the Level of the Spillway

The outlet pipes is at an elevation of 240 m (amsl) and the spillway at an elevation of 258.3 m (amsl), which makes the outlet pipes to be 16.3 m below level of the spillway. The submerged intake structure with a 3 m^2 fixed trash tracks are two NOS 24" diameter steel pipe with concrete surrounds and a downstream stilling basin (Plate 4).



Plate 4. Two 24" diameter outlet pipes, discharging water to a concrete aqueduct, in which it is flowing to the treatment plant

4.5 The Remaining Storage and Rate of Siltation

The current storage is the same as the total storage as well as the active storage of the reservoir presently because the dead storage is already silted up. Remaining storage calculated from the map (Figure 5) method of calculation shown in Table 6 is 21,650,648 m^3 or (21,650,648 m^3 : 28,300,000 m^3) x 100 % = 76.5 % of the original storage. Thus, rate at which the storage shrunk between 1978 and 2010 is 6,649,352 m^3 : 32 years = 207,792.25 m^3 / year, or 23.5 % : 32 years = 0.73 % of the original storage per year. Total storage in year 1978 is 28,300,000 m^3 (NSWB, 1982). Therefore, since impoundment in the year 1978, losses to siltation is (28,300,000 m^3 - 21,650,648 m^3) = 6,649,352 m^3 during a period of 32 years or (6,649,352 m^3 : 32 years) = 207,792.25 m^3 / year. This corresponds to the annual loss to siltation of (207,792.25 m^3 : 28,300,000 m^3) x 100 % = 0.73 %.

The reservoir will be completely silted up in (28,300,000 m^3 : 207,792.25 m^3 / year) = 136 years from the date of impoundment of the reservoir i.e. in the year 2114. Thus, the predicted date of disappearance of the Tagwai reservoir due to complete siltation in the year 2114 is a better than the earlier predicted date of its disappearance from the map as year 2079 due to rate of shrinkage of the open water surface. However, the process of siltation in Tagwai reservoir is quite slow but relentless. The concept of sustainable development as defined by the World Commission on Environment and Development in 1987 (Tortajada, 2001) as development that meets the needs of the present without compromising the ability of the future generation to meet their own needs, be seriously considered because long before it disappear, the reservoir cannot serve its intended purpose.

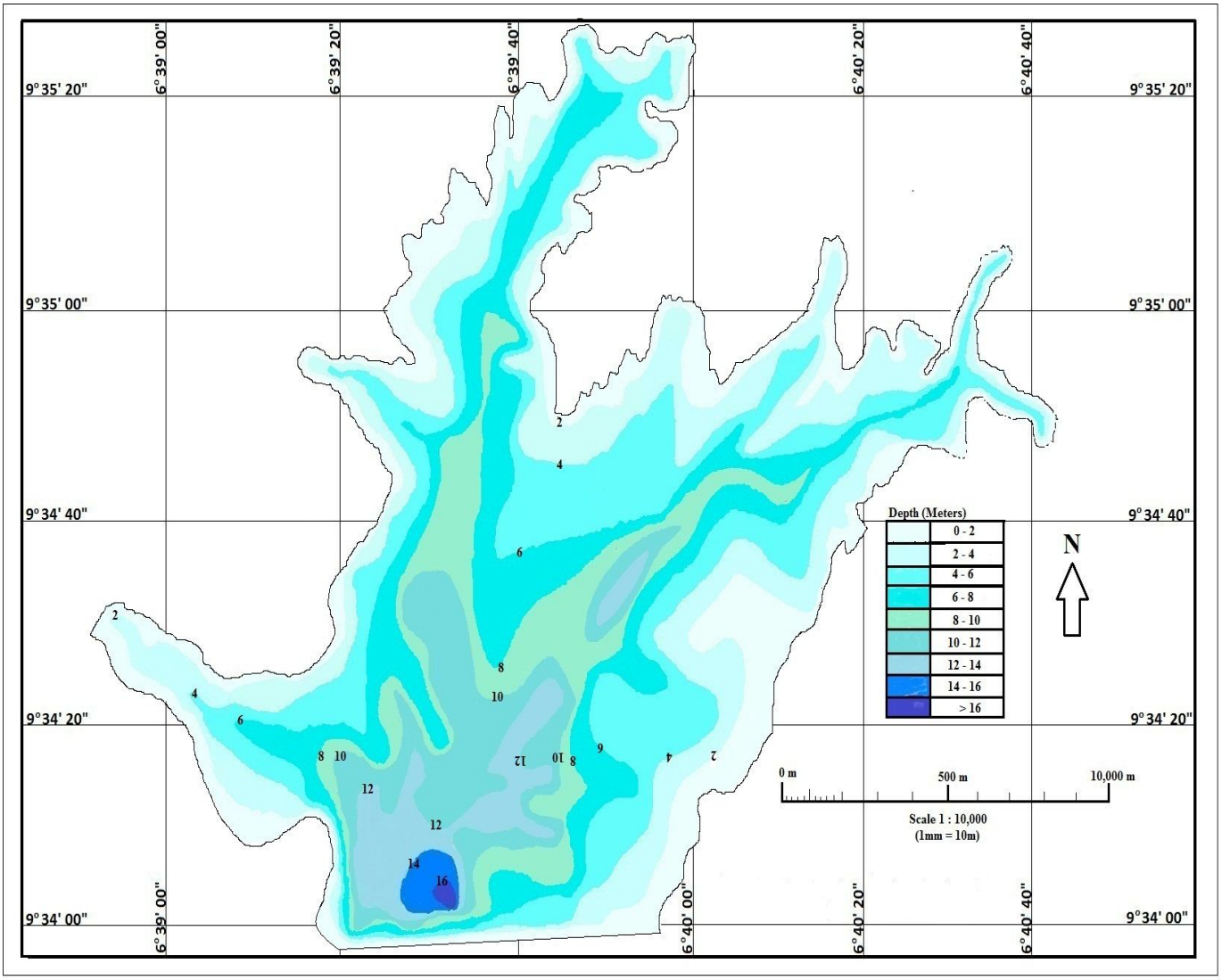


Figure 6. Relief Bathymetric Map of Tagwai Reservoir (Contour Intervals; 2 m).

4.6 Loss on Storage to Evaporation and Seepage

The average date of cessation of spillway flow in Tagwai reservoir is 25th November. From this date to the date of measurement of Tagwai reservoir (15th December, 2010) are 21 days. During these 21 days water surface fell by 0.35 m below the level of the spillway in the reservoir. This correspond to the decrease in volume of water of 1.316 x 10^6 m^3, i.e. (0.35 x 3.76 x 10^6) where 0.35 m is depth of water surface below level of the spillway and 3.76 x 10^6 m^2 is the area of open water surface below the level of the spillway. Out of these, with average pumping rate of 27,000 m^3 / d during the period from 25th November to 15th December, (27,000 x 21) = 567,000 m^3 was pumped out of the reservoir. The remaining referred to as total loss of water on storage, (1.316 x 10^6 – 567,000) = 749,000 m^3 were lost to evaporation during the 21 days between cessation of spillway flow date and date of the measurement.

The daily rate of water loss to evaporation and seepage is (749,000 / 21) = 35,666.67 m^3/d. Mean annual duration of the hydrological dry season is 146 days. The start of the rains in March relieves the pressure on water at about 20th April, which gives a dry period of 146 days. Loss of water to evaporation and seepage during the whole hydrological dry season is (35,667 m^3/d x 146 days) = 5,207,382 m^3. However, there is no visible seepage under the dam, hence loss due to seepage is negligible. Loss of water to evaporation from the open water surface is 5,207,382 m^3/dry season i.e. (5,207,382 m^3/dry season / 3.76 x 10^6 m^2) = 1.385 m/dry season.

4.7 Safe Yield in Dry Season

Safe yield of the reservoir on the last day of depth measurements, 21.12.2010 was ((28,300,000 m^3 - 5,207,382 m^3) / 146 days) = 158,168.616 m^3/d. Since the water storage of the reservoir is reduced by siltation at a rate of 207,792.25 m^3/d, it will take (28,300,000 m^3 - 3,942,000 - 5,207,382 m^3) : 207,792.25 m^3/y = 92 years to reduce safe yield from the present 158,168.616 m^3/d to 27,000 m^3/d that is to the volume of water daily pumped from the reservoir.

This implies that until year 2010 + 92 = 2102 there will be enough water in the Tagwai Reservoir to serve its design purpose. In other words, any water shortage experienced before year 2102 will have its source in the inability of the Waterworks to pump enough water from the reservoir. After (28,300,000 - 5,207,382 m^3) : 207,792.25 m^3 / year = 111 years, i.e. in year 2010 + 111 = 2121, safe yield will be reduced to zero. In other words, from year 2103 to year 2121, water available for pumping will be gradually reduced at the end of this period to zero in the dry season although there will be water during the wet season. From year 2103 to year 2114 Tagwai Reservoir will exist as a shallow, seasonal water body, drying completely up towards end of dry season. In year 2114 to 2121 Tagwai Reservoir will disappear from maps.

4.8 Rate of Surface Erosion (Sediment Yield) in Tagwai Dam Drainage Basin

Various methods can be used to estimate the rate of surface erosion or the rate of sediment yield from a watershed:

- **Universal soil loss equation. A = RKLSCP (Wischmeier and Smith, 1962), where**

A = computed soil loss in tons acre^{-1} year^{-1},
R = rainfall factor,
K = soil-erodibility factor,
L = slope-length factor,
S = slope-steepness factor,
C = cropping-management factor,
P = erosion-control practice factor.

- **Sediment yield as a function of drainage area.**

  $Q_S = 2.4A_d^{-0.229}$ (Strand, 1975)
  $Q_S = 1.84A_d^{-0.24}$ (Strand and Pemberton, 1982)

  Where: Qs = sediment yield in acre-feet per square mile per year
  A_d = drainage area in square miles.

- **Sediment yield as a function of nine drainage basin characteristics.**

This method classifies sediment yield as a function of nine individual drainage basin characteristics. These nine drainage basin characteristics are surface geology, soil, climate, runoff, topography, ground cover, land use, upland erosion, and channel erosion.

This is a subjective procedure for estimating an annual basin erosion rate. It can be used as a reference for assigning drainage basin sediment yield classes.

Table 7. Drainage basin characteristics and possible range of numerical ratings (modified from Pacific Southwest Inter-Agency Committee, Water management Subcommittee, 1968).

Drainage basin Characteristic	Sediment yield levels: High rating	Moderate rating	Low rating
Surface geology	10: marine shales and related mudstones and siltstones	5: rocks of medium hardness moderately weathered and fractured	0: massive hard formations
Soils	10: fine textured and easily dispersed or single grain silts and fine sands	5: medium textured, occasional rock fragments, or caliche crusted layers	0: frequent rock fragments, aggregated clays, or high organic content
Climate	10: frequent intense convective storms	5: infrequent convective storms, moderate intensity	0: humid climate low intensity rain, arid climate with low intensity rainfall, or rare convective rain
Runoff	10: high flows or volume per unit area	5: moderate flows or run off volume per unit area	0: low flows or volume per unit area or rare runoff events
Topography	20: steep slopes (in excess of 30%), high relief, little or no flood plain development	10: moderate slopes (about 20%), moderate flood plain development	0: gentle slopes (< 5%), extensive flood plain development
Ground cover	10: ground cover less than 20%, no rock or organic litter in surface soil	0: ground cover < 40%, noticeable organic litter in surface soil	-10: area completely covered by vegetation, rock fragments, organic litter with little opportunity for rainfall to erode soil
Land use	10: more than 50% cultivated, sparse vegetation, and no rock in surface soil	0: < 25% cultivated, < 50% recently logged, < 50% intensively grazed	-10: no cultivation, no recent logging, and only low intensity grazing, if any
Upland erosion	25: rill, gully, or landslide erosion over more than 50% of the area	10: rill, gully, or landslide erosion over about 25% of area	0: no apparent signs or erosion
Channel erosion	25: continuous or frequent bank erosion, or active headcuts and degradation in tributary channels	10: occasional channel erosion of bed or banks	0: wide shallow channels mild slopes, channels in massive rock, large boulders, or dense vegetation or artificially protected channels

Table 8. Drainage basin sediment yield classification (Modified after Randle, 1996).

Drainage basin classification number	Total rating	Annual sediment yield (mm)
1	>100	>0.147
2	75 to 100	0.049 – 0.147
3	50 to 75	0.0245 – 0.049
4	25 to 50	0.0098 – 0.0245
5	0 to 25	<0.0098

Table 9. Estimated numerical ratings for Tagwai reservoir drainage basin.

Drainage basin characteristics	possible ratings	Estimated sediment yield rating	Estimated description
Surface geology	0 – 10	5 Moderate	varies from crystalline rocks to unconsolidated alluvium and colluvium
Soil	0 – 10	5 Moderate	surface material is ferruginous soil, rock fragment and bedrock outcrops
Climate	0 – 10	5 Moderate	distinct dry and wet season, moderate intensity rains
Runoff	0 – 10	10 High	high volume / unit area, high runoff
Topography	0 – 20	5 Low	gentle slopes, flood plain development
Grand cover	-10 – 10	0 Moderate	area moderately covered by vegetation, noticeable organic litter in surface soil
Land use	-10 – 10	0 Moderate	active cultivation and grazing
Upland erosion	0 – 25	10 Moderate	low apparent signs of erosion, upland compose of older more consolidated rocks, rill erosion noticeable
Channel erosion	0 – 25	10 Moderate	occasional erosion of beds and Banks, wide channels
Total rating	–	50 Class 3	0.0245 – 0.049 mm

Based on information in Tables 7 and 8, the estimated sediment yield rating and the 100 year sediment yields for the Tagwai Reservoir are shown in Tables 9 and 10, respectively.

Table 10. 100 years sediment yield estimate for Tagwai reservoir drainage basin.

Reservoir	Drainage name	Area (km^2)	100 year sediment yield (m^3): at 0.0245	at 0.049 (mm)
Tagwai dam	Tagwayi (Tagwai)	110	269.5	539

Employing the empirical sediment yield equations developed strictly as a function of the drainage area based on sediment data by Strand (1975) and Strand and Pemberton (1982) gives results within the same bracket with that based on drainage basin characteristics (Table 11).

Table 11. Sediment yield of Tagwai reservoir as a function of drainage area

Empirical sediment yield equation	sediment yield (mm)
$Q_S = 2.4A_d^{-0.229}$ (Strand, 1975)	0.049833
$Q_S = 1.84A_d^{-0.24}$ (Strand and Pemberton, 1982)	0.036652

4.9 Remote Sensing Application

The procedure used to estimate surface area of a reservoir from satellite image follows the acquisition of the images. Two landsat images with ID 214-089 and 220-596, dataset ETM+, WRS: P/R 189/053 produce by USGS, Ortho GLS 2000 and 2005 with date of satellite over pass 24/10/2001 and 7/11/2006 respectively were acquired from the Global land cover facility website.

The images were captured at the end of the rainy season i.e. October and November. The rainy season is typical of a wet period, when the reservoir is expected to be full, so the satellite images capture the reservoir maximum surface area. The reservoir is extracted through maximum likelihood classification (Mather, 1999) of landsat images. The visible

red and the two infra red bands are well suited for the detection and delineation of open water bodies. Using red-green-blue channels, water bodies are depicted in colours ranging from blue to almost black. In bands 4 and 5, the spectra reflectance curve of water is low, whereas that of soil and healthy vegetation are high. This contrast allows us to distinguish between open water and the surrounding land surface. The inclusion of the visible band enhances the contrast between water and soil (Kite and Pietroniro, 2000).

Global mapper 11 package with spatial analyst is used to automate surface area calculations and to provide the surface area of the reservoir.

To derive the reservoir storage volume, the area-volume model equation developed by Liebe *et al.,* (2005) for the estimation of reservoir storage volumes as a function of their remotely sensed surface areas for upper east region of Ghana is adapted. The area based volume estimation is made possible because these regions are morphologically and morphometrically regular. The reservoirs are located in the stream channels, and the morphometry of stream channels are a response to the surface runoff characteristics of these areas (Windmeijer and Andriesse, 1993).

The theoretical derivation of the relationship starts with a square based, top down pyramid that is diagonally cut in half, in order to approximately represent the shape and volume of a reservoir (Figure 7). The goodness of fit between measured and modeled volumes can be evaluated. The widely used model efficiency measures of Nash and Suttcliffe (1970) indicates that the model explains 97.5% of the measured variance. Despite the variety of reservoir shapes, the derived equations are highly consistent. The Area-volume relationship

from different basins point to the fact that the approach is robust and repeatable, and that the method can be used with confidence.

The final equation is summarized as thus: $V = 0.00857 \times A^{1.4367}$ Liebe *et al.*, (2005) is used to derive the storage (Table 12). The result shows progressive decrease in both area and storage of the reservoir for the studied years irrespective of technique used.

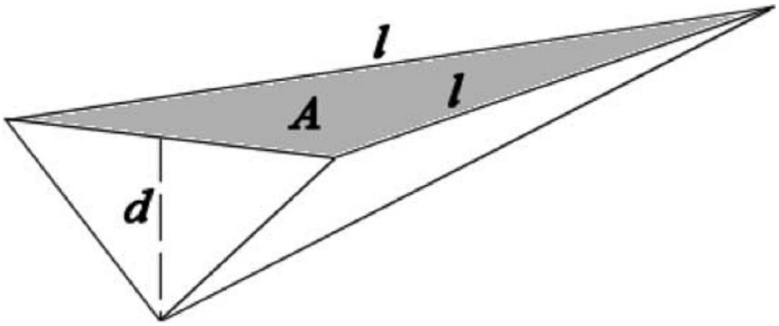


Figure 7. Reservoir model (Liebe et al., 2005).

The volume of such a body is $V_{\text{half pyramid}} = 1/6 \times A \times d$.

A is the area defined by the square of its characteristic side length l. As depth d can be expressed as a fraction 1/f of a side length l, written as $V_{\text{half pyramid}} = 1/6 \times l^2 \times 1/f \times l$.

This is the equation for the expected area–volume relationship on a log–log plot.

Table 12. Tagwai Reservoir remaining storage calculated from Landsat image

Year	Technique	Area (m^2)	Volume (m^3)
2001	Remote sensing	3,988,511	26,083,489.39
2006	Remote sensing	3,864,264	24,924,111.06
2010	Field Measurements	3,759,856	21,650,648.00

CHAPTER 5

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

Depths were measured using the traditional method, a weighted sound line and a handheld Global Positioning System (GPS) device to locate the measurement point. Measurement using the weighted sound line is not limited to areas with relatively clear water and shallow depths. Due to the nature of the reservoir and the presence of submerged vegetation, the sound line method provided more complete coverage by slowly paddling through the submerged vegetation and taking measurements. Data in Table 5; appendix 2 shows the depths measured with their corresponding coordinate.

Figure 5 shows the bathymetry of Tagwai Reservoir with the greatest depths measured close to the dam. These depths are located near the south-west end of the reservoir and left to the spillway on the south-east end.

The 2010 bathymetry for Tagwai Reservoir is presented in Figure 5 and 6. The deepest portion of the reservoir, with depths up to 16 m, is close to the dam. The reservoir depths gradually decrease toward the upstream ends of the main stem and tributaries. The calculated storage volume of the reservoir is presented in Table 6.

Due to the high spatial density of collected data and the shape of the reservoir, the manual method honors every data point and creates a surface that preserves the original data points and shoreline. This method estimated reservoir volumes correctly as it connects

points in order of their magnitude rather than following straight line. In Tagwai Reservoir, the calculated storage volume is 21,650,648 m^3.

In agreement with Leonard and Coughlan (1997), the integration of GPS measurements is successful in producing a bathymetric map and, in this work, a model of Tagwai Reservoir. Data analysis was able to provide the change in storage in the reservoir. At the reference elevation, the overall accuracy of the volume and surface area is expected to be high. The greatest sources of error seem to result from adjusting the open water surface to the reference elevation and from weighted line sounding (measurements) over unconsolidated bottom material (silt and organic mud). The elevational error is greatly reduced because data collection occurred mostly on windless days and during periods when the overall reservoir level is being held constant (no waves). The weighted line sounding (measurements) error is reduced by reading the GPS twice (just before and after measurement) and the boat immobilized with paddles at the time of depth readings, to minimize error of location due to drift at every measurement point, but is never completely overcome in backwater areas.

Several factors need consideration when following these procedures. For example, it was important to have a background map and real-time GPS display of the boat's position. This procedure aided in navigation and eliminated certain gross errors. Nevertheless, and even with all the data augmentation, the bathymetric map is very representative of Tagwai Reservoir and provides a useful water management information. The study allows Water resources managers and researchers to make some informed water management decisions in the future.

5.2 Conclusion

Tagwai Dam was constructed in 1978. Original design records indicate that the reservoir has a 5.50 x 10^6 m^2 surface area and had a total storage capacity 28.3 x 10^6 m^3 of water at full capacity. However, this study delineated 3,759,856 m^2 surface area and a total storage capacity of 21,650,648 m^3 at full capacity i.e. at spillway flowing (Table 6). Average weighted depth of water (5.76 m) is below flowing spillway; total storage capacity is only active storage capacity because dead storage capacity is already silted up. Siltation of the Tagwai Impounding Reservoir, if unchecked and allow to continue at the present rate of 0.73 % of the original volume/year, will result in the disappearance of the reservoir in the year 2114; however, the rate of shrinkage of the surface area of the reservoir between 1978 and 2010 is 1 % of the original area per year i.e. the open water surface of the reservoir will cease to exist in the year 2079. However, long before it ceases to exist, due to siltation, the reservoir will stop to serve its purpose.

This study is based on field measurements and summary of more than 170 literature references. The study will fill the gap in knowledge concerning the present state of Tagwai Reservoir. The existing methods for reservoir water level observations are well developed and sufficient to obtain data accurately enough for further processing and analysis. However, improvements of the techniques and calibration of the instrumentations for water level measurements are necessary. Information about depth is best obtained by performing measurements from a slowly moving boat, utilizing a weighted line or an echo sounder. The procedure is cumbersome and difficult to get measurements that cover the whole reservoir bottom area. Thus, relating the reservoir surface area derived from satellite images to landmark elevation simplifies the procedure of deriving a bathymetry

for reservoir, even if information about the deepest parts cannot be obtained. A problem in determining the bottom configuration is that the wind can significantly tilt the water surface (waves), as well as the fact that because of the extremely small slope of the reservoir shores, the water could move with the wind up the shores during studies.

5.3 Recommendations

1. To prevent siltation of the reservoir their must be reduction especially of the rate of shrinkage of the surface area of the reservoir by environmental upgrading of the drainage area.

2. Grazing and farming activities upstream of the reservoir should be stopped to reduce the volume of sediment carried by erosion water, if possible the entire drainage area.

3. Bush burning and deforestation should be stopped within the drainage basin and afforestation encouraged.

4. The International Data Centre on Hydrology of Lakes and Reservoirs (HYDROLARE) should be made operational and accessible for practical purposes and scientific analysis.

5. Reservoir owners should be proactive in addressing siltation. They should collect data to assess their reservoirs situation, determine when significant shortages may occur, and develop long-range management plan.

6. The Water Resources Ministries / Water Boards should help reservoir owners collect, analyze and interpret the data to determine the extent of siltation and possible impacts to reservoir

users. In addition, they should help identify potentially applicable sediment management alternatives. They should also establish and maintain a long-term database of siltation data and reports.

7. The Water Resources Ministries / Water Boards should identify and exercise options that exist within the law to protect sites for additional and replacement storage capacity, both surface and subsurface.

8. Water users should support organizations that are already involved in watershed management, so they can continue to improve watershed management programs and target problem areas.

9. The Water Resources Ministries / Water Boards should identify and make the most of opportunities to educate and inform the water community about siltation issues.

CHAPTER 6

CONTRIBUTION TO KNOWLEDGE

This study has produced a bathymetric map of Tagwai Reservoir of Minna, Niger State on a scale of 1:10,000 as a contribution to the knowledge of the hydrogeology of the region. Also, the study has updated the knowledge of the remaining storage of the reservoir, which was mostly based on estimated storage at impoundment. This study delineated the maximum surface area of the reservoir at full capacity i.e. when the spillway is flowing. The maximum surface area of the reservoir is superimposed on the topographical map of Minna sheet 164 SW and SE to show the reservoir (water spread area) on the map and the entire drainage basin.

REFERENCES

Abood, M.M., Thamer, A.M., Abdul Halim, G., Ahmed, R.M. and Lariyah, M.S., (2009). Review study and assessment for sedimentation models applied to impounding reservoirs. Journal of Engineering and Applied Sciences. 4(2) :152-160.

A.B.U. Committee on Protection of the Kubanni Dam Drainage Basin. (2008). Reports on results of measurement of the remaining storage in Kubanni Impounding Reservoir and proposal for upgrading the environment in the Kubanni Drainage Basin.

Adediji, A. (2005). Reservoir Sedimentation: The Case of Opa Reservoir Catchment, Southwestern Nigeria. J. S. Afr. Geogr, 87 (2), 123 –128.

Adediji A., and Ajibade L.T. (2008). The change detection of major dams in Osun State, Nigeria using remote sensing (RS) and GIS techniques. Journal of Geography and Regional Planning Vol. 1(6), pp. 110-115. http://www.academicjournals.org/JGRP ISSN 2070-1845

Adekeye, J. I. D and Ishaku, J. M. (2004). Groundwater Contamination in Shallow Aquifers of Jimeta Metropolis, Adamawa State, N.E. Nigeria. *Zuma Journal of Pure and Applied Sciences.* 6 (1):150-159.

Adeniyi, J. O. (1985). Geophysical Investigation of the Central Part of Niger State of Nigeria. Ph.D thesis, University of Wisconsin, Madison. U.S.A.

Ajibade, A.C. (1972). The Geology of the Zungeru Sheet, M.Sc Thesis, University of Ibadan, Nigeria. (Unpublished).

Ajibade, A. C. (1976). Provisional classification and correlation of the schist belt of NW Nigeria In: Kogbe, C.A. (Ed.) Geology of Nigeria. Elizabethan Publ. Co. Lagos, Nigeria. Pp 85-90.

Ajibade A.C. (1980). Proterozoic Crustal Development in the Pan-African Regime of Nigeria. In: C.A. Kogbe (Editor) Geology of Nigeria Published by Rock View (Nigeria) Ltd; pp. 57-63. Ltd; pp. 57-63.

Ajibade, A.C. (1982). The origin and emplacement of older granites of Nigeria, some evidences from Zungeru Region. J.M. Geol. Vol. 19. No. 1 pp. 221-223.

Ajibade, A.C., Woakes, M. and Rahman, M.A. (1987). Proterozoic crustal development in Pan African region of Nigeria, copy right on Amer. Geophysical Union.

Annandale, G. W. (1987). "Reservoir Sedimentation". Vol. 29 in Developments in Water Science. Amsterdam, Netherlands: Elsevier Science Publishers.

Alam, S. (2001). "A critical evaluation of sedimentation management design practice". International Journal on Hydropower & Dams, Issue 1, Aqua-Media International, Sutton, Surrey, ISSN 1352-2523.

Althaus, J.J. and De Cesare, G. (2006). Reservoir Sedimentation. Sustainable Sediment Management in Alpine Reservoirs considering ecological and economical aspects. Volume 3. Neubiberg. www.alpreserv.eu

Arntzen, J. (1995). "Economic Instruments For Sustainable Resource Management: The Case of Botswana's Water Resources" *Ambio*, 24(6): 335–342.

Avendaño Salas, C., Cobo Rayán, R., Sanz Montero, E., and Gómez Montaña, J. L. (1997). "Capacity situation in Spanish reservoirs". Question 74a Performance of reservoirs sedimentation, Proc. of 19th Congress on Large Dams, Florence, Italy, 1997. ICOLD, Paris, France, pp. 849-862.

Avendaño Salas, C., Sanz Montero, E., Cobo Rayán, R., and Gómez Montaña, J. L. (1997). "Sediment yield at Spanish reservoirs and its relationship with the drainage basin area". Question 74a Performance of reservoirs sedimentation, Proc. of 19th Congress on Large Dams, Florence, Italy, 1997. ICOLD, Paris, France, pp. 863-874.

Bartoluci, L. A., Robinson, B. F. & Siiva, *XL XL* (1977) Field measurement of spectral response of natural waters. *Photogvamm. Engng Remote Sens.* 43(5).

Basson and Rooseboom, A. (1999). *Dealing with Reservoir Sedimentation—Dredging.* Water Research Commission, South Africa.

Bertrand, J.M.L. and Caby, R. (1978). Geodynamic evolution of the Pan Africa orogenic belts. A new interpretation of the Hogger shield. Geol. Rundsch., 67, 357-388.

Bobba, A. G. and Singh, V.P. (1997), "Sustainable Development of Water Resources in India," *Environmental Management*, 21(3): 367–393.

Brown, C.B. (1943). Discussion of sedimentation in reservoirs, by J.Witzig, ASCE, 109, PP 1080-1086.

Brown, C. B. (1950). "Sedimentation," Engineering Hydraulics, Hunter Rouse, Ed., Proceedings of the Fourth Hydraulics Conference, Iowa Institute of Hydraulic Research.

Bruk, S. (1985). Methods of computing sedimentation in lakes and reservoirs, IHP-II Project.

Brune, G.M., (1953). Trap efficiency of reservoirs. *Transactions*, American Geophysical Union, Volume 34, Number 3, pp 407-418.

Burke, K., Freeth, S.J. and Grant, N.K. (1976). The structure and sequence of geological events in the Basement Complex of the Ibadan area, Western Nigeria. Precambrian Res., 3, pp537-545.

Butcher, D. P., Clayton, J., Labadz, J. C., Pattison, V. A., Potter, A. W. R. & White, P. (1992). Reservoir sedimentation and colour problems in Southern Pennine reservoirs. *J. Instn Water Environ. Manage.* 6, 418–430.

Campos, R. (2001). Three Dimensional Reservoir Sedimentation Model. PhD Thesis, University of Newcastle-Upon-Tyne, UK.

Carroll, B. and Turpin, T. (1997). "Environmental Strategies for Sustainable Development: A New Town in Mallorca," *Journal of the Chartered Institution of Water and Environmental Management,* 11(4): 235–24.

Carvalho, O.N., (1998). Sedimentation and protection of reservoirs, VI National symposium of erosion control, ABGE, Brazil.

Chakela, Q. K. (1980) Reservoir sedimentation within Roma Valley and Maliele catchments in Lesotho. *Geogr. Ann.* 62A(3–4), 157–169.

Chanson, H. and James, P. (1998). Teaching Case Studies in Reservoir Siltation and Catchment Erosion. Int. J. Engng Ed. Vol. 14, No. 4, p. 265-275.

Charlton, J. (1997). Application of Waste Stabilization Ponds In Bhutan—Lessons within a Sustainable Development Context, *Water Science and Technology*, 35(9): 199–208.

Chella, M. R., Ota, J. J. and Povh, P. H. (2003). In: Althaus, J.J. and De Cesare, G. (2006). Reservoir Sedimentation. Sustainable Sediment Management in Alpine Reservoirs considering ecological and economical aspects. Volume 3. Neubiberg. www.alpreserv.eu

Chikita, K. (1989). "A Field Study on Turbidity Currents initiated from Spring Runoffs". Water Resources Research, Vol. 25, No. 2, pp. 257-271.

Churchill, M.A., (1948). Discussion of "Analysis and use of reservoir sedimentation data" by L.C. Gottschalk, in *Proceedings, Federal Inter-Agency Sedimentation Conference, Denver, Colorado, 1947,* (US Bureau of Reclamation), 139-140.

Cobo Rayán, R., Sanz Montero, E., Gómez Montaña, J. L., Avendaño Salas, C., and Plata Bedmar, A. (1997). "Influence of the Puentes reservoir operation procedure on the sediment accumulation rate between 1954-1994". Question 74a Performance of reservoirs sedimentation, Proc. of 19th Congress on Large Dams, Florence, Italy, 1997. ICOLD, Paris, France, pp. 835-847.

Dearing, J. A. & Foster, I. D. L. (1993) Lake sediments and geomorphological processes: some thoughts. In: *Geomorphology and Sedimentology of Lakes and Reservoirs* (ed. by J. McManus & R. W. Duck), 5–14. John Wiley & Sons Ltd, Chichester, West Sussex, UK.

Dooge , J.C.I., (1984). The waters of the earth. Hydrol. Sci. J. Vol. 29. 149-176.

Dost, R.J.J. and Mannaerts, C.M. (2004). "Bathymetry generation using sonar and satellite imagery". Presented at ISPRS: proceedings of the XXth ISPRS congress : *Geo-imagery bridging continents*, 12-23 July 2004, Istanbul, Turkey.

Duck, R. W. and McManus, J. (1994). A long-term estimate of bedload and suspended sediment yield derived from reservoir deposits. Journal of Hydrology vol. 159 pp 365-373.

Duck, R. W. & McManus, J. (1984) A marker horizon in reservoir sediment cores resulting from wartime agricultural changes in central Scotland. *Scot. Geogr. Mag*. 100, 184–189.

Duck, R. W. and McManus, J. (1990) Relationships between catchment characteristics, land use and sediment yield in the Midland Valley of Scotland. In: *Soil Erosion on Agricultural Land* (ed. by J. Boardman, I. D. L. Foster & J. A. Dearing), 285–299. John Wiley & Sons Ltd, Chichester, West Sussex, UK.

Dunbar, J.A., Allen, P.M., and Higley, P.D., (1999). Multifrequency acoustic profiling for water reservoir sedimentation studies: Journal of Sedimentary Research, v. 69, n. 2, pp. 521-527.

EA Engineering, Science and Technology, Inc., (1989). Sedimentation in Triadelphia and Rocky Gorge Reservoirs: Project # 10769.01, EA Mid-Atlantic Regional Operations, Sparks, Maryland

Eswaran, H., Lal, R., and Reich, P.F. (2001.) Land degradation: an overview. In: Bridges E.M., Hannam, I.D., Oldeman, L.R., Penning de Vries F.W.T., Scherr, S.J., and Sombatpanit, S. (eds) Response to land degradation. Science, Enfield, pp 20–35

Etiosa, U. (2006). Dams are unrenewable - A Discussion Paper. Community Research and Development Centre (CREDC) Nigeria, Benin City Nigeria, p 3-8.

Fan, J. and Morris, G. L. (1992). "Reservoir Sedimentation. II: Reservoir Desiltation and Long-Term Storage Capacity", ASCE, Journal of Hydraulic Engineering, Vol. 118, No. 3.

Federal Surveys of Nigeria, (1967). Topographic map of Minna, Sheet 164 SW and SE In: Tagwai Dam Project Progress Report. Water Resources and Engineering Construction Agency, (WRECA), Kano State.

Ferrari, R. and Dorough, W. (1996). Chapter 3-4 — Measuring deposited materials, and Chapter 3-5 — Determination of volume of deposits. International Conference on Reservoir Sedimentation, Colorado State University, Fort Collins.

Ferrari, R. and Dorough, W. (1998). *Cascade Reservoir 1995 Sedimentation Survey*. Sedimentation and River Hydraulics Group, Water Resources Services, Technical Service Center, Denver

Ford, D. E., and Johnson, M. C. (1981). "Field observations of density currents in impoundments". Proceedings of the Symposium on Surface Water Impoundments, Vol. 2, Minneapolis, Minn, USA, June 2-5 1980. Published by ASCE, New York, pp. 1239-1248.

Foster, I. D. L. and Lees, J. A. (1999) Changes in the physical and geochemical properties of suspended sediment delivered to the headwaters of LOIS river basins over the last 100 years: a preliminary analysis of lake and reservoir bottom sediments. *Hydrol. Processes* 13, 1067–1086.

Frenette, M. and Julien, P.Y., (1996). Physical processes governing reservoir sedimentation. Proceedings of the International Conference on Reservoir Sedimentation. Vol. 1, Colorado State University, Fort Collins, Sept. 11-16, 121-142.

Fried, J.S., Brown, D.G., Zweifler, M.O., and Gold, M.A. (2000). Mapping contributing areas of stormwater discharge to streams using terrain analysis. In *Terrain Analysis, Principles and Applications*, 1st ed.; Wilson, J.P., Gallant, J.C., Eds.; John Wiley & Sons: New York, NY, USA. pp. 183-203.

Garde, R. J. (1995) Reservoir sedimentation. State of art report of Indian National Committee on Hydrology. INCOH/SAR-6/95. National Institute of Hydrology, Roorkee, India.

Goel, M. K. & Jain, Sanjav K. (1996) Evaluation of reservoir sedimentation using multi-temporal IRS-1A I.1SS-11 data. *Asian Pacific Remote Sens. and GIS.J.* 8(2), 39-43.

Goel, M. K. and Jain, Sharad K. (1998) Reservoir sedimentation study for Ukai Dam using satellite data. Report no. UM-1 /97-98, National Institute of Hydrology, Roorkee, India.

Goel, M.K., Sharad K., Jain, S.K. and Agarwal, P.K. (2002). Assessment of sediment deposition rate in Bargi Reservoir using digital image processing. Hydrological Sciences-Journal-des Sciences Hydrologiques, 47(S), 81-92. Special Issue: Towards Integrated Water Resources Management for Sustainable Development.

