ADDIS ABABA UNIVERSITY INISTITUTE OF TECHNOLOGY
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

Estimation of Reservoirs Sedimentation Using Bathymetry Survey: Case Study on Three Koga Night Storage Reservoirs

Hydraulic Engineering Stream

by

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Estimation of Reservoirs Sedimentation Using Bathymetry Survey: Case Study on Three Koga Night Storage Reservoirs

A thesis submitted and presented to the school of graduate studies of Addis Ababa University in partial fulfillment of the degree of Masters of Science in Civil and Environmental Engineering (Hydraulic Engineering Stream)

by

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CERTIFICATION

The undersigned certify that he has read the Thesis entitled **Estimation of Reservoirs Sedimentation by Using Bathymetry Survey: Case Study on Three koga Night Storage Reservoirs** and hereby recommend for acceptance by the Addis Ababa University in partial fulfillment of the requirements for the degree of Master of Science.

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Date

DECLARATION

I, Tamene Dagnaw Mengistu declare that this is my own original work and that it has not been presented and will not be presented to any other University for similar or any degree award.

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ABSTRACT

Reservoir sedimentation is a serious problem that affects the life of reservoirs. Because it reduces the original capacity of the reservoir significantly which in turn affects irrigation, hydropower and drinking water supply activities. This study was conducted in koga night storage reservoirs in Amhara region Upper Blue Nile basin with the objectives of estimating reservoirs sedimentation and life of koga night storage reservoirs using bathymetric survey.

To estimate reservoirs sediment deposition, comparison of initial reservoirs capacity and present capacity. The later obtained by bathymetry survey developing of TIN surface and analyzing volume of reservoirs using ArcGIS 10.4.Sedimentation reduced reservoirs capacity from initial value (design storage) of 32294, 36902 and 36296m^3 in 2012 to 27054, 27722 and 27441m^3 in 2020 for the Tagel, Adbra and Teleta NSR respectively.

The result showed that oga night storage reservoirs have lost on the average 16.2, 24.8 and 24.4% of their capacity, respectively due to sedimentation in 8 years of operation period.

Average rate of sedimentation was estimated to be 655, 1147.5and1106.9 m^3/year with 2.1, 3.1 and 3.04% annual rate of loss for Tagel, Adbra and Teleta NSRs, respectively. Based on bathymetry survey result, the sedimentation rates in live storage zones are found to be 655, 1147.5and1106.9 m^3/years. At the current rate of sedimentation the storage of the Tagel,Adbra and Teleta NSR will be completely lost by sedimentation in 49, 32 and 32 years respectively.

Keywords: Koga night storage reservoirs, Reservoir sedimentation, Bathymetry

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ACRONOMYS

NSR---Night storage reservoir

ABA---Abbay basin authority

ASC---Area storage curve

TSS---Total suspended sediment

SSC---Suspended sediment concentration

EWDI---Equal width and discharge incremental

MPCA--Minnesota pollution control agency

USBR---United State of Bureau of Reclamation

TIN ---Triangulated irregular network

ICOLD---International Commission on Large Dams

HA---Hectare

USGS--United states geology survey

ASTM--American society for testing and material

KDIP---Koga drawing irrigation project

MAE--Mean absolute error

RMSE--Root mean square error

FSL ---Full supply level

GIS---Geographical Information System

GPS---Global Positioning System

RBF--Radial base function

OK---Ordinary kriging

DBD---Dry bulk density

1. Introduction

1.1 Background

Reservoir has the potential for a variety of uses, including water supply for irrigation and domestic use, flood control and water power, but they are susceptible to filling with sediment due to erosion in the watersheds. Reservoir sedimentation is filling of the reservoir with sediment carried into the dam reservoir by streams and the process is universal phenomenon which has been considered as a most critical environment hazard of modern time (Kothyari et al., 2002).Sediment deposition in reservoirs is a serious offsite consequence of soil erosion that threatens the sustainability of dams built for various purposes in Ethiopia (Haregeweyn et al., 2006) as well as in other parts of the world.

In the present situation, worldwide loss of storage capacity in surface water reservoirs due to sedimentation is higher than the increase in storage volume achieved through construction of new reservoirs (White, 2010). Reservoir sedimentation is a severe problem around the world, as it reduces the original capacity of the reservoir significantly which affects the irrigation, hydropower and drinking water supply, flood control and recreational activities. Due to lack of reservoir management practices such as periodical sediment flushing, reservoir sediment routing and catchment management to reduce the soil erosion, the sedimentation of reservoirs is inevitable and it has gradually becoming a greater threat for many countries around the world (Haregeweyn et al., 2012).

Therefore, it is crucial importance to estimate the sedimentation rate and the period of time before sediment accumulation could be interfere with the useful functioning of the reservoir. Different approaches exist for estimating catchment erosion and sediment delivery processes. Distributed physically based models that determine catchment erosion is becoming popular (Van Rompaey et al., 2001).Other approach of estimating sediment yield is Bathymetric survey of existing reservoirs, which is based on comparing the elevation of the sediment level in a reservoir before impoundment with elevation of existing sediment level. Measuring thickness of reservoir Sediment deposits using sediment pits is another possibility of determining sediment yield (Schiefer et al., 2001,Erskine et al., 2002) .

Among the aforementioned approaches, reservoir sedimentation survey methods are more useful and representative because measurements of sediment deposit do not involve generalized statistical models of sediment erosion and transport (Stott et al., 1988).

Bathymetry survey is a direct measurement procedure to assess the volume deposited along with its pattern in the reservoirs and it is more precise in direct methods (strand and pemberton, 1982).

Progressive assessment of reservoir siltation is necessary information for the prediction of storage losses and the probable economic life of reservoir. To maintain the storage capacity of the reservoir using appropriate determination and analysis of sediment yield and their deposition pattern and sediment distribution within the reservoir is essential. With this back ground in view, this study was undertaken to analyze sediment yield change from original capacity to the current capacity of Koga night storage reservoirs and estimate its useful life**.**

1.2 Statement of the Problems

Reservoir sedimentation is a serious off-site consequence of soil erosion with large environmental and economic implications. Sedimentation problems and management techniques vary widely from one site to another, and by studying specific sites one can appreciate the complexity of sediment problems and the manner in which they can be addressed. It is obvious, dams are required to safeguard people against the ill effect of recurrent drought and bring about development, to ensure agricultural based food security. The main objective of water policies is to appreciate the value water use in the most efficient way and gain maximum benefit.

The study of sediment yield of a watershed, reservoir sedimentation of a dam and useful life of designed structure is a great challenge for a hydraulic engineer. There are a number of embankment dams in Ethiopia that are vulnerable to deposition and sedimentation problems. The Koga night storage reservoirs was constructed by China in 2012, for irrigation purpose in Amhara region is a very good example. It is found to be important to conduct this study and to assess this problem since there was no such attempt mad so far. In order to plan appropriate measurement interventions, knowledge of the existing sedimentation rate of reservoirs is necessary. Therefore, this study is to estimate the useful life of the reservoirs and its sedimentation rate.

1.3. Objective

1.3.1 General Objective

The general objective of the thesis work is to determine the rate of sedimentation and remaining capacity of Koga Night Storage Reservoirs.

1.3.2 Specific Objectives

- ✓ To estimate sediment deposition in Koga night storage reservoirs
- ✓ To determine the spatial distribution of sediment deposition in night storage reservoirs.
- ✓ To estimate the life of night storage reservoirs.

1.3.3 Research Question

- ✓ How much storage capacity is reduced due to sedimentation?

1.4 Significance of the Study

Identification of the major causative factors of erosion and other factors that accelerate siltation in reservoirs are necessary to guide targeted management. The result of this study may help in filling the gaps by identifying problems to sustainability and proper functioning of this structures.

The output of this research can be used an input for implementing proper management of the watershed to extend the useful life of Koga night storage reservoirs. Hopefully the research will be an input for the responsible persons in the management and can encourage further construction of new dam structures.

1.5 Thesis Structure and Organization

The report is composed of six main chapters and each chapter has a section and sub-section to elaborate the contents. The short overview of each Section is listed and presented below:-

Section 1: Presents the introduction of the case study including the background information, Statement of the problem description, objective of the study, significance of the study, scope of the study and research questions.

Section 2: In this chapter describes the reviewed literature related to the study on the concept of reservoirs sedimentation, Experience of sedimentation problem of dams in Ethiopia and throughout the world, basic principle and main concept about sediment transportation and deposition of sediments in the reservoirs.

Section 3: In this chapter the explanation of all the methods/methodology and materials to do the research including description of the study area. The various sediment transport formulas, the effect of main reservoir operation, sediment deposition types and locations are discussed based on literature.

Section 4: Presents the data analysis and discussion of the results obtained by the bathymetry survey and it covers predicting the use full life of the reservoirs, effect of main reservoir operation in night storage reservoirs , current deposited volume in reservoirs, Spatial distribution pattern of deposited sediment.

Section 5: In this chapter conclusions and recommendations are presented.

Section 6: References and finally appendixes are included.

2. Literature Review

2.1 Sediment deposition process in the Reservoir

2.1.1 General concepts on sediment transport and deposition of reservoir

The construction of a dam causes a reduction of in inflow momentum and turbulence resulting in settling of sediments carried by the incoming rivers or generally changes the hydraulic characteristics of flow and resultant sediment transport capacity (Yonas, 2005).The Major part of the sediment (bigger suspended particles and most of the bed load) transported into the reach is deposited in the backwater influence area and in the reservoir whereas finer particles may travel some more distance and may finally get deposited farther down in the reservoir (Morris and Fan, 1998) .The retention of sediment in a reservoir depends mostly on the capacity- inflow ratio of the reservoir, inflow sediment type and content.

The reservoir with high capacity-inflow ratio and low sediment content will have low rate of silting and vice versa. The other factors which influence the rate of sedimentation are reservoir operation , discharging facilities, length, size, shape and age of the reservoir, watershed characteristics, land use pattern, geological formation, construction and mining activities, rainfall amount and rainfall intensity, peak discharge, climatic factors, proportion of sediment trapped by upstream reservoir (Strand and Pemberton, 1982).

2.1.2. World Experience on Reservoir Sedimentation

There are a number of studies on sediment measurements which have been conducted to estimate the deposit of sedimentation in reservoirs. There are no accurate data on the rates of reservoir sedimentation worldwide. From the available data about 1% of the worldwide capacity is lost annually, which is equivalent to about 50 km^3 of annual capacity loss (Mahmood, 1987). China has 82,000 reservoirs which are losing storage capacity at an average annual rate of 2.3%, the highest rate of loss of any country in the world, and China also has half of the world's large dams and not surprisingly, China has considerable experience in the management of reservoir sedimentation (Morris and Fan, 1998) The U.S. geological survey has completed a number of reservoirs sedimentation studies in Kansas using a combination of bathymetric surveying and sediment coring. The results indicated that decreases in total water storage capacity ranged from less than 5% to about 55%. The worldwide loss in reservoir storage capacity is estimated to be between 0.5% and 1% per annum (Mahmood, 1987, White, 2010).

2.1.3 Reservoir Sedimentation in Ethiopia

Sediment deposition in reservoir is a consequence of soil erosion that threatens the sustainability of dams built for various purposes in Ethiopia. Previous studies on sediment yield and impacts, conducted mainly in northern Ethiopia have shown that the spatial variability of sediment yield in that region is generally high (Haregeweyn et al., 2006, Tamene et al., 2006).

Many dams constructed to store water for irrigation or drinking purposes were silted up while under construction (Amare, 2005). There were extreme sedimentation cases in Ethiopia such as the Borkena Dam in Wollo, which costed 35 million USD in 1991 and Adrako Dam (Ebinat, South Gondar) where the dead storage volume of the reservoir silted up before completion of its construction (Haregeweyn et al., 2006).

To mitigate agricultural crisis from recurrent drought and erratic rainfall the government of Ethiopia in collaboration with other organizations, constructed more than 50 micro dams for irrigation purpose in Tigray region between 1994 and 2002 (Haregeweyn et al., 2006). Investigation of these micro dams showed that the area specific sediment yield of the reservoir ranged between 345 and 4935ton/km^2/year with a mean of 1900 ton /km^2/year (Tamene 2006).

A related study in this region by Haregeweyn et al. (2006) showed that 50% of the studied micro dams have a siltation problem that will shorten the economic life by half of the design period and another 20% of the reservoir will lose their effectiveness between 50% and 100% of the design life. Angereb Dam, which was constructed in early 1980 on Angereb River, a tributary of the Blue Nile, was primarily built to adequately supply drinking water to Gondar town (Musa et al., 2005). Nevertheless, the Angereb Reservoir has not lived up to the design expectation because of siltation, in which about 1.4 Mm^3 sediment has been accumulated (Amare, 2005; Hathaway, 2008). According to Musa et al. (2005) the mean annual sedimentation rate in Angereb reservoir is 1200 tons/km^2/year. They predicted that the reservoir lost 30% of its volume by the year 2015.

Demesew et al., (2016) studied Koga reservoir sedimentation using bathymetric differencing of by echo sounder. A total of 3,087 points are considered in a regular grid. The result showed that the storage volume shrunk from its design storage of 83.1 Mm^3 in 2009 to 82.7 Mm^3 in 2012, i.e., sediment inflow volume was 339,500m^3.In four years of operation of Koga reservoir. The total reduction in storage capacity due to sedimentation and the specific sediment yield are estimated to be 0.4% and 500t/km^2/yr, respectively.

Worku (2017) studied Koga reservoir the sedimentation in the reservoir resulted in the reduction of the reservoir capacity from design storage of 83.1MCM in 2009 to 80.033MCM in 2017.The result showed that koga reservoir has lost average 3.69% of its capacity due to sedimentation in 8 years operation period. Average rate of sedimentation was estimated to be 383375 m^3/year with 0.46% annual rate of loss. The study indicated that the sedimentation rates in dead storage and live storage zones are 106250 m^3/y and 279605m^3/y respectively this shows that the dead storage and live storage zones have been losing 23% and 2.82% of their storage capacity respectively after 8 years of operation. Based on bathymetry survey result the sediment yield and specific sediment yield of the watershed are 463350.6 tyr^{-1} and 2106.14 tkm^{-2}yr^{-1} respectively. At the current rate of sedimentation the dead storage of the reservoir will be lost by sedimentation in 27 years.

2.1.4. Distribution of Sediment Deposition in Reservoir

The spatial distribution of sediment deposition is dependent on many factors including the size and texture of the sediment particles, the physical characteristics of the reservoir and reservoir operation. There for to determine the sediment distribution pattern to understand the reservoir condition to proper operation. Sediment thickness distribution within in the reservoir has important for reservoir management plan. Raster layer is usually used to compute sediment thickness distribution within the reservoir (Erickson and Stephanie, 2013).

2.1.5. Reservoir Sedimentation Process

The process of sedimentation usually happens by erosion, entrainment, transportation and deposition. These processes are highly complex (Ahmed and Ismail, 2008). River systems erode material from the ground they flow over; these sediments are then transported downstream. When a river is obstructed by structure(dam), the speed of the water is slowed down and thus the ability of the river to transport sediment is reduced and when the speed is too slow the sediments in the river water will begin to settle down (ICOLD, 2009). Delta deposits are formed where the stream enters the reservoir pool and coarse materials are deposited from a homogenous (non- stratified) flow as velocity and transport capacity diminishes (Yonas, 2005).The location and shape of a delta depends on the slope of the valley, length of the reservoir, particle size, its distribution, capacity-inflow ratio, reservoir operation, volume of deposits, shape of reservoir and its construction; and delta grows in upstream and downstream direction Fig. 2-1. Bottom-Set bed depositions are mainly composed of clay and silt fraction, which are transported in the reservoir water body either by the turbulent suspension or by turbidity currents (Sloff, 1997).

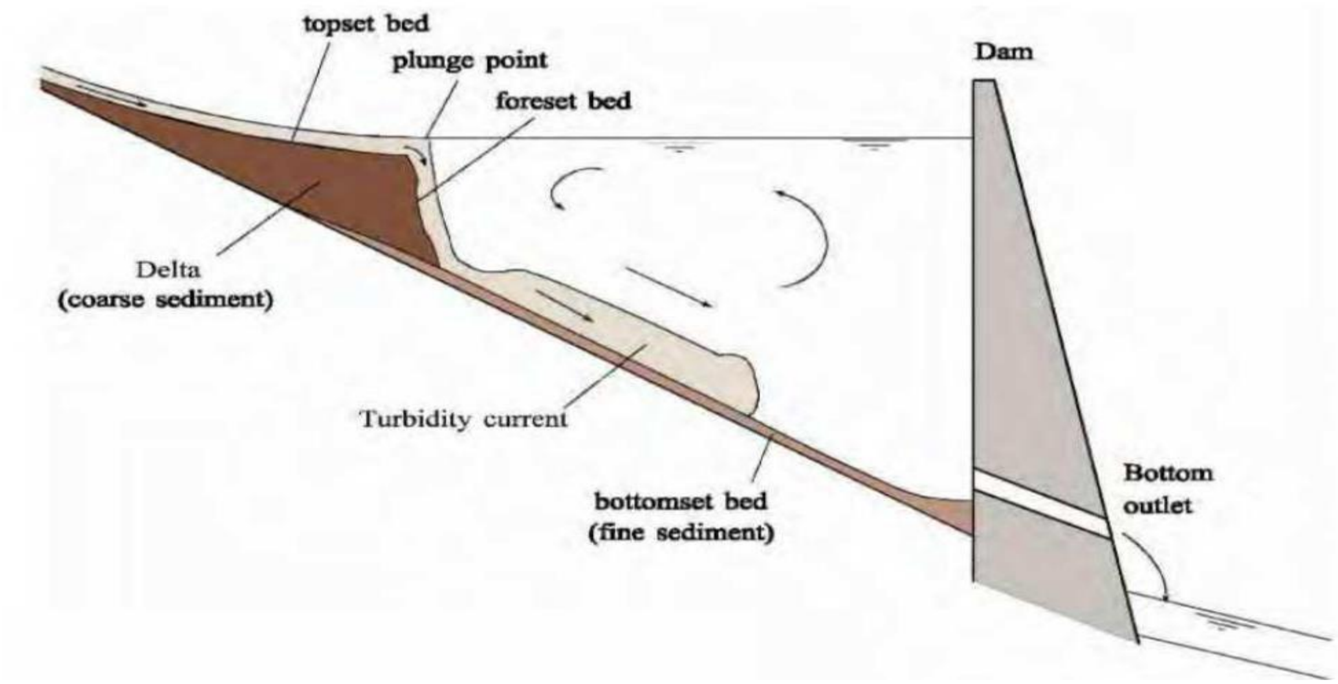


Figure 2-1: Schematic presentation of principal sedimentation processes in river-fed storage reservoirs (Sloff, 1997)

2.2. Methods for Estimation of Reservoir Sedimentation

Systematic determination of sedimentation during operation stage is essential to update knowledge of sedimentation process going on the reservoir and in order to plan reservoir operation for optimum utilization of water. Some of the methods presently in use for estimation/ prediction of sediment deposition in reservoirs are:

1. Empirical and mathematical model
2. Inflow/outflow measurements
3. Remote sensing
4. Bathymetric Surveys

2.2.1 Empirical and Mathematical Methods

The amount of sediment deposit and distribution pattern could be estimated quantitatively and qualitatively by empirical and mathematical methods. Mathematical models solve the governing equations of transport and momentum. Due to the advancement of mathematical models and computer technology, mathematical models for predicting reservoir sedimentation are increasing. Mathematical models are economically effective compared with the site monitoring empirical methods. Methods to predict reservoir sedimentation using one dimensional model has been studied by (Khodashenas, 2006, Gessese and Yonas, 2008).