Gottschalk, L. C. (1951). "Measurement of Sedimentation in Small Reservoirs". Proc. of the ASCE, pp. 4-6.

Gottschalk, L. C. (1964). "Reservoir Sedimentation". In: Handbook of Applied Hydrology, V.T. Chow, (Editor), McGraw-Hill, New York, Section 17, pp. 1-33.

Graf, W. H. (1984). "Storage losses in reservoirs", International Water Power and Dam Construction, Vol. 36, N° 4.

Graf, W. L., E. Wohl, T. Sinha, and J. L. Sabo (2010), Sedimentation and sustainability of western American reservoirs, Water Resour. Res., 46, W12535, doi:10.1029/2009WR008836.

Grant, N.K. (1969). The Late Precambrian to Early Paleozoic Pan African Orogeny in Ghana, Togo, Dahomay and Nigeria. Bull. Geol. Soc. Amer. Vol. 80 pp 45-56.

Grant, N.K. (1970). Geochemistry Precambrian Basement rocks from Ibadan, SW Nig. Earth Planet Sci. Lect. 10, pp 29-38.

Grant, N.K. (1978). Structural distinction between a meta-sedimentary cover and an underlying basement in the 600 Ma old Pan African domain of NW Nig. Bull. Geol. Soc. Amer., Vol. 89 pp 50-58.

Griffin, M.L., Beasley, D.B., Fletcher, J.J., and Foster, G.R. (1988) Estimating soil loss on topographically nonuniform field and farm units. J Soil Water Conserv 43:326–331

Gupta, S. C. (1999) Status paper on reservoir sedimentation assessment using remote sensing techniques. In: *Proc. National Workshop on Reservoir Sedimentation Assessment Using Remote Sensing Data.* National Institute of Hydrology, Roorkee, India.

Guay, B.E., Kunzmann, M., Grünberg, W., and Guertin, D.P. (1999). "Integrating Differential GPS, GIS, and Sonar Measurements to Map the Bathymetry of Topock Marsh, Arizona," *Proceedings of the 1999 ESRI User Conference, San Diego, CA*, Paper 396. http://proceedings.esri.com/library/userconf/proc99/proceed/papers/pap396/p396.htm. [Accessed: 3 August 2009].

Halcrow Water, (2001). Sedimentation in storage reservoirs, final report. Department of the environment, transport and the regions. greenap@halcrow.com

Haregeweyn, N.; Poesen, J.; Nyssen, J.; De Wit, J.; Haile, M.; Govers G.; Deckers S. (2006). Reservoirs in Tigray (Northern Ethiopia): Characteristics and sediment deposition problems. *Land Degrad. Dev. 17*, 211-230.

Heinemann, H. G., and Dvorak, V. I. (1965). "Improved Volumetric Survey and Computation Procedures for Small Reservoirs," from Proceedings of the Federal Inter-Agency Sedimentation Conference, 1963, pp 845-856, Prepared by Agricultural Research Service, U. S. Department of Agriculture, Washington, DC.

Heinemann, H. G., and Rausch, D. L. (1971). Discussion of "Sediment Measurement Techniques: B. Reservoir Deposits," by the Task Committee on Preparation of Sedimentation Manual, Committee on Sedimentation of the Hydraulics Division, Vito A. Vanoni, Chmn, Journal of the Hydraulics Division, ASCE, Vol 97, No. HY 9, Proc. Paper 8345, pp 1555-1561.

Heinemann, H. G. (1984) Reservoir trap efficiency. In: *Erosion and Sediment Yield: Some Methods of Measurement and Modelling* (ed. by R. F. Hadley & D. E. Walling), 825–830. Geobooks, Norwich, UK.

Hill, R. A. (1936). "Silting of reservoirs formed by large dams: its measurement and prevention". Proc. of 2nd Congress on Large Dams, Vol. 5, Washington, USA, 1936. US Government Printing Office, pp. 203-206. In: Althaus, J.J. and De Cesare, G. (2006). Reservoir Sedimentation. Sustainable Sediment Management in Alpine Reservoirs considering ecological and economical aspects. Volume 3. Neubiberg. www.alpreserv.eu

Holeyer, R. J. (1978). Suspended sediment algorithms. Remote Sens. Environ. 10(4), 323-338.

Hufschmidt, M. (1986). Economic Valuation Techniques for the Environment. Baltimore and London: The John Hopkins University Press.

ICOLD (1989). "Sedimentation control of reservoirs". ICOLD International Commission on Large Dams Bulletin 67, Paris, France.

ICOLD (1997). "Question 74a Performance of reservoirs sedimentation". 27 relevant papers, Proc. of 19th Congress on Large Dams, Florence, Italy, 1997. ICOLD, Paris, France.

IGBP-BAHC (International Geosphere–Biosphere Programme) (1997) Modeling the transport and transformation of terrestrial materials to freshwater and coastal ecosystems. IGBP Report, vol. 39. IGBP, Stockholm, Sweden

Iguisi, E. O., (1997). An assessment of the current level of sedimentation of the Kubanni Dam, Savanna Vol. 18. 1. 17-27.

Jacobsen, T. (1999). "Sustainable reservoir development: The challenge of reservoir sedimentation". Hydropower into the next century-III, Gmunden, Austria, Conference Proceedings, pp.719-728.

Jain, M K. and Kothyari, U. C. (2000) Estimation of soil erosion and sediment vield using GIS. *Hydrol. Sci.* .J. 45(5), 771 —786.

Jain, S.K. and Goel, M.K. (2002). Assessing the vulnerability to soil erosion of the Ukai Dam catchments using remote sensing and GIS. Hydrol Sci J 47(1): 31–40

Jain, S. K., Singh, P. and Seth, S. M. (2002). Assessment of sedimentation in Bhakra Reservoir in the western Himalayan region using remotely sensed data. *Hydrol Sci. J.* 47(2), 203-212.

Jain MK, Kothyari UC, and Rangaraju KG (2004). A GIS based distributed rainfall runoff model. J Hydrol, Elsevier Science 299(1–2):107–135

Jain MK, Kothyari UC, and Rangaraju KG (2005). Geographic information system based distributed model for soil erosion and rate of sediment outflow from catchments. J Hydraul Eng ASCE 131(7):755–769

Jain, M.K., and Das, D. (2010). Estimation of Sediment Yield and Areas of Soil Erosion and Deposition for Watershed Prioritization using GIS and Remote Sensing. Water Resour Manage (2010) 24:2091–2112 DOI 10.1007/s11269-009-9540-0

Jeffries, M. and Morris, K. (2000). "Mapping the Bathymetry of Shallow Tundra Lakes Using INSAR Techniques," *Geoscience and Remote Sensing Symposium, 2000, Proceedings*, pp. 2230-2232.

Jervez, L. E. (1985). In: Althaus, J.J. and De Cesare, G. (2006). Reservoir Sedimentation. Sustainable Sediment Management in Alpine Reservoirs considering ecological and economical aspects. Volume 3. Neubiberg. www.alpreserv.eu

Kenndy, R.H, Thornton, K.W, and Ford, D.E. (1985). Characterization of reservoir ecosystems: Developments in hydrology, in Gunnison D (Ed) Microbial Processes in reservoirs. Dr W Junk, Rotterdam.

Khoram, S. (1981) Use of Ocean colour scanner data in water qualitv mapping *Photogrumm. Engwg Remote Sens.* 47(5), 667-676.

Kite, G., and Pietroniro, A., (2000). Remote sensing of surface water. In: Schultz, G.A., Engman, E.T. (Eds.), Remote Sensing in Hydrology and Water Management. Springer, Heidelberg, pp. 217–238.

Kothyari UC, Jain MK, and Rangaraju KG (2002). Estimation of temporal variation of sediment yield using GIS. Hydrol Sci 47(4):693–705

Lee, S. (2004). Soil erosion assessment and its verification using the universal soil loss equation and geographic information system: a case study at Boun, Korea. Environ Geol 45(3):457–465

Leonard, T.J. and Coughlan D.J. (1997). Reservoir bathymetry - Mapping the pitfalls, *Proceedings of the 17th Annual Esri User Conference*. San Diego, California. Paper 538, http://www.Esri.com/library/userconf/proc97/pROC97/tO550/pap538/p538.HTM.

Liebe, J., van de Giesen, N., and Andreini, M., (2005). Estimation of small reservoir storage capacities in a semi-arid environment A case study in the Upper East Region of Ghana. Physics and Chemistry of the Earth, 30 (2005) pp. 448 - 454

Linhart, S.M. and Lund, K.D. (2008). "Bathymetric contour maps for lakes surveyed in Iowa in 2006," United States Geological Survey Scientific Investigations Map 3051, Sheets 2. http://pubs.usgs.gov/sim/3051/. [Accessed 21 July 2009.]

Mahmood, K. (1987). "Reservoir Sedimentation: Impact, Extent, Mitigation". World Bank Technical Report No. 71, Washington, D.C..

Manvalan, P., Rajegowda, G. E. and Srinivas, M. V. (1991) Capacity evaluation of Ghatprabha Reservoir using digital analysis of 1RS L1SS-II data. Project report no. B/003/91, Regional Remote Sensing Service Centre, Bangalore, India.

Mather, P.M. (1999). Processing of Remotely-Sensed Images. An Introduction. Wiley & Sons, Chichester.

McCurry, P. (1970). The Geology of degree sheet 21. Unpublished M.sc Thesis. Dept. of Geol., Ahmadu Bello University, Zaria.

McCurry, P. (1971). Pan African Orogeny in Northern Nigeria. Bull. Geol. Soc. Amer. Vol. 82, pp 3251-3262.

McCurry, P. (1973). Geology of Degree Sheet 21 Zaria, Nigeria. Overseas Geol. Min. Res., No 45, HMSO London.

McCurry, P. (1976). The Geology of the Precambrian to Lower Paleozoic rocks of Northern Nigeria, a review in Geology of Nigeria. Kogbe, C.A. (Ed). Elizabethan Pub. Co. Lagos, pp 15-39.

Minna Water Supply Scheme, (1992). Minna Water Supply – long term studies. Niger State Water and Sanitation Board. Report prepared by Prime Service Engineers, Enugu.

Mohammed, I. N., Aboh, H. O., and Emenike, E. A. (2008). Hydrogeophysical Investigation for Groundwater Potential in Central Minna, Nigeria. Science World Journal Vol. 3 (NO4).

Mohanty, R. B., Mahapatra, G., Mishra, D. and Mahapatra, S. S. (1986). Report on application of remote sensing to sedimentation studies in Hirakud reservoir. Orissa Remote Sensing Application Centre, Bhubaneswar and Hirakud Research Station, Hirakud, India.

Molino, B., Greco, M. and Rowan, J. S. (2001). A 2-D reservoir routing model: Sedimentation history of Abbeystead reservoir, UK. *Water Res. Manage.* 15, 109–122.

Moreno-Amich A. and Garcia-Berthou, E. (1989). "A new bathymetric map based on echo-sounding and morphometrical characterization of the Lake of Banyoles (NE-Spain)," *Hydrobiologia*, vol. 185, pp. 83-90.

Morris, G.L. and J. Fan. (1997). Reservoir Sedimentation Handbook: Design and Management of Dams, Reservoirs and Watersheds for Sustainable Use. New York: McGraw Hill

Morris, G. L., and Fan, J. (1998). "Reservoir Sedimentation Handbook, Design and Management of Dams, Reservoirs and Watersheds for Sustainable Use". New York, McGraw-Hill.

Morris, G.M. and Fan, J. (1999). Reservoir sedimentation Handbook, Design and management of Dams, reservoir and watersheds for sustainable Use. McGraw Hill. 10.6-10.11.

Morris F. L., and Fan J. (2000). "Book Reviews on reservoir sedimentation handbook-design and management of dams, reservoirs, and watershed for sustainable use". J. of. Hydraul. Eng., Volume 126, no.6, pp. 481-482.

Msadala, V.P. (2009). Sediment Yield Prediction Based On Analytical Methods and Mathematical Modelling. Thesis presented in partial fulfilment of the requirements for the degree of Master of Science in Civil Engineering at the University of Stellenbosch, South Africa.

Mueller R. Jr., (2009). "Utilizing Geographic Information Science Advancements for Bathymetric Mapping and Dredging, Assessment of a Small Urban Lake in Southeastern Minnesota." http://www.gis.smumn.edu/GradProjects/MuellerR.pdf. (Accessed 21 July 2009).

Mugabe, F.T., Hodnett, M.G., and Senzanje, A., (2004). Opportunities for increasing productive water use from dam water: a case study from semi-arid Zimbabwe. Agricultural Water Management 62 (2003), 149–163.

Nash, J.E., and Suttcliffe, J.V., (1970). River flow forecasting through conceptual models. A discussion of principles. J. Hydrol. 10, 282–290.

Nguyen, N.T. (2000). *W.C.D. Regional Consultation for East/Southeast Asia: Personal Observations.* Hanoi: World Commission on Dams.

Nigerian Meteorological Agency, NIMET (2006). Mean monthly maximum temperature, (^{o}C) Minna. Meteorological data for school research.

Nigerian Meteorological Agency, NIMET (2006). Monthly total rainfall, (mm) Minna. Meteorological data for school research.

Nigeria Register of Dams, (1995). Federal Ministry of Water Resources and Rural Development. National Subcommittee on Dams / Nigerian Committee on Large Dams.

Niger State Water Board, NSWB, (1982). Making the provision of water a birth right of the people. Progress report for the period of October 1979 to October 1982.

Offodile, M. E. (2002). Groundwater Study and Development in Nigeria. Nigeria. 2nd Ed. Mecon Geology and Engineering Services Ltd. In: C. A. Kogbe (Editor), Geology of Nigeria. Elizabethan Publication. 365-376.

Oklahoma Water Resources Board (OWRB). (2006). Hydrographic Survey of Okemah Lake. State of Oklahoma Water Resources Board the Water Agency.

Ortt, R. A., Jr., Kerhin, R.T., Wells, D.V., and Cornwell, J.C., (2000), Bathymetric Survey and Sedimentation Analysis of Loch Raven and Prettyboy Reservoirs: Maryland Geological Survey, Coastal and Estuarine Geology File Report No. 99-4.

Ortt, R.A., Jr., VanRyswick, S. and Wells, D., (2007). Bathymetry and Sediment Accumulation of Triadelphia and Rocky Gorge Reservoirs: Maryland Geological Survey, Coastal and Estuarine Geology File Report No. 07-03.

Oyawoye, M.O. (1964). The Geology of the Nigerian Basement Complex. Journ. Nig. Min. Geol. And Metell. Soc. Vol. 1 pp 87-102.

Oyawoye, M.O. (1972). The Basement Complex of Nigeria. In African Geology Ibadan 1970 .(Ed) Dessssauvagie and Whiteman. Geol. Dept. Univ. of Ibadan, Nigeria. Pp 67-

99.

Pacific Southwest Inter-Agency Committee, Water Management Subcommittee (1968). Factors Affecting Sediment Yield in the Pacific Southwest Area. Selection and Evaluation of Measures for Reduction of Erosion and Sediment Yield.

Palmieri, A., Shah, F., Annandale, G.W., and Dinar, A., (2003). Reservoir Conservation Volume I: The RESCON Approach: Economic and engineering evaluation of alternative strategies for managing sedimentation in storage reservoirs. Publication of the World Bank, Washington, DC, USA.

Patrick, M. (1996). Sedimentation problems with Dams. www.ing.org/basics/ard/index

Pillco, R.Z. and Bengtsson, L. (2007). Three methods for determining the area–depth relationship of Lake Poopó, a large shallow lake in Bolivia. *Lakes & Reservoirs: Research and Management* 2007. 12: 275–284. Doi: 10.1111/j.1440-1770.2007.00344.x

Pyrkin, Y. G., Samolyubov, B. I., And Lashchenov, S. Y, and Korolev, V. N. (1978). "Transport of suspended Sediments in the Nurek Hydroelectric Station Reservoir by a Density Current and Calculation of Siltation of the reservoir". Translated from Gidrotekhnicheskoe Stroitel'stvo, No. 5, Plenum Publishing Corporation, pp. 9-12.

Qian Zhengying, (1994). *Water Resources Development in China*. China Water and Power Press and Central Board of Irrigation and Power.

Raghunath, H.M. (1986). Reservoir sedimentation, hydrology principle, analysis and design. Wiley Eastern Limited. First reprint. Pp 322-330.

Randle, T. J. (1996). Lower Colorado River Regulatory Storage Study Sedimentation Volume. US Bureau of Reclamation, Technical Service Center, Denver, Colorado. 80225, USA. IAHS Publ. no. 249, 1998.

Rapp A, Murray-Rust D.H, Christinsson C and Berry L (1972). "Soil erosion in four catchments near Dodoma, Tanzania". Geografiska Annaller, 54A (3-4), 255-318.

Rao, I.T. G., Rameshwar Rao and Viswanatham, R. (1985). Project report on capacity evaluation of Sriramsagar reservoir using remote sensing techniques. Andhra Pradesh Engineering Research Lab., Hyderabad, India.

Rooseboom, A. (1978). Sedimentation of Reservoirs. Water J. SA. Vol.4. 14-17.

Rooseboom, A. (1992). *Sediment Transport in Rivers and Reservoirs: A South African Perspective.* Report to the Water Research Commission of South Africa.

Rooseboom, A., and Annandale, G. W. (1982). "Sediment movement through reservoir". Question 54a Reservoirs sedimentation and slope stability, Technical and environmental effects, Proc. of 14th Congress on Large Dams, Rio de Janeiro, Brazil, 1982. ICOLD, Paris, France, pp. 373-381.

Russ, W. (1957). The Geology of Parts Niger, Zaria and Sokoto Provinces with Special Reference to the Occurrence of Gold. Nig. Geol. Survey Bull. No.27 sPp 42.

Sawunyama, T., Senzanje A., and Mhizha, A., (2006) Estimation of small reservoir storage capacities in Limpopo River Basin using geographical information systems (GIS) and remotely sensed surface areas: Case of Mzingwane Catchment

Schoeneich, K. (2003). Water Resources Administration in Nigeria. Nigeria Mining and Geosciences Society (NMGS) 39th Annual International Conference "ITAKPE 2003" March 2-8.

Schoeneich, K., and M.L. Garba (2010). Geol 405 "Hydrogeology" Lecture Notes for Students of Geology, Ahmadu Bello University, Zaria.

Schumm, S.A. (2009). *Streamflow and Sediment Yield*; Encyclopedia Britannica: Chicago, IL, USA.
www.britannica.com/EBchecked/topic/504801/river/29099/Factors-that-influence-sediment-yield (accessed on 20 July 2009).

Shiklomanov, I.A. and Rodda, J.C. (2003). World water resources at the beginning of the 21st cenyury. Cambridge, Cambridge University Press.

Sloff, C.J. (1997). Modeling reservoir sedimentation processes for sediment management studies. Proc. Conf. Hydropower into next century, portoroz, Slovenia, Aqua media Int., UK., sept.15-17. 513-524.

Small, I.F., Rowan, J.S., and Duck, R.W.(2003). Long-term sediment yield in Crombie Reservoir Catchment, Angus; and its regional significance within the Midland Valley of Scotland. Hydrological Sciences–Journal–des Sciences Hydrologiques, 48(4), 619-635.

Smith, S. E., Mancy, K. H. and Latif, A. F. A. (1980). The application of remote sensing techniques towards the management of the Aswan High Dam Reservoir. In: *14th*

Int. Svmp. on Remote Sensing of Environment (San Jose, Costa Rica, 23-30 April 1980), 1297-1307.

Soil Conservation Service, (1973). *National Engineering Handbook*. Section 3, Sediment, USDA, Washington, D.C.

Solomonson, V. V. (1973). Remote sensing applications in water resources. In: *Third Earth Resources Technokrey Svmp.* (Washington DC, USA, 10-14 December, 1973).

Stevenson, K., (2000). The role of small dams in improving rural livelihoods in semi-arid areas. Care Stakeholder Workshop 29–31 August 2000, Masvingo, Zimbabwe.

Strand, R. I. (1975). Bureau of Reclamation procedures for predicting sediment yield, present and prospective technology for predicting sediment yields and sources. In: *Proceedings of the Sediment-Yield Workshop.* USDA Sedimentation Laboratory, Oxford, Mississippi.

Strand, R. I. and Pemberton, E. L. (1982). *Reservoir Sedimentation Technical Guideline for Bureau of Reclamation.* US Bureau of Reclamation, Denver, Colorado.

Tamene, L.; Park, S.J.; Dikau, R.; Vlek, P.L.G. (2006). Reservoir siltation in the semi-arid highlands of Northern Ethiopia: Sediment yield—catchment area relationship and a semi-quantitative approach for predicting sediment yield. *Earth Surf. Process. Landforms 31*, 1364-1383.

Tigrek, S., Gobelez, O. and Aras, T., (2009). Sustainable management of reservoirs and preservation of water quality. Technical perspectives for rational use of water resources in the Mediterranean region. 41-53.

Tortajada, C., (2001). Environmental sustainability of water projects. Doctorial Thesis, Royal Institute of Technology, Stockholm.

Truswell, J.F. and Cope, R.N. (1963). The Geology of parts of Niger and Zaria provinces, Northern Nigeria. Bull. Geol. Surv. Nigeria, 29, 52.

Turner, D.C. (1983). Upper Proterozoic Schist Belts in the Nigerian Sector of the Pan African province of West Africa, Precambrian Res., 21, 55-79.

Turner B.L, Clark W.C, Kates R.W, Richards J.F, Matthews J.T, and Meyer W.B (1990). The earth as transformed by human action. Cambridge Univ. Press, Cambridge

U.S. Army Corps of Engineers (USACE). (1989). Engineering and Design -Sedimentation Investigations of Rivers and Reservoirs, EM 1110-2-4000, Washington, DC 20314-1000.

U.S. Army Corps of Engineers (USACE). (2002). Engineering and Design -Hydrographic Surveying, Publication EM 1110-2-1003, 3rd version.

U.S. Department of Agriculture-Soil Conservation Service. (*1992). Summary Report: National Resources Inventory*; Soil Conservation Service: Washington, DC, USA; Statistical Laboratory, Iowa State University: Ames, IA, USA, 1994.

Utah State Water Plan (USWP). (2010). Managing sediment in Utah's reservoirs. Utah Division of Water Resources.

Varshney, R. S. (1997). Impact of siltation on the useful life of large reservoirs. State of Art Report no. INCOH/SAR-11 /97, INCOH, National Institute of Hydrology, Roorkee, India.

Verstraeten G, Prosser IP, Fogarty P (2007). Predicting the spatial patterns of hillslope sediment delivery to river channels in the Murrumbidgee catchment. Aust J Hydrol 334:440–454

Verstraeten, G. & Poesen, J. (2000). Estimating trap efficiency of small reservoirs and ponds: methods and implications for the assessment of sediment yield. *Progr. Phys. Geogr.* 24, 219–251.

Vibulsresth, S,, Srisangthong, D., Thisayakorn, K,, Suwanwerakamtorn, R., Wongpam, S., Rodpram, C, Leelitharn, S. and Jiltanaon, W. (1988). The reservoir capacity of Ubolratana Dam between 173 and 180 meters above mean sea level. *Asian-Pacific Remote Sens. J.* 1(1).

Visentini, M. (1936). "Alluvial deposits in reservoirs, their importance and the means to lessen or prevent them". Proc. of 2nd Congress on Large Dams, Vol. 5, Washington, USA, US Government Printing Office, pp.169-176. In: Althaus, J.J. and De Cesare, G. (2006). Reservoir Sedimentation. Sustainable Sediment Management in Alpine Reservoirs considering ecological and economical aspects. Volume 3. Neubiberg. www.alpreserv.eu

Vuglinskiy, V., Monteduro, M., Sessa, R., Gronskaya, T., and Cretaux, J.F. (2009). Water level in lakes and reservoirs, water storage. Assessment of the status of the

development of the standards for the Terrestrial Essential Climate Variables. Global Terrestrial Observing System (GTOS) Rome. T4 Version 8.

Walling D. E. (1988). Erosion and sediment yield research—some recent perspectives. J Hydrol 100:113–141

Walling, D.E. (1989). "The erosion problem". Intern, J. Sediment Research, Vol. 4, No 1, pp. 1-11.

Weirich, F. H. (1984). "Turbidity currents: monitoring their occurrence and movement with a three-dimensional sensor network". Science, Vol. 224, pp. 384-387.

Weirich, F. H. (1986). "The record of density-induced underflows in a glacial lake". Sedimentology, No. 33, pp. 261-277.

Weller, K. (2005). In: Nwilo, P.C. and Adeleke, A.A. (2008). Dams and the environment: Building a GIS database for Nigerian Dams. Department of Surveying and Geinformatics, University of Lagos, Akoka, Yaba, Lagos.

White P, Habadz J.C and Budtcher D.P (1996): "Sediment yield estimates from reservoir studies: an appraisal of variability in the southern pennines of the United Kingdom". IAHS Special Publication, 276, 164-173.

White, W.R., (2000). Flushing of sediments from reservoirs, prepared for thematic review IV. 5: Operation, monitoring and Decommissioning of Dams. HR Wallingford, UK.

White W. R. (2001). *Evacuation of Sediments from Reservoirs.* London: Thomas Telford.

White R. (2002). "Book Review on evacuation of sediments from reservoirs". Journal of hydraulic research International Association for Hydraulic Research, volume 40, no. 2, pp. 221.

Wiebe, K. and Brennan, L. (1973). Sedimentation in reservoirs. Pp539-561 in Fluvial sprocesses and Sedimentation. Proc. of the Edmonton Symposium.

Windmeijer, P.N., Andriesse, W. (Eds.), (1993). Inland Valleys in West Africa: An Agro-Ecological Characterization of Rice-Growing Environments, ILRI Publication 52. International Institute for Land Reclamation and Improvement, Wageningen.

Wischmeier, W. H. and Smith, D. D. (1962) Soil-loss estimation as a tool in soil and water management planning. In: *Symposium of Pari. 1-8 October 1962. Commission on Land Erosion,* 148-159. IAHS Publ. no. 59.

Yoon, Y. N. (1992). "The state and the perspective of the direct sediment removal methods from reservoirs". International Journal of Sediment Research, Vol. 7(2), pp. 99-116.

Zhide, Z. and Yuqian L. (2003) Reservoir sedimentation and impact on river processes world meteorological organization (WMO) no. 948 Operational hydrology report no. 47 Manual on sediment management And Measurement by yang xiaoqing

APPENDICES

APPENDIX 1.

Table 4. Coordinates of the Perimeter of Tagwai Reservoir

S/No	Latitude (N)	Longitude (E)
1.	9° 33' 59.8"	6° 39' 55.0"
2.	9° 33' 59.7"	6° 39' 53.5"
3.	9° 33' 59.5"	6° 39' 51.7"
4.	9° 33' 58.9"	6° 39' 48.7"
5.	9° 33' 58.9"	6° 39' 47.3"
6.	9° 33' 58.8"	6° 39' 45.6"
7.	9° 33' 58.8"	6° 39' 43.4"
8.	9° 33' 58.8"	6° 39' 40.4"
9.	9° 33' 58.6"	6° 39' 37.6"
10.	9° 33' 58.5"	6° 39' 34.2"
11.	9° 33' 58.5"	6° 39' 31.1"
12.	9° 33' 58.5"	6° 39' 28.4"
13.	9° 33' 58.4"	6° 39' 25.6"
14.	9° 33' 58.2"	6° 39' 21.6"
15.	9° 33' 58.7"	6° 39' 18.4"
16.	9° 34' 01.3"	6° 39' 16.5"
17.	9° 34' 09.0"	6° 39' 17.0"
18.	9° 34' 10.0"	6° 39' 18.3"
19.	9° 34' 10.9"	6° 39' 16.1"
20.	9° 34' 10.2"	6° 39' 12.9"
21.	9° 34' 08.5"	6° 39' 08.3"
22.	9° 34' 09.5"	6° 39' 06.4"
23.	9° 34' 15.0"	6° 39' 03.6"

24.	**9° 34’ 20.4”**	**6° 39’ 02.3”**
25.	**9° 34’ 23.0”**	**6° 38’ 59.8”**
26.	**9° 34’ 23.7”**	**6° 38’ 56.0”**
27.	**9° 34’ 25.4”**	**6° 38’ 54.5”**
28.	**9° 34’ 29.8”**	**6° 38’ 51.9”**
29.	**9° 34’ 32.1”**	**6° 38’ 54.4”**
30.	**9° 34’ 30.2”**	**6° 38’ 57.1”**
31.	**9° 34’ 28.9”**	**6° 38’ 59.3”**
32.	**9° 34’ 28.3”**	**6° 39’ 01.0”**
33.	**9° 34’ 27.5”**	**6° 39’ 02.9”**
34.	**9° 34’ 24.0”**	**6° 39’ 05.8”**
35.	**9° 34’ 24.4”**	**6° 39’ 12.9”**
36.	**9° 34’ 28.6”**	**6° 39’ 19.0”**
37.	**9° 34’ 30.0”**	**6° 39’ 19.0”**
38.	**9° 34’ 33.0”**	**6° 39’ 18.4”**
39.	**9° 34’ 36.8”**	**6° 39’ 21.1”**
40.	**9° 34’ 44.6”**	**6° 39’ 26.1”**
41.	**9° 34’ 53.0”**	**6° 39’ 19.8”**
42.	**9° 34’ 53.9”**	**6° 39’ 17.6”**
43.	**9° 34’ 56.2”**	**6° 39’ 16.1”**
44.	**9° 34’ 54.9”**	**6° 39’ 19.7”**
45.	**9° 34’ 55.4”**	**6° 39’ 20.2”**
46.	**9° 34’ 54.3”**	**6° 39’ 26.1”**
47.	**9° 34’ 55.1”**	**6° 39’ 28.4”**
48.	**9° 34’ 56.5”**	**6° 39’ 29.0”**
49.	**9° 34’ 57.0’**	**6° 39’ 27.1”**
50.	**9° 34’ 59.2”**	**6° 39’ 25.9”**

51.	**9⁰35’ 02.5”**	**6⁰ 39’ 28.1”**
52.	**9⁰ 35’ 06.1”**	**6⁰ 39’ 27.8”**
53.	**9⁰ 35’ 06.4”**	**6⁰ 39’ 28.9”**
54.	**9⁰ 35’ 07.5”**	**6⁰ 39’ 31.9”**
55.	**9⁰ 35’ 12.2”**	**6⁰ 39’ 33.4”**
56.	**9⁰ 35’ 11.5”**	**6⁰ 39’ 35.2”**
57.	**9⁰ 35’ 08.9”**	**6⁰ 39’ 37.5”**
58.	**9⁰ 35’ 14.6”**	**6⁰ 39’ 37.9”**
59.	**9⁰ 35’ 18.0”**	**6⁰ 39’ 38.9”**
60.	**9⁰ 35’ 16.1”**	**6⁰ 39’ 39.9”**
61.	**9⁰ 35’ 19.4”**	**6⁰ 39’ 40.6”**
62.	**9⁰ 35’ 20.9”**	**6⁰ 39’ 42.4”**
63.	**9⁰ 35’ 18.9”**	**6⁰ 39’ 43.6”**
64.	**9⁰ 35’ 19.9”**	**6⁰ 39’ 45.6”**
65.	**9⁰ 35’ 26.0”**	**6⁰ 39’ 47.7”**
66.	**9⁰ 35’ 25.0”**	**6⁰ 39’ 48.9”**
67.	**9⁰ 35’ 23.5”**	**6⁰ 39’ 49.9”**
68.	**9⁰ 35’ 24.5”**	**6⁰ 39’ 52.6”**
69.	**9⁰ 35’ 23.5”**	**6⁰ 39’ 54.9”**
70.	**9⁰ 35’ 25.2”**	**6⁰ 39’ 55.1”**
71.	**9⁰ 35’ 26.0”**	**6⁰ 39’ 56.9”**
72.	**9⁰ 35’ 24.5”**	**6⁰ 39’ 57.2”**
73.	**9⁰ 35’ 25.7”**	**6⁰ 39’ 59.2”**
74.	**9⁰ 35’ 24.0”**	**6⁰ 39’ 59.6”**
75.	**9⁰ 35’ 18.9”**	**6⁰ 39’ 58.9”**
76.	**9⁰ 35’ 19.0”**	**6⁰ 39’ 54.5”**
77.	**9⁰ 35’ 16.9”**	**6⁰ 39’ 56.4”**

78.	**9^{o} 35’ 16.0”**	**6^{o} 39’ 55.2”**
79.	**9^{o} 35’ 13.9”**	**6^{o} 39’ 48.7”**
80.	**9^{o} 35’ 11.2”**	**6^{o} 39’ 48.2”**
81.	**9^{o} 35’ 09.7”**	**6^{o} 39’ 46.2”**
82.	**9^{o} 35’ 07.8”**	**6^{o} 39’ 47.9”**
83.	**9^{o} 35’ 05.2”**	**6^{o} 39’ 45.4”**
84.	**9^{o} 35’ 05.4”**	**6^{o} 39’ 43.2”**
85.	**9^{o} 35’ 02.6”**	**6^{o} 39’ 43.2”**
86.	**9^{o} 34’ 59.9”**	**6^{o} 39’ 41.3”**
87.	**9^{o} 34’ 55.9”**	**6^{o} 39’ 43.9”**
88.	**9^{o} 34’ 50.6”**	**6^{o} 39’ 43.8”**
89.	**9^{o} 34’ 49.9”**	**6^{o} 39’ 46.2”**
90.	**9^{o} 34’ 01.7”**	**6^{o} 39’ 55.8”**
91.	**9^{o} 34’ 04.8”**	**6^{o} 39’ 57.9”**
92.	**9^{o} 34’ 06.5”**	**6^{o} 39’ 58.2”**
93.	**9^{o} 34’ 08.2”**	**6^{o} 39’ 59.7”**
94.	**9^{o} 34’ 12.9”**	**6^{o} 40’ 01.0”**
95.	**9^{o} 34’ 13.1”**	**6^{o} 40’ 04.2”**
96.	**9^{o} 34’ 17.7”**	**6^{o} 40’ 08.0”**
97.	**9^{o} 34’ 24.1”**	**6^{o} 40’ 08.9”**
98.	**9^{o} 34’ 27.6”**	**6^{o} 40’ 10.8”**
99.	**9^{o} 34’ 29.4”**	**6^{o} 40’ 13.7”**
100.	**9^{o} 34’ 33.1”**	**6^{o} 40’ 14.9”**
101.	**9^{o} 34’ 34.8”**	**6^{o} 40’ 15.7”**
102.	**9^{o} 34’ 36.5”**	**6^{o} 40’ 15.7”**
103.	**9^{o} 34’ 38.0”**	**6^{o} 40’ 17.4”**
104.	**9^{o} 34’ 36.9”**	**6^{o} 40’ 18.2”**

105.	**9^{o} 34’ 38.2”**	**6^{o} 40’ 18.7”**
106.	**9^{o} 34’ 38.3”**	**6^{o} 40’ 19.6”**
107.	**9^{o} 34’ 42.0”**	**6^{o} 40’ 20.6”**
108.	**9^{o} 34’ 44.3”**	**6^{o} 40’ 23.8”**
109.	**9^{o} 34’ 46.2”**	**6^{o} 40’ 31.1”**
110.	**9^{o} 34’ 52.2”**	**6^{o} 40’ 32.6”**
111.	**9^{o} 34’ 49.9”**	**6^{o} 40’ 36.7”**
112.	**9^{o} 34’ 49.8”**	**6^{o} 40’ 39.9”**
113.	**9^{o} 34’ 47.1”**	**6^{o} 40’ 41.2”**
114.	**9^{o} 34’ 50.9”**	**6^{o} 40’ 42.4”**
115.	**9^{o} 34’ 54.9”**	**6^{o} 40’ 34.4”**
116.	**9^{o} 34’ 58.3”**	**6^{o} 40’ 33.7”**
117.	**9^{o} 35’ 05.4”**	**6^{o} 40’ 37.2”**
118.	**9^{o} 35’ 03.1”**	**6^{o} 40’ 33.1”**
119.	**9^{o} 34’ 57.8”**	**6^{o} 40’ 30.3”**
120.	**9^{o} 34’ 55.9”**	**6^{o} 40’ 29.9”**
121.	**9^{o} 34’ 54.0”**	**6^{o} 40’ 28.4”**
122.	**9^{o} 34’ 53.5”**	**6^{o} 40’ 26.9”**
123.	**9^{o} 34’ 56.2”**	**6^{o} 40’ 28.7”**
124.	**9^{o} 34’ 58.5”**	**6^{o} 40’ 25.9”**
125.	**9^{o} 34’ 56.0”**	**6^{o} 40’ 23.9”**
126.	**9^{o} 34’ 57.9”**	**6^{o} 40’ 22.2”**
127.	**9^{o} 34’ 57.0”**	**6^{o} 40’ 20.9”**
128.	**9^{o} 34’ 54.0”**	**6^{o} 40’ 17.9”**
129.	**9^{o} 34’ 56.4”**	**6^{o} 40’ 16.3”**
130.	**9^{o} 35’ 05.8”**	**6^{o} 40’ 15.9”**
131.	**9^{o} 35’ 02.4”**	**6^{o} 40’ 14.8”**

132.	**9° 34' 58.5"**	**6° 40' 12.9"**
133.	**9° 34' 54.5"**	**6° 40' 05.2"**
134.	**9° 34' 52.9"**	**6° 40' 04.6"**
135.	**9° 34' 52.7"**	**6° 40' 03.0"**
136.	**9° 34' 54.3"**	**6° 40' 01.2"**
137.	**9° 34' 58.9"**	**6° 40' 01.0"**
138.	**9° 34' 59.9"**	**6° 39' 56.5"**
139.	**9° 34' 56.4"**	**6° 39' 55.2"**
140.	**9° 34' 52.7"**	**6° 39' 49.7"**
141.	**9° 34' 50.4"**	**6° 39' 47.0"**

APPENDIX 2.