These methods are simple, low precision and accuracy, limited application and required less data, but can be used for preliminary estimation purpose or help on the feasibility design stage of the reservoirs.

One dimensional mathematical model is used to analyze sediment transport along reaches of rivers or in reservoir, where essential transport processes can be simulated with a one dimensional flow field. One dimensional model solves the unsteady, cross sectional averaged equations for the mass balance of suspended sediment (Rijn, 1986).This method was developed based on field survey gathered data from reservoirs in the USA with capacities range from 49million m^3 to 36.9 billion m^3 (Annandale,1987).

2.2.2 Remote Sensing Method

In recent times, Satellite Remote Sensing techniques provide multispectral satellite data using remote sensing and it is receiving broader application for capacity surveys of reservoirs. Efficient reservoir management needs periodic assessment of its capacity. To quantify the capacity of a reservoir, the only thematic information that has to be extracted from the satellite data is the water spread area at different water levels of the reservoir (Morris and Fan, 1998). Reduction if any, in the water spread area for a particular elevation indicates deposition of sediment at that level and when we integrate it with elevation we can compute the capacity of the reservoir or volume of storage loss due to sedimentation. The major limitation of remote sensing based approach is that the revised capacity below the lowest observed and above the highest observed reservoir water levels cannot be determined. It is only possible to calculate the sedimentation rate within the zone of fluctuation of reservoir water levels. The amount of sediments deposited below the lowest observed water level cannot be determine through Remote Sensing and thus, it is not possible to estimate the actual sedimentation rate in the whole reservoir (Jain and Singh ,2003).

2.2.3 Bathymetry Surveying Method

Bathymetry surveying techniques provides effective method for determining reservoir sedimentation. For bathymetric survey techniques selection, the optimal survey pattern is determined considering a number of constraints, namely budget, time availability, and equipment availability. To reduce the time and cost associated with underwater data collection, aerial data should be collected when the reservoir is as empty as possible or the bathymetric survey should be conducted when the reservoir is as full as possible (Strand and Pemberton, 1982).The main purpose of a reservoir resurvey is to compare the storage capacity with that of an earlier survey (usually the original survey), and the difference will be the sediment accumulation (USBR, 1987).

The storage volume computations are made from an area-capacity curve corresponding to each elevation in the area- elevation plot. The end product of the area- capacity computation is a plot of the areas and capacities for the original and new surveys (Strand and Pemberton, 1982).According to Carvalho et al. (2000), generalized reservoir surveys are required for, determination of the new capacity and sedimentation level, which is the main purpose of the bathymetric survey. But general procedures for reservoir surveys have undergone changes due to scientific development and the emergence of new technologies and equipment.

There are two general methods of conducting the reservoir survey. These are contour survey and Range Line (RL) survey. Selecting a method depends on the purpose and scope, size of reservoir, and degree of accuracy required (Morris and Fan, 1998).

i. Contour surveys

Contour survey use more complete topographic or bathymetric information to prepare a contour map of the reservoir. It is the simplest and accurate technique for determining volume and also provides the most complete information on sediment distribution. Recent advances in automated survey techniques now make hydrographic contour surveying very economical for smaller and midsize reservoirs, which may require only a few days of field time using automated depth measurement and positioning systems to collect bathymetry data. To apply this method, it is important to have a good contour map of the reservoir before filling.

The contour method is usually used for small reservoirs, when the highest degree of accuracy is required (Chitata et al., 2014).It consists of a survey of the area and perimeter of the water surface at different levels by means of topographic survey techniques. It shall be preferably applied during emptying of the reservoir or in reservoirs with high water level elevation variation.

i i. Range line survey

Range line survey uses a series of range or cross-section lines across the reservoir which are resurveyed at intervals and used to compute volume change by geometric formulas. Range surveys are faster and more economical to perform than contour surveys because field data requirements are greatly reduced compared to contour surveys. They have historically been the most commonly employed technique to monitor sedimentation, but are increasingly being supplanted by automated contour surveying methods. The number of ranges depends on reservoir size and geometry, with a minimum of three ranges required for even the smallest impoundment (Morris and Fan, 1998). The basic procedure for this method involves the determination of bed elevation on the reservoir. These measurements are almost always made by measuring the water depth beneath a boat and the exact location of the boat on the lake's surface. So two basic types of measurements are required; position measurements and depth or bed elevation measurements. The simplest way of measuring the water depth is to use a sounding weight or digital sonar to obtain it directly.

2.3 Reservoir Survey Frequency

The reservoir survey frequency should be based on individual site characteristics. At reservoirs that losing capacity very slowly, a survey frequency on the order of 20 years or even longer may be adequate. By contrast, at important sites which are losing capacity rapidly, or where the impact of sediment management is being evaluated, a survey interval as short as 2 or 3 years might be used. Reservoir should also be surveyed as soon as a new reservoir is close upstream to provide a baseline for computation of the new sedimentation rate from the reduced area of uncontrolled drainage. The minimum survey frequency depends on the precision of the survey technique and the rate and pattern of storage loss. For instance, if the reservoir is losing capacity at 0.25 percent per year a 4-year survey interval may be too short to produce reliable information (Morris and Fan, 1998).

2.4. Reservoir Survey Section Interval

Reservoir survey distance interval within range lines and from one point to another along the survey line depends on the surveying method to be used, the reservoir size, topography of the reservoir, available resources and other factors. Recommend survey distance intervals from one to another survey point is given Table 2-1, (Carvalho et al., 2000).

Table 2-1: Distance between sections and frequency of surveying (Carvalho et al., 2000)

S.N o	Map scale	Distance between Section (m)	Capacity (MCM)	Types of reservoir based on capacity	Survey Frequency
1	1:2000	20	<10	Small	Every 2 years
2	1:5000	50	<10-100	Medium	Every 5 years
3	1:10000	100	>100	Large	Every 10 years

2.5. Estimation of Reservoir Storage Capacity by using TIN Model

The point files resulting from all the survey data and interpolation or extrapolation must be exported, and used in conjunction with the sounding and boundary files to create a Triangulated Irregular Network (TIN) model with the 3D Analyst Extension of Arc GIS for area, volume, and contour calculations. In a TIN model, a prismatic volume is computed between a horizontal reference level and each triangle, the triangle is inside the area where the volume has to be computed (De Wulf et al., 2012).The Triangulated Irregular Network (TIN) model by Arc/GIS software is developed to establish the area and volume of the Musol dam reservoir in Tigres River to develop ASC by using bathymetry survey data, (Issa, 2015).

By using TIN model, the maximum deposition and spatial distribution of Musol dam reservoir was Shawn. In lake Linganore on Linganore Creek in central Frederick Country, TIN models have been used to accurately represent reservoir bottom surfaces for the purpose of determining both water and sediment volume (Sekellick and Banks, 2010).For the John Redmond reservoir in Kansas, TIN model was carried out for accurate estimation of Revised Area–Elevation–Capacity computation (Kansas Biological, 2010). On the other hand (Erickson and Stephani,

2013) conducted a bathymetry survey to develop the morphology map and spatial distribution of sediment at Zippel and Bostic Bays Lake of the Woods in Minnesota.

2.6. Useful Life of Reservoir

The global average for the useful life of a reservoir is less than 25 years (Mahmood, 1987). The useful life is a period that the sediment deposited does not affect the economic feasibility and sustainability of water resources demand. In general, useful life of the reservoir is the time period when the reservoirs depleted 50% of its storage capacity or the dead storage is completely filled with sediment (Gill, 1979). The useful life of a reservoir is generally determined from the rate of dead storage capacity loss rather than the total capacity loss (Haregeweyn et al., 2012).

On the other hand (Jain and Singh, 2003) described that the volume of dead storage of most of the old dams were kept equal to likely inflow volume of sediment during designed life period, assuming that the entire sediment will be trapped in the dead storage zone but the reality is different. Dead storage volume is a function of: (1) the expected sediment input from the watershed, (2) the intended life of the reservoir, and (3) any planned sediment management to take place after construction of the dam (Haregeweyn et al., 2006).

2.7 Specific Weight of Sediment Deposit

The term specific weight is used to denote the dry weight of sediment particles of a total, in place volume of sediment mass (Rupasingha, 2002).The volume occupied by the sediment in the reservoir depends on the average dry specific weight of the deposited material, defined by dry weight of sediment per unit total volume including voids.

The dry specific weight of finer sediments varies with time due to the consolidation and compaction of the material and exposure to the air. Strand and Pemberton, (1982) described the basic factors influencing density of sediment deposits in a reservoir considering type of operation, texture and size of deposited sediment particles, and compaction or consolidation rate of deposited sediments. Sediments that have been deposited in reservoirs subjected to considerable drawdown are exposed for long periods and undergo a greater amount of consolidation.

3. MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1. Location

Koga Night Storages irrigation development project is located in Amhara National Regional state, West Gojjam Zone, Mecha Woreda. It is found at a distance of 41 km from Bahir Dar town and 7km to 15km from Merawi town at the right side on main highway from Bahir Dar to Adds Ababa. The Night Storage Reservoir site is geographically located at $37^{0}08'$ E and $11^{0}\ 20'$ N and 1983-1906m.a.s.l average elevation. The study area map is as shown in Figure 3-1.

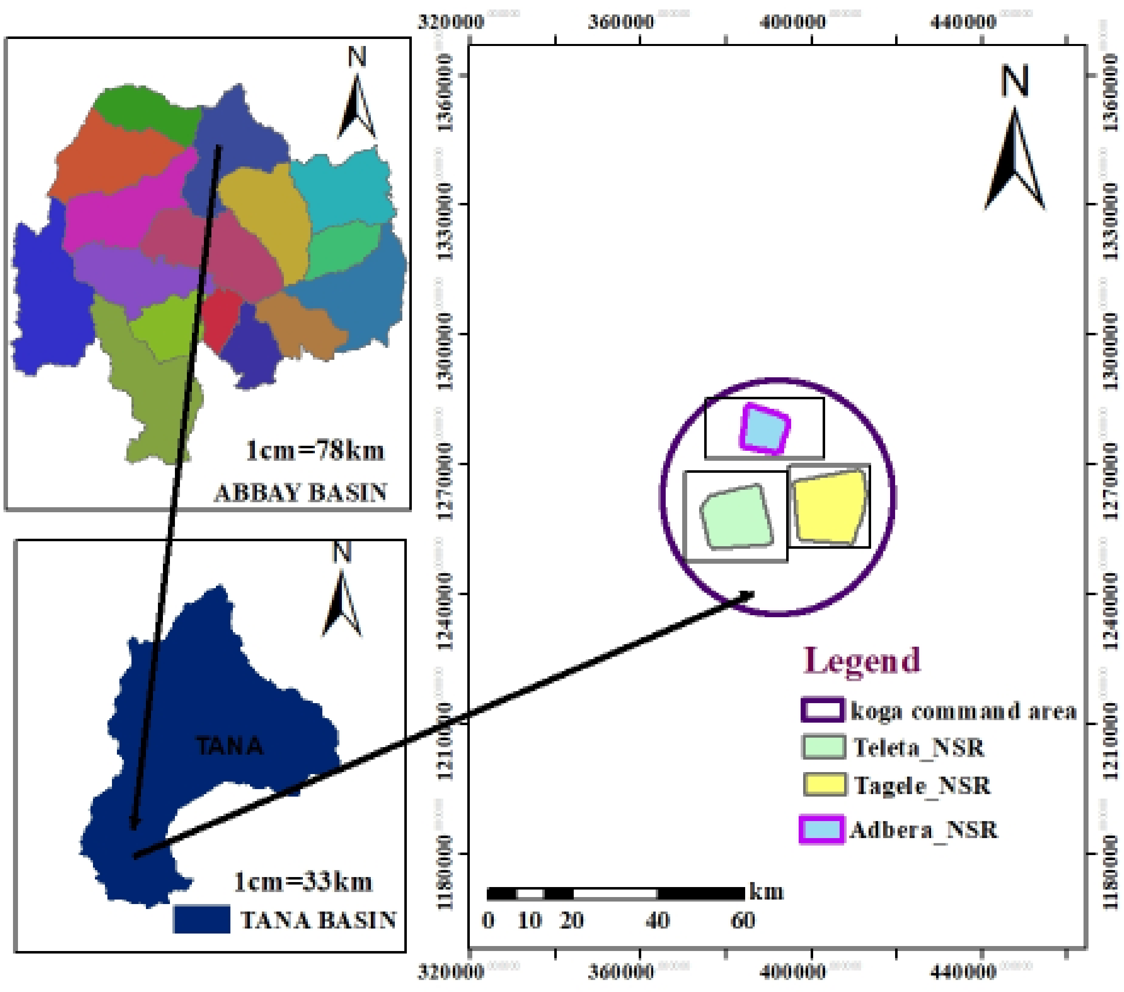


Figure 3-1: Location map of the study area by using ARC-GIS 2020

Table 3-1: Salient features of the Koga night storage reservoirs

Name of NSR	Item	Unit	Features
TELETA NSR	Bed level	masl	1903.4
	Level of out let	masl	1903.4
	Capacity	m^3	36296
	Normal crest level	masl	1907.8
	Full supply level	masl	1907.415
	Command area	ha	611
	Area of reservoir	m^2	25615
ADEBERA NSR	Bed level	masl	1983.4
	level of outlet	masl	1983.4
	Capacity	m^3	36902
	Normal crest level	masl	1986.944
	Full supply level	masl	1986.675
	Command area	ha	694
	Area of reservoir	m^2	25975
	Bed level	masl	1991.4
	level of outlet	masl	1991.4
	Capacity	m^3	32294
	Normal crest level	masl	1995.30
	Full supply level	masl	1994.89
	Command area	ha	494
	Area of reservoir	m^2	22818

Bed level =Inverted level of culvert /level of outlet

Figure 1-2: Map of the study area on Google Earth taken 2020

3.1.2. Materials

In the Koga night storage reservoirs bathymetric survey chart plotter Garmin GPS Map 421*s* single beam echo sounder provided by Bahir Dar Institute of Technology was used to collect depth sounding with their corresponding location measured. The echo sounder is powered by 12vsealed lead acid chargeable battery and fitted to a local boat. Besides Etrex- Garmin hand held GPS was used to guide our local boat along the geo referenced transect rout, also to record geographical coordinate point of the reservoirs boundary. The material listed Table 3-2.

Table 1-2: List of equipment used in the NSR bathymetric survey and sediment sampling

ID	Equipment Name
1	Hand held GPS map 62s
2	Topographical point data NSR area(during design time) original point
3	Soil Core cutter
4	Garmin GPS421s and echo-sounder to measure the depth of water
5	Local boat
6	Soil sampler and soil container
7	Drying oven
8	Any necessary software such as ArcGIS and computer

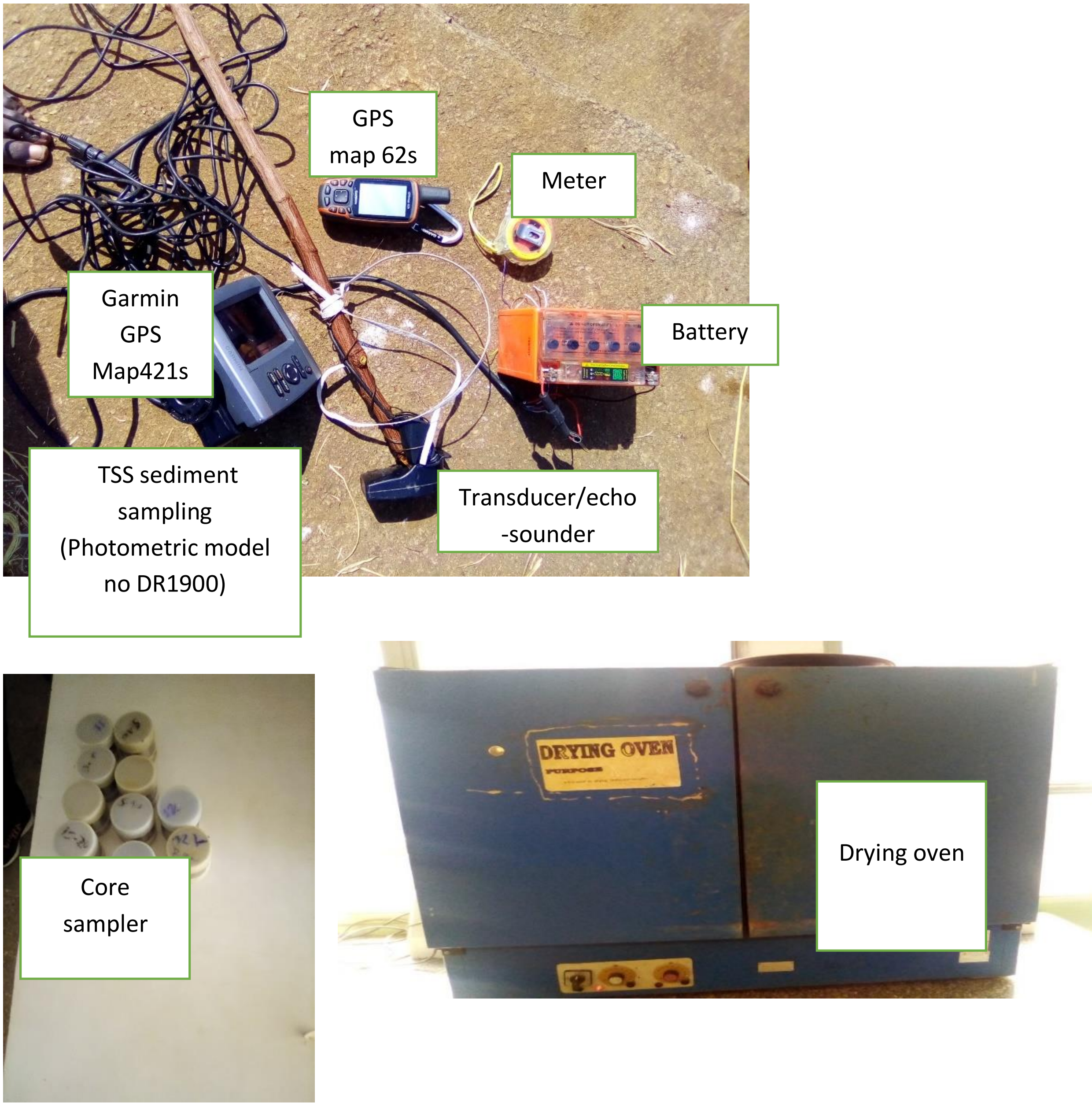


Figure 3-3: Photo of material used at field and laboratory taken during surveying

3.2 Calibration of the Sounding Instrument

Before use of the instrument, calibration is necessary with local field conditions to ensure that instrument provides accurate readings. Therefore, the echo sounding instrument with Garmin TM GPS Map 421*s* was first tested at koga night storage reservoir and comparisons were made with the repetitive manual measurements using five meter long graduated staff using measuring tape as shown Figure (3-4).