Table 5. Coordinates of the measured points of depth of the Tagwai Reservoir. Measurements were made on 15th to 21st December, 2010 from a boat and located with a GPS. 0.35 m is mean depth below the level of the spillway to the open water surface on the days of measurements.

S/No	Latitude (N)	Longitude (E)	Depth below Water Table (m)	Depth below level of Spillway (m)
1.	**9° 34' 02.1"**	**6° 39' 16.6"**	**0.81**	**1.16**

2.	**9^o 34’ 0.8”**	**6^o 39’ 17.5”**	**1.76**	**2.11**
3.	**9^o 33’ 59.8”**	**6^o 39’ 19.0”**	**1.96**	**2.31**
4.	**9^o 33’ 59’6”**	**6^o 39’ 20.5”**	**3.19**	**3.54**
5.	**9^o 33’ 59.6”**	**6^o 39’ 22.3”**	**3.49**	**3.84**
6.	**9^o 33’ 59.6”**	**6^o 39’ 25.1”**	**2.33**	**2.68**
7.	**9^o 33’ 59.7”**	**6^o 39’ 27.1”**	**3.02**	**3.37**
8.	**9^o 33’ 59.7”**	**6^o 39’ 29.7”**	**2.28**	**2.63**
9.	**9^o 33’ 59.8”**	**6^o 39’ 33.5”**	**2.38**	**2.73**
10.	**9^o 33’ 59.9**	**6^o 39’ 37.9”**	**2.72**	**3.07**
11.	**9^o 34’ 0.0”**	**6^o 39’ 43.8”**	**2.46**	**2.81**
12.	**9^o 34’ 0.0”**	**6^o 39’ 47.3”**	**2.96**	**3.31**
13.	**9^o 34’ 0.2”**	**6^o 39’ 48.5”**	**2.11**	**2.46**
14.	**9^o 34’ 0.4”**	**6^o 39’ 49.1”**	**1.13**	**1.48**
15.	**9^o 34’ 0.5”**	**6^o 39’ 52.7”**	**0.64**	**0.99**
16.	**9^o 34’ 0.6”**	**6^o 39’ 54.3”**	**0.33**	**0.68**
17.	**9^o 34’ 0.8”**	**6^o 39’ 53.2”**	**0.54**	**0.89**
18.	**9^o 34’ 0.5”**	**6^o 39’ 53.9”**	**1.12**	**1.47**
19.	**9^o 34’ 0.7”**	**6^o 39’ 50.5”**	**1.47**	**1.82**
20.	**9^o 34’ 0.6”**	**6^o 39’ 47.9”**	**2.32**	**2.67**
21.	**9^o 34’ 0.7”**	**6^o 39’ 43.8”**	**4.01**	**4.36**
22.	**9^o 34’ 0.7”**	**6^o 39’ 43.0”**	**4.91**	**5.26**
23.	**9^o 34’ 0.4”**	**6^o 39’ 39.2”**	**5.31**	**5.66**
24.	**9^o 34’ 0.5”**	**6^o 39’ 36.3”**	**5.91**	**6.26**
25.	**9^o 34’ 0.2”**	**6^o 39’ 33.3”**	**6.50**	**6.85**
26.	**9^o 34’ 0.1”**	**6^o 39’ 31.9”**	**7.80**	**8.15**
27.	**9^o 34’ 0.4”**	**6^o 39’ 28.7”**	**8.51**	**8.86**
28.	**9^o 34’ 0.3”**	**6^o 39’ 26.2”**	**10.61**	**10.96**
29.	**9^o 34’ 0.2”**	**6^o 39’ 24.8”**	**8.58**	**8.93**
30.	**9^o 34’ 0.0”**	**6^o 39’ 22.4”**	**8.06**	**8.41**
31.	**9^o 34’ 0.2”**	**6^o 39’ 20.0”**	**10.58**	**10.93**
32.	**9^o 34’ 1.0”**	**6^o 39’ 17.5”**	**1.91**	**2.26**
33.	**9^o 34’ 1.7”**	**6^o 39’ 17.1”**	**3.15**	**3.50**
34.	**9^o 34’ 2.3”**	**6^o 39’ 16.7”**	**2.71**	**3.06**
35.	**9^o 34’ 2.8’’**	**6^o 39’ 16.1’’**	**0.71**	**1.06**
36.	**9^o 34’ 2.1’’**	**6^o 39’ 17.7’’**	**6.07**	**6.42**
37.	**9^o 34’ 1.4’’**	**6^o 39’ 19.1’’**	**9.41**	**9.76**
38.	**9^o 34’ 1.3’’**	**6^o 39’ 20.0’’**	**12.51**	**12.86**
39.	**9^o 34’ 1.0’’**	**6^o 39’ 20.9’’**	**12.21**	**12.56**
40.	**9^o 34’ 1.0’’**	**6^o 39’ 22.3’’**	**11.90**	**12.25**
41.	**9^o 34’ 0.8’’**	**6^o 39’ 23.8’’**	**11.55**	**11.90**
42.	**9^o 34’ 0.8’’**	**6^o 39’ 25.3’’**	**12.38**	**12.73**
43.	**9^o 34’ 5.7’’**	**6^o 39’ 20.3’’**	**12.59**	**12.94**
44.	**9^o 34’ 4.8’’**	**6^o 39’ 23.5’’**	**13.36**	**13.71**
45.	**9^o 34’ 4.8’’**	**6^o 39’ 27.0’’**	**14.76**	**15.11**
46.	**9^o 34’ 6.0’’**	**6^o 39’ 30.1’’**	**14.72**	**15.07**
47.	**9^o 34’ 5.4’’**	**6^o 39’ 31.3’’**	**14.53**	**14.88**

48.	**9° 34’ 5.6’’**	**6° 39’ 34.2’’**	**9.48**	**9.83**
49.	**9° 34’ 6.8’’**	**6° 39’ 37.1’’**	**9.41**	**9.76**
50.	**9° 34’ 5.7’’**	**6° 39’ 40.3’’**	**8.53**	**8.88**
51.	**9° 34’ 6.8’’**	**6° 39’ 42.5’’**	**8.58**	**8.93**
52.	**9° 34’ 5.7’’**	**6° 39’ 44.8’’**	**8.12**	**8.47**
53.	**9° 34’ 6.0’’**	**6° 39’ 48.0’’**	**4.49**	**4.84**
54.	**9° 34’ 5.4’’**	**6° 39’ 52.8’’**	**3.64**	**3.99**
55.	**9° 34’ 6.0’’**	**6° 39’ 57.6’’**	**0.96**	**1.31**
56.	**9° 34’ 2.5’’**	**6° 39’ 54.9’’**	**1.14**	**1.49**
57.	**9° 34’ 2.6’’**	**6° 39’ 53.5’’**	**2.86**	**3.21**
58.	**9° 34’ 2.4’’**	**6° 39’ 51.5’’**	**3.16**	**3.51**
59.	**9° 34’ 2.3’’**	**6° 39’ 48.9’’**	**3.25**	**3.60**
60.	**9° 34’ 2.1’’**	**6° 39’ 46.6’’**	**3.76**	**4.11**
61.	**9° 34’ 2.2’’**	**6° 39’ 44.2’’**	**4.88**	**5.23**
62.	**9° 34’ 2.2’’**	**6° 39’ 41.6’’**	**5.89**	**6.24**
63.	**9° 34’ 2.3’’**	**6° 39’ 37.9’’**	**6.07**	**6.42**
64.	**9° 34’ 2.2’’**	**6° 39’ 34.8’’**	**8.21**	**8.56**
65.	**9° 34’ 2.2’’**	**6° 39’ 31.2’’**	**16.51**	**16.86**
66.	**9° 34’ 2.0’’**	**6° 39’ 28.8’’**	**15.81**	**16.16**
67.	**9° 34’ 2.2’’**	**6° 39’ 26.2’’**	**15.31**	**15.66**
68.	**9° 34’ 2.5’’**	**6° 39’ 23.6’’**	**12.29**	**12.64**
69.	**9° 34’ 2.9’’**	**6° 39’ 20.9’’**	**13.49**	**13.84**
70.	**9° 34’ 3.2’’**	**6° 39’ 18.8’’**	**7.75**	**8.10**
71.	**9° 34’ 3.9’’**	**6° 39’ 17.6’’**	**3.33**	**3.68**
72.	**9° 34’ 5.2’’**	**6° 39’ 17.7’’**	**2.16**	**2.51**
73.	**9° 34’ 6.6’’**	**6° 39’ 18.5’’**	**2.51**	**2.86**
74.	**9° 34’ 7.7’’**	**6° 39’ 18.5’’**	**3.02**	**3.37**
75.	**9° 34’ 7.9’’**	**6° 39’ 20.5’’**	**12.89**	**13.24**
76.	**9° 34’ 8.0’’**	**6° 39’ 24.1’’**	**13.33**	**13.68**
77.	**9° 34’ 8.2’’**	**6° 39’ 26.6’’**	**12.93**	**13.28**
78.	**9° 34’ 8.2’’**	**6° 39’ 32.9’’**	**11.25**	**11.60**
79.	**9° 34’ 8.6’’**	**6° 39’ 38.2’’**	**11.58**	**11.93**
80.	**9° 34’ 8.9’’**	**6° 39’ 43.1’’**	**12.03**	**12.38**
81.	**9° 34’ 9.4’’**	**6° 39’ 45.8’’**	**6.92**	**7.27**
82.	**9° 34’ 9.9’’**	**6° 39’ 49.1’’**	**5.42**	**5.77**
83.	**9° 34’ 10.3’’**	**6° 39’ 52.8’’**	**5.88**	**6.23**
84.	**9° 34’ 10.4’’**	**6° 39’ 57.8’’**	**1.49**	**1.84**
85.	**9° 34’ 10.5’’**	**6° 39’ 59.6’’**	**0.59**	**0.94**
86.	**9° 34’ 12.1’’**	**6° 39’ 59.2’’**	**1.34**	**1.69**
87.	**9° 34’ 13.9’’**	**6° 39’ 59.9’’**	**1.44**	**1.79**
88.	**9° 34’ 13.8’’**	**6° 39’ 56.4’’**	**2.87**	**3.22**
89.	**9° 34’ 13.4’’**	**6° 39’ 51.5’’**	**6.05**	**6.40**
90.	**9° 34’ 12.6’’**	**6° 39’ 45.1’’**	**9.38**	**9.73**
91.	**9° 34’ 12.2’’**	**6° 39’ 41.3’’**	**8.60**	**8.95**
92.	**9° 34’ 11.8’’**	**6° 39’ 34.4’’**	**12.24**	**12.59**
93.	**9° 34’ 11.4’’**	**6° 39’ 30.2’’**	**10.47**	**10.82**

94.	**9° 34’ 11.2’’**	**6° 39’ 27.2’’**	**12.98**	**13.33**
95.	**9° 34’ 10.7’’**	**6° 39’ 22.4’’**	**13.31**	**13.66**
96.	**9° 34’ 10.1’’**	**6° 39’ 18.8’’**	**8.08**	**8.43**
97.	**9° 34’ 10.7’’**	**6° 39’ 17.3’’**	**1.77**	**2.12**
98.	**9° 34’ 11.9’’**	**6° 39’ 16.1’’**	**2.52**	**2.87**
99.	**9° 34’ 12.7’’**	**6° 39’ 15.2’’**	**2.90**	**3.25**
100.	**9° 34’ 13.3’’**	**6° 39’ 18.6’’**	**11.45**	**11.80**
101.	**9° 34’ 13.6’**	**6° 39’ 21.7’’**	**12.24**	**12.59**
102.	**9° 34’ 13.7’’**	**6° 39’ 23.6’’**	**11.73**	**12.08**
103.	**9° 34’ 13.9’’**	**6° 39’ 27.8’’**	**11.57**	**11.92**
104.	**9° 34’ 14.1’’**	**6° 39’ 32.6’’**	**10.75**	**11.10**
105.	**9° 34’ 14.3’’**	**6° 39’ 36.5’’**	**11.80**	**12.15**
106.	**9° 34’ 14.5’’**	**6° 39’ 42.2’’**	**13.78**	**14.13**
107.	**9° 34’ 14.8’’**	**6° 39’ 49.3’’**	**7.34**	**7.69**
108.	**9° 34’ 15.1’’**	**6° 39’ 58.6’’**	**2.95**	**3.30**
109.	**9° 34’ 15.4’’**	**6° 40’ 2.3’’**	**1.48**	**1.83**
110.	**9° 34’ 15.7’’**	**6° 40’ 5.1’’**	**1.53**	**1.88**
111.	**9° 34’ 17.0’’**	**6° 40’ 4.9’’**	**1.29**	**1.64**
112.	**9° 34’ 18.5’’**	**6° 40’ 5.0’’**	**1.99**	**2.34**
113.	**9° 34’ 20.8’’**	**6° 40’ 5.5’’**	**1.92**	**2.27**
114.	**9° 34’ 20.6’’**	**6° 40’ 3.7’’**	**3.32**	**3.67**
115.	**9° 34’ 20.0’’**	**6° 39’ 59.2’’**	**5.09**	**5.44**
116.	**9° 34’ 19.3’’**	**6° 39’ 54.5’’**	**4.75**	**5.10**
117.	**9° 34’ 18.5’’**	**6° 39’ 50.5’’**	**5.89**	**6.24**
118.	**9° 34’ 17.9’’**	**6° 39’ 46.5’’**	**7.33**	**7.68**
119.	**9° 34’ 16.9’’**	**6° 39’ 40.7’’**	**8.17**	**8.52**
120.	**9° 34’ 16.1’’**	**6° 39’ 34.9’’**	**11.83**	**12.18**
121.	**9° 34’ 15.7’’**	**6° 39’ 32.1’’**	**10.37**	**10.72**
122.	**9° 34’ 15.1’’**	**6° 39’ 27.7’’**	**13.58**	**13.93**
123.	**9° 34’ 14.8’’**	**6° 39’ 25.0’’**	**11.20**	**11.55**
124.	**9° 34’ 14.2’’**	**6° 39’ 21.7’’**	**11.65**	**12.00**
125.	**9° 34’ 13.7’’**	**6° 39’ 18.8’’**	**10.83**	**11.18**
126.	**9° 34’ 13.0’’**	**6° 39’ 15.3’’**	**6.08**	**6.43**
127.	**9° 34’ 12.2’’**	**6° 39’ 13.0’’**	**3.48**	**3.83**
128.	**9° 34’ 11.4’’**	**6° 39’ 9.8’’**	**1.78**	**2.13**
129.	**9° 34’ 11.2’’**	**6° 39’ 8.3’’**	**1.43**	**1.78**
130.	**9° 34’ 10.9’’**	**6° 39’ 7.3’’**	**0.49**	**0.84**
131.	**9° 34’ 11.8’’**	**6° 39’ 8.1’’**	**1.55**	**1.90**
132.	**9° 34’ 13.0’’**	**6° 39’ 10.6’’**	**2.47**	**2.82**
133.	**9° 34’ 14.3’’**	**6° 39’ 13.7’’**	**5.50**	**5.85**
134.	**9° 34’ 15.4’’**	**6° 39’ 16.5’’**	**9.33**	**9.68**
135.	**9° 34’ 15.4’’**	**6° 39’ 18.6’’**	**10.75**	**11.10**
136.	**9° 34’ 15.6’’**	**6° 39’ 22.4’’**	**10.56**	**10.91**
137.	**9° 34’ 15.7’’**	**6° 39’ 27.5’’**	**12.40**	**12.75**
138.	**9° 34’ 15.7’’**	**6° 39’ 31.8’’**	**10.35**	**10.70**
139.	**9° 34’ 16.1’’**	**6° 39’ 35.4’’**	**11.97**	**12.32**

140.	**9° 34’ 16.6’’**	**6° 39° 42.4’’**	**10.55**	**10.90**
141.	**9° 34’ 17.2’’**	**6° 39’ 46.7’’**	**7.28**	**7.63**
142.	**9° 34’ 17.9’’**	**6° 39’ 51.7’’**	**5.22**	**5.57**
143.	**9° 34’ 19.0’’**	**6° 39’ 55.7’’**	**4.82**	**5.17**
144.	**9° 34’ 21.1’’**	**6° 40’ 1.6’’**	**4.95**	**5.30**
145.	**9° 34’ 22.0’’**	**6° 40’ 4.6’’**	**3.82**	**4.17**
146.	**9° 34’ 22.8’’**	**6° 40’ 6.9’’**	**1.97**	**2.32**
147.	**9° 34’ 23.6’’**	**6° 40’ 7.2’’**	**0.77**	**1.12**
148.	**9° 34’ 24.9’’**	**6° 40’ 7.9’’**	**0.63**	**0.98**
149.	**9° 34’ 26.9’’**	**6° 40’ 8.2’’**	**1.70**	**2.05**
150.	**9° 34’ 26.7’’**	**6° 40’ 4.7’’**	**2.52**	**2.87**
151.	**9° 34’ 25.5’’**	**6° 39’ 59.9’’**	**3.33**	**3.68**
152.	**9° 34’ 24.4’’**	**6° 39’ 55.3’’**	**6.47**	**6.82**
153.	**9° 34’ 23.2’’**	**6° 39’ 48.9’’**	**4.40**	**4.75**
154.	**9° 34’ 22.0’’**	**6° 39’ 44.0’’**	**13.70**	**14.05**
155.	**9° 34’ 21.4’’**	**6° 39’ 42.4’’**	**12.53**	**12.88**
156.	**9° 34’ 20.2’’**	**6° 39’ 37.0’’**	**10.14**	**10.49**
157.	**9° 34’ 18.7’’**	**6° 39’ 30.1’’**	**9.47**	**9.82**
158.	**9° 34’ 17.2’’**	**6° 39’ 23.8’’**	**5.09**	**5.44**
159.	**9° 34’ 16.4’’**	**6° 39’ 18.8’’**	**10.59**	**10.94**
160.	**9° 34’ 15.4’’**	**6° 39’ 14.9’’**	**7.12**	**7.47**
161.	**9° 34’ 13.9’’**	**6° 39’ 11.6’’**	**3.49**	**3.84**
162.	**9° 34’ 14.0’’**	**6° 39’ 6.7’’**	**2.39**	**2.74**
163.	**9° 34’ 15.1’’**	**6° 39’ 5.3’’**	**2.29**	**2.64**
164.	**9° 34’ 16.7’’**	**6° 39’ 3.9’’**	**1.87**	**2.22**
165.	**9° 34’ 16.9’’**	**6° 39’ 4.9’’**	**2.99**	**3.34**
166.	**9° 34’ 17.5’’**	**6° 39’ 8.0’’**	**4.48**	**4.83**
167.	**9° 34’ 18.3’’**	**6° 39’ 10.9’’**	**7.64**	**7.99**
168.	**9° 34’ 19.1’’**	**6° 39’ 14.6’’**	**7.21**	**7.56**
169.	**9° 34’ 19.9’’**	**6° 39’ 17.9’’**	**6.25**	**6.60**
170.	**9° 34’ 20.5’’**	**6° 39’ 20.2’’**	**5.97**	**6.32**
171.	**9° 34’ 21.6’’**	**6° 39’ 24.5’’**	**8.17**	**8.52**
172.	**9° 34’ 22.0’’**	**6° 39’ 26.0’’**	**13.47**	**13.82**
173.	**9° 34’ 22.6’’**	**6° 39’ 27.8’’**	**9.63**	**9.98**
174.	**9° 34’ 23.6’’**	**6° 39’ 30.4’’**	**10.41**	**10.76**
175.	**9° 34’ 24.4’’**	**6° 39’ 33.6’’**	**11.07**	**11.42**
176.	**9° 34’ 24.8’’**	**6° 39’ 35.2’’**	**8.16**	**8.51**
177.	**9° 34’ 25.9’’**	**6° 39’ 39.9’’**	**8.47**	**8.82**
178.	**9° 34’ 26.6’’**	**6° 39’ 44.3’’**	**9.98**	**10.33**
179.	**9° 34’ 26.9’’**	**6° 39’ 46.3’’**	**9.09**	**9.44**
180.	**9° 34’ 27.6’’**	**6° 39’ 50.1’’**	**9.05**	**9.40**
181.	**9° 34’ 28.3’’**	**6° 39’ 53.7’’**	**4.40**	**4.75**
182.	**9° 34’ 28.7’’**	**6° 39’ 56.6’’**	**2.57**	**2.92**
183.	**9° 34’ 28.9’’**	**6° 40’ 0.2’’**	**1.87**	**2.22**
184.	**9° 34’ 29.2’’**	**6° 40’ 4.8’’**	**1.56**	**1.91**
185.	**9° 34’ 29.9’’**	**6° 40’ 9.3’’**	**1.85**	**2.20**

186.	**9° 34’ 30.1’’**	**6° 40’ 11.8’’**	**1.99**	**2.34**
187.	**9° 34’ 31.6’’**	**6° 40’ 13.2’’**	**2.16**	**2.51**
188.	**9° 34’ 34.4’’**	**6° 40’ 14.5’’**	**2.58**	**2.93**
189.	**9° 34’ 36.4’’**	**6° 40’ 14.5’’**	**3.15**	**3.50**
190.	**9° 34’ 35.9’’**	**6° 40’ 11.9’’**	**5.60**	**5.95**
191.	**9° 34’ 35.2’’**	**6° 40’ 7.9’’**	**3.29**	**3.64**
192.	**9° 34’ 33.5’’**	**6° 40’ 1.1’’**	**3.22**	**3.57**
193.	**9° 34’ 32.2’’**	**6° 39’ 54.8’’**	**6.01**	**6.36**
194.	**9° 34’ 30.9’’**	**6° 39’ 49.5’’**	**12.06**	**12.41**
195.	**9° 34’ 30.5’’**	**6° 39’ 46.1’’**	**8.64**	**8.99**
196.	**9° 34’ 29.3’’**	**6° 39’ 40.2’’**	**9.36**	**9.71**
197.	**9° 34’ 28.8’’**	**6° 39’ 36.4’’**	**7.23**	**7.58**
198.	**9° 34’ 27.8’’**	**6° 39’ 30.4’’**	**10.46**	**10.81**
199.	**9° 34’ 27.0’’**	**6° 39’ 25.7’’**	**6.78**	**7.13**
200.	**9° 34’ 25.9’’**	**6° 39’ 20.5’’**	**4.81**	**5.16**
201.	**9° 34’ 24.2’’**	**6° 39’ 15.0’’**	**5.01**	**5.36**
202.	**9° 34’ 21.7’’**	**6° 39’ 8.4’’**	**5.53**	**5.88**
203.	**9° 34’ 20.2’’**	**6° 39’ 4.7’’**	**2.31**	**2.66**
204.	**9° 34’ 22.9’’**	**6° 39’ 0.6’’**	**2.15**	**2.50**
205.	**9° 34’ 24.1’’**	**6° 39’ 1.1’’**	**2.16**	**2.51**
206.	**9° 34’ 25.1’’**	**6° 38’ 59.4’’**	**2.91**	**3.26**
207.	**9° 34’ 26.2’’**	**6° 38’ 57.1’’**	**3.56**	**3.91**
208.	**9° 34’ 29.1’’**	**6° 38’ 54.2’’**	**1.66**	**2.01**
209.	**9° 34’ 30.1’’**	**6° 38’ 54.1’’**	**2.16**	**2.51**
210.	**9° 34’ 29.3’’**	**6° 38’ 55.9’’**	**2.46**	**2.81**
211.	**9° 34’ 28.4’’**	**6° 38’ 57.7’’**	**1.96**	**2.31**
212.	**9° 34’ 27.9’’**	**6° 38’ 59.2’’**	**2.26**	**2.61**
213.	**9° 34’ 26.9’’**	**6° 39’ 0.8’’**	**3.46**	**3.81**
214.	**9° 34’ 25.6’’**	**6° 39’ 2.5’’**	**2.60**	**2.95**
215.	**9° 34’ 23.8’’**	**6° 39’ 5.2’’**	**3.66**	**4.01**
216.	**9° 34’ 22.0’’**	**6° 39’ 7.5’’**	**5.81**	**6.16**
217.	**9° 34’ 22.7’’**	**6° 39’ 9.4’’**	**2.96**	**3.31**
218.	**9° 34’ 24.1’’**	**6° 39’ 12.7’’**	**3.76**	**4.11**
219.	**9° 34’ 25.6’’**	**6° 39’ 16.3’’**	**3.53**	**3.88**
220.	**9° 34’ 27.1’’**	**6° 39’ 19.4’’**	**3.76**	**4.11**
221.	**9° 34’ 29.0’’**	**6° 39’ 23.7’’**	**6.58**	**6.93**
222.	**9° 34’ 30.5’’**	**6° 39’ 27.2’’**	**10.86**	**11.21**
223.	**9° 34’ 31.9’’**	**6° 39’ 30.5’’**	**11.08**	**11.43**
224.	**9° 34’ 34.1’’**	**6° 39’ 35.9’’**	**7.31**	**7.66**
225.	**9° 34’ 35.9’’**	**6° 39’ 40.7’’**	**6.86**	**7.21**
226.	**9° 34’ 38.8’’**	**6° 39’ 47.9’’**	**6.06**	**6.41**
227.	**9° 34’ 40.7’’**	**6° 39’ 55.0’’**	**5.11**	**5.46**
228.	**9° 34’ 41.5’’**	**6° 40’ 0.3’’**	**8.99**	**9.34**
229.	**9° 34’ 41.9’’**	**6° 40’ 4.1’’**	**6.26**	**6.61**
230.	**9° 34’ 41.9’’**	**6° 40’ 10.2’’**	**8.34**	**8.69**
231.	**9° 34’ 41.9’’**	**6° 40’ 15.4’’**	**3.66**	**4.01**

232.	**9° 34’ 42.2’’**	**6° 40’ 19.5’’**	**2.41**	**2.76**
233.	**9° 34’ 43.6’’**	**6° 40’ 21.6’’**	**1.37**	**1.72**
234.	**9° 34’ 45.2’’**	**6° 40’ 23.7’’**	**1.41**	**1.76**
235.	**9° 34’ 47.2’’**	**6° 40’ 24.9’’**	**1.55**	**1.90**
236.	**9° 34’ 47.2’’**	**6° 40’ 27.6’’**	**4.61**	**4.96**
237.	**9° 34’ 48.4’’**	**6° 40’ 26.3’’**	**3.81**	**4.16**
238.	**9° 34’ 48.5’’**	**6° 40’ 24.5’’**	**5.16**	**5.51**
239.	**9° 34’ 48.5’’**	**6° 40’ 22.7’’**	**6.36**	**6.71**
240.	**9° 34’ 48.2’’**	**6° 40’ 18.9’’**	**6.26**	**6.61**
241.	**9° 34’ 47.9’’**	**6° 40’ 14.9’’**	**6.41**	**6.76**
242.	**9° 34’ 47.4’’**	**6° 40’ 11.6’’**	**4.31**	**4.66**
243.	**9° 34’ 46.8’’**	**6° 40’ 6.8’’**	**3.11**	**3.46**
244.	**9° 34’ 46.3’’**	**6° 40’ 3.3’’**	**7.76**	**8.11**
245.	**9° 34’ 45.6’’**	**6° 39’ 59.0’’**	**3.96**	**4.31**
246.	**9° 34’ 45.0’’**	**6° 39’ 56.3’’**	**4.29**	**4.64**
247.	**9° 34’ 44.5’’**	**6° 39’ 54.1’’**	**4.71**	**5.06**
248.	**9° 34’ 43.9’’**	**6° 39’ 50.2’’**	**6.54**	**6.89**
249.	**9° 34’ 43.0’’**	**6° 39’ 45.4’’**	**5.03**	**5.38**
250.	**9° 34’ 42.5’’**	**6° 39’ 40.4’’**	**4.96**	**5.31**
251.	**9° 34’ 41.8’’**	**6° 39’ 36.6’’**	**6.86**	**7.21**
252.	**9° 34’ 41.3’’**	**6° 39’ 33.7’’**	**9.81**	**10.16**
253.	**9° 34’ 41.3’’**	**6° 39’ 32.8’’**	**8.66**	**9.01**
254.	**9° 34’ 40.8’’**	**6° 39’ 30.7’’**	**8.61**	**8.96**
255.	**9° 34’ 40.3’’**	**6° 39’ 28.4’’**	**6.06**	**6.41**
256.	**9° 34’ 39.8’’**	**6° 39’ 25.7’’**	**4.58**	**4.93**
257.	**9° 34’ 39.2’’**	**6° 39’ 23.6’’**	**2.11**	**2.46**
258.	**9° 34’ 37.1’’**	**6° 39’ 22.7’’**	**2.86**	**3.21**
259.	**9° 34’ 34.6’’**	**6° 39’ 21.4’’**	**4.11**	**4.46**
260.	**9° 34’ 31.9’’**	**6° 39’ 20.2’’**	**3.19**	**3.54**
261.	**9° 34’ 30.2’’**	**6° 39’ 19.7’’**	**1.83**	**2.18**
262.	**9° 34’ 26.1’’**	**6° 39’ 17.7’’**	**2.86**	**3.21**
263.	**9° 34’ 23.5’’**	**6° 39’ 15.9’’**	**5.01**	**5.36**
264.	**9° 34’ 20.2’’**	**6° 39’ 13.4’’**	**5.44**	**5.79**
265.	**9° 34’ 15.8’’**	**6° 39’ 10.4’’**	**4.71**	**5.06**
266.	**9° 34’ 14.1’’**	**6° 39’ 9.3’’**	**3.31**	**3.66**
267.	**9° 34’ 12.5’’**	**6° 39’ 8.2’’**	**2.56**	**2.91**
268.	**9° 34’ 11.7’’**	**6° 39’ 7.6’’**	**1.16**	**1.51**
269.	**9° 34’ 11.1’’**	**6° 39’ 7.3’’**	**0.56**	**0.91**
270.	**9° 34’ 10.9’’**	**6° 39’ 7.1’’**	**0.23**	**0.58**
271.	**9° 34’ 37.0’’**	**6° 39’ 22.9’’**	**3.06**	**3.41**
272.	**9° 34’ 40.8’’**	**6° 39’ 25.1’’**	**2.53**	**2.88**
273.	**9° 34’ 43.4’’**	**6° 39’ 26.5’’**	**1.99**	**2.34**
274.	**9° 34’ 45.4’’**	**6° 39’ 26.9’’**	**2.56**	**2.91**
275.	**9° 34’ 48.2’’**	**6° 39’ 24.5’’**	**2.85**	**3.20**
276.	**9° 34’ 51.0’’**	**6° 39’ 22.8’’**	**2.61**	**2.96**
277.	**9° 34’ 52.9’’**	**6° 39’ 21.5’’**	**2.99**	**3.34**

278.	**9° 34’ 54.1’’**	**6° 39’ 19.1’’**	**4.16**	**4.51**
279.	**9° 34’ 54.7’’**	**6° 39’ 17.7’’**	**3.16**	**3.51**
280.	**9° 34’ 55.3’’**	**6° 39’ 16.6’’**	**0.81**	**1.16**
281.	**9° 34’ 55.1’’**	**6° 39’ 17.1’’**	**2.04**	**2.39**
282.	**9° 34’ 54.8’’**	**6° 39’ 17.7’’**	**3.19**	**3.54**
283.	**9° 34’ 54.5’’**	**6° 39’ 18.3’’**	**3.79**	**4.14**
284.	**9° 34’ 54.2’’**	**6° 39’ 19.4’’**	**2.73**	**3.08**
285.	**9° 34’ 53.8’’**	**6° 39’ 21.8’’**	**4.83**	**5.18**
286.	**9° 34’ 53.3’’**	**6° 39’ 23.6’’**	**4.66**	**5.01**
287.	**9° 34’ 52.3’’**	**6° 39’ 26.7’’**	**3.44**	**3.79**
288.	**9° 34’ 51.7’’**	**6° 39’ 28.7’’**	**3.76**	**4.11**
289.	**9° 34’ 50.8’’**	**6° 39’ 31.9’’**	**4.11**	**4.46**
290.	**9° 34’ 50.2’’**	**6° 39’ 34.7’’**	**7.91**	**8.26**
291.	**9° 34’ 49.7’’**	**6° 39’ 36.5’’**	**8.81**	**9.16**
292.	**9° 34’ 49.4’’**	**6° 39’ 38.1’’**	**9.86**	**10.21**
293.	**9° 34’ 49.0’’**	**6° 39’ 40.3’’**	**3.66**	**4.01**
294.	**9° 34’ 48.7’’**	**6° 39’ 41.9’’**	**2.93**	**3.28**
295.	**9° 34’ 48.1’’**	**6° 39’ 45.4’’**	**2.31**	**2.66**
296.	**9° 34’ 48.1’’**	**6° 39’ 47.6’’**	**4.43**	**4.78**
297.	**9° 34’ 48.1’’**	**6° 39’ 50.0’’**	**3.06**	**3.41**
298.	**9° 34’ 48.3’’**	**6° 39’ 52.6’’**	**6.39**	**6.74**
299.	**9° 34’ 48.7’’**	**6° 39’ 56.6’’**	**4.96**	**5.31**
300.	**9° 34’ 48.9’’**	**6° 40’ 0.8’’**	**3.58**	**3.93**
301.	**9° 34’ 49.4’’**	**6° 40’ 6.1’’**	**5.36**	**5.71**
302.	**9° 34’ 49.8’’**	**6° 40’ 11.0’’**	**2.06**	**2.41**
303.	**9° 34’ 50.1’’**	**6° 40’ 14.0’’**	**2.86**	**3.21**
304.	**9° 34’ 50.6’’**	**6° 40’ 17.8’’**	**2.26**	**2.61**
305.	**9° 34’ 51.1’’**	**6° 40’ 20.9’’**	**4.86**	**5.21**
306.	**9° 34’ 51.2’’**	**6° 40’ 22.9’’**	**4.36**	**4.71**
307.	**9° 34’ 51.4’’**	**6° 40’ 24.9’’**	**5.81**	**6.16**
308.	**9° 34’ 51.7’’**	**6° 40’ 28.0’’**	**6.36**	**6.71**
309.	**9° 34’ 52.1’’**	**6° 40’ 31.0’’**	**4.66**	**5.01**
310.	**9° 34’ 52.7’’**	**6° 40’ 34.0’’**	**5.26**	**5.61**
311.	**9° 34’ 50.9’’**	**6° 40’ 36.0’’**	**5.16**	**5.51**
312.	**9° 34’ 50.2’’**	**6° 40’ 36.8’’**	**3.26**	**3.61**
313.	**9° 34’ 49.9’’**	**6° 40’ 37.8’’**	**2.31**	**2.66**
314.	**9° 34’ 50.5’’**	**6° 40’ 39.0’’**	**2.26**	**2.61**
315.	**9° 34’ 50.6’’**	**6° 40’ 40.3’’**	**3.86**	**4.21**
316.	**9° 34’ 49.8’’**	**6° 40’ 41.2’’**	**3.96**	**4.31**
317.	**9° 34’ 49.2’’**	**6° 40’ 41.5’’**	**2.61**	**2.96**
318.	**9° 34’ 48.6’’**	**6° 40’ 41.1’’**	**4.01**	**4.36**
319.	**9° 34’ 47.8’’**	**6° 40’ 41.2’’**	**4.21**	**4.56**
320.	**9° 34’ 50.5’’**	**6° 40’ 40.7’’**	**5.06**	**5.41**
321.	**9° 34’ 50.9’’**	**6° 40’ 39.6’’**	**4.91**	**5.26**
322.	**9° 34’ 51.4’’**	**6° 40’ 38.0’’**	**4.61**	**4.96**
323.	**9° 34’ 52.3’’**	**6° 40’ 36.5’’**	**2.21**	**2.56**

324.	**9° 34’ 53.5’’**	**6° 40’ 34.8’’**	**3.06**	**3.41**
325.	**9° 34’ 54.4’’**	**6° 40’ 33.2’’**	**3.01**	**3.36**
326.	**9° 34’ 56.3’’**	**6° 40’ 32.8’’**	**3.61**	**3.96**
327.	**9° 34’ 58.6’’**	**6° 40’ 32.6’’**	**5.21**	**5.56**
328.	**9° 35’ 0.2’’**	**6° 40’ 33.2’’**	**3.56**	**3.91**
329.	**9° 35’ 1.4’’**	**6° 40’ 33.8’’**	**3.21**	**3.56**
330.	**9° 35’ 2.8’’**	**6° 40’ 34.0’’**	**2.66**	**3.01**
331.	**9° 35’ 3.9’’**	**6° 40’ 35.4’’**	**3.11**	**3.46**
332.	**9° 35’ 4.8’’**	**6° 40’ 36.8’’**	**4.31**	**4.66**
333.	**9° 35’ 4.9’’**	**6° 40’ 36.0’’**	**4.51**	**4.86**
334.	**9° 35’ 4.1’’**	**6° 40’ 34.3’’**	**5.01**	**5.36**
335.	**9° 35’ 3.2’’**	**6° 40’ 33.6’’**	**5.11**	**5.46**
336.	**9° 35’ 1.5’’**	**6° 40’ 32.5’’**	**3.46**	**3.81**
337.	**9° 34’ 59.3’’**	**6° 40’ 31.5’’**	**3.36**	**3.71**
338.	**9° 34’ 57.6’’**	**6° 40’ 31.1’’**	**3.76**	**4.11**
339.	**9° 34’ 55.1’’**	**6° 40’ 30.2’’**	**2.86**	**3.21**
340.	**9° 34’ 53.7’’**	**6° 40’ 28.3’’**	**3.46**	**3.81**
341.	**9° 34’ 52.9’’**	**6° 40’ 26.3’’**	**3.76**	**4.11**
342.	**9° 34’ 53.9’’**	**6° 40’ 25.3’’**	**3.36**	**3.71**
343.	**9° 34’ 55.5’’**	**6° 40’ 27.2’’**	**2.31**	**2.66**
344.	**9° 34’ 56.9’’**	**6° 40’ 28.4’’**	**1.96**	**2.31**
345.	**9° 34’ 56.3’’**	**6° 40’ 26.7’’**	**2.36**	**2.71**
346.	**9° 34’ 57.3’’**	**6° 40’ 24.8’’**	**2.81**	**3.16**
347.	**9° 34’ 54.0’’**	**6° 40’ 23.4’’**	**2.66**	**3.01**
348.	**9° 34’ 52.6’’**	**6° 40’ 21.7’’**	**1.71**	**2.06**
349.	**9° 34’ 54.6’’**	**6° 40’ 21.5’’**	**2.56**	**2.91**
350.	**9° 34’ 56.3’’**	**6° 40’ 21.4’’**	**2.36**	**2.71**
351.	**9° 34’ 56.3’’**	**6° 40’ 20.8’’**	**2.66**	**3.01**
352.	**9° 34’ 54.3’’**	**6° 40’ 19.9’’**	**2.81**	**3.16**
353.	**9° 34’ 52.6’’**	**6° 40’ 19.0’’**	**3.06**	**3.41**
354.	**9° 34’ 52.7’’**	**6° 40’ 16.6’’**	**1.91**	**2.26**
355.	**9° 34’ 52.9’’**	**6° 40’ 15.3’’**	**2.06**	**2.41**
356.	**9° 34’ 54.9’’**	**6° 40’ 15.7’’**	**1.51**	**1.86**
357.	**9° 34’ 56.5’’**	**6° 40’ 15.9’’**	**1.06**	**1.41**
358.	**9° 34’ 58.4’’**	**6° 40’ 15.7’’**	**1.71**	**2.06**
359.	**9° 35’ 1.7’’**	**6° 40’ 16.3’’**	**2.26**	**2.61**
360.	**9° 35’ 4.1’’**	**6° 40’ 16.5’’**	**2.06**	**2.41**
361.	**9° 35’ 6.1’’**	**6° 40’ 16.6’’**	**1.91**	**2.26**
362.	**9° 35’ 5.6’’**	**6° 40’ 16.0’’**	**2.21**	**2.56**
363.	**9° 35’ 4.1’’**	**6° 40’ 15.6’’**	**2.16**	**2.51**
364.	**9° 35’ 2.2’’**	**6° 40’ 15.1’’**	**2.56**	**2.91**
365.	**9° 34’ 59.5’’**	**6° 40’ 14.2’’**	**2.41**	**2.76**
366.	**9° 34’ 57.3’’**	**6° 40’ 12.5’’**	**2.61**	**2.96**
367.	**9° 34’ 55.7’’**	**6° 40’ 10.1’’**	**4.01**	**4.36**
368.	**9° 34’ 54.1’’**	**6° 40’ 7.3’’**	**3.61**	**3.96**
369.	**9° 34’ 52.3’’**	**6° 40’ 4.5’’**	**3.06**	**3.41**

370.	**9° 34’ 51.5’’**	**6° 40’ 1.7’’**	**1.71**	**2.06**
371.	**9° 34’ 53.5’’**	**6° 39’ 59.9’’**	**1.76**	**2.11**
372.	**9° 34’ 56.5’’**	**6° 39’ 59.5’’**	**1.76**	**2.11**
373.	**9° 34’ 58.8’’**	**6° 39’ 58.7’’**	**2.31**	**2.66**
374.	**9° 34’ 59.4’’**	**6° 39’ 58.0’’**	**2.21**	**2.56**
375.	**9° 34’ 58.3’’**	**6° 39’ 56.9’’**	**2.46**	**2.81**
376.	**9° 34’ 56.5’’**	**6° 39’ 56.3’’**	**2.91**	**3.26**
377.	**9° 34’ 54.1’’**	**6° 39’ 55.1’’**	**2.61**	**2.96**
378.	**9° 34’ 52.3’’**	**6° 39’ 52.9’’**	**2.76**	**3.11**
379.	**9° 34’ 50.7’’**	**6° 39’ 51.1’’**	**2.01**	**2.36**
380.	**9° 34’ 49.4’’**	**6° 39’ 47.8’’**	**2.86**	**3.21**
381.	**9° 34’ 49.2’’**	**6° 39’ 42.9’’**	**2.21**	**2.56**
382.	**9° 34’ 52.6’’**	**6° 39’ 40.6’’**	**4.31**	**4.66**
383.	**9° 34’ 55.3’’**	**6° 39’ 39.1’’**	**0.21**	**0.56**
384.	**9° 34’ 57.2’’**	**6° 39’ 39.6’’**	**8.21**	**8.56**
385.	**9° 35’ 1.0’’**	**6° 39’ 40.3’’**	**3.11**	**3.46**
386.	**9° 35’ 4.4’’**	**6° 39’ 41.5’’**	**3.86**	**4.21**
387.	**9° 35’ 7.9’’**	**6° 39’ 43.8’’**	**4.81**	**5.16**
388.	**9° 35’ 11.6’’**	**6° 39’ 45.4’’**	**4.51**	**4.86**
389.	**9° 35’ 14.5’’**	**6° 39’ 47.6’’**	**5.71**	**6.06**
390.	**9° 35’ 14.8’’**	**6° 39’ 49.9’’**	**5.81**	**6.16**
391.	**9° 35’ 14.6’’**	**6° 39’ 52.2’’**	**4.21**	**4.56**
392.	**9° 35’ 15.2’’**	**6° 39’ 54.7’’**	**4.66**	**5.01**
393.	**9° 35’ 16.3’’**	**6° 39’ 56.4’’**	**2.56**	**2.91**
394.	**9° 35’ 16.2’’**	**6° 39’ 53.6’’**	**3.21**	**3.56**
395.	**9° 35’ 16.9’’**	**6° 39’ 52.6’’**	**3.41**	**3.76**
396.	**9° 35’ 19.1’’**	**6° 39’ 53.4’’**	**4.51**	**4.86**
397.	**9° 35’ 20.0’’**	**6° 39’ 56.9’’**	**4.06**	**4.41**
398.	**9° 35’ 21.9’’**	**6° 39’ 58.1’’**	**2.81**	**3.16**
399.	**9° 35’ 23.5’’**	**6° 39’ 59.0’’**	**3.21**	**3.56**
400.	**9° 35’ 23.9’’**	**6° 39’ 57.0’’**	**4.06**	**4.41**
401.	**9° 35’ 24.6’’**	**6° 39’ 55.9’’**	**3.91**	**4.26**
402.	**9° 35’ 22.4’’**	**6° 39’ 53.2’’**	**3.36**	**3.71**
403.	**9° 35’ 23.0’’**	**6° 39’ 51.0’’**	**3.56**	**3.91**
404.	**9° 35’ 23.3’’**	**6° 39’ 48.7’’**	**4.56**	**4.91**
405.	**9° 35’ 24.9’’**	**6° 39’ 48.1’’**	**4.81**	**5.16**
406.	**9° 35’ 25.0’’**	**6° 39’ 47.3’’**	**4.81**	**5.16**
407.	**9° 35’ 19.9’’**	**6° 39’ 46.4’’**	**6.01**	**6.36**
408.	**9° 35’ 16.7’’**	**6° 39’ 42.9’’**	**3.61**	**3.96**
409.	**9° 35’ 11.6’’**	**6° 39’ 38.3’’**	**3.11**	**3.46**
410.	**9° 35’ 6.4’’**	**6° 39’ 35.3’’**	**3.31**	**3.66**
411.	**9° 35’ 0.9’’**	**6° 39’ 33.0’’**	**5.91**	**6.26**
412.	**9° 34’ 55.3’’**	**6° 39’ 31.3’’**	**3.36**	**3.71**
413.	**9° 34’ 49.9’’**	**6° 39’ 28.8’’**	**5.21**	**5.56**
414.	**9° 34’ 47.3’’**	**6° 39’ 28.1’’**	**5.91**	**6.26**
415.	**9° 34’ 43.6’’**	**6° 39’ 26.9’’**	**2.56**	**2.91**

CHAPTER 1

INTRODUCTION

1.1 Concept of the Remaining Storage

Water resources planning and management is a major challenge to most developing nation, in their struggle to secure water. However, this depends on the availability of water, which is increasingly becoming a scarce resource. All the sources of water need to be considered in its management. In this study, reservoir is the focus.

Reservoirs are water storage structures created by construction of dams across rivers to store and capture runoff water for the purposes of water supply, hydro power generation, irrigation, flood control, tourism, aquaculture etc. Environmental impact and long term morphological changes of the natural water course and drainage basin due to human activities are inevitable. Many river basins experience severe and uncontrolled environmental degradation. This results into enhanced soil erosion in the drainage basin and excessive reservoir siltation which are considered as threat.

The term "siltation" means the increased deposition and accumulation of sediments in reservoirs. These sediments originating from erosion processes in the drainage basin are propagated along with the river flow. When the flow of a river is stored in a reservoir, the sediments settle in the reservoirs and reduce their storage capacity. It is the major problem which affects and threatens the performance and sustainability of reservoirs apart from structural stability. Reduction in the storage capacity of a reservoir beyond a limit hampers the purpose for which it is designed i.e. the gradual loss of storage capacity reduces the effective life of reservoirs and diminishes benefits for its intended uses. For example the

Kubanni Impounding Reservoir in Ahmadu Bello University (A.B.U), Main Campus Zaria is being silted up. A.B.U. Committee on Protection of the Kubanni Dam Drainage Basin (2008) said that "Kubanni impounding reservoir, the major source of water for the Ahmadu Bello University, A.B.U Main Campus, is shrinking. In year 2008, it still has more than enough water to meet water demand from the Campus, but from year 2022 onwards water will be rationed. From year 2059 onwards water rationing will stop because there will be no water in the Kubanni impounding reservoir. Kubanni impounding reservoir will be then completely silted up. Excessive siltation of the reservoir is caused by the over exploitation of biological environment in its drainage basin".

The consequences of siltation can be economically serious. Storage capacity losses in reservoirs mean financial losses due to the shortening of their useful lifetime. Thus from management point of view, the existence of reservoirs as well as their distribution and storage capacities must be known. The lack of adequate knowledge on reservoirs remaining storage capacities has been a constraint in decision making processes regarding planning and management of existing water resources. Mugabe *et al*, (2004) cited that 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 resources management. This justifies the need to establish the current storage capacities of reservoirs.

1.2 Background to the Study

Tagwai Reservoir is located on River Tagwayi, (NSWB, 1982). Tagwayi River is a tributary to River Chanchaga in Niger State. The reservoir is currently used as water supply source, to augment the source of raw water for the Chanchaga treatment plant (Minna Water

Supply Scheme, 1992). The dam was commissioned on 1st November, 1978. The dam is classified as a large dam (Nigeria Register of Dams, 1995). The large dam classification means that it satisfies the International Commission on Large Dams (ICOD) definition (Nigeria Register of Dams, 1995). i.e.

(1) All dams with heights of 15 m or more, measured from the lowest portion of the general foundation area to the crest.

(2) Dams between 10 m and 15 m can be included if desired, provided they comply with at least one of the following conditions: (i) the length of crest not less than 500 m (ii) the capacity of the reservoir formed by the dam not less than 1 million m^3 (iii) the maximum flood discharge dealt with by spillway not less than 2000 m^3/sec (iv) the dam has special foundation problems (v) the dam is of unusual design.

The existing water supply scheme in Minna, Niger State capital, is far from adequate, water is being rationed and no one area receives a 24 hour supply except to institutions and households with internal storage facilities. Some areas, like Maitumbi, receive pipe-borne water only a few hours, twice or thrice in a week (Minna Water Supply Scheme, 1992).

The current estimate of total reservoir storage worldwide is around 7000 km^3 (ICOLD, 1997). This storage is used for residential water supply, irrigation, hydropower generation and flood control. Concern about loss of reservoir storage capacity due to siltation was raised by Mahmood (1987) and has recently been expressed in many fora and publications (Palmieri, *et al.,* 2003). It is estimated that between 0.5 % and 1.0 % of global water storage volume is lost annually as a result siltation (White, 2001). The annual loss of storage in reservoir is roughly 1%, corresponding to about 50 km^3 worldwide (Mahmood, 1987). For example, annual loss of storage in the Kubanni reservoir in Ahmadu Bello University,

Zaria, Nigeria is 1.16 % (A.B.U Committee on Protection of the Kubanni Dam Drainage Basin, 2008). Some reservoirs have a much higher storage losses that may exceed 1.7 % annually (Patrick, 1996). Using an intermediate rate, this loss in storage is approximately 45 km^3 per year for the world (Palmieri, *et al.,* 2003). If it is further assumed that the average reservoir volume is 150 million m^3, 300 large dams should be built annually just to maintain current total worldwide storage (Palmieri, *et al.,* 2003). The lack of knowledge of the current storage capacity of many reservoirs around the world has limited the uses for which they are intended, hence the need for bathymetric mapping of such reservoirs i.e. the measurement of underwater depth. To be able to assess the siltation rate or to determine sustainable water withdrawal rates, the water level-volume lake area or stage curve relationship provides invaluable information. However, 40 % of the world's largest lakes (impounding reservoirs) have not been studied and their volumes are therefore approximated (Shiklomanov and Rodda, 2003). About 82% of Nigeria dry season surface water is in man-made impounding reservoirs (Schoeneich, 2003), Most of these dams belong to the category of small and middle size dams. Consequently they are even more endangered by siltation.

Bathymetry is mapping depth of the bottom of a body of water i.e. the measurement of underwater depth. It is the underwater equivalent to hypsometry – elevation of land surface. A bathymetric map usually shows floor relief or terrain as contour lines called depth contours or isobaths. The purpose of the bathymetry is to provide accurate determinations of current storage capacities of reservoirs. Obtaining accurate storage volumes is an integral tool used in the management of water supply. For many reservoirs, the only available storage volumes are those that were estimated when the dam was first

constructed. Because of sediment deposition that occurs in reservoirs, the volume can be grossly reduced over time. By conducting a reservoir bathymetric mapping, the managing authority of a reservoir can be better equipped to handle critical water management issues because of the invaluable information generated.

1.3 Statement of the Problem

Growing water demand creates need for a very sound water resources management, based on reliable data within the context of resource sustainability. To improve the management of water resources many rivers have been dammed; siltation of their reservoirs is a significant problem on which little information is available. Systematic plans and policies are needed to reduce the adverse impacts of siltation and prolong the useful life of reservoirs. Water resources managers routinely need bathymetric maps of inland water bodies to be able to respond effectively to the challenges.

1.4 Aim of the Research

The determination of the Remaining Storage of Tagwai Impounding Reservoir in comparison with the design capacity in order to calculate the rate of siltation in the reservoir and rate of erosion in the drainage basin.

This aim will be achieved through:

- **Review of literatures relevant to Tagwai Reservoir and Reservoir Siltation Studies**
- **Measurement of the remaining surface area of Tagwai Reservoir**
- **Measurement of the remaining depths of Tagwai Reservoir**

1.5 Scope of the study

The scope of this study includes:

- **Delineation of the drainage area of the reservoir;**
- **Collection of available relevant information of the drainage basin;**
- **Geological mapping of the drainage area;**
- **Mapping of the water edges of the reservoir;**
- **Bathymetric mapping of the reservoir;**
- **Calculation of the volume of water in the reservoir;**
- **Calculation of the rate of siltation in the reservoir;**
- **Calculation of the rate of erosion in the drainage basin.**

1.6 Justification of the study

In Nigeria, over 323 dams and reservoirs have been constructed and many more are under construction in different parts of the country (Etiosa, 2006). The Tagwai impounded reservoir is one of them and it is the major source of piped-borne water supply to Minna and its environs. The reservoir at impoundment in 1978, had dead storage of 1.8 x 10^6 m^3, while the active storage was 26.5 x 10^6 m^3. Since its impoundment in 1978 part of the original storage has been lost to siltation because of environmental degradation within the drainage basin. This part is still unknown? This study sought to determine the remaining storage, rate of siltation in the reservoir, and rate of erosion in the drainage basin.

1.7 The Study Area

1.7.1 Location

The study area is the drainage basin of Tagwayi River upstream of the Tagwai Reservoir embankment. It lies in the southeastern part of Minna, Niger State capital (Figure 1).

The drainage basin lies on part of sheet 164 Minna, SW and SE of the first edition of 1:50,000 topographic maps of 1967, within latitudes 9^o 33' 0" N to 9^o 41' 0" N and longitudes 6^o 31' 30" E to 6^o 50' 0" E (Figure 2a and 2b).

The dam is built across River Tagwayi which is a tributary of River Chanchaga in Niger State. The dam is an earth filled dam, initiated by the Niger State Government in 1976 and completed in 1978 to augment the source of raw water supply for the Chanchaga treatment plant.

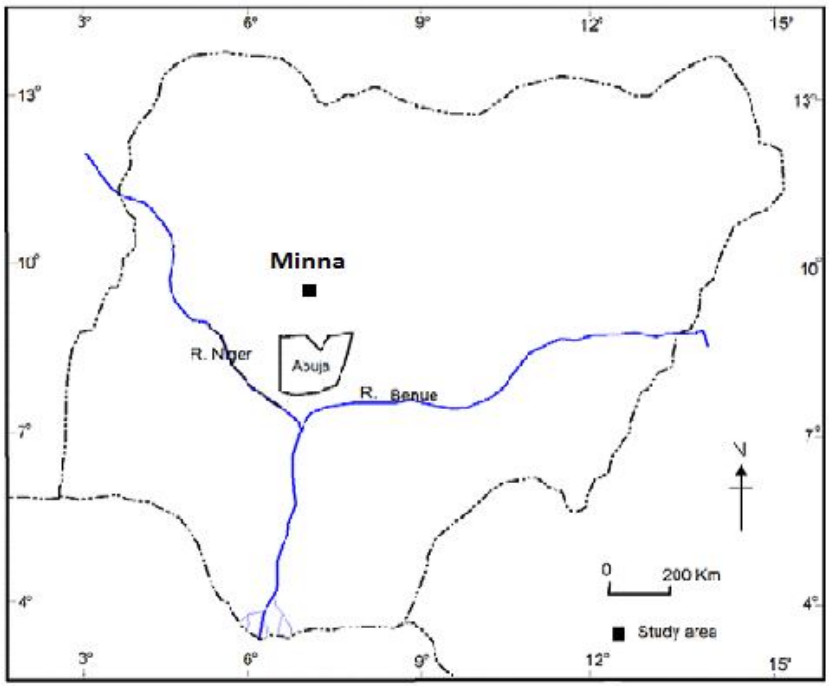


Figure 1. Map of Nigeria showing study area.

1.7.2 Climate and Vegetation

The climatic feature of the study area is a product of its location in the tropical region of West Africa and falls within the Guinea Savanna vegetation zone in Nigeria, marked by

distinct wet and dry seasons. The wet season starts, on long term average, on 9th April and ends on 25th October, lasting 200 days (Table 2). The dry season starts on 26th October and ends on 8th April, lasting 165 days.

The most heavy rains that fall at the beginning of wet season are usually short lived. The last stages of the rainy season are marked by light showers and thunderstorms.

TABLE 1. TAGWAI DAM PROJECT DATA. (NSWB, 1982)

26.	**Average annual precipitation**	**1270 mm**
27.	**Catchment area**	**110 km^2**
28.	**Average annual run off**	**25 x 10^6 m^3**
29.	**Type of Dam**	**Zone earth fill**
30.	**Crest length**	**1770 m**
31.	**Crest level**	**259 m O.D**
32.	**Free Board**	**3 m**
33.	**Maximum flood level**	**257.5 m O.D**
34.	**Full supply level**	**256 m O.D**
35.	**Crest width**	**10 m**
36.	**Maximum structural height**	**25 m O.G.L**
37.	**Hydraulic height**	**21 m**
38.	**Maximum width of base**	**150 m**
39.	**Total storage capacity**	**28.3 x 10^6 m^3**
40.	**Active storage capacity**	**26.5 x 10^6 m^3**
41.	**Dead storage capacity**	**1.8 x 10^6 m^3**
42.	**Dead storage level**	**245.5 m**
43.	**Surface area of lake**	**5.50 x 10^6 m^2**
44.	**Total volume of Earthwork**	**870,000 m^3**
45.	**Service spillway**	**110 m long with crest elevation 258.3 m**
46.	**Emergency spillway**	**170 m long with crest elevation 258.3 m**
47.	**Intake tower**	**2 (24'')** diameter of steel pipe penstocks with guan and control valve.
48.	**Date of commencement**	**20th September, 1977**
49.	**Date of completion**	**1st November, 1978**
50.	**Cost**	**₦ 6,960,000**

O.D – Ordnance datum, Ordnance ground level.

TABLE 2. MONTHLY TOTAL RAINFALL, MINNA (mm). (NIGERIAN METEOROLOGICAL AGENCY, NIMET, 2006).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	0	0	0	3.6	135.9	231	208.8	308.5	303	153.4	0	0
2001	0	0	0	93.9	139	331.7	244.6	230.2	298.8	25.7	0	0
2002	0	0	5.7	98.8	42.6	201	143.2	226.5	260.6	180.3	0.3	0
2003	0	5.7	0	17.4	114.6	203	123	191.6	188.2	192.4	2.3	0

2004	0	0	0	32.2	151.9	194.9	210.3	211.4	241.5	77.6	0	0
2005	0	0	7.5	49.1		173.9	294.2	127.8	226.4	94.8	0	0
2006	11.2	0	0	29.9	195	107.7	229.7	317.1	360.5	172.1	0	0

The mean annual depth of rainfall recorded by Minna Hydrometeorological Station from year 2000 until year 2006 was 1270 mm. This is in agreement with datum read from Figure 3 below, 1250 mm/a.

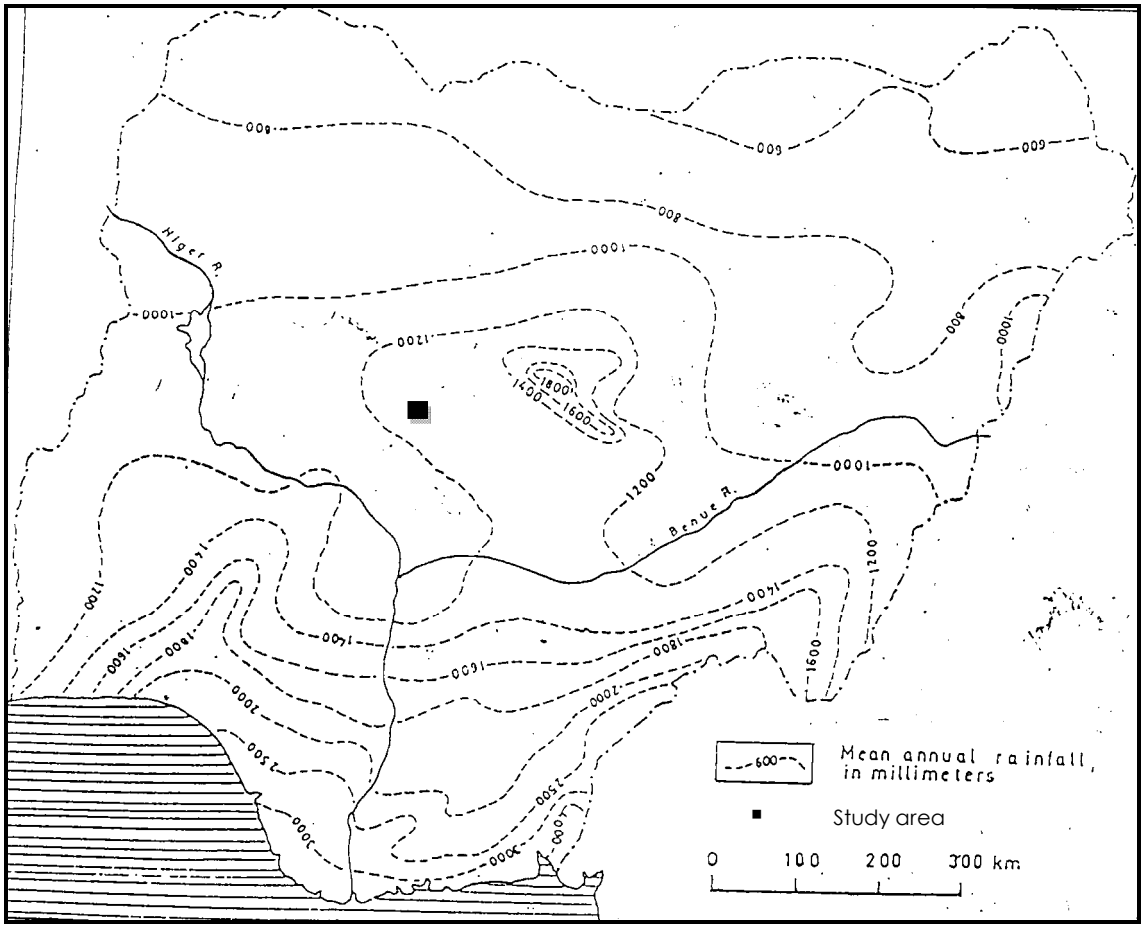


Figure 3. Map of mean annual depth of rainfall in Nigeria (Schoeneich, 2003)

The dry season is characterized by the prevalence of the dry continental northeasterly harmattan wind from the Sahara desert and across the study area.

The vegetation of the study area consist of scattered trees and shrubs. Main trees are *Vitellaria paradoxa* (shear butter), *Parkia biglobosa* (locust bean), *Magnifera indica* (mango).

The study area has mean annual Stevenson Screen temperature of 27.2 ^{o}C according to Schoeneich and Garba (2010). The mean maximum monthly temperatures for Minna are presented in Table 3.

TABLE 3. MEAN MONTHLY MAXIMUM TEMPERATURE (^{O}C) at MINNA. (NIGRTIAN METEOROLOGICAL AGENCY, NIMET, 2006).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	35.7	34.8	38.1	37.3	35.1	30.6	29.2	28.9	30.2	31.5	35.4	34.8
2001	34.8	36.1	38.9	36.3	33.7	30.9	29.1	28.3	29.5	33	36	36.4
2002	33.5	37	38.6	35.8	35.7	32	29.9	29.4	29.2	31.3	34.7	34.9
2003	35.3	38.2	39	36.6	34.7	31.2	29.8	28.8	29.8	31.8	35.5	35.2
2004	34.8	36.7	37.6	37.6	33.5	31	29.2	29	29.9	30	34.8	34.8
2005	33.7	38.3	39.4	37.6	33.7	31.4	29.4	28.8	30.5	31.5	35.1	34.6
2006	35.7	37.5	38.4	31.9	31.5	30.1	28.5	30.1	31.3	30	34.7	34.6

1.7.3 Relief and Drainage

The study area is generally gently undulating; sloping gently from the high lands in the northern part of the area, with highest point as 410m to the southern part of the area, with lowest point as 250m. The drainage pattern is dendritic. The area is drained by the river Tagwayi and its tributaries.

1.7.4 Geology and Hydrogeology

The study area is located within the Crystalline Hydrogeological Province of Nigeria. The rocks of the area are mostly crystalline rocks consisting of granites and metasedimentary schist. The granitic outcrops are highly jointed, fractured and in some places appear as boulders (Plate 1) (Adeniyi, 1985). In addition to these two major rock types, there are other rock types in form of minor intrusive such as quartz veins. They are closely associated with the granitic rocks.



Plate 1. An outcrop of granite, in form of ruware inselberg, at north - east edge of the reservoir.

The flow regime of the rivers in the study area is a function of the rainfall pattern and lithology over which the rivers are flowing. Generally, rivers on the basement tend to be ephemeral or flashy and with very low dry season flow.

Minna area is made up of only the Crystalline Hydrogeological Province, as there is complete absence of sedimentary rocks in the study area (Mohammed *et al.,* 2008). This Crystalline Hydrogeological Province is made up of two interconnected aquifers: the soft overburden aquifer within the mostly allochtonous products of chemical weathering, and the Fractured Crystalline Aquifer within the weak zone and the partially weathered / fractured basement. The depth to the water table lies on the average between 3 m and 15 m below the ground surface in the Crystalline Basement Complex (Offodile, 2002). The average yield of borehole in these aquifers is between 0.75 and 1.80 l / sec. In Minna, existing borehole data indicate that the weathered mantle is on the average thin. Areas of rugged topography subjected to high rate of erosion have a thin weathered zone. The water in the weathered zone aquifer is unconfined and shallow, but follows the topography in a suppressed manner.

CHAPTER 2

LITERATURE REVIEW

2.1 Regional Geology

To understand the geology of the study area, knowledge of the regional geology is necessary. The study area is part of sheet 164 Minna SW and SE, which is an integral part of the Northern Nigerian Basement Complex.

The study area is underlain by rocks of Northern Nigeria Basement Complex and consists of rocks that are of Precambrian to Palaeozoic in age (Ajibade, 1972). The Nigerian basement is believed by most workers to have been affected by at least two cycles of orogenesis (Russ, 1957; Oyawoye, 1964; Grant, 1969; 1970; 1978; McCurry, 1970; 1971; Ajibade, 1972; and Turner, 1983) except for Truswell and Cope (1963), who suggested one orogenic cycle.

Both orogenic cycles led to wide spread sedimentation, metamorphism, folding, faulting and remobilization of pre-existing Basement Complex rocks to produce suites of granitoids. The earlier orogeny is characterized by intense deformation and folding about E-W axes which are accompanied by regional metamorphism (McCurry, 1970). The later orogeny is the Pan African, being more intense and nearly erasing all the signs of the earlier orogeny resulting in N-S structural trend of fold axes (McCurry, 1970). This fact is supported by the synclinorial belts of metasediments in large areas of northwestern Nigeria including the Kushaka, the Kusheriki and Zungeru Formations in Niger State.

It was concluded by Oyawoye (1964), McCurry (1971, 1973) and Ajibade (1972), that there are at least two orogenic cycles in Nigerian Basement, one in which the gneisses were

emplaced, the other leading to the emplacement of the schist and Older Granites. The close contact between the contrasting metamorphic grade type, migmatites and the Younger metasedimentary schist accented. Ajibade (1982) interpreted this close contact relationship as a result of the emplacement of a sufficiently large amount of Older Granite that engulfs most of the metasedimentary schist. Different migmatitic structures were formed due to varying degree of assimilation of the schist.

The Northern Nigerian Basement Complex is part of the Pan African Mobile Belt that separates the West African Craton to the west and the Congo Craton to the east. The evolution of the Basement Complex was suggested to be during the late Proterozoic. This is related to the activities occurring at the plate margins. The deposition of rocks of schist belt was subsequent effect of initial crustal extension and continental rifting at the West African Craton margin at about 1000 m.a.

Grant (1969), Betrand and Caby (1978) suggested that the above view supports a well defined geodynamics model for the western margin of the Pan African mobile belt. The deformation of sediments, reactivation of the pre – existing rocks and emplacement of the Pan African granites was due to closure of the ocean at the cratonic margin about 600 M.a. and crustal thickening in the Dahomay (Ajibade *et al.,* 1987). Burke *et al.,* (1976) and Ajibade *et al.,* (1987) suggested that the relics of older rocks exist which may have escaped the effect of the Pan African Orogeny during the emplacement of the granite and associated metamorphic rocks.

Three broad lithological groups are usually distinguished within the Northern Nigerian Basement Complex (Russ, 1957; Truswell and Cope, 1963; Grant, 1969; McCurry, 1970).

1. A polymetamorphic migmatite – gneiss complex which is composed largely of migmatites and gneisses of various compositions and amphibolites. Relict metasedimentary rocks represented by medium to high grade calcareous, pelitic and quartzitic rocks occur within the migmatites and gneisses, and they have been described as ancient "metasediments" (Oyawoye, 1972). Ajibade (1982) differentiated the migmatites into migmatites with no relics of schists or gneisses and migmatites with relics of alternating light bands formed by tonalite and dark band of schist. The complex structures within the migmatite may be due to differential stresses arising from multi layering of adjacent competent and less competent beds so that buckling and differential movement results (McCurry, 1970).

2. Low grade Metasediment dominated schists which form narrow belts have been described as "Newer Metasediments" (Oyawoye, 1972) and "Younger Metasediments" (McCurry, 1976). The schist belts are believed to be relicts of a supracrustal cover which was infolded into the migmatite – gneiss complex (Russ, 1957; McCurry, 1973). They are linear belts of generally green schist facies metamorphism. They are chiefly pelitic and semi – pelitic rocks with inter bedded orthoquartzites and micaceous psammites (Ajibade, 1976). They are believed to be upper Proterozoic (McCurry, 1970; Grant, 1978) and were believed to have been deposited on the granitized basement. The different lithological associations occurring in different belts have led to the suggestion that each belt developed in a separate basin (Truswell and Cope, 1963; Grant, 1978).

3. The granitiods are syntectonic to late tectonic cutting both the migmatite – gneiss complex and the schist belts. The granitoids include rocks varying in composition from granite to tonalite and charnockite with smaller bodies of syenite and gabbro. These Pan African granitoids are called Older Granites in Nigeria to distinguish them from the

Mesozoic tin bearing granite complexes of central Nigeria which are referred to as the Younger Granites. Both the migmatite – gneiss complex and the rocks of the schist belts have parallel N – S structures and have conformable field relations.

2.2 Reservoir Siltation

Hill as well as Visentini (1936) and Brown (1943) were among the first authors having described the importance and the means to control reservoir siltation. Methods and techniques for achieving the sustainable use of reservoirs are described in several books and papers, 15 of which are the most comprehensive ones all date from the eighties and nineties (Annandale, 1987; Mahmood, 1987; ICOLD, 1989; Morris and Fan, 1998, Palmieri *et al.,* 2003). Some other observations and measurements before 1990 are reported in Tadjikistan (Pyrkin *et al.,* 1978), USA (Ford and Johnson, 1981), Canada (Weirich, 1984, 1986), Ecuador (Jervez, 1985), and Japan (Chikita, 1989).

A daily measurement of stage is usually sufficient in lakes and reservoirs for the purpose of calculating changes in storage (Vuglinskiy *et al.,* 2009). Estimation of the amount of sediment stored in reservoirs is the product of complex bathymetry, uncertain knowledge of prereservoir topography, and uncertain estimates of the density of the stored sediments (Graf *et al.,* 2010). Progress in surveying and mapping methods and in instrumentation has been rather pronounced in recent decades. Electronic distance meters such as microwaves, lasers and infra red light devices are widely used. Aerial surveys together with underwater depth sounding are also commonly used. The Global Positioning System (GPS) or the Global Navigation Satellite System (GNSS) positions the soundings with respect to the

surface of the earth. The Global Positioning System (GPS) and Geographic Information System (GIS) have caused a revolution in this field (Zhide and Yuqian, 2003).

Each reservoir independent of its use can have its storage capacity reduced as a result of deposition over the years (Althaus and De Cesare, 2006). A dam causes reduction in flow velocity and consequently in turbulence, which causes the settling process of the materials carried by the river (Frenette and Julien, 1996; Campos, 2001; Chella *et al.,* 2003; Abood *et al*., 2009). Due to flow deceleration, when a river approaches a reservoir, the sediment transport capacity decreases and some of the incoming sediment is trapped and deposited in the reservoir (Raghunath, 1986; Frenette and Julien, 1996). The coarser materials deposit first forming delta at the head of the reservoir, and then finer material settles forming the bottom sediment, spreading throughout the reservoir (Abood *et al*., 2009; Tigrek *et al*., 2009). As the water continues to flow into the reservoir, the delta continues to grow in the direction of the dam, until it eventually fills the entire reservoir volume (Figure 4).