Figure 3-4: Calibration of the sounding instrument at koga night storage reservoir

To make sure that measurements are accurate, calibration was again carried out in koga night storage reservoirs. During this phase it was tried to ensure the smooth execution of the field work by locating the sounder at the appropriate point to connecting the GPSMAP 421*s* to the transducer, measuring the submerged depth of the transducer from the water surface, checking whether the package is synchronized with each other or not.

Some trial sample preliminary measurements were collected randomly for primary calibration and the results were reported in Appendix-2 showing readings from both techniques as well as x and y coordinate. Depth calibration was performed twice daily (at the starting and finishing time) during the period of data collection by placing a long graduate staff for a shallower depth at different locations in the reservoir.

To check the precision in this measurement the square root of the mean of the squared error (RMSE) was calculated by using Eq.3 .About 12 quality assurance data points were taken during bathymetry survey.

$$\text{RMSE}=\sqrt{\frac{1}{n}\ \sum_{k=1}^{n}(ZM-ZS)\ \hat{}2} \qquad 3$$

Where RMSE- root mean square error of Z or vertical component, Zm and Zs are the depth reading by tape measurement on stick and Echo sounder reading depth respectively and n is the number of measured points. Using Eq. 3.1, the error values (RMSE) of water depth measurements were 0.0332m when water depth was in the range of 1.5 to 1.8m within the night storage reservoir. According to (NDEP, 2004) guide line a factor of 1.96 is multiplied by the RMSE to estimate vertical accuracy at 95 percent of confidence interval and the value 0.136 m was obtained. This error was acceptable according to (NDEP, 2004, Sekellick and Banks, 2010).

3.3. Estimating Reservoir Sediment Deposition

The reservoir sedimentation assessment includes the evaluation of the rate of Sedimentation in Koga night storage reservoirs and its sediment distribution using bathymetric survey. This survey is often supplemented with some type of topographic survey to obtain land surface altitude data up to the escape weir crest level or higher. It is based on comparing the volume of reservoirs capacity at different periods.

Topographic map before impoundment was used to develop a contour map for the reservoirs before construction of the dam. In this case, information on the original capacity of the reservoirs is required to be used as a benchmark against which the existing storage capacity can be compared. Then the original reservoir topography map was acquired. The original design topographic data was available in soft copy in Abbay Basin Authority Drawing Nr KDIP/2004/.

The original data was initially picked from original map then written in excel and transfered in to Arc GIS window. Then the topographic data was projected to Arc GIS 10.4, by Universal Transverse Mercator (UTM) projection, Africa-Adindan.UTM-Zone 37N' in the Arc-GIS software. Then, it has been imported to ARC-GIS 10.4 and to make workable form in Arc GIS environment and to export as a shape file Contours and TIN surface has been developed by using 3D Analyst tool in Arc-GIS software. This is used to compute original reservoir capacity.

To derive existing storage capacity, bathymetric survey and topographic survey were conducted using echo- sounding instrument fitted on a local boat and global positioning system (hand held GPS). The GPS was used to determine the interval of the recording depth and compass was used to find the boat transect line from one end to other end. The echo sounder and GPSMap are synchronized and used to record the depth from the water surface to the top of the sediment. It also records the geographic position of the boat when recording each depth measurement simultaneously as shown Fig. 3-5.

Figure *3-5*: The bathymetry survey of Koga night storage reservoir photo taken during field work.

In the reservoirs area, there is minimum drawdown area and excess sediment deposition above the water depth. Apart from the nature of the reservoirs for bathymetric survey selection, the optimal survey pattern is also determined considering a number of constraints, namely budget, time availability, and equipment availability.

Processing of the survey data was done by entering the data to Microsoft excel for review and checkup. In order to convert the raw depths recorded by the echo-sounder into elevations, the depth reading at each coordinate was subtracted from the corresponding water surface elevation.

Storage capacity and water surface area of the reservoirs at each 0.5m interval were calculated using 3D tools in ARC_GIS, based on which the current area-capacity curves of the reservoirs were constructed. The total volume (m^3) of sediment deposition was calculated by subtracting current water storage capacity from original water storage capacity before impoundment.

3.3.1. Determine Spatial Distribution of Sediment Deposition

The two periods of reservoir depth data for koga night storage reservoirs area; one before dam construction (2012) and the other in 2020 from bathymetry survey were used to assess sediment distribution in the reservoirs. For this assessment 2012 and 2020 depth points were converted to TIN surface using 3D analysis tool in ARC-GIS 10.4 software and raster map is developed. Then the2012 bed elevation raster layer was subtracted from 2020 reservoirs bed elevation raster using raster math-minus tool in ARC_GIS. The difference between the two raster layers represented the sediment deposit distribution within the reservoirs during their operation period.

3.3.2. Estimation of the Useful life/ Life expectancy of Night Storage Reservoir

The period up to which the reservoir can serve the defined purpose is called useful life. It is an important design parameter of a reservoir which may affect the economic feasibility and sustainability of a water resources project (Gill, 1979).The useful life of the reservoirs will be estimated by using Eq.3-1 (Haregeweyn et al., 2012).

$$LE = \frac{DSV}{SR} \qquad 3.1$$

Where, LE is the life expectancy of the reservoir (in years), DSV is the dead storage volume of the reservoir, calculated as the capacity loss at the dead storage level and SR is the sediment deposition rate($m^3 year^{-1}$),and calculated byEq.3.2.

$$SR = \frac{SV}{\Delta T} \qquad 3.2$$

Where, SV is the sediment volume (m^3) that accumulated between the year of construction & bathymetry surveys below the dead storage level and ΔT is the time interval between the two successive reservoir surveys.

3.3.3. Methodology of Study

The overall work has been carried out in two phases as; the Field Work Phase, and the Office Work Phase. Before carrying out the field work, pre field work preparation made that includes the selection of suitable research methodology to carry out the study, searching literatures related to the topic from different sources, gathering the available data from different sources and collection of materials for field data collection.

During field work calibration of instrument bathymetric sediment sample collections in reservoirs and in the secondary canals is carried out. The methodology of study shown in Fig.3-6 is used to achieve the research objectives.

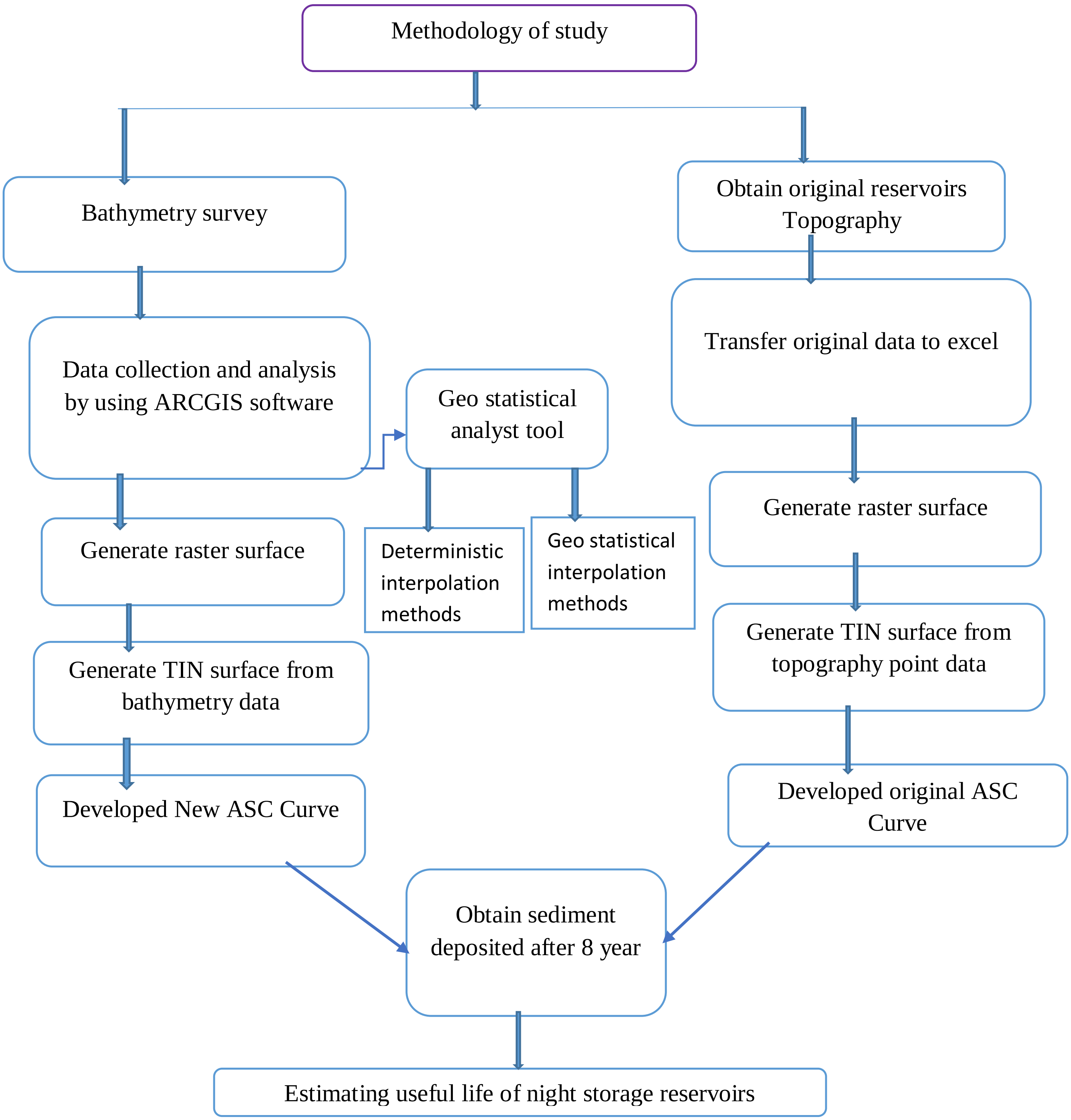


Figure 3-6: Flow chart of methodology for estimating night storage reservoirs sedimentation

3.3.4 Reservoir sediment sample collection and dry bulk density estimation

In order to be able to compare sedimentation rate of different reservoirs, it is necessary to convert the measured sediment volume (m^3) to sediment mass (tons) using dry bulk density (Verstraeten and Poesen, 2001). The measured sediment volume was multiplied by its DBD to estimate the sediment mass. Twelve undisturbed sediment samples were collected in core sampler as described earlier and oven-dried for 24 hour at 105°C and the mass of the sediment before and after oven-drying were measured. It was collected the time of maximum drawdown area of the reservoirs to obtain undisturbed samples from the different parts of the reservoirs.

The number and nature of sediment sample to be collected depends on the kind of the reservoirs and the nature of the reservoirs operation. Taking those factors in to consideration total 12 Undisturbed known volume of soil samples were collected during the dry period for the analysis of dry bulk density. It was not possible to obtain undisturbed samples from some center parts of the reservoir because lack of the necessary equipment. Soil sample were taken up to a maximum of 70 cm depth, but I am taken maximum 15 cm depth to determine dry density in laboratory. The sample was taken during reservoirs drawdown condition or when reservoirs elevation reaches minimum level between 9:00pm -12:00pm for 3 continuous days on 10, 11, and 12 February 2020. The spatial distribution of soil sample points is as shown in Figures 3-7, 3-8, 3-9 and 3-10.Laboratory results and analysis of sediment dry bulk density of this sample are reported in chapter four.