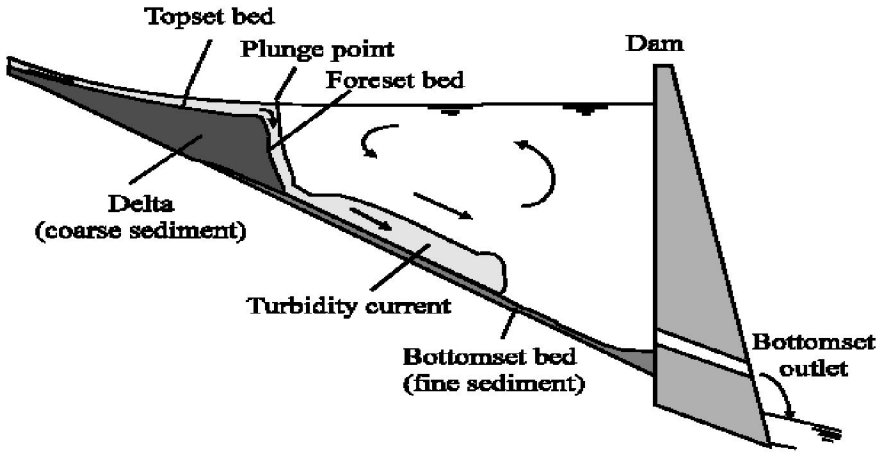


Figure 4. Schematic presentation of siltation mechanism in reservoirs (Sloff, 1997)

Sediment deposition in reservoirs causes loss of water storage capacity (Graf, 1984; Fan and Morris, 1992; Yoon, 1992; Cobo *et al.,* 1997; Avendano *et al.,* 1997; Sloff, 1997; Carvalho, 1998; White, 2000; Goel *et al.,* 2002; and Jain *et al.,* 2002). Both catchment and impoundment characteristics control the rate and pattern of sediment deposition within a reservoir (Molino *et al*., 2001). Hydrology, geology and land use determine the sediment yield, and the properties of sediment delivered to the reservoir (Jain and Kothyari 2000; Small *et al.,* 2003; Lee 2004; Jain *et al.,* 2005). The rate at which a watershed contributes sediment to its streams is affected by both natural and human factors; the primary natural factors include rainfall amounts and intensity, soil type, bed rock outcrop, topography, groundcover and vegetation (Fried *et al.,* 2000; Abood *et al*., 2009; USWP, 2010). Human activities can alter most of these natural factors and consequently can have a strong impact upon the resulting erosion and siltation rates.

The current estimate of total reservoir storage worldwide is around 7000 km^3 (ICOLD, 1997). Mahmood (1987) raised concerns about loss of reservoir storage capacity due to sedimentation. It is estimated that more than 0.5 % of the total reservoir storage volume in the world is lost annually as a result of sedimentation (White, 2001). However, Jacobsen (1999) states that there are no accurate data on the rates of reservoir sedimentation worldwide, but it is commonly accepted that about 1 – 2 % of the worldwide capacity is lost annually. The introductions of sediment management measures in some older dams, were appropriate, and in the design of new ones could help to reduce sedimentation problem (Palmieri *et al.,* 2003). There have been a few case studies conducted on sustainable management of water resources, e.g., by Arntzen (1995), Bobba and Singh (1997), Carroll and Turpin (1997), Charlton (1997), Nguyen (2000). These studies strongly call for

incorporating the sustainability criteria in early stages of planning. A balance must be struck between current and future water requirements on the one hand and maintenance of a minimum water level, on the other. As many of the reservoirs end up holding much of the sediment load themselves (Chakela, 1980; Iguisi, 1997; Verstraeten and Poesen, 2000; Haregeweyn *et al.,* 2006; Tamene *et al.,* 2006; Schumm, 2009).

Sediment load is defined as debris eroded from an area drained by a stream, delivered to and transported by the stream itself (Schumm, 2009). The sediment yields of various drainage basins are expected to be high because of the observed poor environmental practices (Turner *et al.*, 1990; IGBP-BAHC 1997). The current pace of environmental change prompted partly by degradation continues at an alarming proportion (Eswaran *et al.,* 2001; Weller 2005 in Nwilo and Adeleke, 2008). Reservoirs whose drainage basins are rapidly undergoing urbanization, continuous cultivation, logging, mining and perennial bush burning are usually more vulnerable to siltation (Iguisi, 1997; A.B.U. Committee on protection of the Kubanni dam drainage basin, 2008; Jain and Das, 2010). Many reservoirs are losing storage capacity at alarming rate due to environmental degradation within the drainage basin (A.B.U. Committee on protection of the Kubanni dam drainage basin, 2008). Sediment movement into water channels by flood and storm water occur as a result of soil erosion in the drainage basin. Erosion processes are generally slow; however, the annual volumes of sediment load involved are huge (U.S. Department of Agriculture-Soil Conservation Service, 1992). According to an estimate, the global production of sediment is about 2×10^{10} t / year (Alam, 2001).

Due to continuous deposition and encroachment of the live storage by sediment, siltation study is gaining much attention (Garde, 1995; Morris and Fan, 1997; Varshney, 1997). The

approach adopted to study a particular reservoir depends upon the size of the reservoir in relation to its inflows, the sediment regime in the river and the purpose of the reservoir. There are several guidelines which one can use to decide how critical siltation is likely to be in a particular reservoir; Churchill (1948); Brown (1950) and Brune (1953) produce trap efficiency of reservoir which is defined as the percentage of total inflowing sediment that is retained in the reservoir.

Gottschalk (1951); USACE (1989); Zhide and Yuqian (2003), outlined methods of conducting reservoir siltation studies. The volume of sediment accumulated in a reservoir is computed as the difference between the present water capacity of the reservoir and a known water capacity of some prior date usually the original capacity. Heinemann and Rausch (1971) stated that the sediment deposits may change because of compaction between successive studies. USACE (1989) and Zhide and Yuqian, (2003) outline that three methods are most commonly used to measure erosion and deposition in reservoirs and river reaches, namely the Contour area (topographic survey) methods, Cross-section area (range-line) methods and the composite method (combination cross-section contour Area methods). However, Utah State Water Plan, (USWP) (2010) outline two ways to measure the present reservoir volume, a range survey and a contour survey. A range survey uses a sonar device to measure water depth along preset range lines that cross the reservoir at regular intervals. The contour survey (or bathymetric survey) also uses a sonar device to measure water depth, and incorporates a Global Positioning System (GPS) to determine the boat location. An approximate grid pattern is followed across the entire reservoir surface. The overall sedimentation rate is determined using the original reservoir volume, the present volume, and the number of years since the reservoir began storing water.

Selecting a method depends mainly on the topography of the studied area and the accuracy desired (Zhide and Yuqian, 2003). The contour area methods are based upon the assumption that the area encompassed by a contour line and the contour interval can adequately represent the volume between any successive contour elevations. There are four contour area methods: Stage-area, Modified prismoidal, Average contour area, and Simpson's rule.

a. Stage-Area Method: This method requires an accurate stage-area curve. The stage-area curve is developed by planimetering the area inside a contour line and plotting it against the contour elevation. Reservoir volume is calculated by integrating the area between this "contour area curves".

b. Modified Prismoidal Method: This method is based upon an averaging of the areas of two successive contour lines and a geometric mean area all multiplied by the contour interval to obtain the volume between the contour elevations. It is expressed mathematical as the frustum cone formula: $V = 1/3\ (A + B + (AB)^{1/2})\ L$.

Where V = Volume between two contour elevations, L = Contour interval, A = Area of lower contour, B = Area of upper contour.

c. Average Contour Area Method: This method uses the averaging of two contour areas multiplied by the contour interval. It is expressed mathematical as $V = (L/2) \times (A+ B)$, variables are same as above.

d. Simpson's Rule: This method requires the contour interval to be constant if using contour-area data. If cross section area data is used, the cross sections must be parallel and evenly spaced, both requiring even number of segments.

The development of current collection systems has made the contour method the preferred method for data collection and analysis. Manual sounding poles, sounding weights and echo sounders are commonly used for depth measurements (Zhide and Yuqian, 2003). A bell shaped sounding weight or a sounding pole may be used to take soundings where an echo sounder is not available (Soil Conservation Service, 1973). The accuracy of a sedimentation survey, needless to say, relies on the accurate positioning of measuring points, particularly in places where the sediment deposition is not appreciable (Zhide and Yuqian, 2003). The use of Differential Global Positioning System (DGPS) made possible positioning accuracies of 1 to 2 m, which is acceptable in a hydrographic survey (Ferrari and Dorough, 1998). Ferrari and Dorough (1996) used two approaches in computing the reservoir capacity from topographic survey data: the point elevation-area method and the conventional contour-area method. A computer program is used for efficient and economically feasible data evaluation. In the point elevation-area method, the surveyed area is large and has a high data density. With the development of electronic measuring and computerized collection and analysis systems, the contour method of creating new reservoir topographic maps has become the preferred method for reservoir sedimentation surveys. The ARC/INFO package is used to develop reservoir topography from the collected data. ARC/INFO is a software package for using the GIS. Contours for the reservoir area at selected elevation intervals are computed from the compiled data using the TIN (triangular irregular network) modelling package within ARC/INFO. The Area-Capacity Computation Program is used to generate elevation versus capacity and / or surface area for the reservoir area. The amount of deposition or erosion is the difference of capacities under the specified elevation computed for two surveys (Ferrari and Dorough,

1996). Obviously, at points where no deposition or erosion takes place, the elevation of the bed surface should coincide with that measured in a previous study. This is a good check of the accuracy and reliability of the siltation measurement method. Heinemann and Dvorak (1965) determined reservoir capacity of several small reservoirs using stage-area, modified prismoidal, Eakin's range formula, Simpson's Rule (range cross-sectional area method), average contour area, and cross-sectional area versus distance from dam methods. They found all these methods to be fairly accurate. Contour methods are generally used for original volume computation because of availability of contour maps or the relative ease of obtaining more accurate contour maps by aerial photometric procedures.

Methods used to collect information necessary for water storage capacities and sediment accumulation investigations in reservoirs have changed over the decades. Changes in the methodologies substantially affect the ability to quantitatively compare results between studies and temporal changes in sediment accumulation; however, it improves the quality of results obtained. Natural Resources Conservation Service (NRCS) used the range method, which utilized a number of transects to determine the cross-sectional area of reservoirs at different locations (EA Engineering, Science and Technology, Inc., 1989). The OWRB (2006) conducted hydrographic survey of Okemah lake adhering to US Army Corps of Engineer (USACE) standards (USACE, 2002) using a combination of Echo sounder and GPS, the depths are then checked manually with a weighted measuring tape to ensure that the echo sounder is properly calibrated and operating correctly. It has been standard practices to estimate a lake stage curve from its bathymetry since the 1930's using sounding lines and since the 1950's using fathometers (Dost and Mannaerts, 2004). With the introduction of Global positioning system (GPS) satellite navigator in the 1990's the

positioning of the depth recordings improved (Dunbar *et al.,* 1999). In recent years radar altimetry proves to be an efficient alternative to monitor periodic variations in large water bodies and has potential to measure inland water surfaces as well. It is derived from the topography within its footprint resulting in an area aggregation and not a point measurement such as obtained using traditional gauges (Dost and Mannaerts, 2004).

By the use of remote sensing in conjunction with geographic information system (GIS), the temporal change in water-spread area can by analyzed to evaluate the sediment disposition (Goel *et al.,* 2002). With the availability of high-resolution satellite data, capacity surveys of reservoirs by remote sensing technique are gaining recognition and acceptance. A number of studies using this approach have been carried out (Solomonson, 1973; Bartoluci *et al.,* 1977; Holeyer, 1978; Khoram, 1981; Manvalan *et al.,* 1991; Goel and Jain, 1996; 1998; Gupta, 1999; Goel *et al.,* 2002; Jain *et al.,* 2002; Liebe *et al.,* 2005; Adediji, 2005; Sawunyama *et al.,* 2006; Pillco and Bengtsson, 2007; Adediji and Ajibade, 2008). Smith *et al.,* (1980) determined siltation in the Aswan High Dam Reservoir by comparing reflectance values in the green and red portions of the spectrum. The surface area of the entire reservoir was determined by totalling all pixels classified as water. Rao *et al.,* (1985) used a visual interpretation technique on large scale imagery of Landsat-MSS to estimate the water-spread area at different levels. They used these water-spread estimates to evaluate the capacity of the reservoir and concluded that the results are comparable with hydrographic survey observations. Mohanty *et al.,* (1986) computed water spread of Hirakud Reservoir from multi-date Landsat-MSS imagery and reported that the area capacity curves derived using remote sensing data, were almost similar to the curves obtained from the conventional methods. Vibulsresth *et al.,* (1988) employed digital

techniques in which density slicing of Landsat-MSS near-infrared (IR) data was performed for extracting the water-spread area of Ubolratana Reservoir in Thailand. They correlated computed surface areas with the water levels and calculated the reservoir capacity based on the surface area obtained using cone formulae. Goel and Jain (1996) carried out a reservoir sedimentation study using the density-slicing approach for water-spread area extraction. They used IRS-1 A (LISS II) data to evaluate reservoir sedimentation in Dharoi Reservoir, India.

Bathymetric studies can be accomplished using many different techniques; the simplest approach is to measure depth using a weighted line or an echo sounding device (Moreno and Garcia, 1989; Linhart and Lund, 2008). Ortt *et al.,* (2000, 2007) collected bathymetry data for the following reservoirs in USA, Loch Raven and pretty boy, liberty, Triadelphia and Rocky Gorge respectively using differential global positioning system (DGPS) techniques and digital echo sounding equipment. Some recent studies employed the use of satellite technology such as interfrometric synthetic aperture radar (INSAR) to measure lake depth (Jeffries and Morris, 2000). The most common method for sample location is the recording of GPS coordinates, depths and location can then be imported into a GIS to generate bathymetric maps or three dimensional models and calculate lake area and volume (Leonard and Coughlan, 1997; Guay *et al.,* 1999; Mueller, 2009). Pillco and Bengtsson (2007) determine the hypsographic curve for Lake Poopo in Bolivia by combining manual measurements using rod, analysis of satellite images, and water balance computations. They state that the bathymetry of a lake is usually determined rather easily by traversing the lake in a fast boat, using echo sounding and GPS. The existing techniques for estimating reservoir capacity include direct methods (reservoir surveys) and indirect

methods (use of topographical maps) (Sawunyama *et al.,* 2006). Sawunyama *et al.,* (2006) estimate small reservoir capacities using remotely sensed surface areas, in conjunction with depths of water accompanied with their coordinates acquired from the field. Liebe *et al.,* (2005) mapped the outline of reservoirs using GPS and the reservoir surface using GPS referenced depth measurements with a telescopic stadia rod from a boat.

Yoon, (1992) states that approximately 1 % of the storage volume of worlds reservoir is lost annually due to sediment deposition. The 'useful' life of a reservoir is often defined as the time taken for 90 % of the live storage to be depleted (Halcrow Water, 2001). The operational life of a reservoir is normally determined by the point in time at which sediment accumulations reduce the reservoir yield below supply requirements. Mahmood (1987) give the global average total sediment yield as 190 t/km^2/yr. Walling (1988), Dearing and Foster (1993) give 50 t/km^2/yr as typical value of suspended sediment yield for Britain and cites site specific yield measurements between 1 and 488t/km^2/yr. In Britain, the rate at which reservoir capacity is lost by sedimentation is low by global standards (Halcrow Water, 2001). It is reported that the global average for the useful life of a reservoir is less than 25 years (Mahmood, 1987) whereas the average for British reservoirs is considerably longer and in a number of cases already exceeds 100 years (Halcrow Water, 2001). In China; in 1989, 232 large and medium size reservoirs had a total loss of 11.5 billion m^3 accounting for 14.3 % of the total capacity of 80.4 billion m^3 (Qian, 1994). In India, measurements of reservoir sedimentation indicate that the average annual loss in storage capacity of nine important reservoirs is between 0.34 and 1.79 percent (Zhide and Yuqian, 2003). The analysis of the reservoir sediment deposit data for South African dams showed that almost 25 % of the total numbers of reservoirs have lost between 10 to 30 % of their

original storage (Msadala, 2009). Analysis of the results showed that the average annual storage loss due to sedimentation in South African reservoirs is approximately 0.3 %. This scenario adversely affects the long term sustainability of the reservoirs (Msadala, 2009). Rooseboom (1978) estimated that the total sediment delivery from South Africa, Lesotho and Swaziland amounts to between 100 and 150 Million t/a. Sediment yields vary from less than 1000 t/km^2/a in specific catchments. The Welbedacht reservoir in South Africa, completed in 1973 with a 152.2 million m^3 storage capacity, lost most of its storage capacity (66%) within the first 13 years of its existence (Rooseboom, 1992). In Brazil, many reservoirs have been subjected to increasing losses of their storage capacities (Carvalho, 1998). Wiebe and Brennan (1973) noted that the John Martin reservoir (Colorado, USA) lost 7.5 % of its capacity in its first 15 years but that half of this loss was the product of two extreme storms. The Habra reservoir in Algeria lost 58 % in 22 years, and the Wuchieh reservoir in Taiwan lost 98.7 % in 35 years (Zhide and Yuqian, 2003). In arid and semi-arid regions, reservoir sedimentation problems become most acute where the loss of storage capacity by reservoir sedimentation is above 1 to 2 percent per year and the lifetime of most reservoirs is only 20 to 30 years (Zhide and Yuqian, 2003).

The rates of sedimentation calculated are dependent upon the accuracy not only of a recent study but also of the original survey at the time of dam construction and on comparability between the two (White *et al.,* 1996; Halcrow Water, 2001). Duck and McManus (1994); Foster and Lees (1999) carried out measurements of reservoir sediment to estimate the rate of infilling since construction. Foster and Lees (1999) used dated reservoir bottom sediment to provide long term measures of sediment yield, relying on the sediment within the reservoir being relatively undisturbed. The interaction between catchment characteristics,

climate and population pressure, determines the sediment yield from drainage basins (Dooge, 1984). Rooseboom (1978) delineated areas with similar sediment yield potentials on the basis of soil type, geomorphology and geology. Rapp *et al.,* (1972) monitored sedimentation in four reservoirs in Tanzania by periodic relevelling and concluded that some of them would have a total life of only 30 years. Bruk (1985) summarized the views of an international panel of expert contributors and concluded that, in the long run, watershed management is the best way to reduce the yield of sediment and its entry into the reservoir. Kennedy *et al.,* (1985) state that reservoirs are greatly influenced by tributary inflows and their water conditions reflect geographic, climatic and watershed characteristics. White *et al.,* (1996) state that the nature of the vegetation and land use in a catchment will have some impact on the sediment yield of rivers draining it. Bassoon and Rooseboom (1999) also commented upon the complex nature of the relationship between erosion and sediment yield. Butcher *et al.,* (1992) highlighted the need to consider the importance of changing management practices such as the introduction and abandonment of catchwater systems that influence sediment transfer. Mahmood (1987) stated that, intuitively, the first method of reducing reservoir siltation would be to reduce sediment yield from the basin upstream by watershed (catchment) management. However, Hufschmidt, (1986) has shown that intensive conservation efforts spanning several decades may be needed to reduce sediment yields by 10–20 percent for catchments that exceed 1000 km^2. The rate of siltation in a reservoir decreases with time as the storage capacity is reduced, until a residual river channel remains in the reservoir. The difference between the original total storage capacity and the remaining storage is called the storage of siltation. It

is important to estimate the process of siltation in order to estimate the benefit of a reservoir.

CHAPTER 3

MATERIALS AND METHODS

The following are the list of materials and data used in this study.

- **Boat, GPS, metric tape and weight (weighted line), graph paper and notebook.**
- **Topographic map of Minna, sheet 164 SW and SE on a scale of 1:50,000.**
- **Google image of Tagwai Reservoir on a scale of 1:10,000 and a paper coordinator.**
- **Digitized Topographic Map of Tagwai Dam Drainage Area on a scale of 1:50,000.**
- **Landsat images of Tagwai Reservoir**
- **Global mapper and Google earth softwares**

3.1 Study approach

The collection of coordinates along the edges of the reservoir to delineate edge of the open water surface with satellite navigator (GPS). Measurement of the remaining depth is carried out in a slow moving boat, using a weighted line and a hand held GPS. Depth in meters below the open water surface is measured from a boat (plate 2) with a weighted line. Northeasterly wind caused waves which reduce vertical accuracy of measurements. Also, due to this wind, the water surface is not horizontal but sloped slightly from the northeast to the southwest.

Points of measurement are located with a Global Positioning System (GPS). It is read twice (just before and after measurement) and the boat is immobilized with paddles at the time of depth readings, to minimize error of location due to drift at every measurement point.



Plate 2. MEASUREMENT OF THE REMAINING DEPTH IN THE TAGWAI IMPOUNDING RESERVOIR ON 15TH DECEMBER, 2010. The tools used are boat, satellite navigator, and metric tape and weight (Weighted line).

Measurements of depth are adjusted to the level of the spillway (Plate 3) located on the map in Figure 5. Outline of the open water surface in Figure 5 is gotten from the perimeter coordinates measured using GPS on 13th and 14th December, 2010 Table 4 in appendix 1, and reconciled with the Google image of the reservoir gotten from the internet website "Google-Earth". It represents the extent of water spread area of the reservoir in the year 2010.

Measurements were carried out at the time when the reservoir has a maximum storage capacity, at the end of rainy season.

For the depth measurement, irregular network of points was used. This was done from a boat using a measuring tape with a weight tied to its end. This is the remaining depth,

measured in metres at that particular point. The same procedure was repeated for all sampling points randomly selected but closely spaced, within the extent of the reservoir surface area in order to determine the depth at each respective point.



Plate 3. Spillway with open water surface 0.35 m below level of the spillway.

Depth measurements already taken from points are then located on an already prepared map from coordinates collected from edge of open water surface to a scale 1:10,000 using a paper coordinator. Isobaths were interpolated between the depth points.

The area bounded by the water body was then measured by the least square method (graph paper method). The area calculated, which is enclosed between successive isobaths is then multiplied by the average depth obtained to get the volume.

3.2 Bathymetric Data Collection

3.2.1 Bathymetric Mapping

Track lines running perpendicular to the river channels were established; these track lines were spaced approximately 5 m close to the dam and 10m upstream and extended shoreline to shoreline. Additionally, the track lines were run along the perimeter of the reservoir to assist in the surface modeling. The track lines are evident in Figure 5. The bathymetric mapping was conducted in December, 2010.

3.2.2 Mean Pool Level Adjustment

The bathymetric data collected presented measurements based upon the distance between the surface of the water in the reservoir and the top of the water-sediment interface. Due to fluctuations in the reservoirs level, the bathymetric data are adjusted to a known reference level i.e. the level of the spillway. These water levels and adjustments are documented in Table 5 appendix 2.

3.3 Bathymetric Interpretation and Volumetric Calculations

Bathymetric data were interpreted manually by inspection and averaging the values. Development of sounding systems that use global positioning systems technology for horizontal position location enabled whole reservoir coverage. The raw data are processed using a coordinator and least square method. This help to create bottom topography model of the reservoir. A two meter isobaths were drawn by analyzing the depths, from which storage and siltation rates can be calculated by finding the area enclosed by the individual isobaths using the least square method.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 The Bathymetry

The results of this study provided various resource maps and reasonable estimates of the reservoir's volume, surface area, and depth. Figure 5 is the bathymetric map of Tagwai reservoir. It illustrates the relationship of the reservoir's volume, surface area, and depth.

All results of measurements done from 15th to 21st December, 2010, Table 5 in appendix 2 are plotted on map in Figure 5. Results shown in Table 6 are derived from map Figure 5. It is observed that the year 2010 average weighted depth of the reservoir is 5.76 meters below the level of the spillway.

Table 6. Results of the measurements of the remaining storage.

Depth interval Below Spillway (m)	Area of Depth Interval (m^2)	Average Depth of Water (m)	Volume of Water (m^3)
0 – 2	503,999	1	503,999
2 – 4	840,259	3	2,520,777
4 – 6	887,179	5	4,435,895
6 – 8	591,583	7	4,141,081
8 – 10	404,685	9	3,642,165
10 – 12	298,724	11	3,285,964
12 – 14	194,718	13	2,531,334
14 – 16	32,844	15	492,660
>16	5,865	16.5	96,773
TOTAL	3,759,856	5.76	21,650,648

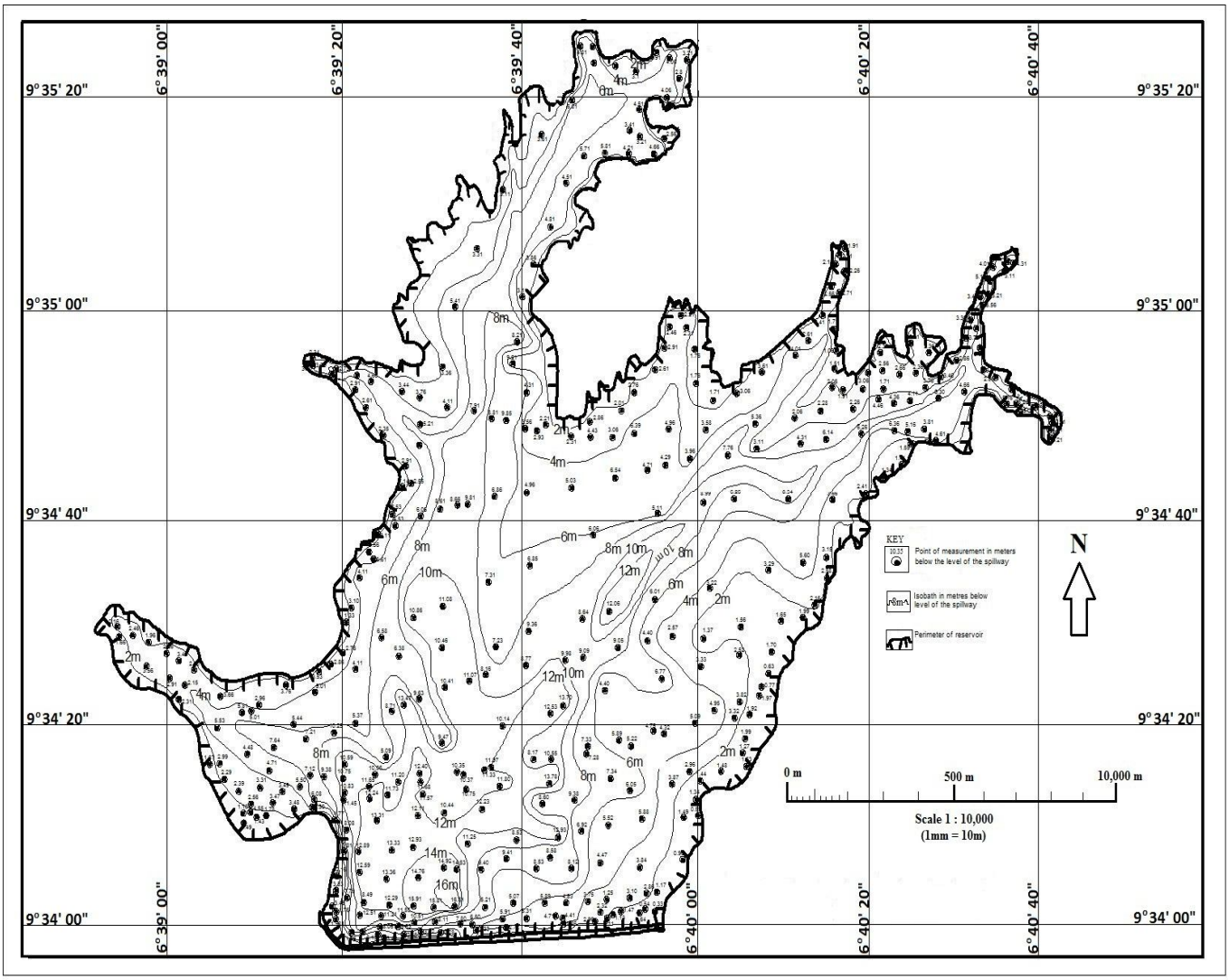


Figure 5. Bathymetric Map of Tagwai Reservoir (Contour Intervals; 2 m).

4.2 Onset and Cessation of the Hydrological Dry Season

Recording of the gauge readings, on the gauges installed by Niger State Water Board upstream from the reservoir, has since long ago stopped. However, meteorological dry season (i.e. from the cessation of the rains to the onset of the rains) starts in Minna, as earlier mentioned, on 26th October and ends on 8th April i.e. 165 days later. For the purpose of this study, it is the Hydrological dry season (i.e. the period between the cessation and the beginning of the spillway flow at Tagwai dam) that is needed and not the meteorological dry season.

The average date of cessation of spillway flow, as observed by the author himself in years 2010 and 2011, is 25th November. The start of the rains in April relieves the pressure on water at about 20th April, which gives a dry period of 146 days.

4.3 Area of the Open Water Surface

Outline of the open water surface in Figure 5 is derived from the perimeter coordinates measured using GPS on 13th and 14th December, 2010 presented in Table 4; appendix 1 and reconciled with the Google image of the reservoir downloaded from the internet website "Google-Earth" of European Space Agency (ESA) satellite image. The image was downloaded on the 13th of December 2010; therefore it represents the extent of water spread area of the reservoir in the hydrological dry season.

Area of open water table measured by least square method (graph paper method) is 3,759,856 m^2. Thus, since impoundment in 1978, the area of open water surface is reduced by (5,500,000 - 3,759,856) = 1,740,144 m^2 to remaining (3,759,856 : 5,500,000) x 100 % = 68 percent of the original area. Thus, rate at which the area shrunk between 1978 and 2010 is

1,740,144 m^2 : 32 years = 54,380 m^2 / year, or 32 % : 32 years = 1 % of the original area per year.

The open water surface of the reservoir will cease to exist in 100 % : 1 % = 100 years from the date of impoundment of the reservoir i.e. in the year 2079. However, long before it ceases to exist, due to siltation, the reservoir will stop to serve its purpose.

4.4 Position of the outlet Pipes Relative to the Level of the Spillway

The outlet pipes is at an elevation of 240 m (amsl) and the spillway at an elevation of 258.3 m (amsl), which makes the outlet pipes to be 16.3 m below level of the spillway. The submerged intake structure with a 3 m^2 fixed trash tracks are two NOS 24" diameter steel pipe with concrete surrounds and a downstream stilling basin (Plate 4).



Plate 4. Two 24" diameter outlet pipes, discharging water to a concrete aqueduct, in which it is flowing to the treatment plant

4.5 The Remaining Storage and Rate of Siltation

The current storage is the same as the total storage as well as the active storage of the reservoir presently because the dead storage is already silted up. Remaining storage calculated from the map (Figure 5) method of calculation shown in Table 6 is 21,650,648 m^3 or (21,650,648 m^3 : 28,300,000 m^3) x 100 % = 76.5 % of the original storage. Thus, rate at which the storage shrunk between 1978 and 2010 is 6,649,352 m^3 : 32 years = 207,792.25 m^3 / year, or 23.5 % : 32 years = 0.73 % of the original storage per year. Total storage in year 1978 is 28,300,000 m^3 (NSWB, 1982). Therefore, since impoundment in the year 1978, losses to siltation is (28,300,000 m^3 - 21,650,648 m^3) = 6,649,352 m^3 during a period of 32 years or (6,649,352 m^3 : 32 years) = 207,792.25 m^3 / year. This corresponds to the annual loss to siltation of (207,792.25 m^3 : 28,300,000 m^3) x 100 % = 0.73 %.

The reservoir will be completely silted up in (28,300,000 m^3 : 207,792.25 m^3 / year) = 136 years from the date of impoundment of the reservoir i.e. in the year 2114. Thus, the predicted date of disappearance of the Tagwai reservoir due to complete siltation in the year 2114 is a better than the earlier predicted date of its disappearance from the map as year 2079 due to rate of shrinkage of the open water surface. However, the process of siltation in Tagwai reservoir is quite slow but relentless. The concept of sustainable development as defined by the World Commission on Environment and Development in 1987 (Tortajada, 2001) as development that meets the needs of the present without compromising the ability of the future generation to meet their own needs, be seriously considered because long before it disappear, the reservoir cannot serve its intended purpose.

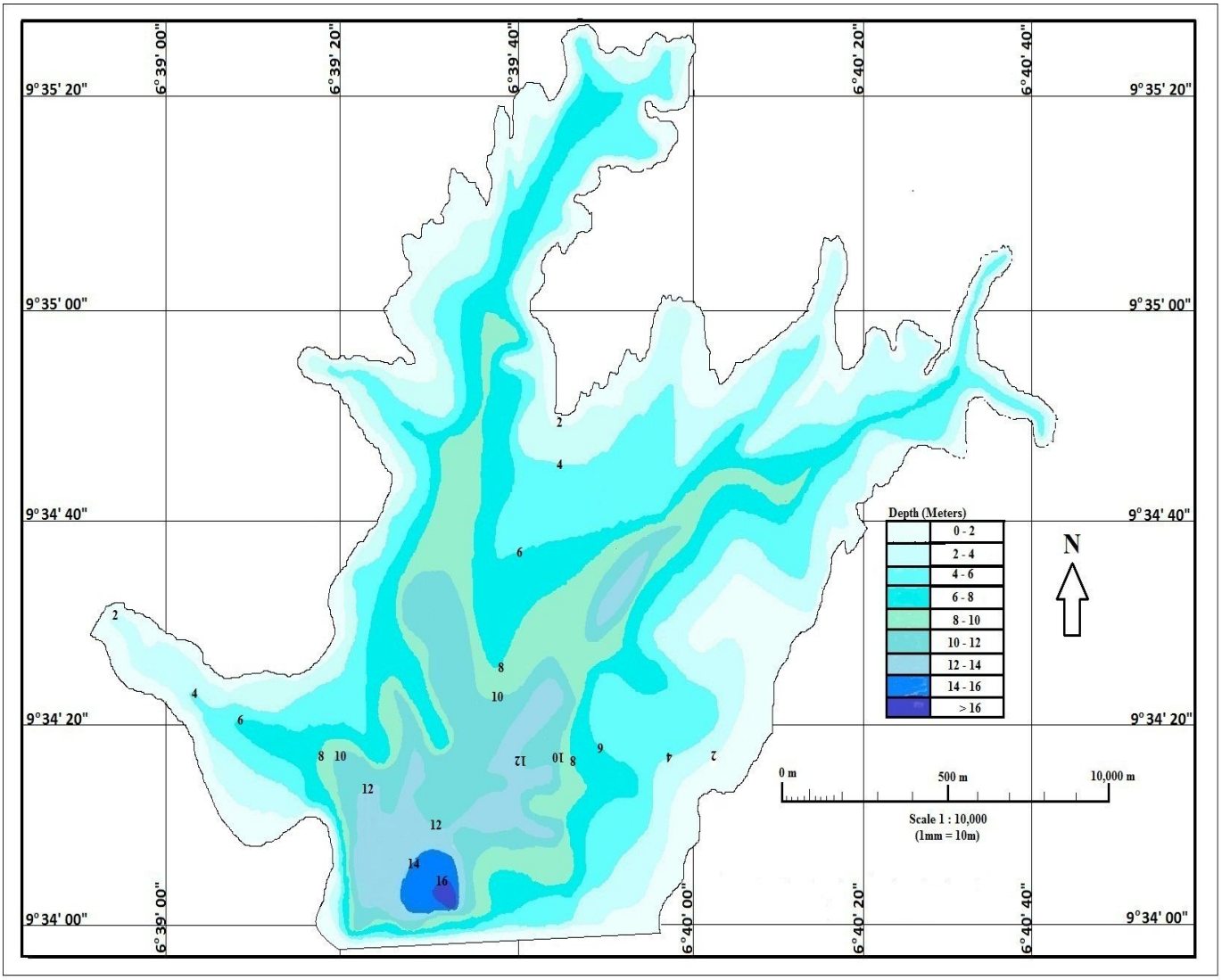


Figure 6. Relief Bathymetric Map of Tagwai Reservoir (Contour Intervals; 2 m).

4.6 Loss on Storage to Evaporation and Seepage

The average date of cessation of spillway flow in Tagwai reservoir is 25th November. From this date to the date of measurement of Tagwai reservoir (15th December, 2010) are 21 days. During these 21 days water surface fell by 0.35 m below the level of the spillway in the reservoir. This correspond to the decrease in volume of water of 1.316 x 10^6 m^3, i.e. (0.35 x 3.76 x 10^6) where 0.35 m is depth of water surface below level of the spillway and 3.76 x 10^6 m^2 is the area of open water surface below the level of the spillway. Out of these, with average pumping rate of 27,000 m^3 / d during the period from 25th November to 15th December, (27,000 x 21) = 567,000 m^3 was pumped out of the reservoir. The remaining referred to as total loss of water on storage, (1.316 x 10^6 – 567,000) = 749,000 m^3 were lost to evaporation during the 21 days between cessation of spillway flow date and date of the measurement.

The daily rate of water loss to evaporation and seepage is (749,000 / 21) = 35,666.67 m^3/d. Mean annual duration of the hydrological dry season is 146 days. The start of the rains in March relieves the pressure on water at about 20th April, which gives a dry period of 146 days. Loss of water to evaporation and seepage during the whole hydrological dry season is (35,667 m^3/d x 146 days) = 5,207,382 m^3. However, there is no visible seepage under the dam, hence loss due to seepage is negligible. Loss of water to evaporation from the open water surface is 5,207,382 m^3/dry season i.e. (5,207,382 m^3/dry season / 3.76 x 10^6 m^2) = 1.385 m/dry season.

4.7 Safe Yield in Dry Season

Safe yield of the reservoir on the last day of depth measurements, 21.12.2010 was ((28,300,000 m^3 - 5,207,382 m^3) / 146 days) = 158,168.616 m^3/d. Since the water storage of the reservoir is reduced by siltation at a rate of 207,792.25 m^3/d, it will take (28,300,000 m^3 - 3,942,000 - 5,207,382 m^3) : 207,792.25 m^3/y = 92 years to reduce safe yield from the present 158,168.616 m^3/d to 27,000 m^3/d that is to the volume of water daily pumped from the reservoir.

This implies that until year 2010 + 92 = 2102 there will be enough water in the Tagwai Reservoir to serve its design purpose. In other words, any water shortage experienced before year 2102 will have its source in the inability of the Waterworks to pump enough water from the reservoir. After (28,300,000 - 5,207,382 m^3) : 207,792.25 m^3 / year = 111 years, i.e. in year 2010 + 111 = 2121, safe yield will be reduced to zero. In other words, from year 2103 to year 2121, water available for pumping will be gradually reduced at the end of this period to zero in the dry season although there will be water during the wet season. From year 2103 to year 2114 Tagwai Reservoir will exist as a shallow, seasonal water body, drying completely up towards end of dry season. In year 2114 to 2121 Tagwai Reservoir will disappear from maps.

4.8 Rate of Surface Erosion (Sediment Yield) in Tagwai Dam Drainage Basin

Various methods can be used to estimate the rate of surface erosion or the rate of sediment yield from a watershed:

- **Universal soil loss equation. A = RKLSCP (Wischmeier and Smith, 1962), where**

  A = computed soil loss in tons $acre^{-1}$ $year^{-1}$,
  R = rainfall factor,

K = soil-erodibility factor,
L = slope-length factor,
S = slope-steepness factor,
C = cropping-management factor,
P = erosion-control practice factor.

- **Sediment yield as a function of drainage area.**

  $Q_S = 2.4A_d^{-0.229}$ (Strand, 1975)
  $Q_S = 1.84A_d^{-0.24}$ (Strand and Pemberton, 1982)

  Where: Qs = sediment yield in acre-feet per square mile per year
  A_d = drainage area in square miles.

- **Sediment yield as a function of nine drainage basin characteristics.**

This method classifies sediment yield as a function of nine individual drainage basin characteristics. These nine drainage basin characteristics are surface geology, soil, climate, runoff, topography, ground cover, land use, upland erosion, and channel erosion.

This is a subjective procedure for estimating an annual basin erosion rate. It can be used as a reference for assigning drainage basin sediment yield classes.

Table 7. Drainage basin characteristics and possible range of numerical ratings (modified from Pacific Southwest Inter-Agency Committee, Water management Subcommittee, 1968).

Drainage basin	Sediment yield levels:

Characteristic	High rating	Moderate rating	Low rating
Surface geology	**10: marine shales and related mudstones and siltstones**	**5: rocks of medium hardness moderately weathered and fractured**	**0: massive hard formations**
Soils	**10: fine textured and easily dispersed or single grain silts and fine sands**	**5: medium textured, occasional rock fragments, or caliche crusted layers**	**0: frequent rock fragments, aggregated clays, or high organic content**
Climate	**10: frequent intense convective storms**	**5: infrequent convective storms, moderate intensity**	**0: humid climate low intensity rain, arid climate with low intensity rainfall, or rare convective rain**
Runoff	**10: high flows or volume per unit area**	**5: moderate flows or run off volume per unit area**	**0: low flows or volume per unit area or rare runoff events**
Topography	**20: steep slopes (in excess of 30%), high relief, little or no flood plain development**	**10: moderate slopes (about 20%), moderate flood plain development**	**0: gentle slopes (< 5%), extensive flood plain development**
Ground cover	**10: ground cover less than 20%, no rock or organic litter in surface soil**	**0: ground cover < 40%, noticeable organic litter in surface soil**	**-10: area completely covered by vegetation, rock fragments, organic litter with little opportunity for rainfall to erode soil**
Land use	**10: more than 50% cultivated, sparse vegetation, and no rock in surface soil**	**0: < 25% cultivated, < 50% recently logged, < 50% intensively grazed**	**-10: no cultivation, no recent logging, and only low intensity grazing, if any**
Upland erosion	**25: rill, gully, or landslide erosion over more than 50% of the area**	**10: rill, gully, or landslide erosion over about 25% of area**	**0: no apparent signs or erosion**
Channel erosion	**25: continuous or frequent bank erosion, or active headcuts and degradation in tributary channels**	**10: occasional channel erosion of bed or banks**	**0: wide shallow channels mild slopes, channels in massive rock, large boulders, or dense vegetation or artificially protected channels**

Table 8. Drainage basin sediment yield classification (Modified after Randle, 1996).

Drainage basin classification number	Total rating	Annual sediment yield (mm)
1	**>100**	**>0.147**
2	**75 to 100**	**0.049 – 0.147**

3	50 to 75	0.0245 – 0.049
4	25 to 50	0.0098 – 0.0245
5	0 to 25	<0.0098

Table 9. Estimated numerical ratings for Tagwai reservoir drainage basin.

Drainage basin characteristics	possible ratings	Estimated sediment yield rating	Estimated description
Surface geology	0 – 10	5 Moderate	varies from crystalline rocks to unconsolidated alluvium and colluvium
Soil	0 – 10	5 Moderate	surface material is ferruginous soil, rock fragment and bedrock outcrops
Climate	0 – 10	5 Moderate	distinct dry and wet season, moderate intensity rains
Runoff	0 – 10	10 High	high volume / unit area, high runoff
Topography	0 – 20	5 Low	gentle slopes, flood plain development
Grand cover	-10 – 10	0 Moderate	area moderately covered by vegetation, noticeable organic litter in surface soil
Land use	-10 – 10	0 Moderate	active cultivation and grazing
Upland erosion	0 – 25	10 Moderate	low apparent signs of erosion, upland compose of older more consolidated rocks, rill erosion noticeable
Channel erosion	0 – 25	10 Moderate	occasional erosion of beds and Banks, wide channels
Total rating	–	50 Class 3	0.0245 – 0.049 mm

Based on information in Tables 7 and 8, the estimated sediment yield rating and the 100 year sediment yields for the Tagwai Reservoir are shown in Tables 9 and 10, respectively.

Table 10. 100 years sediment yield estimate for Tagwai reservoir drainage basin.

Reservoir	Drainage name	Area (km^2)	100 year sediment yield (m^3): at 0.0245	at 0.049 (mm)
Tagwai dam	Tagwayi (Tagwai)	110	269.5	539

Employing the empirical sediment yield equations developed strictly as a function of the drainage area based on sediment data by Strand (1975) and Strand and Pemberton (1982) gives results within the same bracket with that based on drainage basin characteristics (Table 11).

Table 11. Sediment yield of Tagwai reservoir as a function of drainage area

Empirical sediment yield equation	sediment yield (mm)
$Q_S = 2.4A_d^{-0.229}$ (Strand, 1975)	0.049833
$Q_S = 1.84A_d^{-0.24}$ (Strand and Pemberton, 1982)	0.036652

4.9 Remote Sensing Application

The procedure used to estimate surface area of a reservoir from satellite image follows the acquisition of the images. Two landsat images with ID 214-089 and 220-596, dataset ETM+, WRS: P/R 189/053 produce by USGS, Ortho GLS 2000 and 2005 with date of satellite over pass 24/10/2001 and 7/11/2006 respectively were acquired from the Global land cover facility website.

The images were captured at the end of the rainy season i.e. October and November. The rainy season is typical of a wet period, when the reservoir is expected to be full, so the satellite images capture the reservoir maximum surface area. The reservoir is extracted through maximum likelihood classification (Mather, 1999) of landsat images. The visible red and the two infra red bands are well suited for the detection and delineation of open water bodies. Using red-green-blue channels, water bodies are depicted in colours ranging from blue to almost black. In bands 4 and 5, the spectra reflectance curve of water is low,

whereas that of soil and healthy vegetation are high. This contrast allows us to distinguish between open water and the surrounding land surface. The inclusion of the visible band enhances the contrast between water and soil (Kite and Pietroniro, 2000).

Global mapper 11 package with spatial analyst is used to automate surface area calculations and to provide the surface area of the reservoir.

To derive the reservoir storage volume, the area-volume model equation developed by Liebe *et al.*, (2005) for the estimation of reservoir storage volumes as a function of their remotely sensed surface areas for upper east region of Ghana is adapted. The area based volume estimation is made possible because these regions are morphologically and morphometrically regular. The reservoirs are located in the stream channels, and the morphometry of stream channels are a response to the surface runoff characteristics of these areas (Windmeijer and Andriesse, 1993).

The theoretical derivation of the relationship starts with a square based, top down pyramid that is diagonally cut in half, in order to approximately represent the shape and volume of a reservoir (Figure 7). The goodness of fit between measured and modeled volumes can be evaluated. The widely used model efficiency measures of Nash and Suttcliffe (1970) indicates that the model explains 97.5% of the measured variance. Despite the variety of reservoir shapes, the derived equations are highly consistent. The Area-volume relationship from different basins point to the fact that the approach is robust and repeatable, and that the method can be used with confidence.

The final equation is summarized as thus: $V = 0.00857 \times A^{1.4367}$ Liebe *et al.*, (2005) is used to derive the storage (Table 12). The result shows progressive decrease in both area and storage of the reservoir for the studied years irrespective of technique used.

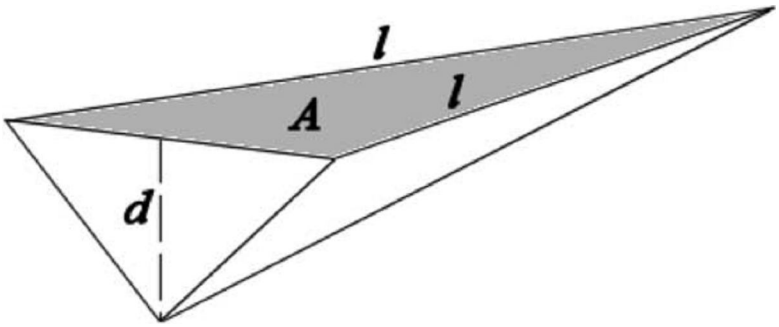


Figure 7. Reservoir model (Liebe et al., 2005).

The volume of such a body is $V_{half\ pyramid} = 1/6 \times A \times d$.

A is the area defined by the square of its characteristic side length l. As depth d can be expressed as a fraction 1/f of a side length l, written as $V_{half\ pyramid} = 1/6 \times l^2 \times 1/f \times l$.

This is the equation for the expected area–volume relationship on a log–log plot.

Table 12. Tagwai Reservoir remaining storage calculated from Landsat image

Year	Technique	Area (m^2)	Volume (m^3)
2001	Remote sensing	3,988,511	26,083,489.39
2006	Remote sensing	3,864,264	24,924,111.06
2010	Field Measurements	3,759,856	21,650,648.00

CHAPTER 5

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.2 Summary

Depths were measured using the traditional method, a weighted sound line and a handheld Global Positioning System (GPS) device to locate the measurement point. Measurement using the weighted sound line is not limited to areas with relatively clear water and shallow depths. Due to the nature of the reservoir and the presence of submerged vegetation, the sound line method provided more complete coverage by slowly paddling through the submerged vegetation and taking measurements. Data in Table 5; appendix 2 shows the depths measured with their corresponding coordinate.

Figure 5 shows the bathymetry of Tagwai Reservoir with the greatest depths measured close to the dam. These depths are located near the south-west end of the reservoir and left to the spillway on the south-east end.

The 2010 bathymetry for Tagwai Reservoir is presented in Figure 5 and 6. The deepest portion of the reservoir, with depths up to 16 m, is close to the dam. The reservoir depths gradually decrease toward the upstream ends of the main stem and tributaries. The calculated storage volume of the reservoir is presented in Table 6.

Due to the high spatial density of collected data and the shape of the reservoir, the manual method honors every data point and creates a surface that preserves the original data points and shoreline. This method estimated reservoir volumes correctly as it connects points in order of their magnitude rather than following straight line. In Tagwai Reservoir, the calculated storage volume is 21,650,648 m^3.

In agreement with Leonard and Coughlan (1997), the integration of GPS measurements is successful in producing a bathymetric map and, in this work, a model of Tagwai Reservoir.

Data analysis was able to provide the change in storage in the reservoir. At the reference elevation, the overall accuracy of the volume and surface area is expected to be high. The greatest sources of error seem to result from adjusting the open water surface to the reference elevation and from weighted line sounding (measurements) over unconsolidated bottom material (silt and organic mud). The elevational error is greatly reduced because data collection occurred mostly on windless days and during periods when the overall reservoir level is being held constant (no waves). The weighted line sounding (measurements) error is reduced by reading the GPS twice (just before and after measurement) and the boat immobilized with paddles at the time of depth readings, to minimize error of location due to drift at every measurement point, but is never completely overcome in backwater areas.

Several factors need consideration when following these procedures. For example, it was important to have a background map and real-time GPS display of the boat's position. This procedure aided in navigation and eliminated certain gross errors. Nevertheless, and even with all the data augmentation, the bathymetric map is very representative of Tagwai Reservoir and provides a useful water management information. The study allows Water resources managers and researchers to make some informed water management decisions in the future.

5.2 Conclusion

Tagwai Dam was constructed in 1978. Original design records indicate that the reservoir has a 5.50 x 10^6 m^2 surface area and had a total storage capacity 28.3 x 10^6 m^3 of water at full capacity. However, this study delineated 3,759,856 m^2 surface area and a total storage

capacity of 21,650,648 m^3 at full capacity i.e. at spillway flowing (Table 6). Average weighted depth of water (5.76 m) is below flowing spillway; total storage capacity is only active storage capacity because dead storage capacity is already silted up. Siltation of the Tagwai Impounding Reservoir, if unchecked and allow to continue at the present rate of 0.73 % of the original volume/year, will result in the disappearance of the reservoir in the year 2114; however, the rate of shrinkage of the surface area of the reservoir between 1978 and 2010 is 1 % of the original area per year i.e. the open water surface of the reservoir will cease to exist in the year 2079. However, long before it ceases to exist, due to siltation, the reservoir will stop to serve its purpose.

This study is based on field measurements and summary of more than 170 literature references. The study will fill the gap in knowledge concerning the present state of Tagwai Reservoir. The existing methods for reservoir water level observations are well developed and sufficient to obtain data accurately enough for further processing and analysis. However, improvements of the techniques and calibration of the instrumentations for water level measurements are necessary. Information about depth is best obtained by performing measurements from a slowly moving boat, utilizing a weighted line or an echo sounder. The procedure is cumbersome and difficult to get measurements that cover the whole reservoir bottom area. Thus, relating the reservoir surface area derived from satellite images to landmark elevation simplifies the procedure of deriving a bathymetry for reservoir, even if information about the deepest parts cannot be obtained. A problem in determining the bottom configuration is that the wind can significantly tilt the water surface (waves), as well as the fact that because of the extremely small slope of the reservoir shores, the water could move with the wind up the shores during studies.

5.3 Recommendations

1. To prevent siltation of the reservoir their must be reduction especially of the rate of shrinkage of the surface area of the reservoir by environmental upgrading of the drainage area.

2. Grazing and farming activities upstream of the reservoir should be stopped to reduce the volume of sediment carried by erosion water, if possible the entire drainage area.

3. Bush burning and deforestation should be stopped within the drainage basin and afforestation encouraged.

4. The International Data Centre on Hydrology of Lakes and Reservoirs (HYDROLARE) should be made operational and accessible for practical purposes and scientific analysis.

5. Reservoir owners should be proactive in addressing siltation. They should collect data to assess their reservoirs situation, determine when significant shortages may occur, and develop long-range management plan.

6. The Water Resources Ministries / Water Boards should help reservoir owners collect, analyze and interpret the data to determine the extent of siltation and possible impacts to reservoir users. In addition, they should help identify potentially applicable sediment management alternatives. They should also establish and maintain a long-term database of siltation data and reports.

7. The Water Resources Ministries / Water Boards should identify and exercise options that exist within the law to protect sites for additional and replacement storage capacity, both surface and subsurface.

8. Water users should support organizations that are already involved in watershed management, so they can continue to improve watershed management programs and target problem areas.

9. The Water Resources Ministries / Water Boards should identify and make the most of opportunities to educate and inform the water community about siltation issues.

CHAPTER 6

CONTRIBUTION TO KNOWLEDGE

This study has produced a bathymetric map of Tagwai Reservoir of Minna, Niger State on a scale of 1:10,000 as a contribution to the knowledge of the hydrogeology of the region. Also, the study has updated the knowledge of the remaining storage of the reservoir, which

was mostly based on estimated storage at impoundment. This study delineated the maximum surface area of the reservoir at full capacity i.e. when the spillway is flowing. The maximum surface area of the reservoir is superimposed on the topographical map of Minna sheet 164 SW and SE to show the reservoir (water spread area) on the map and the entire drainage basin.

REFERENCES

Abood, M.M., Thamer, A.M., Abdul Halim, G., Ahmed, R.M. and Lariyah, M.S., (2009). Review study and assessment for sedimentation models applied to impounding reservoirs. Journal of Engineering and Applied Sciences. 4(2) :152-160.

A.B.U. Committee on Protection of the Kubanni Dam Drainage Basin. (2008). Reports on results of measurement of the remaining storage in Kubanni Impounding Reservoir and proposal for upgrading the environment in the Kubanni Drainage Basin.

Adediji, A. (2005). Reservoir Sedimentation: The Case of Opa Reservoir Catchment, Southwestern Nigeria. J. S. Afr. Geogr, 87 (2), 123 –128.

Adediji A., and Ajibade L.T. (2008). The change detection of major dams in Osun State, Nigeria using remote sensing (RS) and GIS techniques. Journal of Geography and Regional Planning Vol. 1(6), pp. 110-115. http://www.academicjournals.org/JGRP ISSN 2070-1845

Adekeye, J. I. D and Ishaku, J. M. (2004). Groundwater Contamination in Shallow Aquifers of Jimeta Metropolis, Adamawa State, N.E. Nigeria. *Zuma Journal of Pure and Applied Sciences.* 6 (1):150-159.

Adeniyi, J. O. (1985). Geophysical Investigation of the Central Part of Niger State of Nigeria. Ph.D thesis, University of Wisconsin, Madison. U.S.A.

Ajibade, A.C. (1972). The Geology of the Zungeru Sheet, M.Sc Thesis, University of Ibadan, Nigeria. (Unpublished).

Ajibade, A. C. (1976). Provisional classification and correlation of the schist belt of NW Nigeria In: Kogbe, C.A. (Ed.) Geology of Nigeria. Elizabethan Publ. Co. Lagos, Nigeria. Pp 85-90.

Ajibade A.C. (1980). Proterozoic Crustal Development in the Pan-African Regime of Nigeria. In: C.A. Kogbe (Editor) Geology of Nigeria Published by Rock View (Nigeria) Ltd; pp. 57-63. Ltd; pp. 57-63.

Ajibade, A.C. (1982). The origin and emplacement of older granites of Nigeria, some evidences from Zungeru Region. J.M. Geol. Vol. 19. No. 1 pp. 221-223.

Ajibade, A.C., Woakes, M. and Rahman, M.A. (1987). Proterozoic crustal development in Pan African region of Nigeria, copy right on Amer. Geophysical Union.

Annandale, G. W. (1987). "Reservoir Sedimentation". Vol. 29 in Developments in Water Science. Amsterdam, Netherlands: Elsevier Science Publishers.

Alam, S. (2001). "A critical evaluation of sedimentation management design practice". International Journal on Hydropower & Dams, Issue 1, Aqua-Media International, Sutton, Surrey, ISSN 1352-2523.

Althaus, J.J. and De Cesare, G. (2006). Reservoir Sedimentation. Sustainable Sediment Management in Alpine Reservoirs considering ecological and economical aspects. Volume 3. Neubiberg. www.alpreserv.eu

Arntzen, J. (1995). "Economic Instruments For Sustainable Resource Management: The Case of Botswana's Water Resources" *Ambio*, 24(6): 335–342.

Avendaño Salas, C., Cobo Rayán, R., Sanz Montero, E., and Gómez Montaña, J. L. (1997). "Capacity situation in Spanish reservoirs". Question 74a Performance of reservoirs sedimentation, Proc. of 19th Congress on Large Dams, Florence, Italy, 1997. ICOLD, Paris, France, pp. 849-862.

Avendaño Salas, C., Sanz Montero, E., Cobo Rayán, R., and Gómez Montaña, J. L. (1997). "Sediment yield at Spanish reservoirs and its relationship with the drainage basin area". Question 74a Performance of reservoirs sedimentation, Proc. of 19th Congress on Large Dams, Florence, Italy, 1997. ICOLD, Paris, France, pp. 863-874.

Bartoluci, L. A., Robinson, B. F. & Siiva, *XL XL* (1977) Field measurement of spectral response of natural waters. *Photogvamm. Engng Remote Sens.* 43(5).

Basson and Rooseboom, A. (1999). *Dealing with Reservoir Sedimentation—Dredging.* Water Research Commission, South Africa.

Bertrand, J.M.L. and Caby, R. (1978). Geodynamic evolution of the Pan Africa orogenic belts. A new interpretation of the Hogger shield. Geol. Rundsch., 67, 357-388.

Bobba, A. G. and Singh, V.P. (1997), "Sustainable Development of Water Resources in India," *Environmental Management*, 21(3): 367–393.

Brown, C.B. (1943). Discussion of sedimentation in reservoirs, by J.Witzig, ASCE, 109, PP 1080-1086.

Brown, C. B. (1950). "Sedimentation," Engineering Hydraulics, Hunter Rouse, Ed., Proceedings of the Fourth Hydraulics Conference, Iowa Institute of Hydraulic Research.

Bruk, S. (1985). Methods of computing sedimentation in lakes and reservoirs, IHP-II Project.

Brune, G.M., (1953). Trap efficiency of reservoirs. *Transactions*, American Geophysical Union, Volume 34, Number 3, pp 407-418.

Burke, K., Freeth, S.J. and Grant, N.K. (1976). The structure and sequence of geological events in the Basement Complex of the Ibadan area, Western Nigeria. Precambrian Res., 3, pp537-545.

Butcher, D. P., Clayton, J., Labadz, J. C., Pattison, V. A., Potter, A. W. R. & White, P. (1992). Reservoir sedimentation and colour problems in Southern Pennine reservoirs. *J. Instn Water Environ. Manage.* 6, 418–430.

Campos, R. (2001). Three Dimensional Reservoir Sedimentation Model. PhD Thesis, University of Newcastle-Upon-Tyne, UK.

Carroll, B. and Turpin, T. (1997). "Environmental Strategies for Sustainable Development: A New Town in Mallorca," *Journal of the Chartered Institution of Water and Environmental Management,* 11(4): 235–24.

Carvalho, O.N., (1998). Sedimentation and protection of reservoirs, VI National symposium of erosion control, ABGE, Brazil.

Chakela, Q. K. (1980) Reservoir sedimentation within Roma Valley and Maliele catchments in Lesotho. *Geogr. Ann.* 62A(3–4), 157–169.

Chanson, H. and James, P. (1998). Teaching Case Studies in Reservoir Siltation and Catchment Erosion. Int. J. Engng Ed. Vol. 14, No. 4, p. 265-275.

Charlton, J. (1997). Application of Waste Stabilization Ponds In Bhutan—Lessons within a Sustainable Development Context, *Water Science and Technology*, 35(9): 199–208.

Chella, M. R., Ota, J. J. and Povh, P. H. (2003). In: Althaus, J.J. and De Cesare, G. (2006). Reservoir Sedimentation. Sustainable Sediment Management in Alpine Reservoirs considering ecological and economical aspects. Volume 3. Neubiberg. www.alpreserv.eu

Chikita, K. (1989). "A Field Study on Turbidity Currents initiated from Spring Runoffs". Water Resources Research, Vol. 25, No. 2, pp. 257-271.

Churchill, M.A., (1948). Discussion of "Analysis and use of reservoir sedimentation data" by L.C. Gottschalk, in *Proceedings, Federal Inter-Agency Sedimentation Conference, Denver, Colorado, 1947,* (US Bureau of Reclamation), 139-140.

Cobo Rayán, R., Sanz Montero, E., Gómez Montaña, J. L., Avendaño Salas, C., and Plata Bedmar, A. (1997). "Influence of the Puentes reservoir operation procedure on the sediment accumulation rate between 1954-1994". Question 74a Performance of reservoirs sedimentation, Proc. of 19th Congress on Large Dams, Florence, Italy, 1997. ICOLD, Paris, France, pp. 835-847.

Dearing, J. A. & Foster, I. D. L. (1993) Lake sediments and geomorphological processes: some thoughts. In: *Geomorphology and Sedimentology of Lakes and Reservoirs* (ed. by J. McManus & R. W. Duck), 5–14. John Wiley & Sons Ltd, Chichester, West Sussex, UK.

Dooge , J.C.I., (1984). The waters of the earth. Hydrol. Sci. J. Vol. 29. 149-176.

Dost, R.J.J. and Mannaerts, C.M. (2004). "Bathymetry generation using sonar and satellite imagery". Presented at ISPRS: proceedings of the XXth ISPRS congress : *Geo-imagery bridging continents*, 12-23 July 2004, Istanbul, Turkey.

Duck, R. W. and McManus, J. (1994). A long-term estimate of bedload and suspended sediment yield derived from reservoir deposits. Journal of Hydrology vol. 159 pp 365-373.

Duck, R. W. & McManus, J. (1984) A marker horizon in reservoir sediment cores resulting from wartime agricultural changes in central Scotland. *Scot. Geogr. Mag*. 100, 184–189.

Duck, R. W. and McManus, J. (1990) Relationships between catchment characteristics, land use and sediment yield in the Midland Valley of Scotland. In: *Soil Erosion on Agricultural Land* (ed. by J. Boardman, I. D. L. Foster & J. A. Dearing), 285–299. John Wiley & Sons Ltd, Chichester, West Sussex, UK.

Dunbar, J.A., Allen, P.M., and Higley, P.D., (1999). Multifrequency acoustic profiling for water reservoir sedimentation studies: Journal of Sedimentary Research, v. 69, n. 2, pp. 521-527.

EA Engineering, Science and Technology, Inc., (1989). Sedimentation in Triadelphia and Rocky Gorge Reservoirs: Project # 10769.01, EA Mid-Atlantic Regional Operations, Sparks, Maryland

Eswaran, H., Lal, R., and Reich, P.F. (2001.) Land degradation: an overview. In: Bridges E.M., Hannam, I.D., Oldeman, L.R., Penning de Vries F.W.T., Scherr, S.J., and Sombatpanit, S. (eds) Response to land degradation. Science, Enfield, pp 20–35

Etiosa, U. (2006). Dams are unrenewable - A Discussion Paper. Community Research and Development Centre (CREDC) Nigeria, Benin City Nigeria, p 3-8.

Fan, J. and Morris, G. L. (1992). "Reservoir Sedimentation. II: Reservoir Desiltation and Long-Term Storage Capacity", ASCE, Journal of Hydraulic Engineering, Vol. 118, No. 3.

Federal Surveys of Nigeria, (1967). Topographic map of Minna, Sheet 164 SW and SE In: Tagwai Dam Project Progress Report. Water Resources and Engineering Construction Agency, (WRECA), Kano State.

Ferrari, R. and Dorough, W. (1996). Chapter 3-4 — Measuring deposited materials, and Chapter 3-5 — Determination of volume of deposits. International Conference on Reservoir Sedimentation, Colorado State University, Fort Collins.

Ferrari, R. and Dorough, W. (1998). *Cascade Reservoir 1995 Sedimentation Survey*. Sedimentation and River Hydraulics Group, Water Resources Services, Technical Service Center, Denver

Ford, D. E., and Johnson, M. C. (1981). "Field observations of density currents in impoundments". Proceedings of the Symposium on Surface Water Impoundments, Vol. 2, Minneapolis, Minn, USA, June 2-5 1980. Published by ASCE, New York, pp. 1239-1248.

Foster, I. D. L. and Lees, J. A. (1999) Changes in the physical and geochemical properties of suspended sediment delivered to the headwaters of LOIS river basins over the last 100 years: a preliminary analysis of lake and reservoir bottom sediments. *Hydrol. Processes* 13, 1067–1086.

Frenette, M. and Julien, P.Y., (1996). Physical processes governing reservoir sedimentation. Proceedings of the International Conference on Reservoir Sedimentation. Vol. 1, Colorado State University, Fort Collins, Sept. 11-16, 121-142.

Fried, J.S., Brown, D.G., Zweifler, M.O., and Gold, M.A. (2000). Mapping contributing areas of stormwater discharge to streams using terrain analysis. In *Terrain Analysis, Principles and Applications*, 1st ed.; Wilson, J.P., Gallant, J.C., Eds.; John Wiley & Sons: New York, NY, USA. pp. 183-203.

Garde, R. J. (1995) Reservoir sedimentation. State of art report of Indian National Committee on Hydrology. INCOH/SAR-6/95. National Institute of Hydrology, Roorkee, India.

Goel, M. K. & Jain, Sanjav K. (1996) Evaluation of reservoir sedimentation using multi-temporal IRS-1A I.1SS-11 data. ***Asian Pacific Remote Sens. and GIS.J.*** **8(2), 39-43.**

Goel, M. K. and Jain, Sharad K. (1998) Reservoir sedimentation study for Ukai Dam using satellite data. Report no. UM-1 /97-98, National Institute of Hydrology, Roorkee, India.

Goel, M.K., Sharad K., Jain, S.K. and Agarwal, P.K. (2002). Assessment of sediment deposition rate in Bargi Reservoir using digital image processing. Hydrological Sciences-Journal-des Sciences Hydrologiques, 47(S), 81-92. Special Issue: Towards Integrated Water Resources Management for Sustainable Development.

Gottschalk, L. C. (1951). "Measurement of Sedimentation in Small Reservoirs". Proc. of the ASCE, pp. 4-6.

Gottschalk, L. C. (1964). "Reservoir Sedimentation". In: Handbook of Applied Hydrology, V.T. Chow, (Editor), McGraw-Hill, New York, Section 17, pp. 1-33.

Graf, W. H. (1984). "Storage losses in reservoirs", International Water Power and Dam Construction, Vol. 36, N° 4.

Graf, W. L., E. Wohl, T. Sinha, and J. L. Sabo (2010), Sedimentation and sustainability of western American reservoirs, Water Resour. Res., 46, W12535, doi:10.1029/2009WR008836.

Grant, N.K. (1969). The Late Precambrian to Early Paleozoic Pan African Orogeny in Ghana, Togo, Dahomay and Nigeria. Bull. Geol. Soc. Amer. Vol. 80 pp 45-56.

Grant, N.K. (1970). Geochemistry Precambrian Basement rocks from Ibadan, SW Nig. Earth Planet Sci. Lect. 10, pp 29-38.

Grant, N.K. (1978). Structural distinction between a meta-sedimentary cover and an underlying basement in the 600 Ma old Pan African domain of NW Nig. Bull. Geol. Soc. Amer., Vol. 89 pp 50-58.

Griffin, M.L., Beasley, D.B., Fletcher, J.J., and Foster, G.R. (1988) Estimating soil loss on topographically nonuniform field and farm units. J Soil Water Conserv 43:326–331

Gupta, S. C. (1999) Status paper on reservoir sedimentation assessment using remote sensing techniques. In: ***Proc. National Workshop on Reservoir Sedimentation Assessment Using Remote Sensing Data.*** **National Institute of Hydrology, Roorkee, India.**

Guay, B.E., Kunzmann, M., Grünberg, W., and Guertin, D.P. (1999). "Integrating Differential GPS, GIS, and Sonar Measurements to Map the Bathymetry of Topock Marsh, Arizona," *Proceedings of the 1999 ESRI User Conference, San Diego, CA*, Paper 396. http://proceedings.esri.com/library/userconf/proc99/proceed/papers/pap396/p396.htm. [Accessed: 3 August 2009].

Halcrow Water, (2001). Sedimentation in storage reservoirs, final report. Department of the environment, transport and the regions. greenap@halcrow.com

Haregeweyn, N.; Poesen, J.; Nyssen, J.; De Wit, J.; Haile, M.; Govers G.; Deckers S. (2006). Reservoirs in Tigray (Northern Ethiopia): Characteristics and sediment deposition problems. *Land Degrad. Dev. 17*, 211-230.

Heinemann, H. G., and Dvorak, V. I. (1965). "Improved Volumetric Survey and Computation Procedures for Small Reservoirs," from Proceedings of the Federal Inter-Agency Sedimentation Conference, 1963, pp 845-856, Prepared by Agricultural Research Service, U. S. Department of Agriculture, Washington, DC.

Heinemann, H. G., and Rausch, D. L. (1971). Discussion of "Sediment Measurement Techniques: B. Reservoir Deposits," by the Task Committee on Preparation of Sedimentation Manual, Committee on Sedimentation of the Hydraulics Division, Vito A. Vanoni, Chmn, Journal of the Hydraulics Division, ASCE, Vol 97, No. HY 9, Proc. Paper 8345, pp 1555-1561.

Heinemann, H. G. (1984) Reservoir trap efficiency. In: *Erosion and Sediment Yield: Some Methods of Measurement and Modelling* (ed. by R. F. Hadley & D. E. Walling), 825–830. Geobooks, Norwich, UK.

Hill, R. A. (1936). "Silting of reservoirs formed by large dams: its measurement and prevention". Proc. of 2nd Congress on Large Dams, Vol. 5, Washington, USA, 1936. US Government Printing Office, pp. 203-206. In: Althaus, J.J. and De Cesare, G. (2006). Reservoir Sedimentation. Sustainable Sediment Management in Alpine Reservoirs considering ecological and economical aspects. Volume 3. Neubiberg. www.alpreserv.eu

Holeyer, R. J. (1978). Suspended sediment algorithms. Remote Sens. Environ. 10(4), 323-338.

Hufschmidt, M. (1986). Economic Valuation Techniques for the Environment. Baltimore and London: The John Hopkins University Press.

ICOLD (1989). "Sedimentation control of reservoirs". ICOLD International Commission on Large Dams Bulletin 67, Paris, France.

ICOLD (1997). "Question 74a Performance of reservoirs sedimentation". 27 relevant papers, Proc. of 19th Congress on Large Dams, Florence, Italy, 1997. ICOLD, Paris, France.

IGBP-BAHC (International Geosphere–Biosphere Programme) (1997) Modeling the transport and transformation of terrestrial materials to freshwater and coastal ecosystems. IGBP Report, vol. 39. IGBP, Stockholm, Sweden

Iguisi, E. O., (1997). An assessment of the current level of sedimentation of the Kubanni Dam, Savanna Vol. 18. 1. 17-27.

Jacobsen, T. (1999). "Sustainable reservoir development: The challenge of reservoir sedimentation". Hydropower into the next century-III, Gmunden, Austria, Conference Proceedings, pp.719-728.

Jain, M K. and Kothyari, U. C. (2000) Estimation of soil erosion and sediment yield using GIS. *Hydrol. Sci.* .J. 45(5), 771 —786.

Jain, S.K. and Goel, M.K. (2002). Assessing the vulnerability to soil erosion of the Ukai Dam catchments using remote sensing and GIS. Hydrol Sci J 47(1): 31–40

Jain, S. K., Singh, P. and Seth, S. M. (2002). Assessment of sedimentation in Bhakra Reservoir in the western Himalayan region using remotely sensed data. *Hydrol Sci. J.* 47(2), 203-212.

Jain MK, Kothyari UC, and Rangaraju KG (2004). A GIS based distributed rainfall runoff model. J Hydrol, Elsevier Science 299(1–2):107–135

Jain MK, Kothyari UC, and Rangaraju KG (2005). Geographic information system based distributed model for soil erosion and rate of sediment outflow from catchments. J Hydraul Eng ASCE 131(7):755–769

Jain, M.K., and Das, D. (2010). Estimation of Sediment Yield and Areas of Soil Erosion and Deposition for Watershed Prioritization using GIS and Remote Sensing. Water Resour Manage (2010) 24:2091–2112 DOI 10.1007/s11269-009-9540-0

Jeffries, M. and Morris, K. (2000). "Mapping the Bathymetry of Shallow Tundra Lakes Using INSAR Techniques," *Geoscience and Remote Sensing Symposium, 2000, Proceedings*, pp. 2230-2232.

Jervez, L. E. (1985). In: Althaus, J.J. and De Cesare, G. (2006). Reservoir Sedimentation. Sustainable Sediment Management in Alpine Reservoirs considering ecological and economical aspects. Volume 3. Neubiberg. www.alpreserv.eu

Kenndy, R.H, Thornton, K.W, and Ford, D.E. (1985). Characterization of reservoir ecosystems: Developments in hydrology, in Gunnison D (Ed) Microbial Processes in reservoirs. Dr W Junk, Rotterdam.