Figure 3-7: Photo taken during soil sample collection in NSR

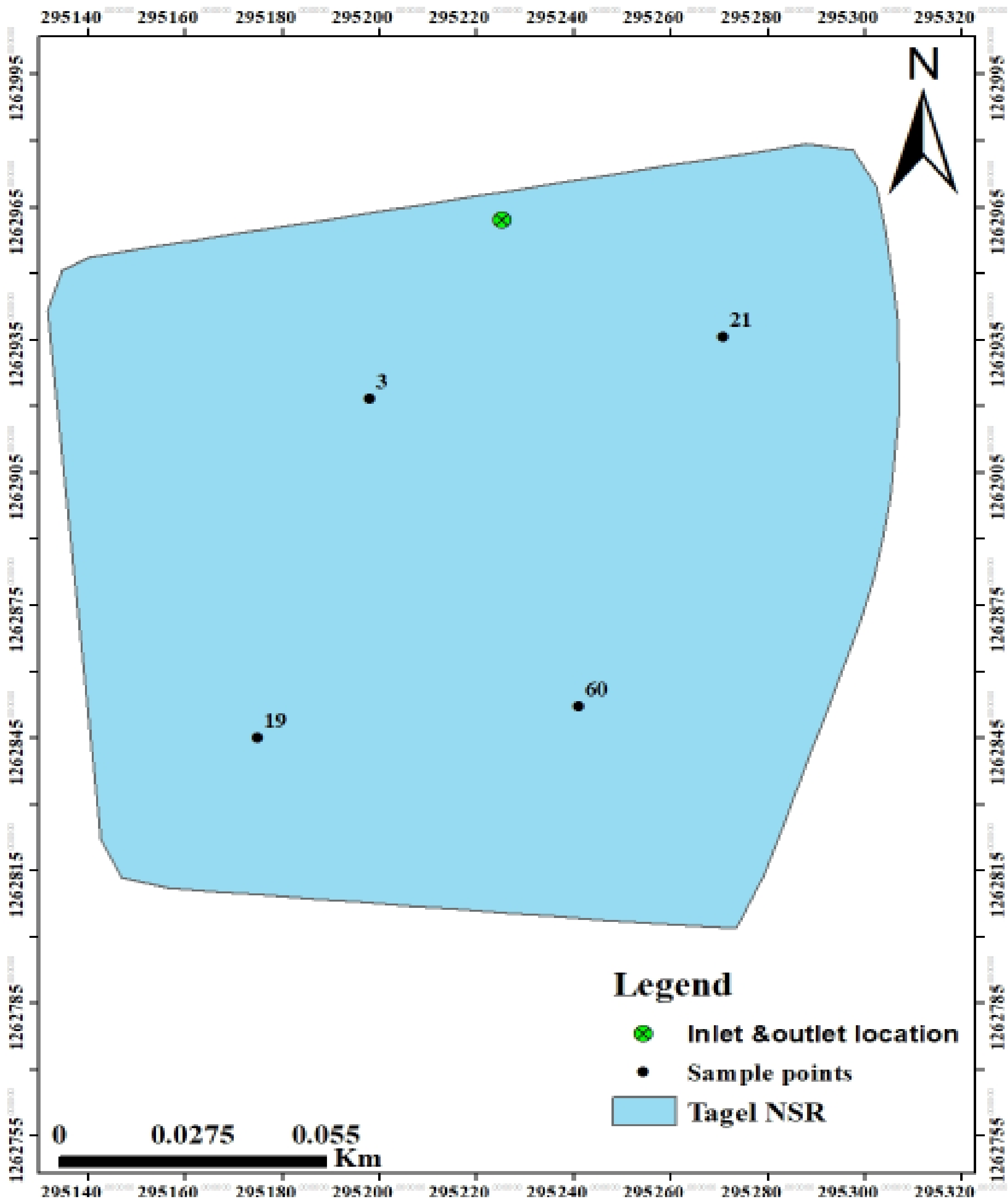


Figure 3-8: Location of soil sampling with ID in Tagel NSR

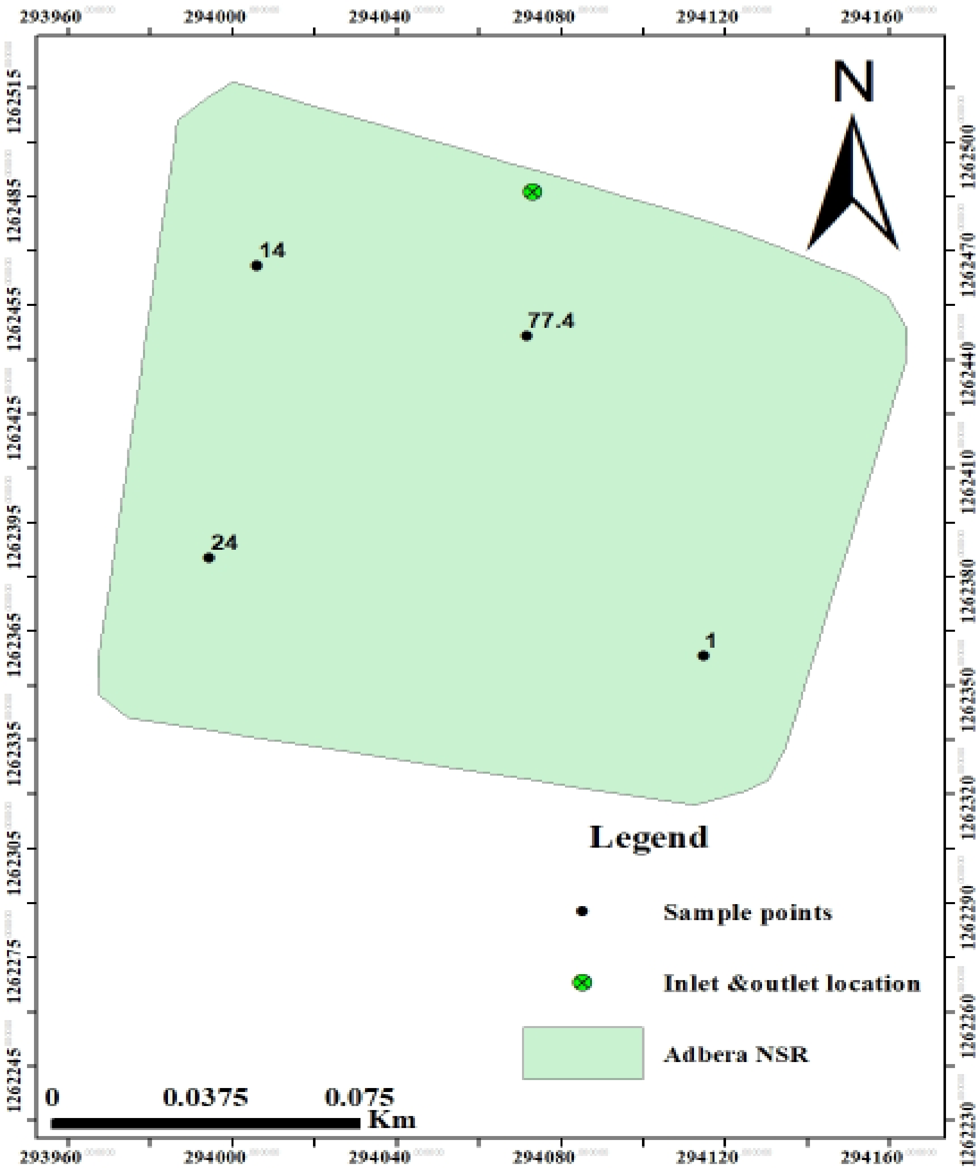


Figure 3-9: Location of soil sampling with ID in Adebra NSR

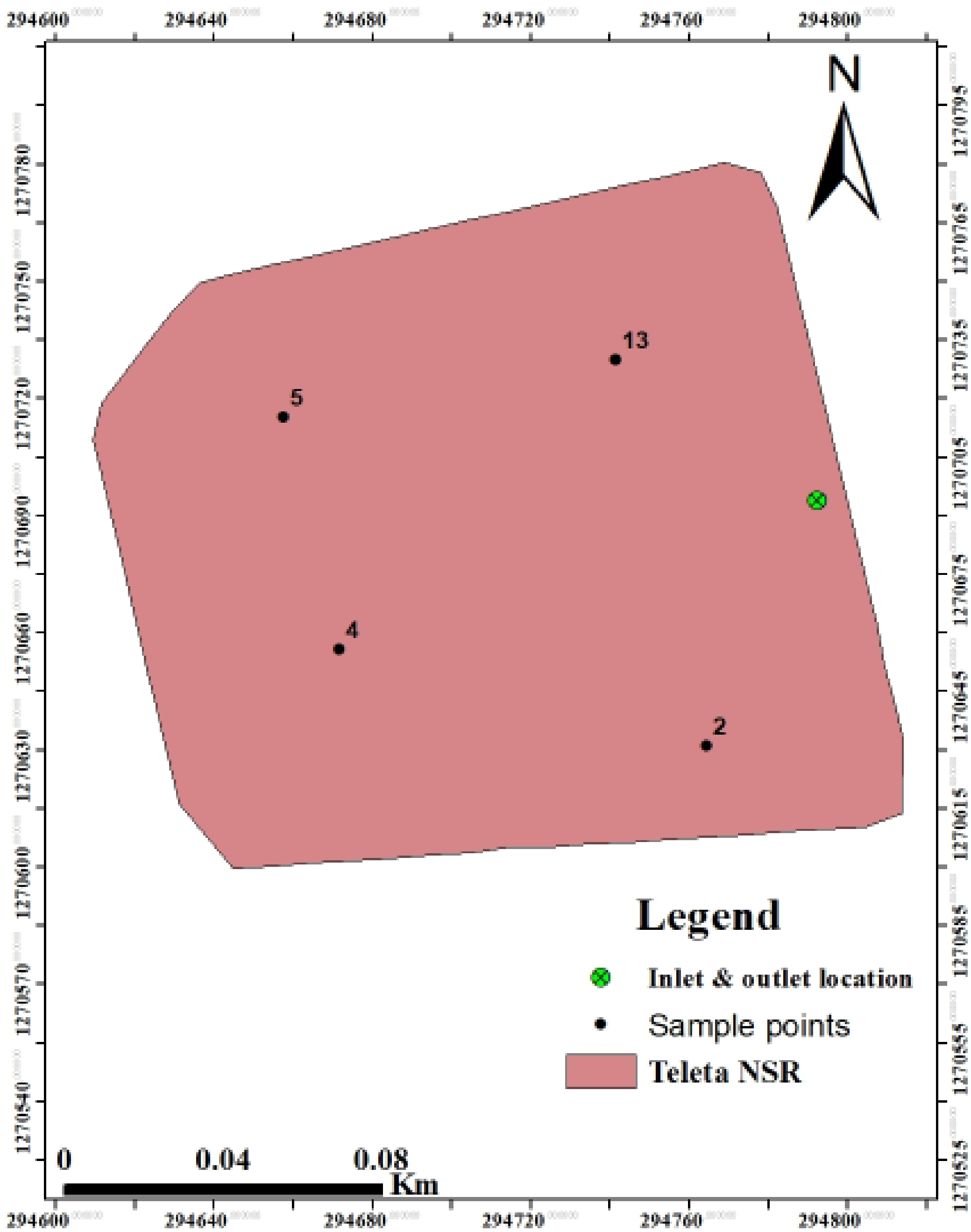


Figure 3-10*:* Location of soil sampling with ID in Teleta NSR

3.4. Data types and data collection process

Primary data is collected by establishing bathymetric survey and at reservoirs periphery using sediment core sampling collection. Secondary data including topographic, hydrologic data was also collected from office.

3.4.1. Reservoir Bathymetry Surveying Data

Reservoirs topography was surveyed in detail by using bathymetric was carried out over the entire water surface area by using echo-sounder above 400 samples were collected from 20 to 28 February and Additional reservoirs boundary data was collected during 1 to 9 March 2020 by using etrx-Garmin GPS.

For this activity the elevation of the water surface level on the day of measurement was taken from the escape weir crest level measured by handle GPS or from staff gage. During this activity, the daily water surface elevation measurement was taken once a day because during data collection time the NSRs had to be closed.

Reservoirs depth were collected by echo-sounder and reservoirs bed elevations were calculated by reducing the depth readings of the sounder and the depth of the transducer (DT= 20cm used in this survey) bellow the water surface see Eq. (3.3).

$$RBE = WSL - (SD + DT) \qquad 3.3$$

where

RBE = Reservoir bed elevation or sediment elevation (m)

WSL = Water surface level (m)

SD = Sounding depth (m)

DT = Depth of Transducer from the water surface (m)

Bathymetric survey was done at grid interval ranges in between 15 m and 20 m North –East respectively across the reservoirs area. But to follow the predefined line was very difficult because the local boat could not follow exactly the previously defined cross sections. The Bathymetry survey was conducted during calm condition then due to this reason the effect of wave height on the water depth measurement was neglected. For bathymetric techniques above 400 total sampling points were collected from all night storage reservoirs see Figures (3-11, 3-12 and 3-13).The bathymetric data is attached at appendix-7.

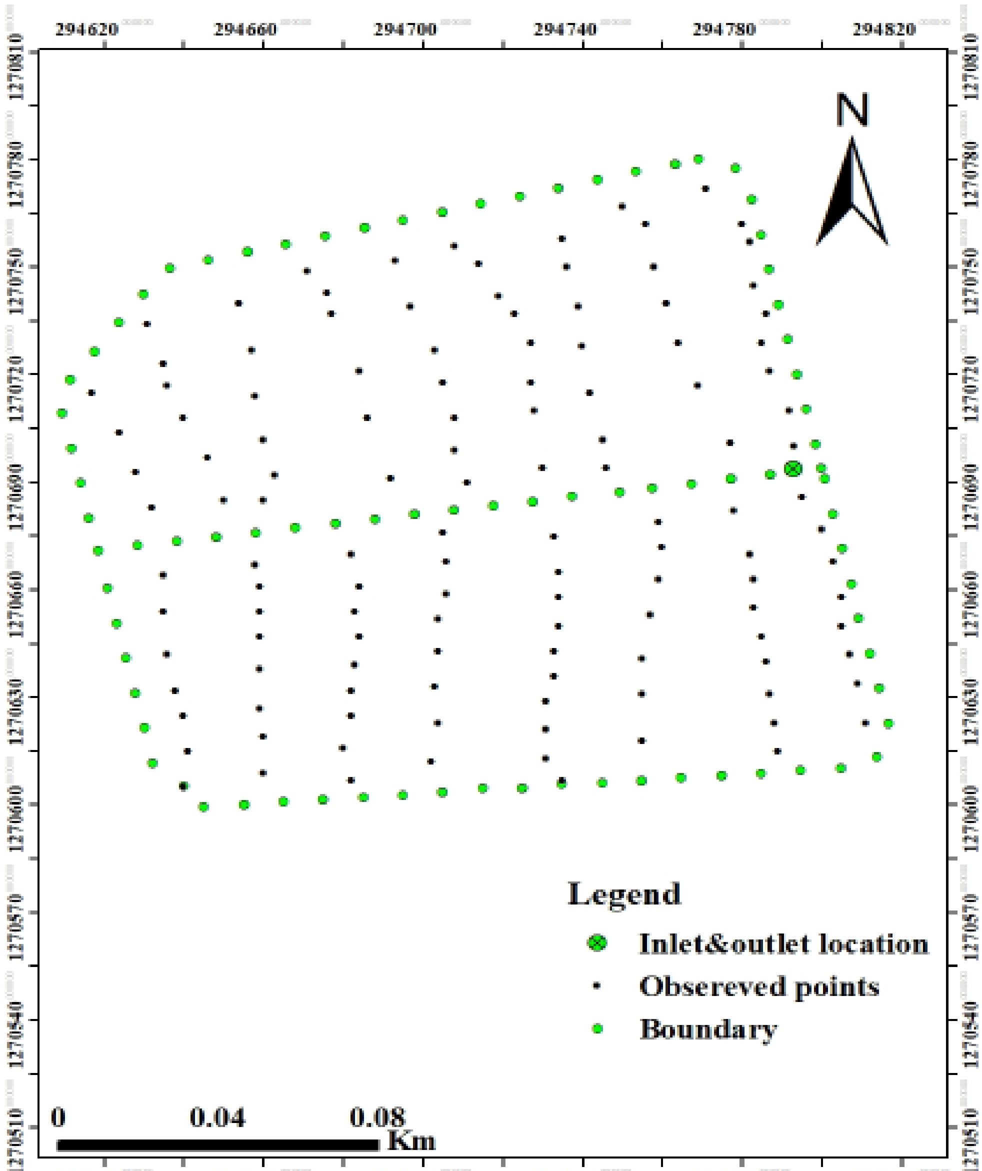


Figure 3-11: Teleta NSR bathymetric survey observed points

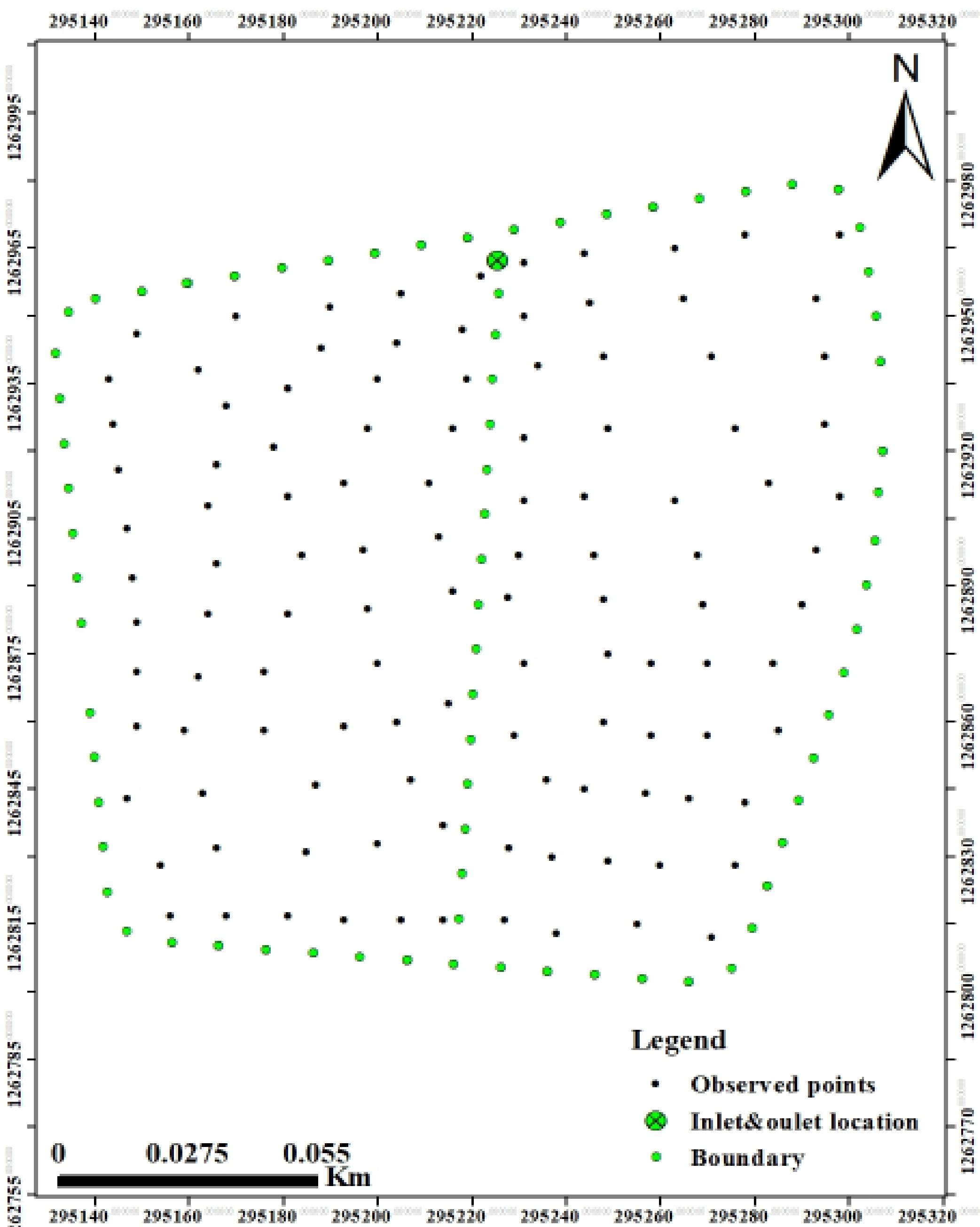


Figure 3-12: Tagel NSR bathymetric survey observed points

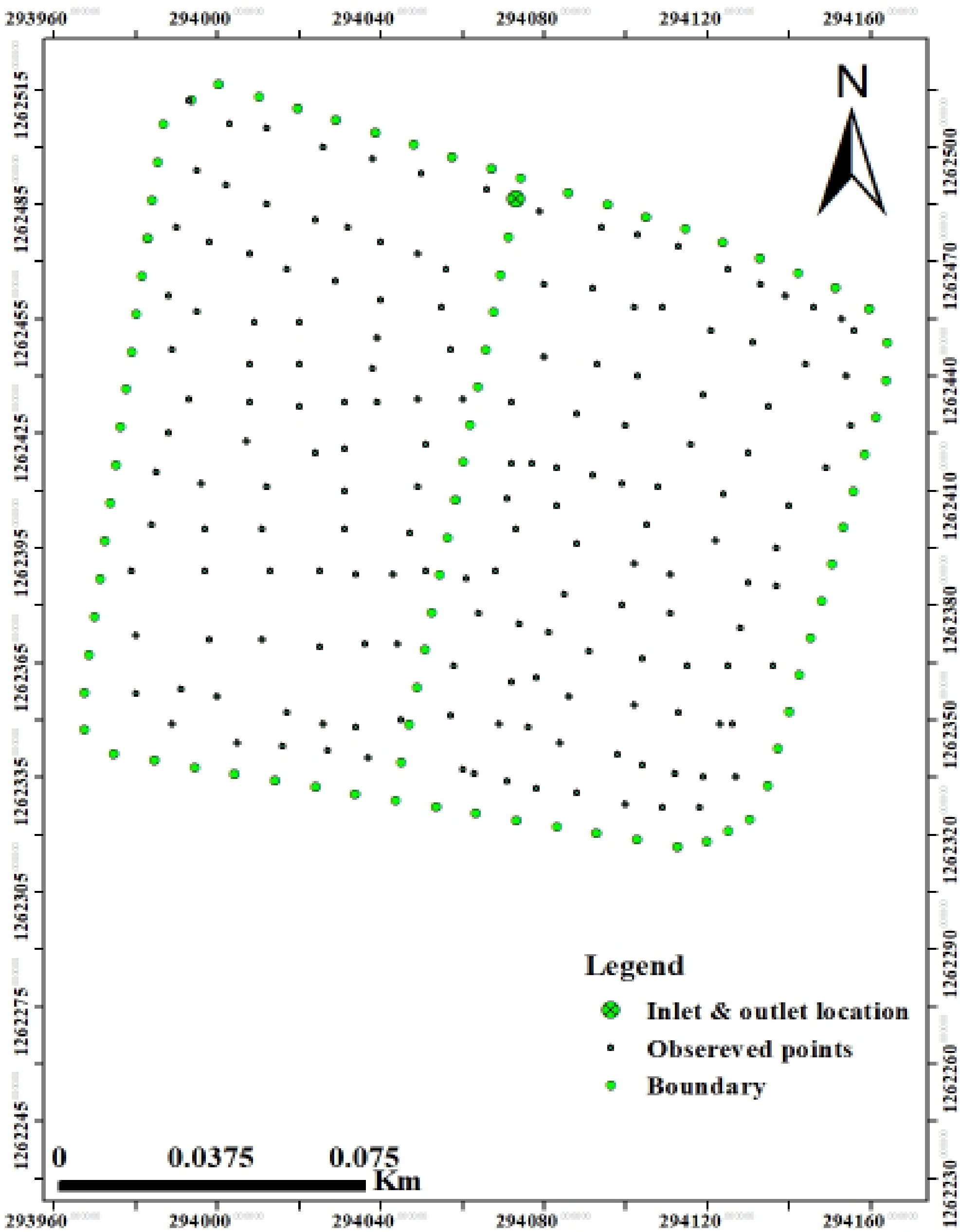


Figure 3-13: Adbera NSR bathymetric survey observed points

3.4.2. Selection of Interpolation Methods

All the bathymetric survey data are organized, refined and converted in the way that can be supported by the Arc GIS platform. The next step is generation of bathymetric map through selection of various surface interpolation methods. The spatial interpolation was conducted using four different interpolation methods, which are available in the Arc-GIS 10.4 Geo-statistical interpolation Analyst tool of data analysis is important to make the best use of observed data and to estimate the depth parameters in other locations. These methods are under Determistic methods [Inverse Distance Weighting (IDW), local polynomial interpolation (LPI) and Radial Base Function (RBF)] and under Geostatistical methods[ordinary kriging (OK)].They were chosen because they are widely used in the literature and are frequently used to interpolate bathymetric data in different aquatic systems (David, 2003).Validation for each spatial interpolation method was conducted using the cross-validation technique, a popular statistical technique used to evaluate interpolation methods (Cressie, 1993). Validation was performed on each dataset using a training dataset (80%) and test dataset (20%) of each dataset population and the best interpolation method was selected with low root mean square error and high correlation coefficient (Sterling, 2003). In addition to the above evaluation methods, coefficient of determination (R^2) value is used to check the performance of the methods on the spatial interpolation techniques.

$$\text{MAE}=\frac{1}{n}\sum_{k=1}^{n}|(Dobs-Dint)| \qquad 3.4$$

$$\text{RMSE}=\sqrt{\frac{1}{n}\sum_{k=1}^{n}(Dobs-Dint)\ \hat{}\ 2} \qquad 3.5$$

where n: number of sample points, Dobs = observed dataset and Dint = interpolated value.

Tagel NSR: - From the four interpolation methods tested, the Local Polynomial interpolation gave the lowest MAE (0.0019), RMSE (0.199) and higher coefficient of correlation with (R^2 =0.8794).

Teleta NSR: - From the four interpolation methods tested, the Ordinary Kriging interpolation gave the lowest MAE (0.0018), RMSE (0.170) and higher coefficient of correlation with (R^2 =0.9525).

Adbra NSR: - From the four interpolation methods tested, the Radial base function interpolation gave the lowest MAE (0.0045), RMSE (0.1947) and higher coefficient of correlation with (R^2 =0.9486).

The results of these analysis are shown in Tables 3-3, 3-4 and 3-5 and Figures 3-14, 3-15 and 3-16 .Therefore for this study Ordinary Kriging, Radial base function and Local polynomial interpolation methods work best and create a good representation of the data and they were chosen for spatial interpolations.