Khoram, S. (1981) Use of Ocean colour scanner data in water qualitv mapping *Photogrumm. Engwg Remote Sens.* 47(5), 667-676.

Kite, G., and Pietroniro, A., (2000). Remote sensing of surface water. In: Schultz, G.A., Engman, E.T. (Eds.), Remote Sensing in Hydrology and Water Management. Springer, Heidelberg, pp. 217–238.

Kothyari UC, Jain MK, and Rangaraju KG (2002). Estimation of temporal variation of sediment yield using GIS. Hydrol Sci 47(4):693–705

Lee, S. (2004). Soil erosion assessment and its verification using the universal soil loss equation and geographic information system: a case study at Boun, Korea. Environ Geol 45(3):457–465

Leonard, T.J. and Coughlan D.J. (1997). Reservoir bathymetry - Mapping the pitfalls, *Proceedings of the 17th Annual Esri User Conference*. San Diego, California. Paper 538, http://www.Esri.com/library/userconf/proc97/pROC97/tO550/pap538/p538.HTM.

Liebe, J., van de Giesen, N., and Andreini, M., (2005). Estimation of small reservoir storage capacities in a semi-arid environment A case study in the Upper East Region of Ghana. Physics and Chemistry of the Earth, 30 (2005) pp. 448 - 454

Linhart, S.M. and Lund, K.D. (2008). "Bathymetric contour maps for lakes surveyed in Iowa in 2006," United States Geological Survey Scientific Investigations Map 3051, Sheets 2. http://pubs.usgs.gov/sim/3051/. [Accessed 21 July 2009.]

Mahmood, K. (1987). "Reservoir Sedimentation: Impact, Extent, Mitigation". World Bank Technical Report No. 71, Washington, D.C..

Manvalan, P., Rajegowda, G. E. and Srinivas, M. V. (1991) Capacity evaluation of Ghatprabha Reservoir using digital analysis of 1RS L1SS-II data. Project report no. B/003/91, Regional Remote Sensing Service Centre, Bangalore, India.

Mather, P.M. (1999). Processing of Remotely-Sensed Images. An Introduction. Wiley & Sons, Chichester.

McCurry, P. (1970). The Geology of degree sheet 21. Unpublished M.sc Thesis. Dept. of Geol., Ahmadu Bello University, Zaria.

McCurry, P. (1971). Pan African Orogeny in Northern Nigeria. Bull. Geol. Soc. Amer. Vol. 82, pp 3251-3262.

McCurry, P. (1973). Geology of Degree Sheet 21 Zaria, Nigeria. Overseas Geol. Min. Res., No 45, HMSO London.

McCurry, P. (1976). The Geology of the Precambrian to Lower Paleozoic rocks of Northern Nigeria, a review in Geology of Nigeria. Kogbe, C.A. (Ed). Elizabethan Pub. Co. Lagos, pp 15-39.

Minna Water Supply Scheme, (1992). Minna Water Supply – long term studies. Niger State Water and Sanitation Board. Report prepared by Prime Service Engineers, Enugu.

Mohammed, I. N., Aboh, H. O., and Emenike, E. A. (2008). Hydrogeophysical Investigation for Groundwater Potential in Central Minna, Nigeria. Science World Journal Vol. 3 (NO4).

Mohanty, R. B., Mahapatra, G., Mishra, D. and Mahapatra, S. S. (1986). Report on application of remote sensing to sedimentation studies in Hirakud reservoir. Orissa Remote Sensing Application Centre, Bhubaneswar and Hirakud Research Station, Hirakud, India.

Molino, B., Greco, M. and Rowan, J. S. (2001). A 2-D reservoir routing model: Sedimentation history of Abbeystead reservoir, UK. *Water Res. Manage.* 15, 109–122.

Moreno-Amich A. and Garcia-Berthou, E. (1989). "A new bathymetric map based on echo-sounding and morphometrical characterization of the Lake of Banyoles (NE-Spain)," *Hydrobiologia*, vol. 185, pp. 83-90.

Morris, G.L. and J. Fan. (1997). Reservoir Sedimentation Handbook: Design and Management of Dams, Reservoirs and Watersheds for Sustainable Use. New York: McGraw Hill

Morris, G. L., and Fan, J. (1998). "Reservoir Sedimentation Handbook, Design and Management of Dams, Reservoirs and Watersheds for Sustainable Use". New York, McGraw-Hill.

Morris, G.M. and Fan, J. (1999). Reservoir sedimentation Handbook, Design and management of Dams, reservoir and watersheds for sustainable Use. McGraw Hill. 10.6-10.11.

Morris F. L., and Fan J. (2000). "Book Reviews on reservoir sedimentation handbook-design and management of dams, reservoirs, and watershed for sustainable use". J. of. Hydraul. Eng., Volume 126, no.6, pp. 481-482.

Msadala, V.P. (2009). Sediment Yield Prediction Based On Analytical Methods and Mathematical Modelling. Thesis presented in partial fulfilment of the requirements for the degree of Master of Science in Civil Engineering at the University of Stellenbosch, South Africa.

Mueller R. Jr., (2009). "Utilizing Geographic Information Science Advancements for Bathymetric Mapping and Dredging, Assessment of a Small Urban Lake in Southeastern Minnesota." http://www.gis.smumn.edu/GradProjects/MuellerR.pdf. (Accessed 21 July 2009).

Mugabe, F.T., Hodnett, M.G., and Senzanje, A., (2004). Opportunities for increasing productive water use from dam water: a case study from semi-arid Zimbabwe. Agricultural Water Management 62 (2003), 149–163.

Nash, J.E., and Suttcliffe, J.V., (1970). River flow forecasting through conceptual models. A discussion of principles. J. Hydrol. 10, 282–290.

Nguyen, N.T. (2000). *W.C.D. Regional Consultation for East/Southeast Asia: Personal Observations.* Hanoi: World Commission on Dams.

Nigerian Meteorological Agency, NIMET (2006). Mean monthly maximum temperature, (^{o}C) Minna. Meteorological data for school research.

Nigerian Meteorological Agency, NIMET (2006). Monthly total rainfall, (mm) Minna. Meteorological data for school research.

Nigeria Register of Dams, (1995). Federal Ministry of Water Resources and Rural Development. National Subcommittee on Dams / Nigerian Committee on Large Dams.

Niger State Water Board, NSWB, (1982). Making the provision of water a birth right of the people. Progress report for the period of October 1979 to October 1982.

Offodile, M. E. (2002). Groundwater Study and Development in Nigeria. Nigeria. 2nd Ed. Mecon Geology and Engineering Services Ltd. In: C. A. Kogbe (Editor), Geology of Nigeria. Elizabethan Publication. 365-376.

Oklahoma Water Resources Board (OWRB). (2006). Hydrographic Survey of Okemah Lake. State of Oklahoma Water Resources Board the Water Agency.

Ortt, R. A., Jr., Kerhin, R.T., Wells, D.V., and Cornwell, J.C., (2000), Bathymetric Survey and Sedimentation Analysis of Loch Raven and Prettyboy Reservoirs: Maryland Geological Survey, Coastal and Estuarine Geology File Report No. 99-4.

Ortt, R.A., Jr., VanRyswick, S. and Wells, D., (2007). Bathymetry and Sediment Accumulation of Triadelphia and Rocky Gorge Reservoirs: Maryland Geological Survey, Coastal and Estuarine Geology File Report No. 07-03.

Oyawoye, M.O. (1964). The Geology of the Nigerian Basement Complex. Journ. Nig. Min. Geol. And Metell. Soc. Vol. 1 pp 87-102.

Oyawoye, M.O. (1972). The Basement Complex of Nigeria. In African Geology Ibadan 1970 .(Ed) Dessssauvagie and Whiteman. Geol. Dept. Univ. of Ibadan, Nigeria. Pp 67-99.

Pacific Southwest Inter-Agency Committee, Water Management Subcommittee (1968). Factors Affecting Sediment Yield in the Pacific Southwest Area. Selection and Evaluation of Measures for Reduction of Erosion and Sediment Yield.

Palmieri, A., Shah, F., Annandale, G.W., and Dinar, A., (2003). Reservoir Conservation Volume I: The RESCON Approach: Economic and engineering evaluation of alternative strategies for managing sedimentation in storage reservoirs. Publication of the World Bank, Washington, DC, USA.

Patrick, M. (1996). Sedimentation problems with Dams. www.ing.org/basics/ard/index

Pillco, R.Z. and Bengtsson, L. (2007). Three methods for determining the area–depth relationship of Lake Poopó, a large shallow lake in Bolivia. *Lakes & Reservoirs: Research and Management* 2007. 12: 275–284. Doi: 10.1111/j.1440-1770.2007.00344.x

Pyrkin, Y. G., Samolyubov, B. I., And Lashchenov, S. Y, and Korolev, V. N. (1978). "Transport of suspended Sediments in the Nurek Hydroelectric Station Reservoir by a Density Current and Calculation of Siltation of the reservoir". Translated from Gidrotekhnicheskoe Stroitel'stvo, No. 5, Plenum Publishing Corporation, pp. 9-12.

Qian Zhengying, (1994). *Water Resources Development in China*. China Water and Power Press and Central Board of Irrigation and Power.

Raghunath, H.M. (1986). Reservoir sedimentation, hydrology principle, analysis and design. Wiley Eastern Limited. First reprint. Pp 322-330.

Randle, T. J. (1996). Lower Colorado River Regulatory Storage Study Sedimentation Volume. US Bureau of Reclamation, Technical Service Center, Denver, Colorado. 80225, USA. IAHS Publ. no. 249, 1998.

Rapp A, Murray-Rust D.H, Christinsson C and Berry L (1972). "Soil erosion in four catchments near Dodoma, Tanzania". Geografiska Annaller, 54A (3-4), 255-318.

Rao, I.T. G., Rameshwar Rao and Viswanatham, R. (1985). Project report on capacity evaluation of Sriramsagar reservoir using remote sensing techniques. Andhra Pradesh Engineering Research Lab., Hyderabad, India.

Rooseboom, A. (1978). Sedimentation of Reservoirs. Water J. SA. Vol.4. 14-17.

Rooseboom, A. (1992). *Sediment Transport in Rivers and Reservoirs: A South African Perspective.* Report to the Water Research Commission of South Africa.

Rooseboom, A., and Annandale, G. W. (1982). "Sediment movement through reservoir". Question 54a Reservoirs sedimentation and slope stability, Technical and environmental effects, Proc. of 14th Congress on Large Dams, Rio de Janeiro, Brazil, 1982. ICOLD, Paris, France, pp. 373-381.

Russ, W. (1957). The Geology of Parts Niger, Zaria and Sokoto Provinces with Special Reference to the Occurrence of Gold. Nig. Geol. Survey Bull. No.27 sPp 42.

Sawunyama, T., Senzanje A., and Mhizha, A., (2006) Estimation of small reservoir storage capacities in Limpopo River Basin using geographical information systems (GIS) and remotely sensed surface areas: Case of Mzingwane Catchment

Schoeneich, K. (2003). Water Resources Administration in Nigeria. Nigeria Mining and Geosciences Society (NMGS) 39th Annual International Conference "ITAKPE 2003" March 2-8.

Schoeneich, K., and M.L. Garba (2010). Geol 405 "Hydrogeology" Lecture Notes for Students of Geology, Ahmadu Bello University, Zaria.

Schumm, S.A. (2009). *Streamflow and Sediment Yield*; Encyclopedia Britannica: Chicago, IL, USA. www.britannica.com/EBchecked/topic/504801/river/29099/Factors-that-influence-sediment-yield (accessed on 20 July 2009).

Shiklomanov, I.A. and Rodda, J.C. (2003). World water resources at the beginning of the 21st cenyury. Cambridge, Cambridge University Press.

Sloff, C.J. (1997). Modeling reservoir sedimentation processes for sediment management studies. Proc. Conf. Hydropower into next century, portoroz, Slovenia, Aqua media Int., UK., sept.15-17. 513-524.

Small, I.F., Rowan, J.S., and Duck, R.W.(2003). Long-term sediment yield in Crombie Reservoir Catchment, Angus; and its regional significance within the Midland Valley of Scotland. Hydrological Sciences–Journal–des Sciences Hydrologiques, 48(4), 619-635.

Smith, S. E., Mancy, K. H. and Latif, A. F. A. (1980). The application of remote sensing techniques towards the management of the Aswan High Dam Reservoir. In: *14th Int. Svmp. on Remote Sensing of Environment* (San Jose, Costa Rica, 23-30 April 1980), 1297-1307.

Soil Conservation Service, (1973). *National Engineering Handbook*. Section 3, Sediment, USDA, Washington, D.C.

Solomonson, V. V. (1973). Remote sensing applications in water resources. In: *Third Earth Resources Technokrey Svmp.* (Washington DC, USA, 10-14 December, 1973).

Stevenson, K., (2000). The role of small dams in improving rural livelihoods in semi-arid areas. Care Stakeholder Workshop 29–31 August 2000, Masvingo, Zimbabwe.

Strand, R. I. (1975). Bureau of Reclamation procedures for predicting sediment yield, present and prospective technology for predicting sediment yields and sources. In: *Proceedings of the Sediment-Yield Workshop.* USDA Sedimentation Laboratory, Oxford, Mississippi.

Strand, R. I. and Pemberton, E. L. (1982). *Reservoir Sedimentation Technical Guideline for Bureau of Reclamation.* US Bureau of Reclamation, Denver, Colorado.

Tamene, L.; Park, S.J.; Dikau, R.; Vlek, P.L.G. (2006). Reservoir siltation in the semi-arid highlands of Northern Ethiopia: Sediment yield—catchment area relationship and a semi-quantitative approach for predicting sediment yield. *Earth Surf. Process. Landforms 31*, 1364-1383.

Tigrek, S., Gobelez, O. and Aras, T., (2009). Sustainable management of reservoirs and preservation of water quality. Technical perspectives for rational use of water resources in the Mediterranean region. 41-53.

Tortajada, C., (2001). Environmental sustainability of water projects. Doctorial Thesis, Royal Institute of Technology, Stockholm.

Truswell, J.F. and Cope, R.N. (1963). The Geology of parts of Niger and Zaria provinces, Northern Nigeria. Bull. Geol. Surv. Nigeria, 29, 52.

Turner, D.C. (1983). Upper Proterozoic Schist Belts in the Nigerian Sector of the Pan African province of West Africa, Precambrian Res., 21, 55-79.

Turner B.L, Clark W.C, Kates R.W, Richards J.F, Matthews J.T, and Meyer W.B (1990). The earth as transformed by human action. Cambridge Univ. Press, Cambridge

U.S. Army Corps of Engineers (USACE). (1989). Engineering and Design -Sedimentation Investigations of Rivers and Reservoirs, EM 1110-2-4000, Washington, DC 20314-1000.

U.S. Army Corps of Engineers (USACE). (2002). Engineering and Design -Hydrographic Surveying, Publication EM 1110-2-1003, 3rd version.

U.S. Department of Agriculture-Soil Conservation Service. (*1992). Summary Report: National Resources Inventory*; Soil Conservation Service: Washington, DC, USA; Statistical Laboratory, Iowa State University: Ames, IA, USA, 1994.

Utah State Water Plan (USWP). (2010). Managing sediment in Utah's reservoirs. Utah Division of Water Resources.

Varshney, R. S. (1997). Impact of siltation on the useful life of large reservoirs. State of Art Report no. INCOH/SAR-11 /97, INCOH, National Institute of Hydrology, Roorkee, India.

Verstraeten G, Prosser IP, Fogarty P (2007). Predicting the spatial patterns of hillslope sediment delivery to river channels in the Murrumbidgee catchment. Aust J Hydrol 334:440–454

Verstraeten, G. & Poesen, J. (2000). Estimating trap efficiency of small reservoirs and ponds: methods and implications for the assessment of sediment yield. *Progr. Phys. Geogr.* 24, 219–251.

Vibulsresth, S,, Srisangthong, D., Thisayakorn, K,, Suwanwerakamtorn, R., Wongpam, S., Rodpram, C, Leelitharn, S. and Jiltanaon, W. (1988). The reservoir capacity of Ubolratana Dam between 173 and 180 meters above mean sea level. *Asian-Pacific Remote Sens. J.* 1(1).

Visentini, M. (1936). "Alluvial deposits in reservoirs, their importance and the means to lessen or prevent them". Proc. of 2nd Congress on Large Dams, Vol. 5, Washington, USA, US Government Printing Office, pp.169-176. In: Althaus, J.J. and De Cesare, G. (2006). Reservoir Sedimentation. Sustainable Sediment Management in Alpine Reservoirs considering ecological and economical aspects. Volume 3. Neubiberg. www.alpreserv.eu

Vuglinskiy, V., Monteduro, M., Sessa, R., Gronskaya, T., and Cretaux, J.F. (2009). Water level in lakes and reservoirs, water storage. Assessment of the status of the development of the standards for the Terrestrial Essential Climate Variables. Global Terrestrial Observing System (GTOS) Rome. T4 Version 8.

Walling D. E. (1988). Erosion and sediment yield research—some recent perspectives. J Hydrol 100:113–141

Walling, D.E. (1989). "The erosion problem". Intern, J. Sediment Research, Vol. 4, No 1, pp. 1-11.

Weirich, F. H. (1984). "Turbidity currents: monitoring their occurrence and movement with a three-dimensional sensor network". Science, Vol. 224, pp. 384-387.

Weirich, F. H. (1986). "The record of density-induced underflows in a glacial lake". Sedimentology, No. 33, pp. 261-277.

Weller, K. (2005). In: Nwilo, P.C. and Adeleke, A.A. (2008). Dams and the environment: Building a GIS database for Nigerian Dams. Department of Surveying and Geinformatics, University of Lagos, Akoka, Yaba, Lagos.

White P, Habadz J.C and Budtcher D.P (1996): "Sediment yield estimates from reservoir studies: an appraisal of variability in the southern pennines of the United Kingdom". IAHS Special Publication, 276, 164-173.

White, W.R., (2000). Flushing of sediments from reservoirs, prepared for thematic review IV. 5: Operation, monitoring and Decommissioning of Dams. HR Wallingford, UK.

White W. R. (2001). *Evacuation of Sediments from Reservoirs.* London: Thomas Telford.

White R. (2002). "Book Review on evacuation of sediments from reservoirs". Journal of hydraulic research International Association for Hydraulic Research, volume 40, no. 2, pp. 221.

Wiebe, K. and Brennan, L. (1973). Sedimentation in reservoirs. Pp539-561 in Fluvial sprocesses and Sedimentation. Proc. of the Edmonton Symposium.

Windmeijer, P.N., Andriesse, W. (Eds.), (1993). Inland Valleys in West Africa: An Agro-Ecological Characterization of Rice-Growing Environments, ILRI Publication 52. International Institute for Land Reclamation and Improvement, Wageningen.

Wischmeier, W. H. and Smith, D. D. (1962) Soil-loss estimation as a tool in soil and water management planning. In: *Symposium of Pari. 1-8 October 1962. Commission on Land Erosion,* 148-159. IAHS Publ. no. 59.

Yoon, Y. N. (1992). "The state and the perspective of the direct sediment removal methods from reservoirs". International Journal of Sediment Research, Vol. 7(2), pp. 99-116.

Zhide, Z. and Yuqian L. (2003) Reservoir sedimentation and impact on river processes world meteorological organization (WMO) no. 948 Operational hydrology report no. 47 Manual on sediment management And Measurement by yang xiaoqing

APPENDICES

APPENDIX 1.

Table 4. Coordinates of the Perimeter of Tagwai Reservoir

S/No	Latitude (N)	Longitude (E)
1.	9° 33' 59.8"	6° 39' 55.0"
2.	9° 33' 59.7"	6° 39' 53.5"
3.	9° 33' 59.5"	6° 39' 51.7"
4.	9° 33' 58.9"	6° 39' 48.7"
5.	9° 33' 58.9"	6° 39' 47.3"
6.	9° 33' 58.8"	6° 39' 45.6"
7.	9° 33' 58.8"	6° 39' 43.4"
8.	9° 33' 58.8"	6° 39' 40.4"
9.	9° 33' 58.6"	6° 39' 37.6"
10.	9° 33' 58.5"	6° 39' 34.2"
11.	9° 33' 58.5"	6° 39' 31.1"
12.	9° 33' 58.5"	6° 39' 28.4"
13.	9° 33' 58.4"	6° 39' 25.6"
14.	9° 33' 58.2"	6° 39' 21.6"

15.	**9^{o} 33’ 58.7”**	**6^{o} 39’ 18.4”**
16.	**9^{o} 34’ 01.3”**	**6^{o} 39’ 16.5”**
17.	**9^{o} 34’ 09.0”**	**6^{o} 39’ 17.0”**
18.	**9^{o} 34’ 10.0”**	**6^{o} 39’ 18.3”**
19.	**9^{o} 34’ 10.9”**	**6^{o} 39’ 16.1”**
20.	**9^{o} 34’ 10.2”**	**6^{o} 39’ 12.9”**
21.	**9^{o} 34’ 08.5”**	**6^{o} 39’ 08.3”**
22.	**9^{o} 34’ 09.5”**	**6^{o} 39’ 06.4”**
23.	**9^{o} 34’ 15.0”**	**6^{o} 39’ 03.6”**
24.	**9^{o} 34’ 20.4”**	**6^{o} 39’ 02.3”**
25.	**9^{o} 34’ 23.0”**	**6^{o} 38’ 59.8”**
26.	**9^{o} 34’ 23.7”**	**6^{o} 38’ 56.0”**
27.	**9^{o} 34’ 25.4”**	**6^{o} 38’ 54.5”**
28.	**9^{o} 34’ 29.8”**	**6^{o} 38’ 51.9”**
29.	**9^{o} 34’ 32.1”**	**6^{o} 38’ 54.4”**
30.	**9^{o} 34’ 30.2”**	**6^{o} 38’ 57.1”**
31.	**9^{o} 34’ 28.9”**	**6^{o} 38’ 59.3”**
32.	**9^{o} 34’ 28.3”**	**6^{o} 39’ 01.0”**
33.	**9^{o} 34’ 27.5”**	**6^{o} 39’ 02.9”**
34.	**9^{o} 34’ 24.0”**	**6^{o} 39’ 05.8”**
35.	**9^{o} 34’ 24.4”**	**6^{o} 39’ 12.9”**
36.	**9^{o} 34’ 28.6”**	**6^{o} 39’ 19.0”**
37.	**9^{o} 34’ 30.0”**	**6^{o} 39’ 19.0”**
38.	**9^{o} 34’ 33.0”**	**6^{o} 39’ 18.4”**
39.	**9^{o} 34’ 36.8”**	**6^{o} 39’ 21.1”**
40.	**9^{o} 34’ 44.6”**	**6^{o} 39’ 26.1”**
41.	**9^{o} 34’ 53.0”**	**6^{o} 39’ 19.8”**

42.	**9^{o} 34’ 53.9”**	**6^{o} 39’ 17.6”**
43.	**9^{o} 34’ 56.2”**	**6^{o} 39’ 16.1”**
44.	**9^{o} 34’ 54.9”**	**6^{o} 39’ 19.7”**
45.	**9^{o} 34’ 55.4”**	**6^{o} 39’ 20.2”**
46.	**9^{o} 34’ 54.3”**	**6^{o} 39’ 26.1”**
47.	**9^{o} 34’ 55.1”**	**6^{o} 39’ 28.4”**
48.	**9^{o} 34’ 56.5”**	**6^{o} 39’ 29.0”**
49.	**9^{o} 34’ 57.0’**	**6^{o} 39’ 27.1”**
50.	**9^{o} 34’ 59.2”**	**6^{o} 39’ 25.9”**
51.	**9^{o}35’ 02.5”**	**6^{o} 39’ 28.1”**
52.	**9^{o} 35’ 06.1”**	**6^{o} 39’ 27.8”**
53.	**9^{o} 35’ 06.4”**	**6^{o} 39’ 28.9”**
54.	**9^{o} 35’ 07.5”**	**6^{o} 39’ 31.9”**
55.	**9^{o} 35’ 12.2”**	**6^{o} 39’ 33.4”**
56.	**9^{o} 35’ 11.5”**	**6^{o} 39’ 35.2”**
57.	**9^{o} 35’ 08.9”**	**6^{o} 39’ 37.5”**
58.	**9^{o} 35’ 14.6”**	**6^{o} 39’ 37.9”**
59.	**9^{o} 35’ 18.0”**	**6^{o} 39’ 38.9”**
60.	**9^{o} 35’ 16.1”**	**6^{o} 39’ 39.9”**
61.	**9^{o} 35’ 19.4”**	**6^{o} 39’ 40.6”**
62.	**9^{o} 35’ 20.9”**	**6^{o} 39’ 42.4”**
63.	**9^{o} 35’ 18.9”**	**6^{o} 39’ 43.6”**
64.	**9^{o} 35’ 19.9”**	**6^{o} 39’ 45.6”**
65.	**9^{o} 35’ 26.0”**	**6^{o} 39’ 47.7”**
66.	**9^{o} 35’ 25.0”**	**6^{o} 39’ 48.9”**
67.	**9^{o} 35’ 23.5”**	**6^{o} 39’ 49.9”**
68.	**9^{o} 35’ 24.5”**	**6^{o} 39’ 52.6”**

69.	**9^{o} 35’ 23.5”**	**6^{o} 39’ 54.9”**
70.	**9^{o} 35’ 25.2”**	**6^{o} 39’ 55.1”**
71.	**9^{o} 35’ 26.0”**	**6^{o} 39’ 56.9”**
72.	**9^{o} 35’ 24.5”**	**6^{o} 39’ 57.2”**
73.	**9^{o} 35’ 25.7”**	**6^{o} 39’ 59.2”**
74.	**9^{o} 35’ 24.0”**	**6^{o} 39’ 59.6”**
75.	**9^{o} 35’ 18.9”**	**6^{o} 39’ 58.9”**
76.	**9^{o} 35’ 19.0”**	**6^{o} 39’ 54.5”**
77.	**9^{o} 35’ 16.9”**	**6^{o} 39’ 56.4”**
78.	**9^{o} 35’ 16.0”**	**6^{o} 39’ 55.2”**
79.	**9^{o} 35’ 13.9”**	**6^{o} 39’ 48.7”**
80.	**9^{o} 35’ 11.2”**	**6^{o} 39’ 48.2”**
81.	**9^{o} 35’ 09.7”**	**6^{o} 39’ 46.2”**
82.	**9^{o} 35’ 07.8”**	**6^{o} 39’ 47.9”**
83.	**9^{o} 35’ 05.2”**	**6^{o} 39’ 45.4”**
84.	**9^{o} 35’ 05.4”**	**6^{o} 39’ 43.2”**
85.	**9^{o} 35’ 02.6”**	**6^{o} 39’ 43.2”**
86.	**9^{o} 34’ 59.9”**	**6^{o} 39’ 41.3”**
87.	**9^{o} 34’ 55.9”**	**6^{o} 39’ 43.9”**
88.	**9^{o} 34’ 50.6”**	**6^{o} 39’ 43.8”**
89.	**9^{o} 34’ 49.9”**	**6^{o} 39’ 46.2”**
90.	**9^{o} 34’ 01.7”**	**6^{o} 39’ 55.8”**
91.	**9^{o} 34’ 04.8”**	**6^{o} 39’ 57.9”**
92.	**9^{o} 34’ 06.5”**	**6^{o} 39’ 58.2”**
93.	**9^{o} 34’ 08.2”**	**6^{o} 39’ 59.7”**
94.	**9^{o} 34’ 12.9”**	**6^{o} 40’ 01.0”**
95.	**9^{o} 34’ 13.1”**	**6^{o} 40’ 04.2”**

96.	**9° 34’ 17.7”**	**6° 40’ 08.0”**
97.	**9° 34’ 24.1”**	**6° 40’ 08.9”**
98.	**9° 34’ 27.6”**	**6° 40’ 10.8”**
99.	**9° 34’ 29.4”**	**6° 40’ 13.7”**
100.	**9° 34’ 33.1”**	**6° 40’ 14.9”**
101.	**9° 34’ 34.8”**	**6° 40’ 15.7”**
102.	**9° 34’ 36.5”**	**6° 40’ 15.7”**
103.	**9° 34’ 38.0”**	**6° 40’ 17.4”**
104.	**9° 34’ 36.9”**	**6° 40’ 18.2”**
105.	**9° 34’ 38.2”**	**6° 40’ 18.7”**
106.	**9° 34’ 38.3”**	**6° 40’ 19.6”**
107.	**9° 34’ 42.0”**	**6° 40’ 20.6”**
108.	**9° 34’ 44.3”**	**6° 40’ 23.8”**
109.	**9° 34’ 46.2”**	**6° 40’ 31.1”**
110.	**9° 34’ 52.2”**	**6° 40’ 32.6”**
111.	**9° 34’ 49.9”**	**6° 40’ 36.7”**
112.	**9° 34’ 49.8”**	**6° 40’ 39.9”**
113.	**9° 34’ 47.1”**	**6° 40’ 41.2”**
114.	**9° 34’ 50.9”**	**6° 40’ 42.4”**
115.	**9° 34’ 54.9”**	**6° 40’ 34.4”**
116.	**9° 34’ 58.3”**	**6° 40’ 33.7”**
117.	**9° 35’ 05.4”**	**6° 40’ 37.2”**
118.	**9° 35’ 03.1”**	**6° 40’ 33.1”**
119.	**9° 34’ 57.8”**	**6° 40’ 30.3”**
120.	**9° 34’ 55.9”**	**6° 40’ 29.9”**
121.	**9° 34’ 54.0”**	**6° 40’ 28.4”**
122.	**9° 34’ 53.5”**	**6° 40’ 26.9”**

123.	**9^{o} 34’ 56.2”**	**6^{o} 40’ 28.7”**
124.	**9^{o} 34’ 58.5”**	**6^{o} 40’ 25.9”**
125.	**9^{o} 34’ 56.0”**	**6^{o} 40’ 23.9”**
126.	**9^{o} 34’ 57.9”**	**6^{o} 40’ 22.2”**
127.	**9^{o} 34’ 57.0”**	**6^{o} 40’ 20.9”**
128.	**9^{o} 34’ 54.0”**	**6^{o} 40’ 17.9”**
129.	**9^{o} 34’ 56.4”**	**6^{o} 40’ 16.3”**
130.	**9^{o} 35’ 05.8”**	**6^{o} 40’ 15.9”**
131.	**9^{o} 35’ 02.4”**	**6^{o} 40’ 14.8”**
132.	**9^{o} 34’ 58.5”**	**6^{o} 40’ 12.9”**
133.	**9^{o} 34’ 54.5”**	**6^{o} 40’ 05.2”**
134.	**9^{o} 34’ 52.9”**	**6^{o} 40’ 04.6”**
135.	**9^{o} 34’ 52.7”**	**6^{o} 40’ 03.0”**
136.	**9^{o} 34’ 54.3”**	**6^{o} 40’ 01.2”**
137.	**9^{o} 34’ 58.9”**	**6^{o} 40’ 01.0”**
138.	**9^{o} 34’ 59.9”**	**6^{o} 39’ 56.5”**
139.	**9^{o} 34’ 56.4”**	**6^{o} 39’ 55.2”**
140.	**9^{o} 34’ 52.7”**	**6^{o} 39’ 49.7”**
141.	**9^{o} 34’ 50.4”**	**6^{o} 39’ 47.0”**

APPENDIX 2.

Table 5. Coordinates of the measured points of depth of the Tagwai Reservoir. Measurements were made on 15th to 21st December, 2010 from a boat and located with a GPS. 0.35 m is mean depth below the level of the spillway to the open water surface on the days of measurements.

S/No	Latitude (N)	Longitude (E)	Depth below Water Table (m)	Depth below level of Spillway (m)
416.	9° 34' 02.1"	6° 39' 16.6"	0.81	1.16
417.	9° 34' 0.8"	6° 39' 17.5"	1.76	2.11
418.	9° 33' 59.8"	6° 39' 19.0"	1.96	2.31
419.	9° 33' 59'6"	6° 39' 20.5"	3.19	3.54
420.	9° 33' 59.6"	6° 39' 22.3"	3.49	3.84
421.	9° 33' 59.6"	6° 39' 25.1"	2.33	2.68
422.	9° 33' 59.7"	6° 39' 27.1"	3.02	3.37
423.	9° 33' 59.7"	6° 39' 29.7"	2.28	2.63
424.	9° 33' 59.8"	6° 39' 33.5"	2.38	2.73
425.	9° 33' 59.9	6° 39' 37.9"	2.72	3.07
426.	9° 34' 0.0"	6° 39' 43.8"	2.46	2.81
427.	9° 34' 0.0"	6° 39' 47.3"	2.96	3.31
428.	9° 34' 0.2"	6° 39' 48.5"	2.11	2.46
429.	9° 34' 0.4"	6° 39' 49.1"	1.13	1.48
430.	9° 34' 0.5"	6° 39' 52.7"	0.64	0.99
431.	9° 34' 0.6"	6° 39' 54.3"	0.33	0.68
432.	9° 34' 0.8"	6° 39' 53.2"	0.54	0.89
433.	9° 34' 0.5"	6° 39' 53.9"	1.12	1.47
434.	9° 34' 0.7"	6° 39' 50.5"	1.47	1.82
435.	9° 34' 0.6"	6° 39' 47.9"	2.32	2.67
436.	9° 34' 0.7"	6° 39' 43.8"	4.01	4.36
437.	9° 34' 0.7"	6° 39' 43.0"	4.91	5.26
438.	9° 34' 0.4"	6° 39' 39.2"	5.31	5.66
439.	9° 34' 0.5"	6° 39' 36.3"	5.91	6.26
440.	9° 34' 0.2"	6° 39' 33.3"	6.50	6.85
441.	9° 34' 0.1"	6° 39' 31.9"	7.80	8.15
442.	9° 34' 0.4"	6° 39' 28.7"	8.51	8.86
443.	9° 34' 0.3"	6° 39' 26.2"	10.61	10.96
444.	9° 34' 0.2"	6° 39' 24.8"	8.58	8.93
445.	9° 34' 0.0"	6° 39' 22.4"	8.06	8.41
446.	9° 34' 0.2"	6° 39' 20.0"	10.58	10.93
447.	9° 34' 1.0"	6° 39' 17.5"	1.91	2.26

448.	9° 34’ 1.7”	6° 39’ 17.1”	3.15		3.50	
449.	9° 34’ 2.3”	6° 39’ 16.7”	2.71		3.06	
450.	9° 34’ 2.8’’	6° 39’ 16.1’’	0.71		1.06	
451.	9° 34’ 2.1’’	6° 39’ 17.7’’		6.07		6.42
452.	9° 34’ 1.4’’	6° 39’ 19.1’’	9.41		9.76	
453.	9° 34’ 1.3’’	6° 39’ 20.0’’	12.51		12.86	
454.	9° 34’ 1.0’’	6° 39’ 20.9’’	12.21		12.56	
455.	9° 34’ 1.0’’	6° 39’ 22.3’’	11.90		12.25	
456.	9° 34’ 0.8’’	6° 39’ 23.8’’	11.55		11.90	
457.	9° 34’ 0.8’’	6° 39’ 25.3’’		12.38		12.73
458.	9° 34’ 5.7’’	6° 39’ 20.3’’	12.59		12.94	
459.	9° 34’ 4.8’’	6° 39’ 23.5’’	13.36		13.71	
460.	9° 34’ 4.8’’	6° 39’ 27.0’’	14.76		15.11	
461.	9° 34’ 6.0’’	6° 39’ 30.1’’	14.72		15.07	
462.	9° 34’ 5.4’’	6° 39’ 31.3’’	14.53		14.88	
463.	9° 34’ 5.6’’	6° 39’ 34.2’’	9.48		9.83	
464.	9° 34’ 6.8’’	6° 39’ 37.1’’	9.41		9.76	
465.	9° 34’ 5.7’’	6° 39’ 40.3’’	8.53		8.88	
466.	9° 34’ 6.8’’	6° 39’ 42.5’’	8.58		8.93	
467.	9° 34’ 5.7’’	6° 39’ 44.8’’	8.12		8.47	
468.	9° 34’ 6.0’’	6° 39’ 48.0’’	4.49		4.84	
469.	9° 34’ 5.4’’	6° 39’ 52.8’’	3.64		3.99	
470.	9° 34’ 6.0’’	6° 39’ 57.6’’	0.96		1.31	
471.	9° 34’ 2.5’’	6° 39’ 54.9’’	1.14		1.49	
472.	9° 34’ 2.6’’	6° 39’ 53.5’’	2.86		3.21	
473.	9° 34’ 2.4’’	6° 39’ 51.5’’	3.16		3.51	
474.	9° 34’ 2.3’’	6° 39’ 48.9’’		3.25		3.60
475.	9° 34’ 2.1’’	6° 39’ 46.6’’	3.76		4.11	
476.	9° 34’ 2.2’’	6° 39’ 44.2’’		4.88		5.23
477.	9° 34’ 2.2’’	6° 39’ 41.6’’	5.89		6.24	
478.	9° 34’ 2.3’’	6° 39’ 37.9’’	6.07		6.42	
479.	9° 34’ 2.2’’	6° 39’ 34.8’’	8.21		8.56	
480.	9° 34’ 2.2’’	6° 39’ 31.2’’	16.51		16.86	
481.	9° 34’ 2.0’’	6° 39’ 28.8’’	15.81		16.16	
482.	9° 34’ 2.2’’	6° 39’ 26.2’’	15.31		15.66	
483.	9° 34’ 2.5’’	6° 39’ 23.6’’	12.29		12.64	
484.	9° 34’ 2.9’’	6° 39’ 20.9’’	13.49		13.84	
485.	9° 34’ 3.2’’	6° 39’ 18.8’’	7.75		8.10	
486.	9° 34’ 3.9’’	6° 39’ 17.6’’	3.33		3.68	
487.	9° 34’ 5.2’’	6° 39’ 17.7’’	2.16		2.51	
488.	9° 34’ 6.6’’	6° 39’ 18.5’’	2.51		2.86	
489.	9° 34’ 7.7’’	6° 39’ 18.5’’	3.02		3.37	
490.	9° 34’ 7.9’’	6° 39’ 20.5’’	12.89		13.24	
491.	9° 34’ 8.0’’	6° 39’ 24.1’’	13.33		13.68	
492.	9° 34’ 8.2’’	6° 39’ 26.6’’	12.93		13.28	
493.	9° 34’ 8.2’’	6° 39’ 32.9’’	11.25		11.60	