Table 3-3: Tagel NSR summary of interpolation accuracy analysis

Interpolation method	MAE	RMSE	R^2
Ordinary Kriging(OK)	0.0024	0.199	0.8347
Radial base function (RBF	0.0132	0.201	0.8754
Inverse Distance Weighting (IDW)	0.007	0.199	0.8715
Local Polynomial interpolation(LPI)	0.0019	0.199	0.8794

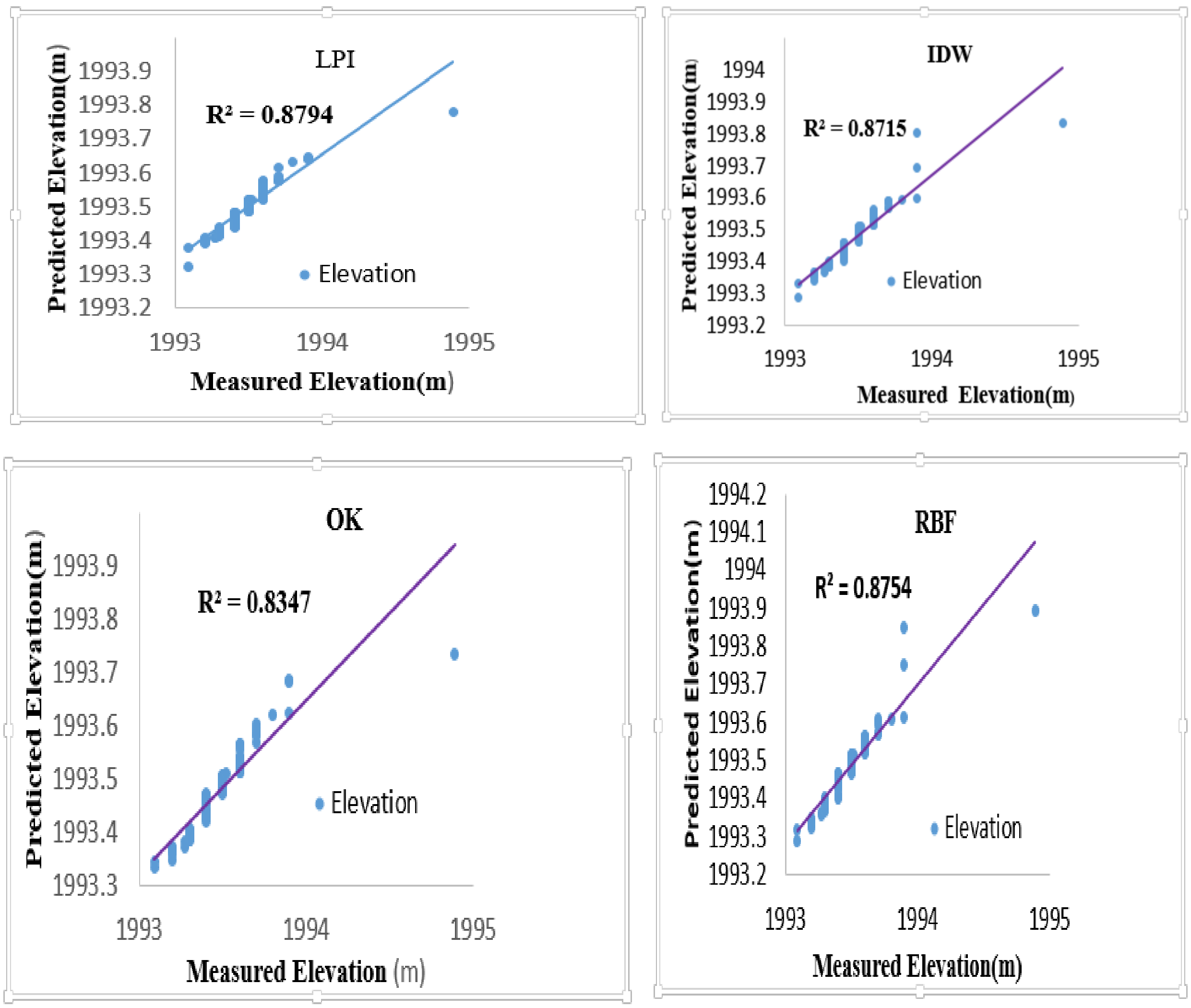


Figure 3-14: Predicted VS measured bed elevation of Tagel NSR test dataset

Table 3-4: Adbra NSR summary of interpolation accuracy analysis

Interpolation method	MAE	RMSE	R^2
Ordinary Kriging(OK)	0.007	0.1955	0.9459
Radial base function (RBF)	0.0045	0.19417	0.9486
Inverse Distance Weighting (IDW)	0.0065	0.1977	0.9399
Local Polynomial interpolation(LPI)	0.098	0.196	0.8965

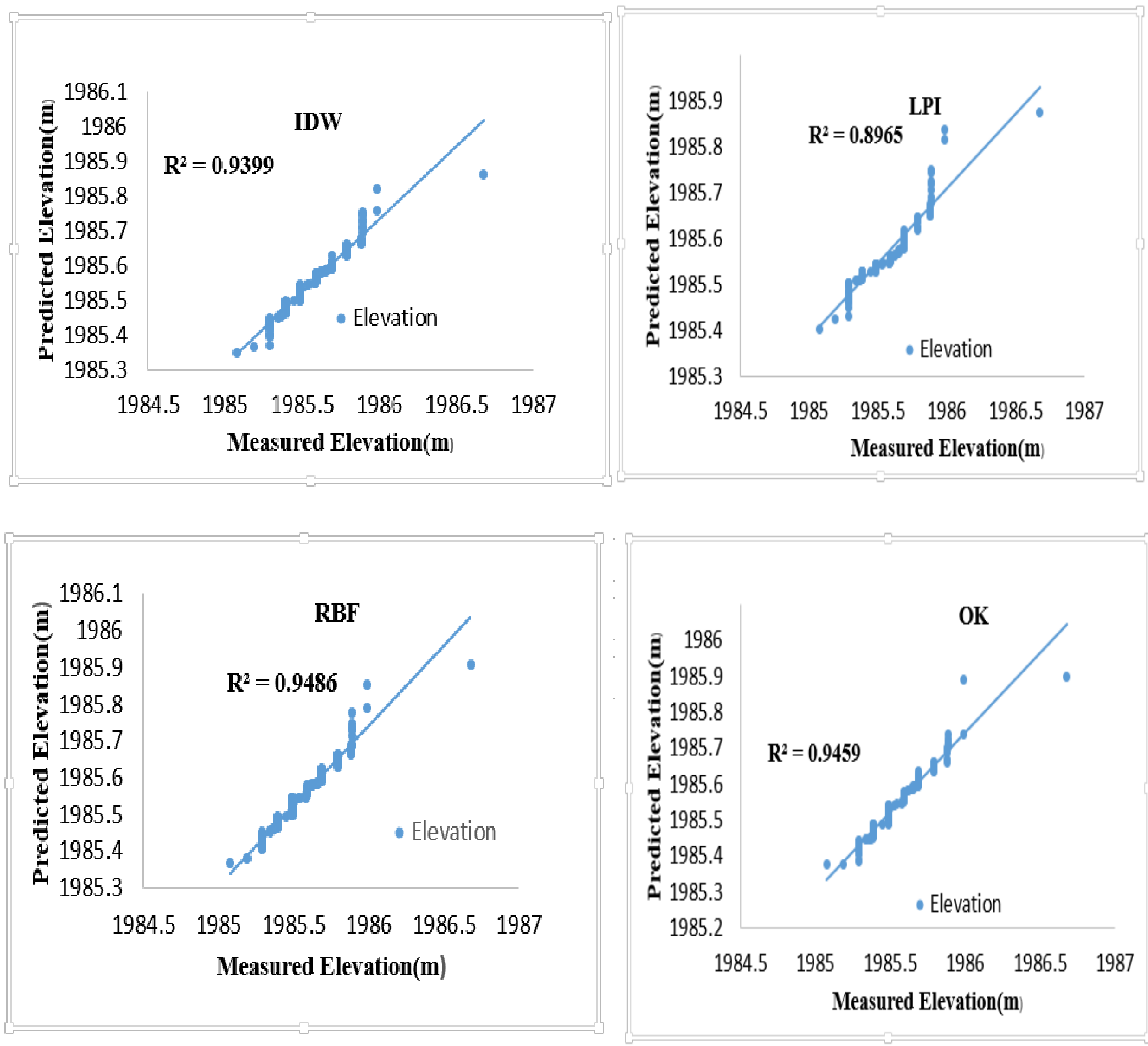


Figure 3-15: Predicted VS measured bed elevation of Adbra NSR test datase

Table 3-5: Teleta NSR summary of interpolation accuracy analysis

Interpolation method	MAE	RMSE	R^2
Ordinary Kriging(OK)	0.0018	0.170	0.9525
Radial base function (RBF	0.0092	0.170	0.9505
Inverse Distance Weighting (IDW)	0.020	0.183	0.9285
Local Polynomial interpolation(LPI)	0.0136	0.17	0.9403

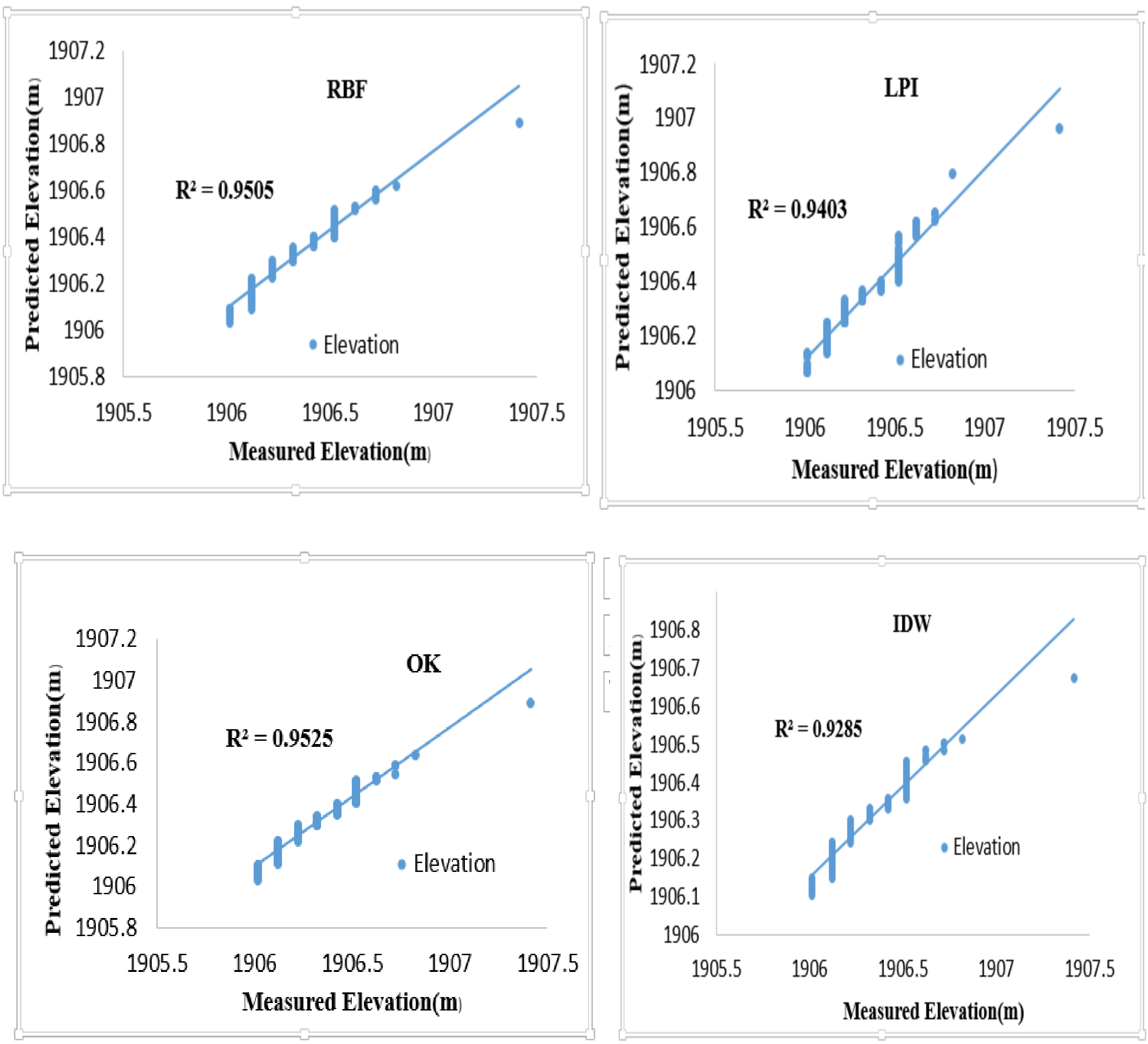


Figure 3-16: Predicted VS measured bed elevation of Teleta NSR test dataset

4. RESULT AND DISCUSSION

4.1. Raster Map Development for the Three Night Storage Reservoirs

To determine night storage reservoirs sediment deposition pattern and sediment thickness raster map was developed from predetermined elevation data of bathymetric survey and digitized data obtained from original topography data using ARC_GIS 10.4 as shown in Figures 4-1,4-2 and 4.3 and Table 4-1. This raster map is a basic input to generate TIN surface map from bathymetry survey.

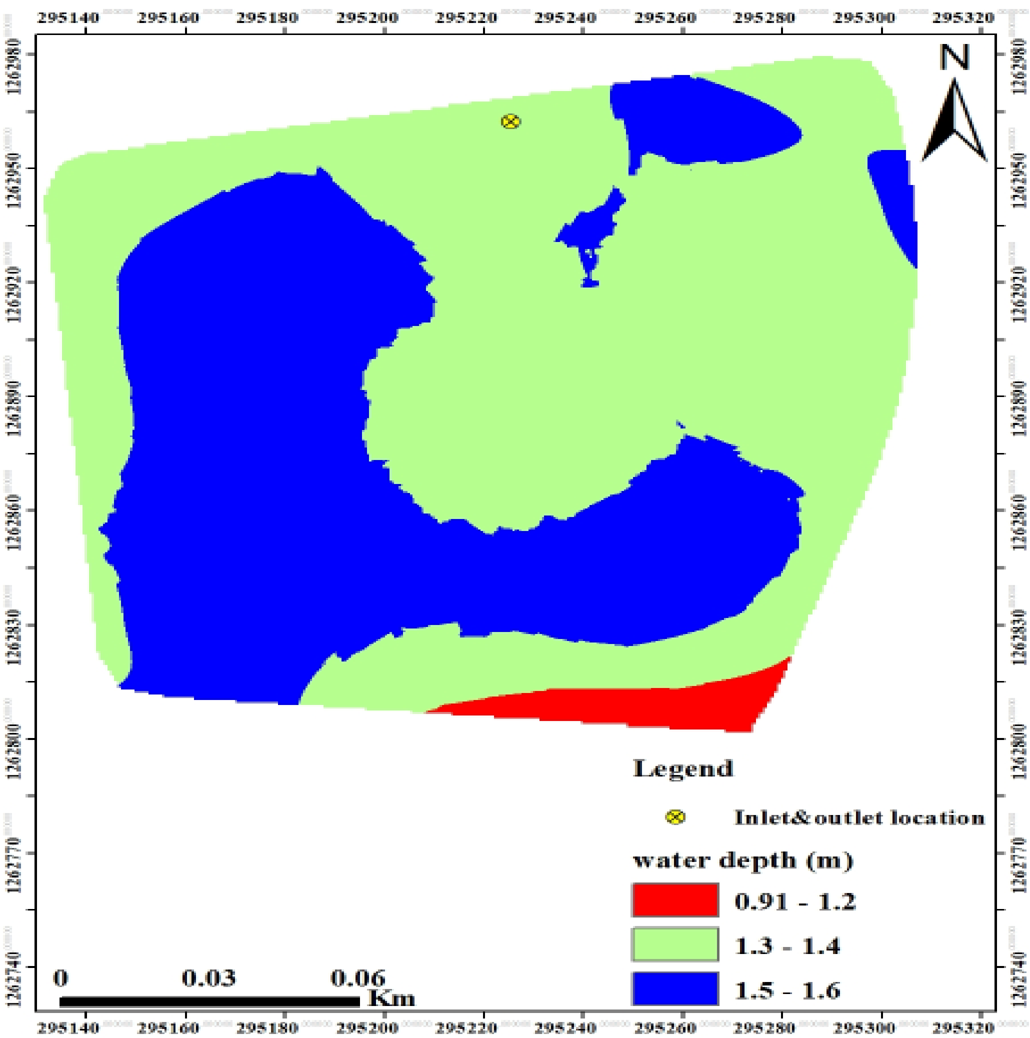


Figure 4-1: Tagel NSR 2020 bathymetry survey (raster) map after LPI method by water depth

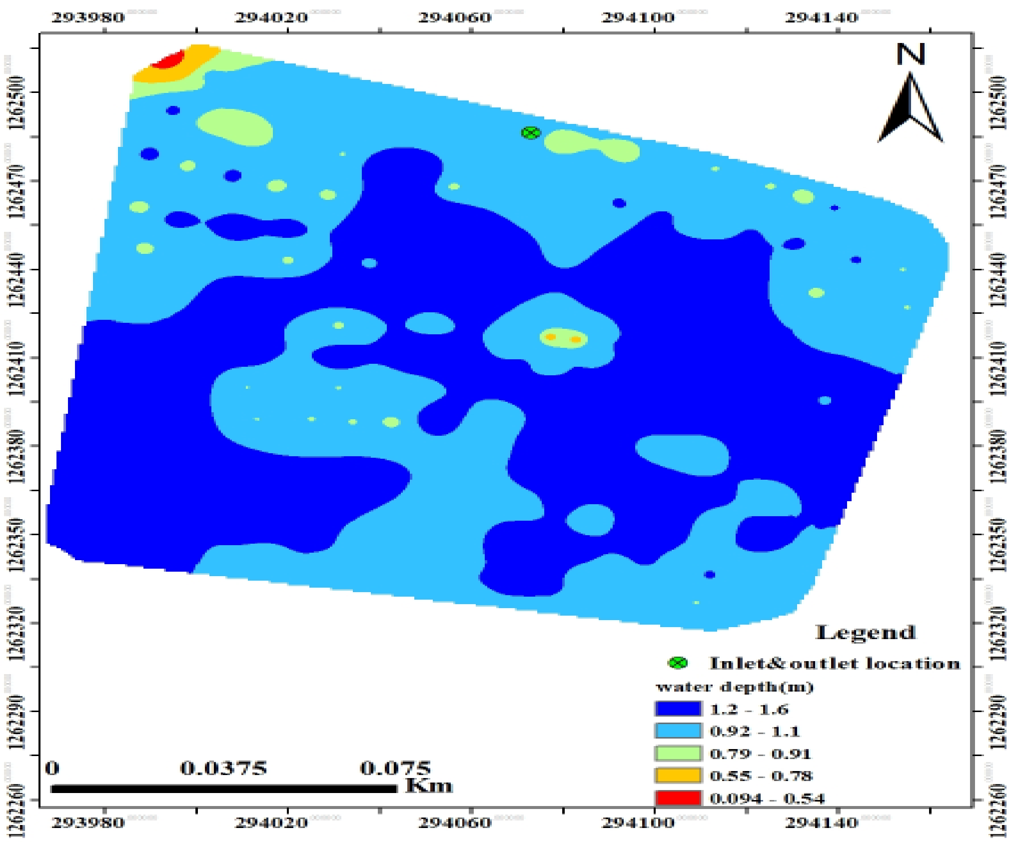


Figure 4-2: Adbra NSR 2020 bathymetry survey (raster) map after RBF method by water depth

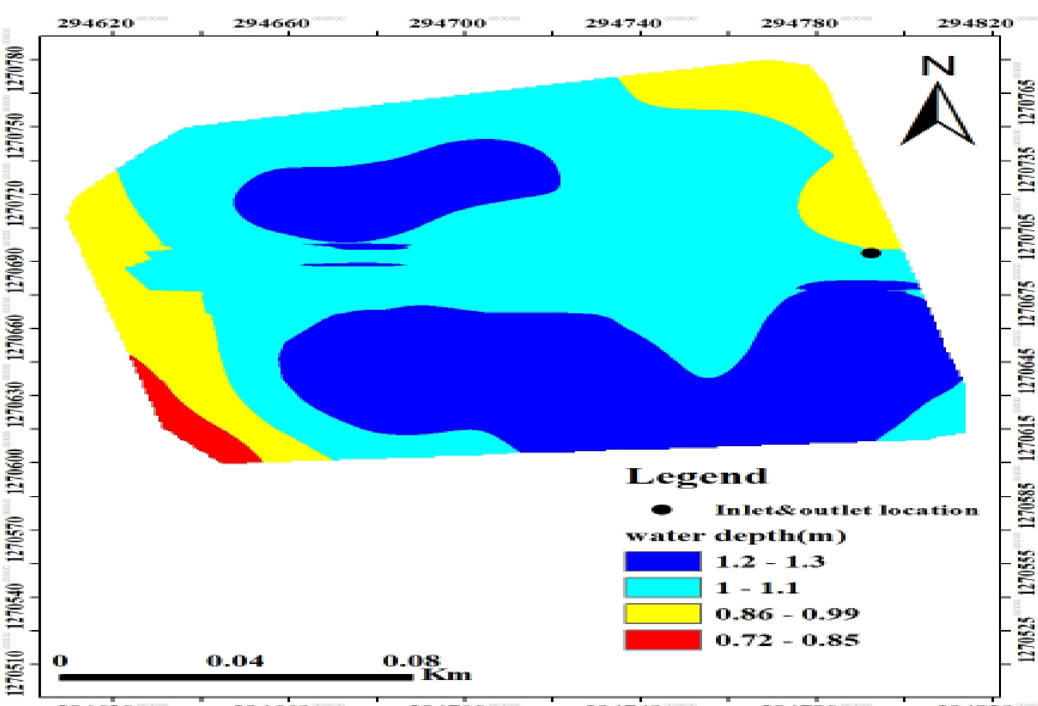


Figure 4-3: Teleta NSR 2020 bathymetry survey (raster) map after OK method by water depth

Table 4-1: Summery of three NSR bathymetry survey water depth in terms of area coverage

Name of NSR	Water depth (m)	Area (m^2)	%Coverage
Tagel NSR	1.5-1.6	616.96	34.8
	1.3-1.4	13058.38	62.94
	0.91-1.2	7072.16	2.974
	Total	20747.5m^2	100
Adbra NSR	1.3-1.6	3546.82	14.5
	0.92-1.2	20136	82.4
	0.79-0.91	618.43	2.53
	0.54-0.78	111.29	0.455
	0.09-0.53	18.95	0.0775
	Total	24431.49m^2	100
Teleta NSR	1.2-1.3	546.116	2.18
	1-1.1	19668.17	78.53
	0.86-0.99	4393.134	17.54
	0.72-0.85	437.086	1.74
	Total	25044.5m^2	100

4.2. TIN Maps Development on Three Night Storage Reservoirs

The appropriate bathymetric maps produced with the entire suited night storage reservoirs bottom elevation data are exported to a raster data. The rasterized map is then converted into a Triangulated Irregular Networks (TIN) which is a digital means to represent surface morphology. The TIN surface generated from the bathymetric survey and digitized points were used for the calculation of Night Storage Reservoirs area and volume.

The TIN surface provide a digital representation of the Night Storage Reservoirs bed surface, made up of irregularly distributed nodes derived from the point measurements with 3D coordinates (x, y, z) that are arranged into a network of non-overlapping triangles (Erickson and Stephani, 2013).The difference between the 2012 survey and 2020 survey represents the sediment deposited within the night storage reservoirs. The TIN surface generated from the bathymetric survey and digitized points are shown in Figures 4-4, 4-5, 4-6, 4-7, 4-8 and 4-9.