494.	9° 34’ 8.6’’	6° 39’ 38.2’’	11.58	11.93
495.	9° 34’ 8.9’’	6° 39’ 43.1’’	12.03	12.38
496.	9° 34’ 9.4’’	6° 39’ 45.8’’	6.92	7.27
497.	9° 34’ 9.9’’	6° 39’ 49.1’’	5.42	5.77
498.	9° 34’ 10.3’’	6° 39’ 52.8’’	5.88	6.23
499.	9° 34’ 10.4’’	6° 39’ 57.8’’	1.49	1.84
500.	9° 34’ 10.5’’	6° 39’ 59.6’’	0.59	0.94
501.	9° 34’ 12.1’’	6° 39’ 59.2’’	1.34	1.69
502.	9° 34’ 13.9’’	6° 39’ 59.9’’	1.44	1.79
503.	9° 34’ 13.8’’	6° 39’ 56.4’’	2.87	3.22
504.	9° 34’ 13.4’’	6° 39’ 51.5’’	6.05	6.40
505.	9° 34’ 12.6’’	6° 39’ 45.1’’	9.38	9.73
506.	9° 34’ 12.2’’	6° 39’ 41.3’’	8.60	8.95
507.	9° 34’ 11.8’’	6° 39’ 34.4’’	12.24	12.59
508.	9° 34’ 11.4’’	6° 39’ 30.2’’	10.47	10.82
509.	9° 34’ 11.2’’	6° 39’ 27.2’’	12.98	13.33
510.	9° 34’ 10.7’’	6° 39’ 22.4’’	13.31	13.66
511.	9° 34’ 10.1’’	6° 39’ 18.8’’	8.08	8.43
512.	9° 34’ 10.7’’	6° 39’ 17.3’’	1.77	2.12
513.	9° 34’ 11.9’’	6° 39’ 16.1’’	2.52	2.87
514.	9° 34’ 12.7’’	6° 39’ 15.2’’	2.90	3.25
515.	9° 34’ 13.3’’	6° 39’ 18.6’’	11.45	11.80
516.	9° 34’ 13.6’	6° 39’ 21.7’’	12.24	12.59
517.	9° 34’ 13.7’’	6° 39’ 23.6’’	11.73	12.08
518.	9° 34’ 13.9’’	6° 39’ 27.8’’	11.57	11.92
519.	9° 34’ 14.1’’	6° 39’ 32.6’’	10.75	11.10
520.	9° 34’ 14.3’’	6° 39’ 36.5’’	11.80	12.15
521.	9° 34’ 14.5’’	6° 39’ 42.2’’	13.78	14.13
522.	9° 34’ 14.8’’	6° 39’ 49.3’’	7.34	7.69
523.	9° 34’ 15.1’’	6° 39’ 58.6’’	2.95	3.30
524.	9° 34’ 15.4’’	6° 40’ 2.3’’	1.48	1.83
525.	9° 34’ 15.7’’	6° 40’ 5.1’’	1.53	1.88
526.	9° 34’ 17.0’’	6° 40’ 4.9’’	1.29	1.64
527.	9° 34’ 18.5’’	6° 40’ 5.0’’	1.99	2.34
528.	9° 34’ 20.8’’	6° 40’ 5.5’’	1.92	2.27
529.	9° 34’ 20.6’’	6° 40’ 3.7’’	3.32	3.67
530.	9° 34’ 20.0’’	6° 39’ 59.2’’	5.09	5.44
531.	9° 34’ 19.3’’	6° 39’ 54.5’’	4.75	5.10
532.	9° 34’ 18.5’’	6° 39’ 50.5’’	5.89	6.24
533.	9° 34’ 17.9’’	6° 39’ 46.5’’	7.33	7.68
534.	9° 34’ 16.9’’	6° 39’ 40.7’’	8.17	8.52
535.	9° 34’ 16.1’’	6° 39’ 34.9’’	11.83	12.18
536.	9° 34’ 15.7’’	6° 39’ 32.1’’	10.37	10.72
537.	9° 34’ 15.1’’	6° 39’ 27.7’’	13.58	13.93
538.	9° 34’ 14.8’’	6° 39’ 25.0’’	11.20	11.55
539.	9° 34’ 14.2’’	6° 39’ 21.7’’	11.65	12.00

540.	**9° 34’ 13.7’’**	**6° 39’ 18.8’’**	**10.83**	**11.18**
541.	**9° 34’ 13.0’’**	**6° 39’ 15.3’’**	**6.08**	**6.43**
542.	**9° 34’ 12.2’’**	**6° 39’ 13.0’’**	**3.48**	**3.83**
543.	**9° 34’ 11.4’’**	**6° 39’ 9.8’’**	**1.78**	**2.13**
544.	**9° 34’ 11.2’’**	**6° 39’ 8.3’’**	**1.43**	**1.78**
545.	**9° 34’ 10.9’’**	**6° 39’ 7.3’’**	**0.49**	**0.84**
546.	**9° 34’ 11.8’’**	**6° 39’ 8.1’’**	**1.55**	**1.90**
547.	**9° 34’ 13.0’’**	**6° 39’ 10.6’’**	**2.47**	**2.82**
548.	**9° 34’ 14.3’’**	**6° 39’ 13.7’’**	**5.50**	**5.85**
549.	**9° 34’ 15.4’’**	**6° 39’ 16.5’’**	**9.33**	**9.68**
550.	**9° 34’ 15.4’’**	**6° 39’ 18.6’’**	**10.75**	**11.10**
551.	**9° 34’ 15.6’’**	**6° 39’ 22.4’’**	**10.56**	**10.91**
552.	**9° 34’ 15.7’’**	**6° 39’ 27.5’’**	**12.40**	**12.75**
553.	**9° 34’ 15.7’’**	**6° 39’ 31.8’’**	**10.35**	**10.70**
554.	**9° 34’ 16.1’’**	**6° 39’ 35.4’’**	**11.97**	**12.32**
555.	**9° 34’ 16.6’’**	**6° 39° 42.4’’**	**10.55**	**10.90**
556.	**9° 34’ 17.2’’**	**6° 39’ 46.7’’**	**7.28**	**7.63**
557.	**9° 34’ 17.9’’**	**6° 39’ 51.7’’**	**5.22**	**5.57**
558.	**9° 34’ 19.0’’**	**6° 39’ 55.7’’**	**4.82**	**5.17**
559.	**9° 34’ 21.1’’**	**6° 40’ 1.6’’**	**4.95**	**5.30**
560.	**9° 34’ 22.0’’**	**6° 40’ 4.6’’**	**3.82**	**4.17**
561.	**9° 34’ 22.8’’**	**6° 40’ 6.9’’**	**1.97**	**2.32**
562.	**9° 34’ 23.6’’**	**6° 40’ 7.2’’**	**0.77**	**1.12**
563.	**9° 34’ 24.9’’**	**6° 40’ 7.9’’**	**0.63**	**0.98**
564.	**9° 34’ 26.9’’**	**6° 40’ 8.2’’**	**1.70**	**2.05**
565.	**9° 34’ 26.7’’**	**6° 40’ 4.7’’**	**2.52**	**2.87**
566.	**9° 34’ 25.5’’**	**6° 39’ 59.9’’**	**3.33**	**3.68**
567.	**9° 34’ 24.4’’**	**6° 39’ 55.3’’**	**6.47**	**6.82**
568.	**9° 34’ 23.2’’**	**6° 39’ 48.9’’**	**4.40**	**4.75**
569.	**9° 34’ 22.0’’**	**6° 39’ 44.0’’**	**13.70**	**14.05**
570.	**9° 34’ 21.4’’**	**6° 39’ 42.4’’**	**12.53**	**12.88**
571.	**9° 34’ 20.2’’**	**6° 39’ 37.0’’**	**10.14**	**10.49**
572.	**9° 34’ 18.7’’**	**6° 39’ 30.1’’**	**9.47**	**9.82**
573.	**9° 34’ 17.2’’**	**6° 39’ 23.8’’**	**5.09**	**5.44**
574.	**9° 34’ 16.4’’**	**6° 39’ 18.8’’**	**10.59**	**10.94**
575.	**9° 34’ 15.4’’**	**6° 39’ 14.9’’**	**7.12**	**7.47**
576.	**9° 34’ 13.9’’**	**6° 39’ 11.6’’**	**3.49**	**3.84**
577.	**9° 34’ 14.0’’**	**6° 39’ 6.7’’**	**2.39**	**2.74**
578.	**9° 34’ 15.1’’**	**6° 39’ 5.3’’**	**2.29**	**2.64**
579.	**9° 34’ 16.7’’**	**6° 39’ 3.9’’**	**1.87**	**2.22**
580.	**9° 34’ 16.9’’**	**6° 39’ 4.9’’**	**2.99**	**3.34**
581.	**9° 34’ 17.5’’**	**6° 39’ 8.0’’**	**4.48**	**4.83**
582.	**9° 34’ 18.3’’**	**6° 39’ 10.9’’**	**7.64**	**7.99**
583.	**9° 34’ 19.1’’**	**6° 39’ 14.6’’**	**7.21**	**7.56**
584.	**9° 34’ 19.9’’**	**6° 39’ 17.9’’**	**6.25**	**6.60**
585.	**9° 34’ 20.5’’**	**6° 39’ 20.2’’**	**5.97**	**6.32**

586.	**9° 34’ 21.6’’**	**6° 39’ 24.5’’**	**8.17**	**8.52**
587.	**9° 34’ 22.0’’**	**6° 39’ 26.0’’**	**13.47**	**13.82**
588.	**9° 34’ 22.6’’**	**6° 39’ 27.8’’**	**9.63**	**9.98**
589.	**9° 34’ 23.6’’**	**6° 39’ 30.4’’**	**10.41**	**10.76**
590.	**9° 34’ 24.4’’**	**6° 39’ 33.6’’**	**11.07**	**11.42**
591.	**9° 34’ 24.8’’**	**6° 39’ 35.2’’**	**8.16**	**8.51**
592.	**9° 34’ 25.9’’**	**6° 39’ 39.9’’**	**8.47**	**8.82**
593.	**9° 34’ 26.6’’**	**6° 39’ 44.3’’**	**9.98**	**10.33**
594.	**9° 34’ 26.9’’**	**6° 39’ 46.3’’**	**9.09**	**9.44**
595.	**9° 34’ 27.6’’**	**6° 39’ 50.1’’**	**9.05**	**9.40**
596.	**9° 34’ 28.3’’**	**6° 39’ 53.7’’**	**4.40**	**4.75**
597.	**9° 34’ 28.7’’**	**6° 39’ 56.6’’**	**2.57**	**2.92**
598.	**9° 34’ 28.9’’**	**6° 40’ 0.2’’**	**1.87**	**2.22**
599.	**9° 34’ 29.2’’**	**6° 40’ 4.8’’**	**1.56**	**1.91**
600.	**9° 34’ 29.9’’**	**6° 40’ 9.3’’**	**1.85**	**2.20**
601.	**9° 34’ 30.1’’**	**6° 40’ 11.8’’**	**1.99**	**2.34**
602.	**9° 34’ 31.6’’**	**6° 40’ 13.2’’**	**2.16**	**2.51**
603.	**9° 34’ 34.4’’**	**6° 40’ 14.5’’**	**2.58**	**2.93**
604.	**9° 34’ 36.4’’**	**6° 40’ 14.5’’**	**3.15**	**3.50**
605.	**9° 34’ 35.9’’**	**6° 40’ 11.9’’**	**5.60**	**5.95**
606.	**9° 34’ 35.2’’**	**6° 40’ 7.9’’**	**3.29**	**3.64**
607.	**9° 34’ 33.5’’**	**6° 40’ 1.1’’**	**3.22**	**3.57**
608.	**9° 34’ 32.2’’**	**6° 39’ 54.8’’**	**6.01**	**6.36**
609.	**9° 34’ 30.9’’**	**6° 39’ 49.5’’**	**12.06**	**12.41**
610.	**9° 34’ 30.5’’**	**6° 39’ 46.1’’**	**8.64**	**8.99**
611.	**9° 34’ 29.3’’**	**6° 39’ 40.2’’**	**9.36**	**9.71**
612.	**9° 34’ 28.8’’**	**6° 39’ 36.4’’**	**7.23**	**7.58**
613.	**9° 34’ 27.8’’**	**6° 39’ 30.4’’**	**10.46**	**10.81**
614.	**9° 34’ 27.0’’**	**6° 39’ 25.7’’**	**6.78**	**7.13**
615.	**9° 34’ 25.9’’**	**6° 39’ 20.5’’**	**4.81**	**5.16**
616.	**9° 34’ 24.2’’**	**6° 39’ 15.0’’**	**5.01**	**5.36**
617.	**9° 34’ 21.7’’**	**6° 39’ 8.4’’**	**5.53**	**5.88**
618.	**9° 34’ 20.2’’**	**6° 39’ 4.7’’**	**2.31**	**2.66**
619.	**9° 34’ 22.9’’**	**6° 39’ 0.6’’**	**2.15**	**2.50**
620.	**9° 34’ 24.1’’**	**6° 39’ 1.1’’**	**2.16**	**2.51**
621.	**9° 34’ 25.1’’**	**6° 38’ 59.4’’**	**2.91**	**3.26**
622.	**9° 34’ 26.2’’**	**6° 38’ 57.1’’**	**3.56**	**3.91**
623.	**9° 34’ 29.1’’**	**6° 38’ 54.2’’**	**1.66**	**2.01**
624.	**9° 34’ 30.1’’**	**6° 38’ 54.1’’**	**2.16**	**2.51**
625.	**9° 34’ 29.3’’**	**6° 38’ 55.9’’**	**2.46**	**2.81**
626.	**9° 34’ 28.4’’**	**6° 38’ 57.7’’**	**1.96**	**2.31**
627.	**9° 34’ 27.9’’**	**6° 38’ 59.2’’**	**2.26**	**2.61**
628.	**9° 34’ 26.9’’**	**6° 39’ 0.8’’**	**3.46**	**3.81**
629.	**9° 34’ 25.6’’**	**6° 39’ 2.5’’**	**2.60**	**2.95**
630.	**9° 34’ 23.8’’**	**6° 39’ 5.2’’**	**3.66**	**4.01**
631.	**9° 34’ 22.0’’**	**6° 39’ 7.5’’**	**5.81**	**6.16**

632.	**9° 34’ 22.7’’**	**6° 39’ 9.4’’**	**2.96**	**3.31**
633.	**9° 34’ 24.1’’**	**6° 39’ 12.7’’**	**3.76**	**4.11**
634.	**9° 34’ 25.6’’**	**6° 39’ 16.3’’**	**3.53**	**3.88**
635.	**9° 34’ 27.1’’**	**6° 39’ 19.4’’**	**3.76**	**4.11**
636.	**9° 34’ 29.0’’**	**6° 39’ 23.7’’**	**6.58**	**6.93**
637.	**9° 34’ 30.5’’**	**6° 39’ 27.2’’**	**10.86**	**11.21**
638.	**9° 34’ 31.9’’**	**6° 39’ 30.5’’**	**11.08**	**11.43**
639.	**9° 34’ 34.1’’**	**6° 39’ 35.9’’**	**7.31**	**7.66**
640.	**9° 34’ 35.9’’**	**6° 39’ 40.7’’**	**6.86**	**7.21**
641.	**9° 34’ 38.8’’**	**6° 39’ 47.9’’**	**6.06**	**6.41**
642.	**9° 34’ 40.7’’**	**6° 39’ 55.0’’**	**5.11**	**5.46**
643.	**9° 34’ 41.5’’**	**6° 40’ 0.3’’**	**8.99**	**9.34**
644.	**9° 34’ 41.9’’**	**6° 40’ 4.1’’**	**6.26**	**6.61**
645.	**9° 34’ 41.9’’**	**6° 40’ 10.2’’**	**8.34**	**8.69**
646.	**9° 34’ 41.9’’**	**6° 40’ 15.4’’**	**3.66**	**4.01**
647.	**9° 34’ 42.2’’**	**6° 40’ 19.5’’**	**2.41**	**2.76**
648.	**9° 34’ 43.6’’**	**6° 40’ 21.6’’**	**1.37**	**1.72**
649.	**9° 34’ 45.2’’**	**6° 40’ 23.7’’**	**1.41**	**1.76**
650.	**9° 34’ 47.2’’**	**6° 40’ 24.9’’**	**1.55**	**1.90**
651.	**9° 34’ 47.2’’**	**6° 40’ 27.6’’**	**4.61**	**4.96**
652.	**9° 34’ 48.4’’**	**6° 40’ 26.3’’**	**3.81**	**4.16**
653.	**9° 34’ 48.5’’**	**6° 40’ 24.5’’**	**5.16**	**5.51**
654.	**9° 34’ 48.5’’**	**6° 40’ 22.7’’**	**6.36**	**6.71**
655.	**9° 34’ 48.2’’**	**6° 40’ 18.9’’**	**6.26**	**6.61**
656.	**9° 34’ 47.9’’**	**6° 40’ 14.9’’**	**6.41**	**6.76**
657.	**9° 34’ 47.4’’**	**6° 40’ 11.6’’**	**4.31**	**4.66**
658.	**9° 34’ 46.8’’**	**6° 40’ 6.8’’**	**3.11**	**3.46**
659.	**9° 34’ 46.3’’**	**6° 40’ 3.3’’**	**7.76**	**8.11**
660.	**9° 34’ 45.6’’**	**6° 39’ 59.0’’**	**3.96**	**4.31**
661.	**9° 34’ 45.0’’**	**6° 39’ 56.3’’**	**4.29**	**4.64**
662.	**9° 34’ 44.5’’**	**6° 39’ 54.1’’**	**4.71**	**5.06**
663.	**9° 34’ 43.9’’**	**6° 39’ 50.2’’**	**6.54**	**6.89**
664.	**9° 34’ 43.0’’**	**6° 39’ 45.4’’**	**5.03**	**5.38**
665.	**9° 34’ 42.5’’**	**6° 39’ 40.4’’**	**4.96**	**5.31**
666.	**9° 34’ 41.8’’**	**6° 39’ 36.6’’**	**6.86**	**7.21**
667.	**9° 34’ 41.3’’**	**6° 39’ 33.7’’**	**9.81**	**10.16**
668.	**9° 34’ 41.3’’**	**6° 39’ 32.8’’**	**8.66**	**9.01**
669.	**9° 34’ 40.8’’**	**6° 39’ 30.7’’**	**8.61**	**8.96**
670.	**9° 34’ 40.3’’**	**6° 39’ 28.4’’**	**6.06**	**6.41**
671.	**9° 34’ 39.8’’**	**6° 39’ 25.7’’**	**4.58**	**4.93**
672.	**9° 34’ 39.2’’**	**6° 39’ 23.6’’**	**2.11**	**2.46**
673.	**9° 34’ 37.1’’**	**6° 39’ 22.7’’**	**2.86**	**3.21**
674.	**9° 34’ 34.6’’**	**6° 39’ 21.4’’**	**4.11**	**4.46**
675.	**9° 34’ 31.9’’**	**6° 39’ 20.2’’**	**3.19**	**3.54**
676.	**9° 34’ 30.2’’**	**6° 39’ 19.7’’**	**1.83**	**2.18**
677.	**9° 34’ 26.1’’**	**6° 39’ 17.7’’**	**2.86**	**3.21**

678.	**9° 34’ 23.5’’**	**6° 39’ 15.9’’**	**5.01**	**5.36**
679.	**9° 34’ 20.2’’**	**6° 39’ 13.4’’**	**5.44**	**5.79**
680.	**9° 34’ 15.8’’**	**6° 39’ 10.4’’**	**4.71**	**5.06**
681.	**9° 34’ 14.1’’**	**6° 39’ 9.3’’**	**3.31**	**3.66**
682.	**9° 34’ 12.5’’**	**6° 39’ 8.2’’**	**2.56**	**2.91**
683.	**9° 34’ 11.7’’**	**6° 39’ 7.6’’**	**1.16**	**1.51**
684.	**9° 34’ 11.1’’**	**6° 39’ 7.3’’**	**0.56**	**0.91**
685.	**9° 34’ 10.9’’**	**6° 39’ 7.1’’**	**0.23**	**0.58**
686.	**9° 34’ 37.0’’**	**6° 39’ 22.9’’**	**3.06**	**3.41**
687.	**9° 34’ 40.8’’**	**6° 39’ 25.1’’**	**2.53**	**2.88**
688.	**9° 34’ 43.4’’**	**6° 39’ 26.5’’**	**1.99**	**2.34**
689.	**9° 34’ 45.4’’**	**6° 39’ 26.9’’**	**2.56**	**2.91**
690.	**9° 34’ 48.2’’**	**6° 39’ 24.5’’**	**2.85**	**3.20**
691.	**9° 34’ 51.0’’**	**6° 39’ 22.8’’**	**2.61**	**2.96**
692.	**9° 34’ 52.9’’**	**6° 39’ 21.5’’**	**2.99**	**3.34**
693.	**9° 34’ 54.1’’**	**6° 39’ 19.1’’**	**4.16**	**4.51**
694.	**9° 34’ 54.7’’**	**6° 39’ 17.7’’**	**3.16**	**3.51**
695.	**9° 34’ 55.3’’**	**6° 39’ 16.6’’**	**0.81**	**1.16**
696.	**9° 34’ 55.1’’**	**6° 39’ 17.1’’**	**2.04**	**2.39**
697.	**9° 34’ 54.8’’**	**6° 39’ 17.7’’**	**3.19**	**3.54**
698.	**9° 34’ 54.5’’**	**6° 39’ 18.3’’**	**3.79**	**4.14**
699.	**9° 34’ 54.2’’**	**6° 39’ 19.4’’**	**2.73**	**3.08**
700.	**9° 34’ 53.8’’**	**6° 39’ 21.8’’**	**4.83**	**5.18**
701.	**9° 34’ 53.3’’**	**6° 39’ 23.6’’**	**4.66**	**5.01**
702.	**9° 34’ 52.3’’**	**6° 39’ 26.7’’**	**3.44**	**3.79**
703.	**9° 34’ 51.7’’**	**6° 39’ 28.7’’**	**3.76**	**4.11**
704.	**9° 34’ 50.8’’**	**6° 39’ 31.9’’**	**4.11**	**4.46**
705.	**9° 34’ 50.2’’**	**6° 39’ 34.7’’**	**7.91**	**8.26**
706.	**9° 34’ 49.7’’**	**6° 39’ 36.5’’**	**8.81**	**9.16**
707.	**9° 34’ 49.4’’**	**6° 39’ 38.1’’**	**9.86**	**10.21**
708.	**9° 34’ 49.0’’**	**6° 39’ 40.3’’**	**3.66**	**4.01**
709.	**9° 34’ 48.7’’**	**6° 39’ 41.9’’**	**2.93**	**3.28**
710.	**9° 34’ 48.1’’**	**6° 39’ 45.4’’**	**2.31**	**2.66**
711.	**9° 34’ 48.1’’**	**6° 39’ 47.6’’**	**4.43**	**4.78**
712.	**9° 34’ 48.1’’**	**6° 39’ 50.0’’**	**3.06**	**3.41**
713.	**9° 34’ 48.3’’**	**6° 39’ 52.6’’**	**6.39**	**6.74**
714.	**9° 34’ 48.7’’**	**6° 39’ 56.6’’**	**4.96**	**5.31**
715.	**9° 34’ 48.9’’**	**6° 40’ 0.8’’**	**3.58**	**3.93**
716.	**9° 34’ 49.4’’**	**6° 40’ 6.1’’**	**5.36**	**5.71**
717.	**9° 34’ 49.8’’**	**6° 40’ 11.0’’**	**2.06**	**2.41**
718.	**9° 34’ 50.1’’**	**6° 40’ 14.0’’**	**2.86**	**3.21**
719.	**9° 34’ 50.6’’**	**6° 40’ 17.8’’**	**2.26**	**2.61**
720.	**9° 34’ 51.1’’**	**6° 40’ 20.9’’**	**4.86**	**5.21**
721.	**9° 34’ 51.2’’**	**6° 40’ 22.9’’**	**4.36**	**4.71**
722.	**9° 34’ 51.4’’**	**6° 40’ 24.9’’**	**5.81**	**6.16**
723.	**9° 34’ 51.7’’**	**6° 40’ 28.0’’**	**6.36**	**6.71**

724.	**9° 34’ 52.1’’**	**6° 40’ 31.0’’**	**4.66**	**5.01**
725.	**9° 34’ 52.7’’**	**6° 40’ 34.0’’**	**5.26**	**5.61**
726.	**9° 34’ 50.9’’**	**6° 40’ 36.0’’**	**5.16**	**5.51**
727.	**9° 34’ 50.2’’**	**6° 40’ 36.8’’**	**3.26**	**3.61**
728.	**9° 34’ 49.9’’**	**6° 40’ 37.8’’**	**2.31**	**2.66**
729.	**9° 34’ 50.5’’**	**6° 40’ 39.0’’**	**2.26**	**2.61**
730.	**9° 34’ 50.6’’**	**6° 40’ 40.3’’**	**3.86**	**4.21**
731.	**9° 34’ 49.8’’**	**6° 40’ 41.2’’**	**3.96**	**4.31**
732.	**9° 34’ 49.2’’**	**6° 40’ 41.5’’**	**2.61**	**2.96**
733.	**9° 34’ 48.6’’**	**6° 40’ 41.1’’**	**4.01**	**4.36**
734.	**9° 34’ 47.8’’**	**6° 40’ 41.2’’**	**4.21**	**4.56**
735.	**9° 34’ 50.5’’**	**6° 40’ 40.7’’**	**5.06**	**5.41**
736.	**9° 34’ 50.9’’**	**6° 40’ 39.6’’**	**4.91**	**5.26**
737.	**9° 34’ 51.4’’**	**6° 40’ 38.0’’**	**4.61**	**4.96**
738.	**9° 34’ 52.3’’**	**6° 40’ 36.5’’**	**2.21**	**2.56**
739.	**9° 34’ 53.5’’**	**6° 40’ 34.8’’**	**3.06**	**3.41**
740.	**9° 34’ 54.4’’**	**6° 40’ 33.2’’**	**3.01**	**3.36**
741.	**9° 34’ 56.3’’**	**6° 40’ 32.8’’**	**3.61**	**3.96**
742.	**9° 34’ 58.6’’**	**6° 40’ 32.6’’**	**5.21**	**5.56**
743.	**9° 35’ 0.2’’**	**6° 40’ 33.2’’**	**3.56**	**3.91**
744.	**9° 35’ 1.4’’**	**6° 40’ 33.8’’**	**3.21**	**3.56**
745.	**9° 35’ 2.8’’**	**6° 40’ 34.0’’**	**2.66**	**3.01**
746.	**9° 35’ 3.9’’**	**6° 40’ 35.4’’**	**3.11**	**3.46**
747.	**9° 35’ 4.8’’**	**6° 40’ 36.8’’**	**4.31**	**4.66**
748.	**9° 35’ 4.9’’**	**6° 40’ 36.0’’**	**4.51**	**4.86**
749.	**9° 35’ 4.1’’**	**6° 40’ 34.3’’**	**5.01**	**5.36**
750.	**9° 35’ 3.2’’**	**6° 40’ 33.6’’**	**5.11**	**5.46**
751.	**9° 35’ 1.5’’**	**6° 40’ 32.5’’**	**3.46**	**3.81**
752.	**9° 34’ 59.3’’**	**6° 40’ 31.5’’**	**3.36**	**3.71**
753.	**9° 34’ 57.6’’**	**6° 40’ 31.1’’**	**3.76**	**4.11**
754.	**9° 34’ 55.1’’**	**6° 40’ 30.2’’**	**2.86**	**3.21**
755.	**9° 34’ 53.7’’**	**6° 40’ 28.3’’**	**3.46**	**3.81**
756.	**9° 34’ 52.9’’**	**6° 40’ 26.3’’**	**3.76**	**4.11**
757.	**9° 34’ 53.9’’**	**6° 40’ 25.3’’**	**3.36**	**3.71**
758.	**9° 34’ 55.5’’**	**6° 40’ 27.2’’**	**2.31**	**2.66**
759.	**9° 34’ 56.9’’**	**6° 40’ 28.4’’**	**1.96**	**2.31**
760.	**9° 34’ 56.3’’**	**6° 40’ 26.7’’**	**2.36**	**2.71**
761.	**9° 34’ 57.3’’**	**6° 40’ 24.8’’**	**2.81**	**3.16**
762.	**9° 34’ 54.0’’**	**6° 40’ 23.4’’**	**2.66**	**3.01**
763.	**9° 34’ 52.6’’**	**6° 40’ 21.7’’**	**1.71**	**2.06**
764.	**9° 34’ 54.6’’**	**6° 40’ 21.5’’**	**2.56**	**2.91**
765.	**9° 34’ 56.3’’**	**6° 40’ 21.4’’**	**2.36**	**2.71**
766.	**9° 34’ 56.3’’**	**6° 40’ 20.8’’**	**2.66**	**3.01**
767.	**9° 34’ 54.3’’**	**6° 40’ 19.9’’**	**2.81**	**3.16**
768.	**9° 34’ 52.6’’**	**6° 40’ 19.0’’**	**3.06**	**3.41**
769.	**9° 34’ 52.7’’**	**6° 40’ 16.6’’**	**1.91**	**2.26**

770.	**9° 34’ 52.9’’**	**6° 40’ 15.3’’**	**2.06**	**2.41**
771.	**9° 34’ 54.9’’**	**6° 40’ 15.7’’**	**1.51**	**1.86**
772.	**9° 34’ 56.5’’**	**6° 40’ 15.9’’**	**1.06**	**1.41**
773.	**9° 34’ 58.4’’**	**6° 40’ 15.7’’**	**1.71**	**2.06**
774.	**9° 35’ 1.7’’**	**6° 40’ 16.3’’**	**2.26**	**2.61**
775.	**9° 35’ 4.1’’**	**6° 40’ 16.5’’**	**2.06**	**2.41**
776.	**9° 35’ 6.1’’**	**6° 40’ 16.6’’**	**1.91**	**2.26**
777.	**9° 35’ 5.6’’**	**6° 40’ 16.0’’**	**2.21**	**2.56**
778.	**9° 35’ 4.1’’**	**6° 40’ 15.6’’**	**2.16**	**2.51**
779.	**9° 35’ 2.2’’**	**6° 40’ 15.1’’**	**2.56**	**2.91**
780.	**9° 34’ 59.5’’**	**6° 40’ 14.2’’**	**2.41**	**2.76**
781.	**9° 34’ 57.3’’**	**6° 40’ 12.5’’**	**2.61**	**2.96**
782.	**9° 34’ 55.7’’**	**6° 40’ 10.1’’**	**4.01**	**4.36**
783.	**9° 34’ 54.1’’**	**6° 40’ 7.3’’**	**3.61**	**3.96**
784.	**9° 34’ 52.3’’**	**6° 40’ 4.5’’**	**3.06**	**3.41**
785.	**9° 34’ 51.5’’**	**6° 40’ 1.7’’**	**1.71**	**2.06**
786.	**9° 34’ 53.5’’**	**6° 39’ 59.9’’**	**1.76**	**2.11**
787.	**9° 34’ 56.5’’**	**6° 39’ 59.5’’**	**1.76**	**2.11**
788.	**9° 34’ 58.8’’**	**6° 39’ 58.7’’**	**2.31**	**2.66**
789.	**9° 34’ 59.4’’**	**6° 39’ 58.0’’**	**2.21**	**2.56**
790.	**9° 34’ 58.3’’**	**6° 39’ 56.9’’**	**2.46**	**2.81**
791.	**9° 34’ 56.5’’**	**6° 39’ 56.3’’**	**2.91**	**3.26**
792.	**9° 34’ 54.1’’**	**6° 39’ 55.1’’**	**2.61**	**2.96**
793.	**9° 34’ 52.3’’**	**6° 39’ 52.9’’**	**2.76**	**3.11**
794.	**9° 34’ 50.7’’**	**6° 39’ 51.1’’**	**2.01**	**2.36**
795.	**9° 34’ 49.4’’**	**6° 39’ 47.8’’**	**2.86**	**3.21**
796.	**9° 34’ 49.2’’**	**6° 39’ 42.9’’**	**2.21**	**2.56**
797.	**9° 34’ 52.6’’**	**6° 39’ 40.6’’**	**4.31**	**4.66**
798.	**9° 34’ 55.3’’**	**6° 39’ 39.1’’**	**0.21**	**0.56**
799.	**9° 34’ 57.2’’**	**6° 39’ 39.6’’**	**8.21**	**8.56**
800.	**9° 35’ 1.0’’**	**6° 39’ 40.3’’**	**3.11**	**3.46**
801.	**9° 35’ 4.4’’**	**6° 39’ 41.5’’**	**3.86**	**4.21**
802.	**9° 35’ 7.9’’**	**6° 39’ 43.8’’**	**4.81**	**5.16**
803.	**9° 35’ 11.6’’**	**6° 39’ 45.4’’**	**4.51**	**4.86**
804.	**9° 35’ 14.5’’**	**6° 39’ 47.6’’**	**5.71**	**6.06**
805.	**9° 35’ 14.8’’**	**6° 39’ 49.9’’**	**5.81**	**6.16**
806.	**9° 35’ 14.6’’**	**6° 39’ 52.2’’**	**4.21**	**4.56**
807.	**9° 35’ 15.2’’**	**6° 39’ 54.7’’**	**4.66**	**5.01**
808.	**9° 35’ 16.3’’**	**6° 39’ 56.4’’**	**2.56**	**2.91**
809.	**9° 35’ 16.2’’**	**6° 39’ 53.6’’**	**3.21**	**3.56**
810.	**9° 35’ 16.9’’**	**6° 39’ 52.6’’**	**3.41**	**3.76**
811.	**9° 35’ 19.1’’**	**6° 39’ 53.4’’**	**4.51**	**4.86**
812.	**9° 35’ 20.0’’**	**6° 39’ 56.9’’**	**4.06**	**4.41**
813.	**9° 35’ 21.9’’**	**6° 39’ 58.1’’**	**2.81**	**3.16**
814.	**9° 35’ 23.5’’**	**6° 39’ 59.0’’**	**3.21**	**3.56**
815.	**9° 35’ 23.9’’**	**6° 39’ 57.0’’**	**4.06**	**4.41**

816.	**9° 35’ 24.6’’**	**6° 39’ 55.9’’**	**3.91**	**4.26**
817.	**9° 35’ 22.4’’**	**6° 39’ 53.2’’**	**3.36**	**3.71**
818.	**9° 35’ 23.0’’**	**6° 39’ 51.0’’**	**3.56**	**3.91**
819.	**9° 35’ 23.3’’**	**6° 39’ 48.7’’**	**4.56**	**4.91**
820.	**9° 35’ 24.9’’**	**6° 39’ 48.1’’**	**4.81**	**5.16**
821.	**9° 35’ 25.0’’**	**6° 39’ 47.3’’**	**4.81**	**5.16**
822.	**9° 35’ 19.9’’**	**6° 39’ 46.4’’**	**6.01**	**6.36**
823.	**9° 35’ 16.7’’**	**6° 39’ 42.9’’**	**3.61**	**3.96**
824.	**9° 35’ 11.6’’**	**6° 39’ 38.3’’**	**3.11**	**3.46**
825.	**9° 35’ 6.4’’**	**6° 39’ 35.3’’**	**3.31**	**3.66**
826.	**9° 35’ 0.9’’**	**6° 39’ 33.0’’**	**5.91**	**6.26**
827.	**9° 34’ 55.3’’**	**6° 39’ 31.3’’**	**3.36**	**3.71**
828.	**9° 34’ 49.9’’**	**6° 39’ 28.8’’**	**5.21**	**5.56**
829.	**9° 34’ 47.3’’**	**6° 39’ 28.1’’**	**5.91**	**6.26**
830.	**9° 34’ 43.6’’**	**6° 39’ 26.9’’**	**2.56**	**2.91**