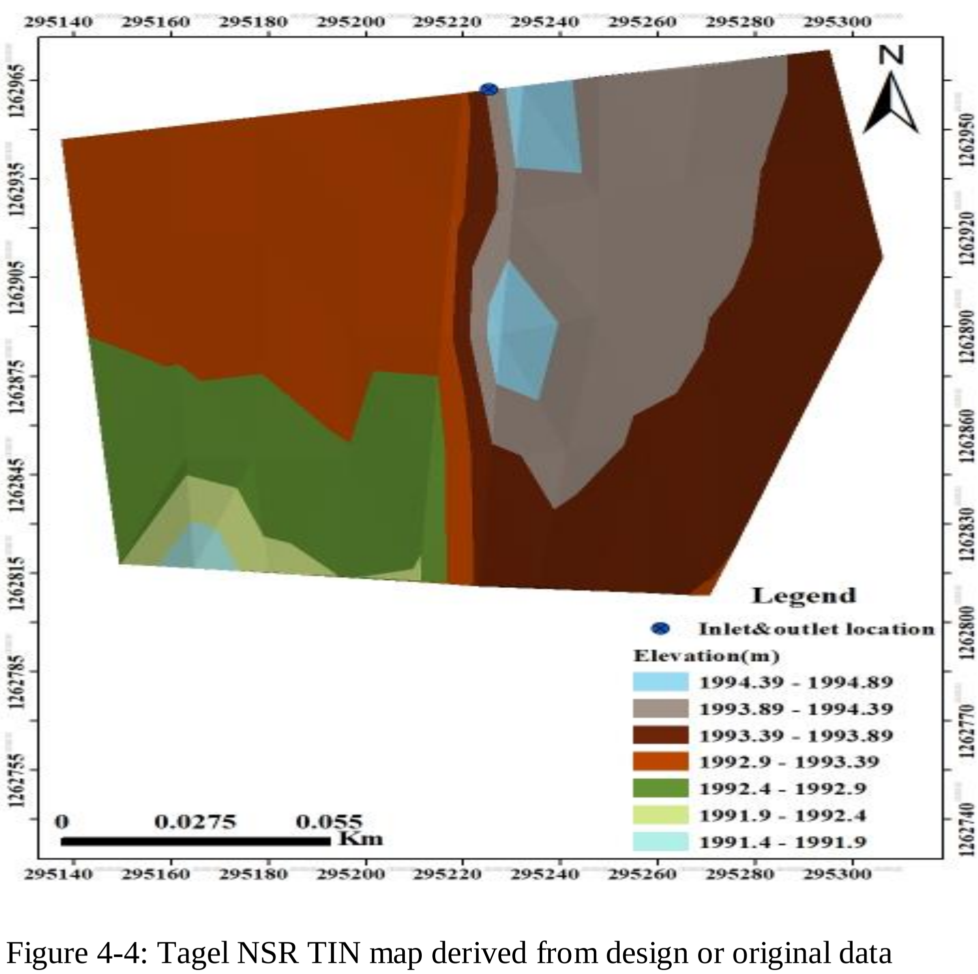


Figure 4-4: Tagel NSR TIN map derived from design or original data

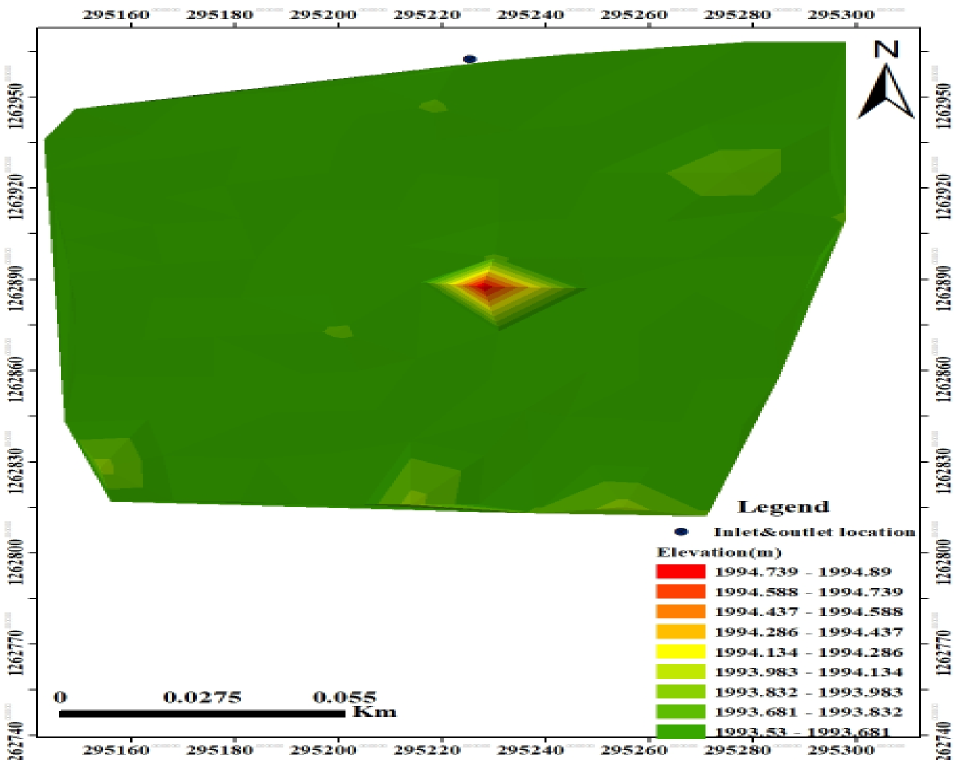


Figure 4-5: Tagel NSR TIN map derived from bathymetry survey

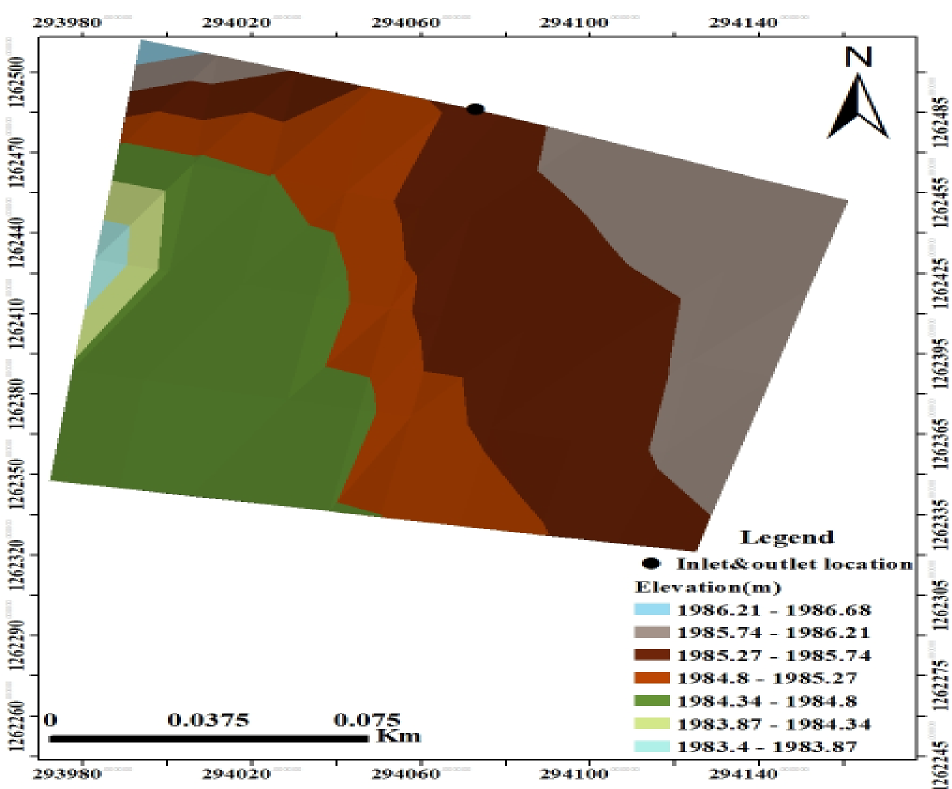


Figure 4-62: Adbra NSR TIN map derived from design or original data

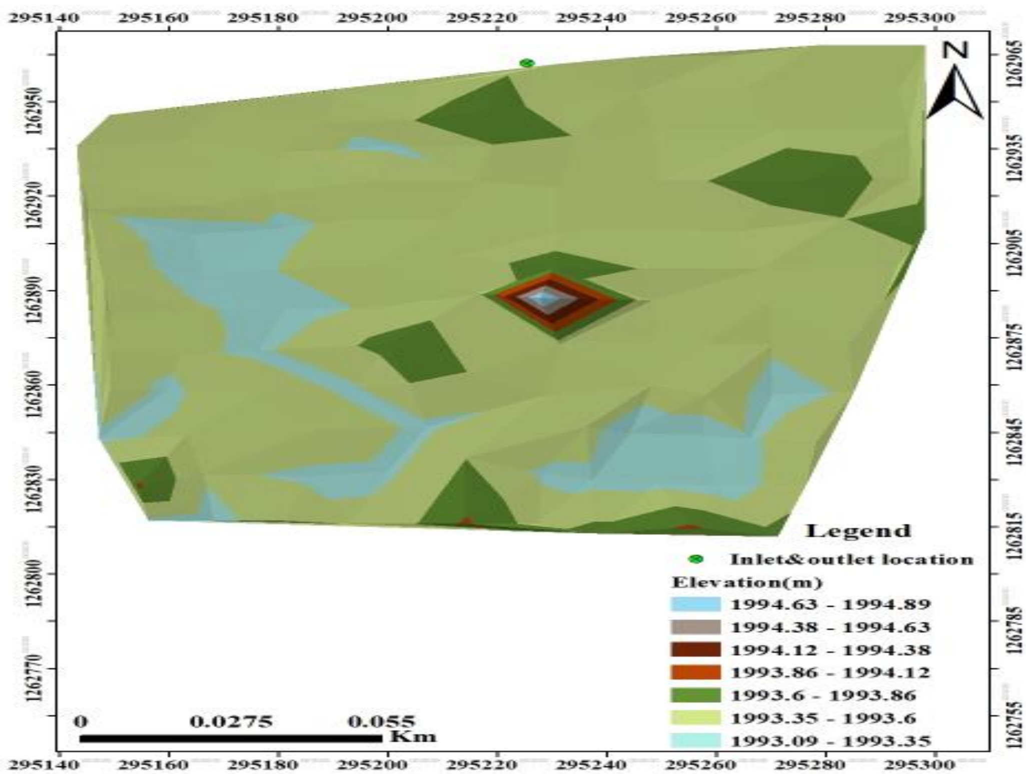


Figure 4-7: Adbra NSR TIN map derived from bathymetry survey

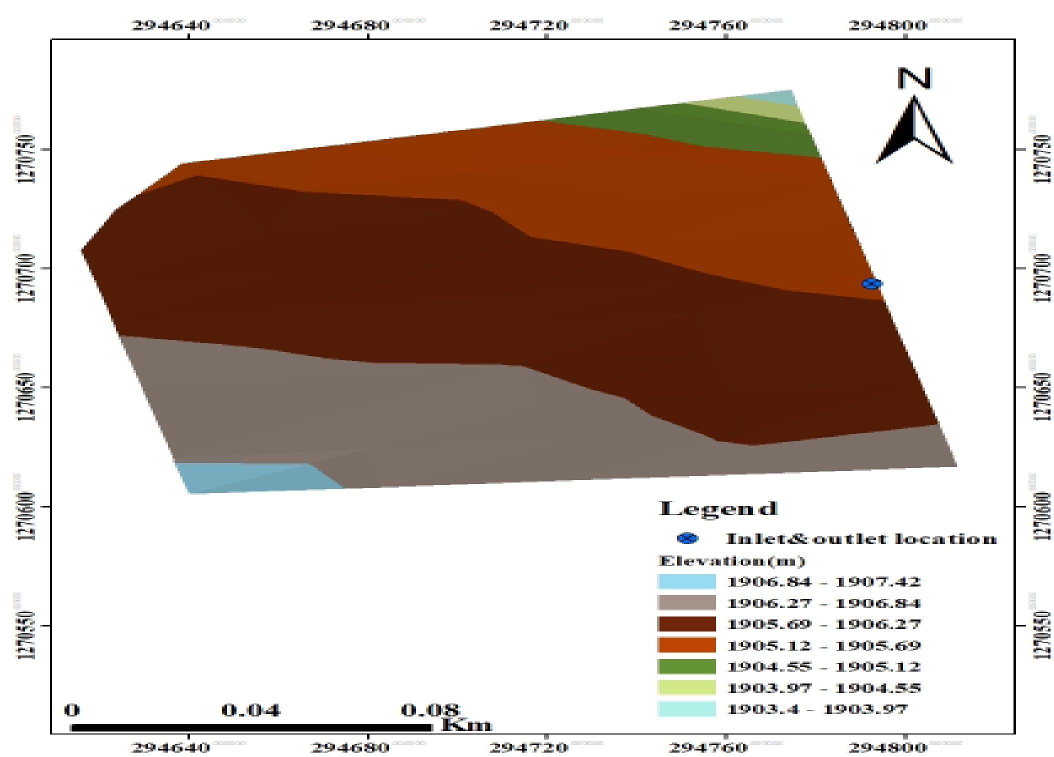


Figure 4-8: Teleta NSR TIN map derived from design or original data

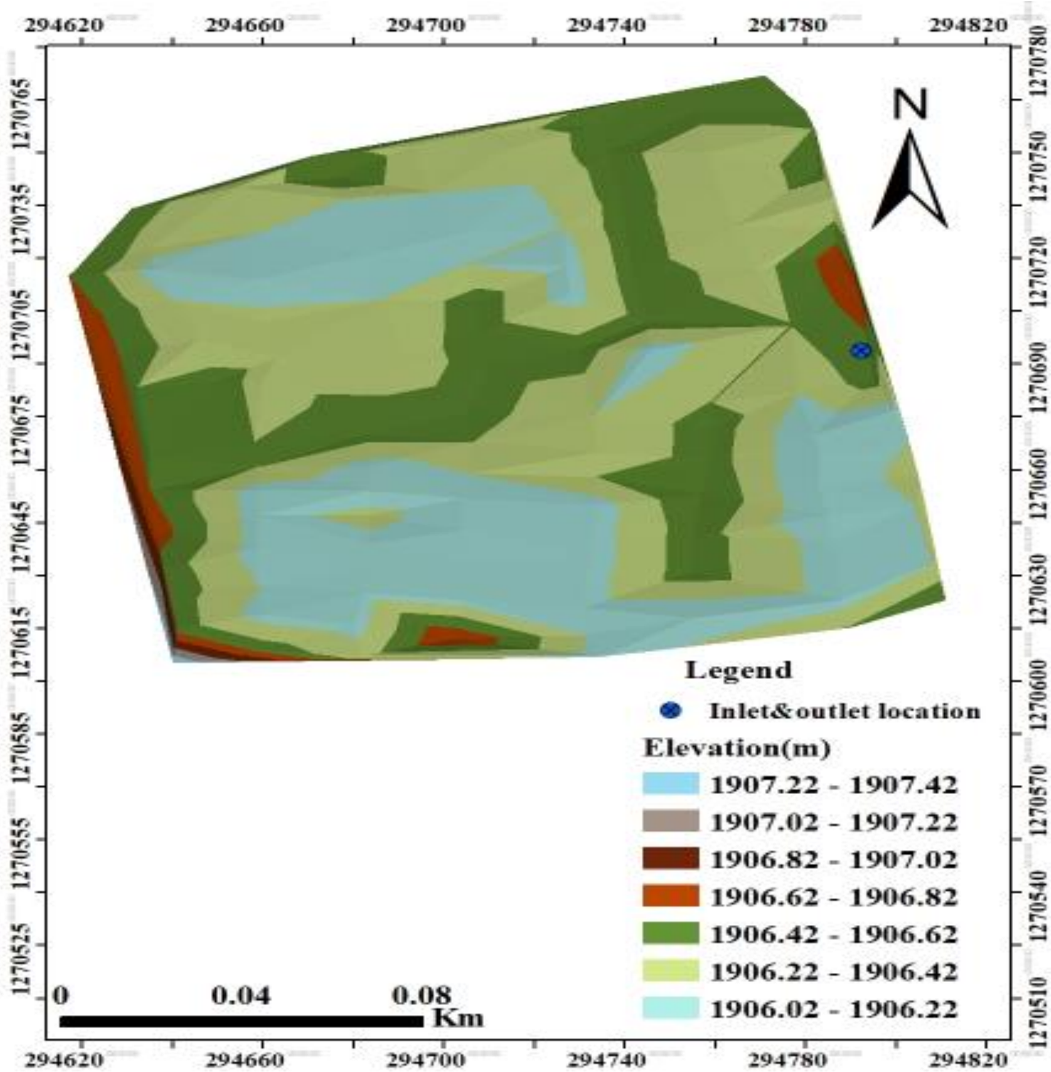


Figure 4-9: Teleta NSR TIN map derived from bathymetry survey

4.3 Computation of Area- Storage- Capacity Curve on Three Night Storage Reservoirs by using Bathymetry TIN model

The main objective of reservoirs survey is calculation of the remaining reservoirs storage capacity, update the existing area storage capacity curve and to determine sediment distribution within the reservoirs. As mentioned above the TIN surface generated from 2020 year bathymetric survey data and digitized data from year 2012 reservoirs topography map was adequate to calculate area and volume of the reservoirs. The reduction in storage capacity of the FRL for the two surveys at different times represents the total volume of sediment accumulated.

The storage capacity of reservoirs is gradually depleted due to sediment accumulation that causes changes in the area-storage capacity curves. The comparisons of capacity in 2020 with the original capacity for Koga Night Storage Reservoirs curves are important for planners, designers and operators of Night Storage Reservoirs. For original and current night storage reservoirs capacity computation in Arc-GIS software the 3D Analyst tool of functional surface was used to reservoirs volume and area at 0.5 meter elevation interval was calculated. To ensure careful operation of Koga Night Storage Reservoirs, new operational curves were established based on the survey conducted in 2020.The TIN for the survey of 2012 and 2020 was used to calculate water surface area and storage capacity as a function of water elevation and the result is presented as follows in Tables 4-2, 4-3 and 4-4 and Figures 4-10, 4-11 and 4-12.

Table 4.2: Tagel NSR water surface area and storage capacity for 2012 & 2020

Elevation(m)	Area for 2012(m^2)	Area for 2020(m^2)	Volume for 2012(m^3)	Volume for 2020(m^3)	Remark
1991.4	0	0	0	0	BL
1991.89	143.6	0	23.5	0	
1992.39	677.1	0	197.5	0	
1992.89	4010.5	0	1227.4	0	
1993.39	10789.7	0	5007.4	0	
1993.89	16338.8	20526.7	11502	6381.5	
1994.39	21555.6	20697.8	21231.6	16689.6	
1994.89	22329.9	20747.5	**32294**	**27054**	FSL

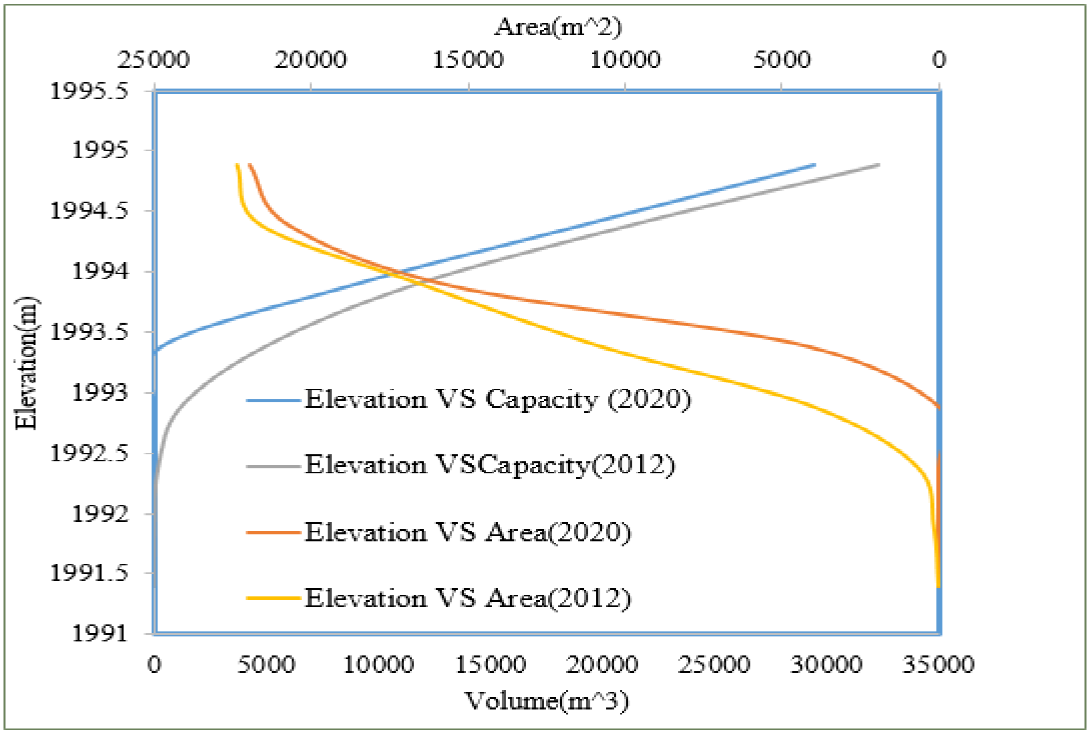


Figure 4-10: Tagel NSR Area Elevation and Capacity Elevation Curve

Table 4-3: Adbra NSR water surface area and storage capacity for 2012 & 2020

Elevation(m)	Area for 2012(m^2)	Area for 2020(m^2)	Volume for 2012(m^3)	Volume for 2020(m^3)	Remark
1983.4	0	0	0	0	BL
1983.675	60.8	0	5.6	0	
1984.175	483.0	0	124.7	0	
1984.675	5789.8	0	1081.8	0	
1985.175	11253.5	22.5	5462.6	0.75	
1985.675	19094.3	19047.8	12825.4	3762.9	
1986.175	25025.3	24375.8	24383.3	15515.5	
1986.675	25114.3	24431.5	**36902**	**27722**	FSL

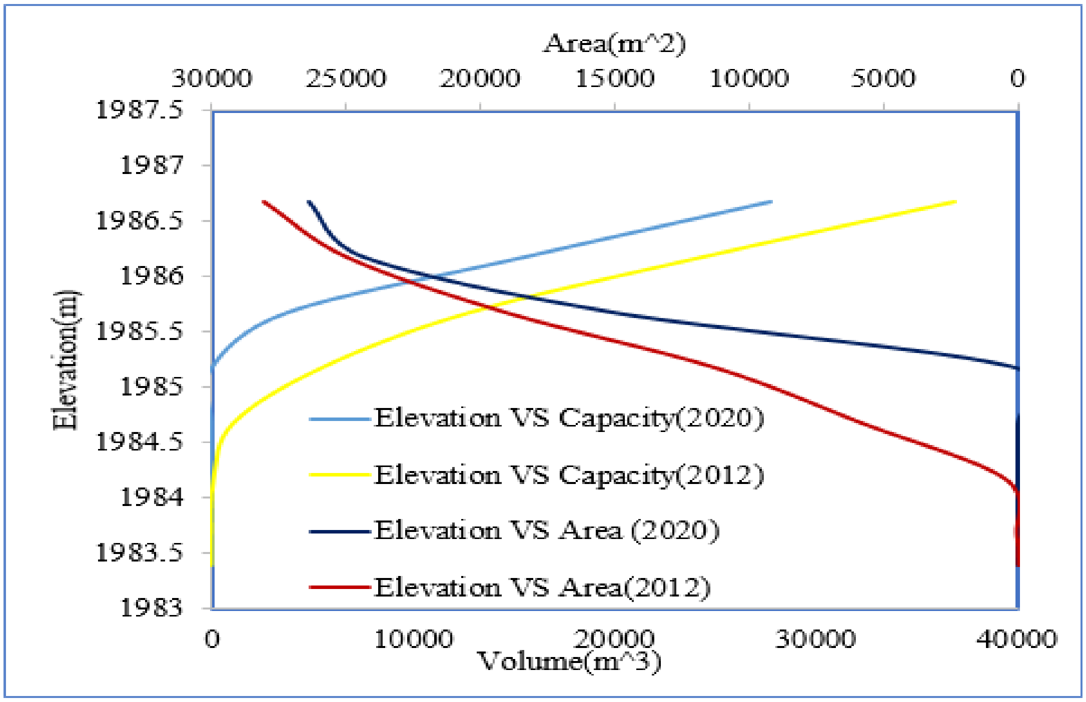


Figure 4-11: Adbra NSR Area Elevation and Capacity Elevation Curve

Table 4-4: Teleta NSR water surface area and storage capacity for 2012 & 2020

Elevation(m)	Area for 2012(m^2)	Area for 2020(m^2)	Volume for 2012(m^3)	Volume for 2020(m^3)	Remark
1903.4	0	0	0	0	BL
1903.915	35.7	0	6.13	0	
1904.415	138.76	0	46.95	0	
1904.915	309.2	0	156.12	0	
1905.415	2541.8	0	744.9	0	
1905.915	11677.9	0	3901.05	0	
1906.415	21263.4	17659.4	12072.65	3119.88	
1906.915	24579.7	24001.08	23906.8	14946.6	
1907.415	25615	25044.4	**36296**	**27441**	FSL

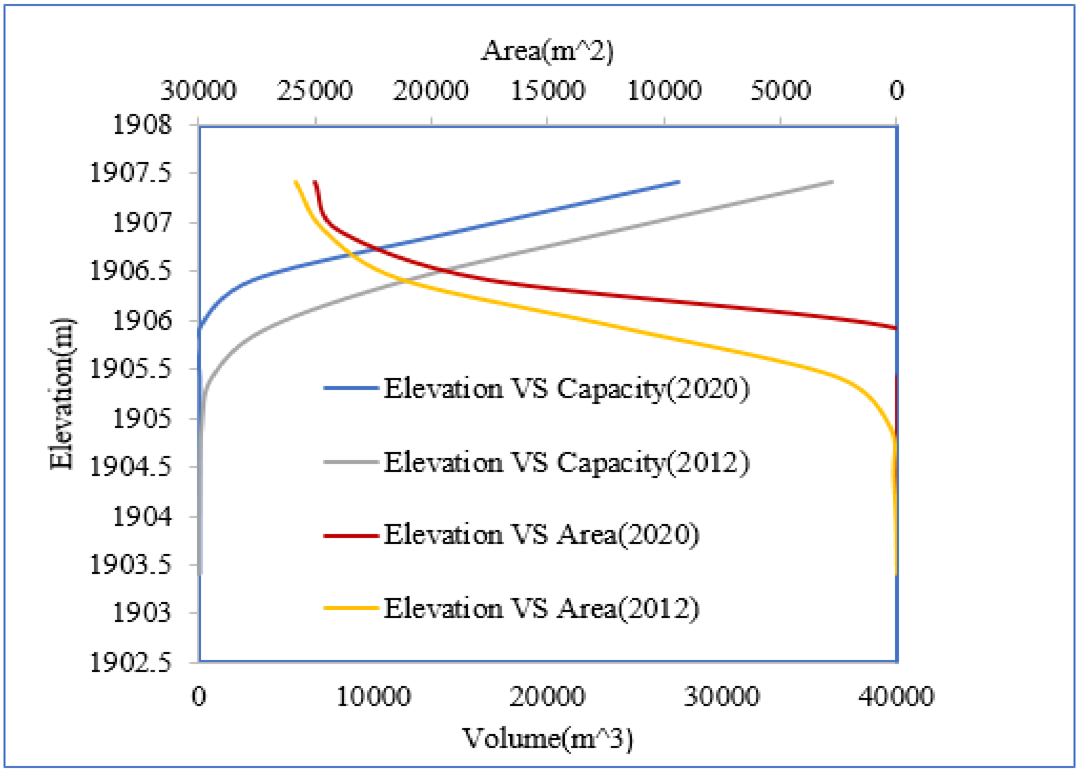


Figure 4-12: Teleta NSR Area Elevation and Capacity Elevation Curve

4.3.1 Computation of Area-Elevation Capacity Curve Three NSRs by using Mathematical method (simple average method)

The important physical characteristics of a reservoir are its storage capacity. The capacity of the reservoir is determined from the contour map of the reservoir area on the selected site; the water spread of the reservoir at any elevation is determined by measuring the area at the contour by a planimeter.

The storage capacity is computed using one of the following ways;

- Trapezoidal formula (simple average formula)

Table 4-5: Tagel NSR water surface area and storage capacity for 2012 & 2020 average formula

Elevation(m)	Area for 2012(m^2)	Area for 2020(m^2)	Volume for 2012(m^3)	Volume for 2020(m^3)	Remark
1991.4	0	0	0	0	BL
1991.89	143.6	0	35.9	0	
1992.39	677.1	0	205.2	0	
1992.89	4010.5	0	1171.9	0	
1993.39	10789.7	0	3700.05	0	
1993.89	16338.8	20526.7	6782.125	5131.67	
1994.39	21555.6	20697.8	9473.6	10306.2	
1994.89	22329.9	20747.5	**10971.37**	**10361.3**	FSL

Table 4-6: Adbera NSR water surface area and storage capacity for 2012 & 2020 average formula

Elevation(m)	Area for 2012(m^2)	Area for 2020(m^2)	Volume for 2012(m^3)	Volume for 2020(m^3)	Remark
1983.4	0	0	0	0	BL
1983.675	60.8	0	8.2	0	
1984.175	483.0	0	135.95	0	
1984.675	5789.8	0	1568.2	0	
1985.175	11253.5	22.5	4260.8	5.625	
1985.675	19094.3	19047.8	7586.95	4767.6	
1986.175	25025.3	24375.8	11029.9	10855.9	
1986.675	25114.3	24431.5	**12534.9**	**12200**	FSL

Table 4-7*:* Teleta NSR water surface area and storage capacity for 2012 & 2020 average formula

Elevation(m)	Area for 2012(m^2)	Area for 2020(m^2)	Volume for 2012(m^3)	Volume for 2020(m^3)	Remark
1903.4	0	0	0	0	BL
1903.915	35.7	0	8.92	0	
1904.415	138.76	0	43.6	0	
1904.915	309.2	0	447.96	0	
1905.415	2541.8	0	712.8	0	
1905.915	11677.9	0	3554.9	0	
1906.415	21263.4	17659.4	8235.4	4414.85	
1906.915	24579.7	24001.08	11460.77	10415.2	
1907.415	25615	25044.4	**12548**	**12260**	FSL

4.3.2 Comparison of results with TIN model and trapezoidal formula methods

In this research the reservoirs capacity of Koga night storage reservoirs compute in two way but as we have seen the result from the table above TIN model is the most precious method than mathematical method (trapezoidal).

Even if the trapezoidal analysis of reservoirs not close the original capacity value that is made under estimate compare with TIN model bathymetric method.

Therefore in my study the TIN model bathymetric method is the most precious compare to the indirect sediment assessment methods. I am took the result produced by TIN model.

4.4. Sediment Deposit in Three Night Storage Reservoirs

The above results were used to compute the volume of sediment deposited and the reduction in the water spread area for each zone of the reservoirs during eight years of operation. According to the result described in Tables 4-2, 4-3 and 4-4 the capacity of the night storage reservoirs Tagel ,Adbra and Teleta NSR decreased from original volume 32294m^{3}to27054m^3, 36902m^3 to 27722m^3 and from 36296 m^{3}to27441 m^3 respectively due to sediment deposition. In terms of volume, the total accumulated sediment between year 2012 and year2020 for the three NSRs Tagel, Adbra and Teleta NSR are estimated to be 5240m^3, 9180m^3 and 8855m^3 which are about 16.2, 24.8 and 24.4% of the total volume in eight years respectively. By assuming a constant rate over the entire period, the annual sedimentation rate becomes 655, 1147.5and 1106.9 m^3/ year for Tagel, Adbra and Teleta NSRs respectively. As per this rate, the annual reduction in storage capacity due to siltation are about 2.1, 3.1 and 3.04% per year Tagel, Adbra and Teleta NSR respectively. This rate are more than the average worldwide rate of 1% that was proposed by (Howard, 2000).

The findings of this study showed that the sedimentation problem is the same as sedimentation of most other reservoirs in other parts of Ethiopia. Haregeweyn et al. (2006) reported annual total capacity loss values of 0.18 – 4% for 13 reservoirs in northern Ethiopia. Moreover, recent studies in the same Tana sub basin showed annual capacity loss of 1.67% per year for Shina micro- earth dam and 2.295 % per year for Selamko (Michael M.M.et al, 2017).This indicates relatively high sedimentation rate for Koga Night Storage Reservoirs compared to other reservoirs with in the basin.

4.5. Sediment Thickness and Distribution Pattern in the Three NSRs

To determine the sediment thickness distribution in the reservoirs first, raster layers were created from the 2012 and 2020 TINs. Then, the 2012 reservoirs bed elevation raster was subtracted from the 2020 reservoirs bed elevation raster using the Raster Math-Minus tool in Arc-GIS. Results of the changes in bathymetry elevations from 2012 to 2020 are shown in Figures 4-13, 4-14 and 4-15.

The average net elevation change in koga night storage reservoirs were computed, the maximum computed net deposition values were 1.9, 2.3 `and 2.5m and the maximum computed decrease in elevations (i.e., net erosion) were -1,-0.85and- 0.57m; meaning that the maximum scouring within the reservoirs were -1,-0.85.and -0.57 m and the maximum filling or depositions were 1.9, 2.3 and 2.5 m in Tagel Adbra and Teleta NSR respectively within eight years of operation. Generally the largest sediment thickness value occurs near the mouth of the night storage reservoirs. This map may be used to indicate sediment deposition areas for night storage reservoirs sediment management.

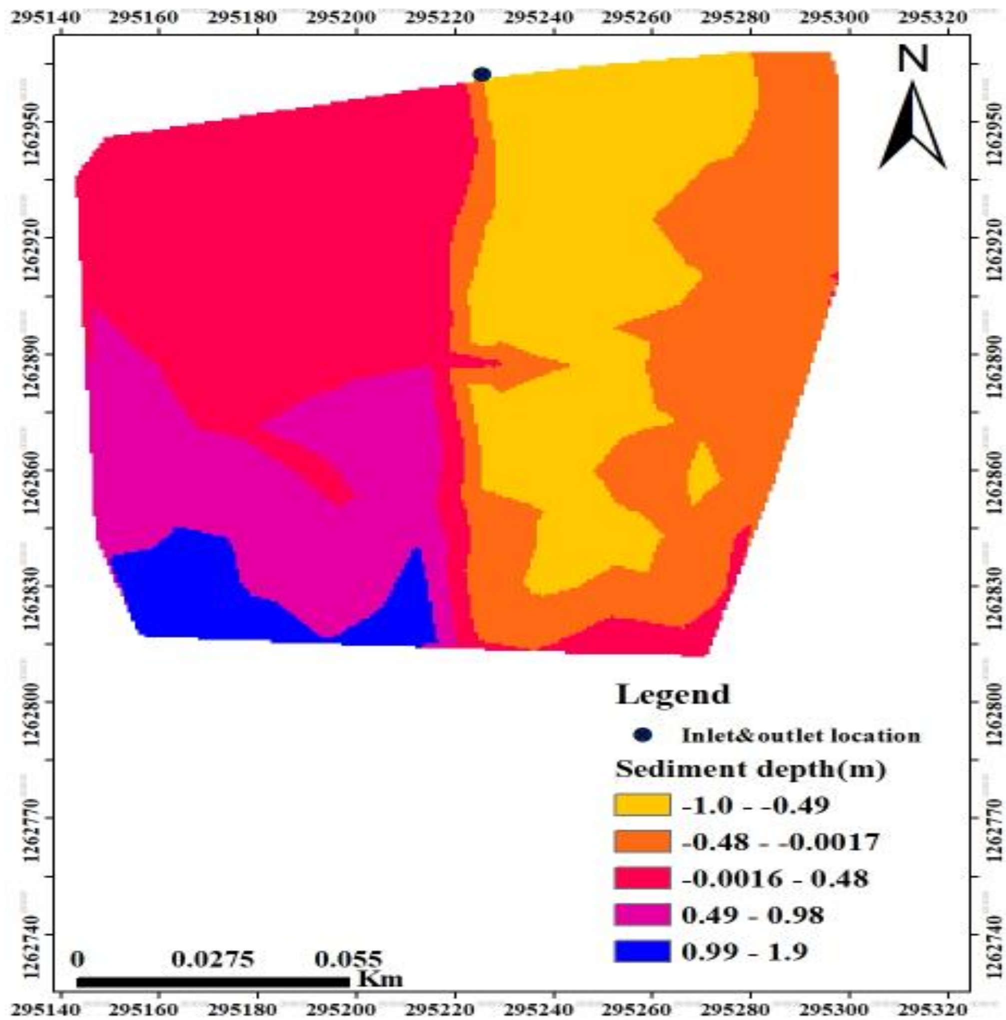


Figure 4-13: Tagel NSR sediment thickness map

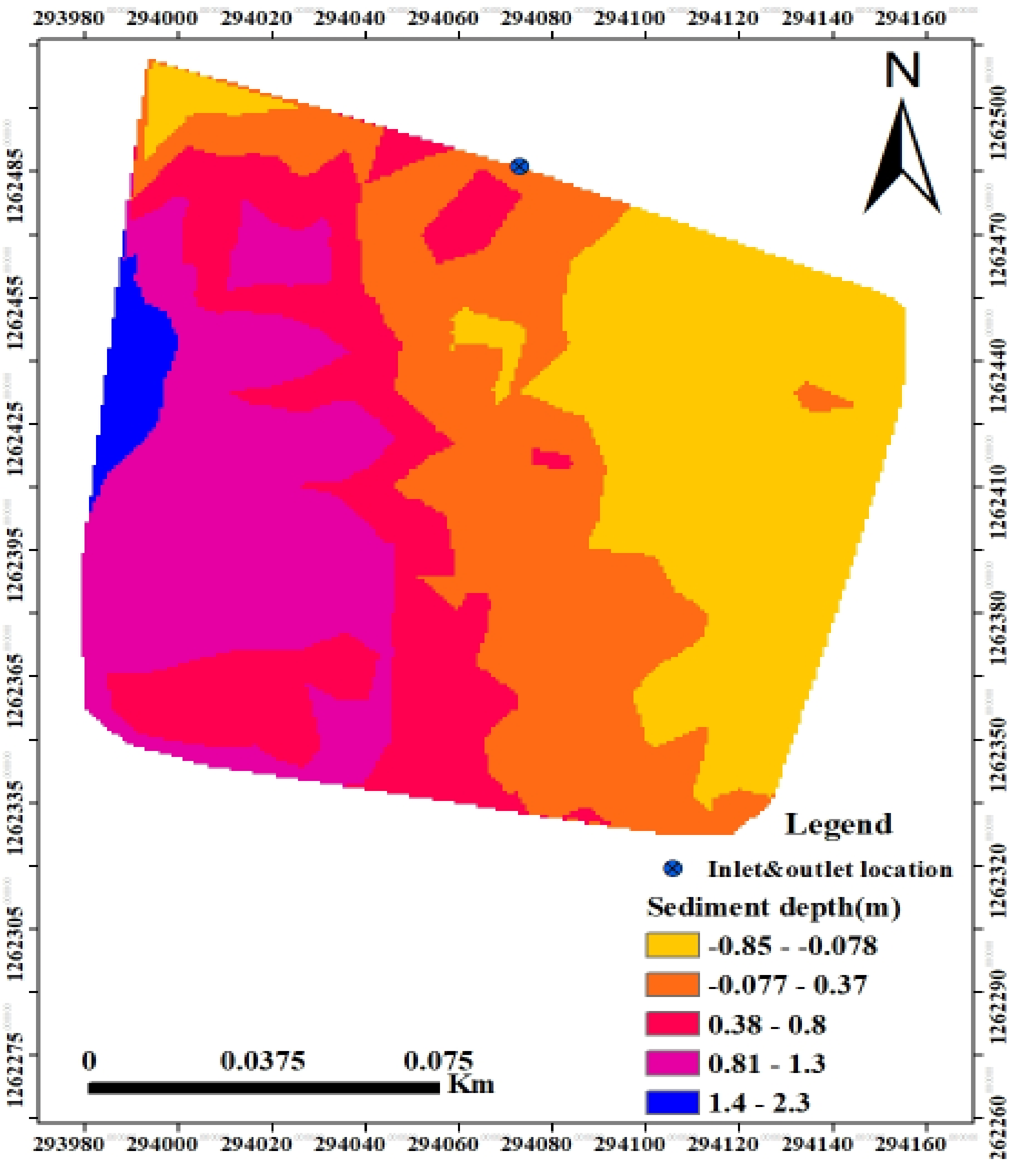


Figure 4-14: Adbra NSR sediment thickness map

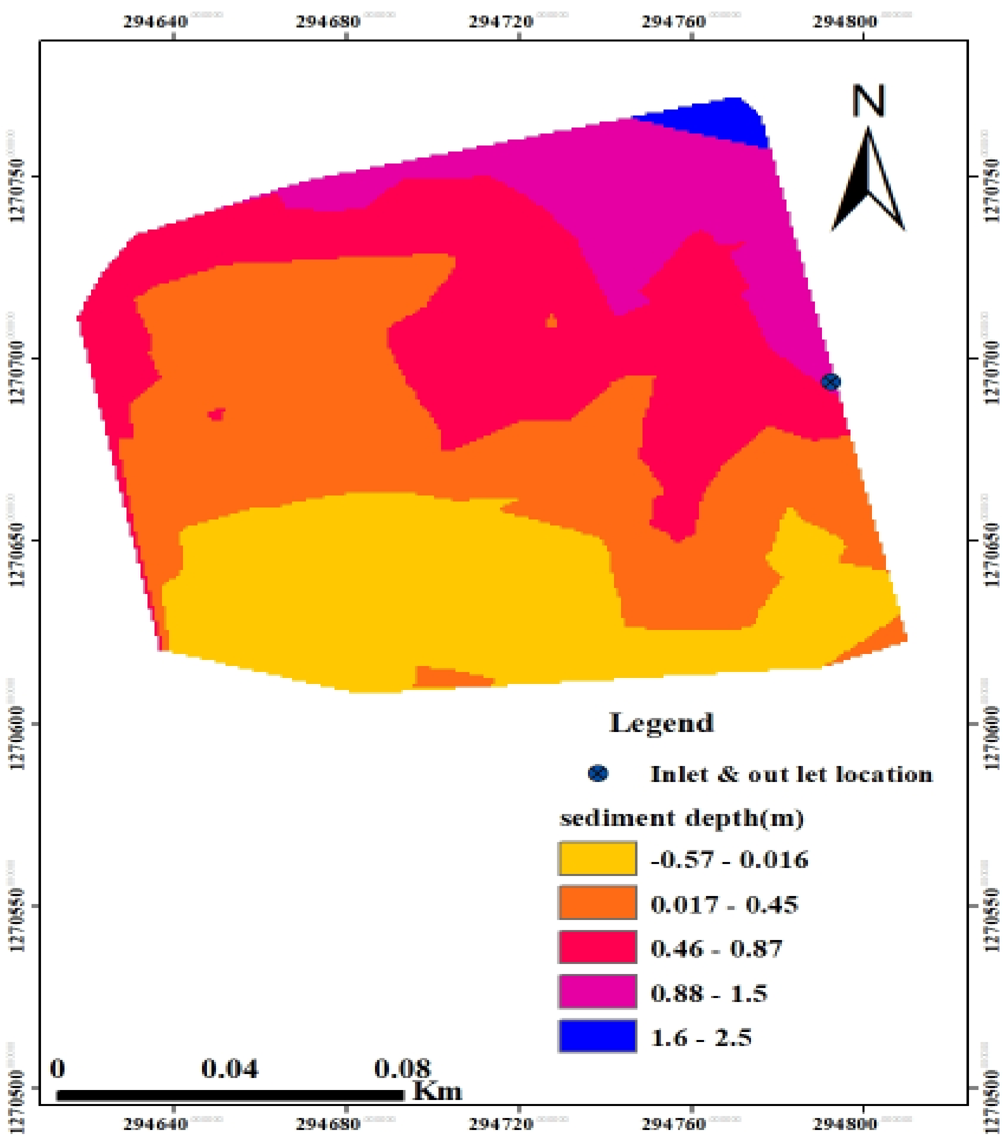
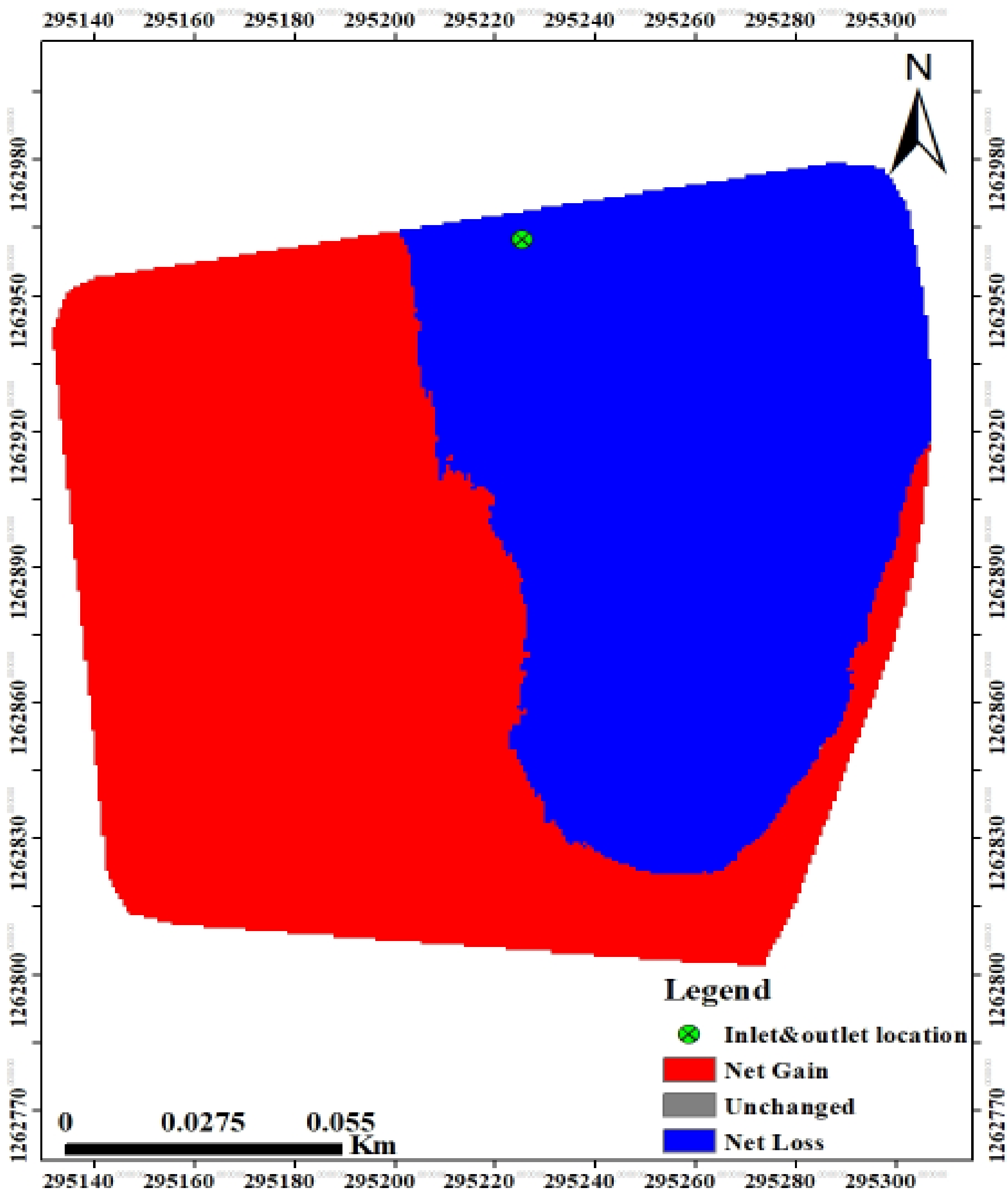


Figure 4-15: Teleta NSR sediment thickness map

Using the two raster, it was attempted to highlight areas where sediment has deposited "net gain" or scoured has occurred "net loss" in koga night storage reservoirs from 2012 to 2020 by using cut/ fill function within 3D analyst tool. Figures 4-16, 4-17 and 4-18 show the results, with red areas indicating net deposition and blue areas net scour and gray areas indicating unchanged situati



on.

Figure 4-16: Net gain and loss of Tagel NSR sediment volume map

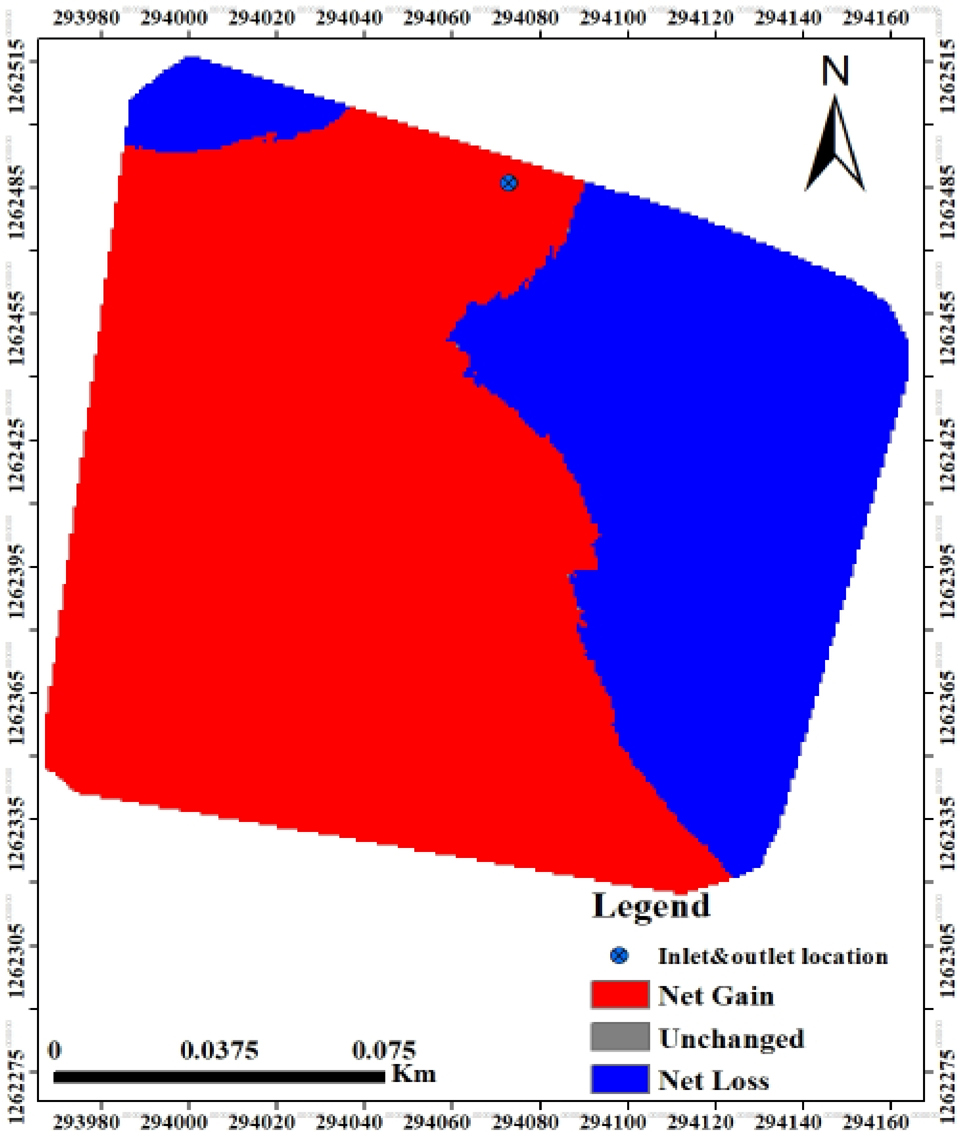


Figure 4-17: Net gain and loss of Adbra NSR sediment volume map

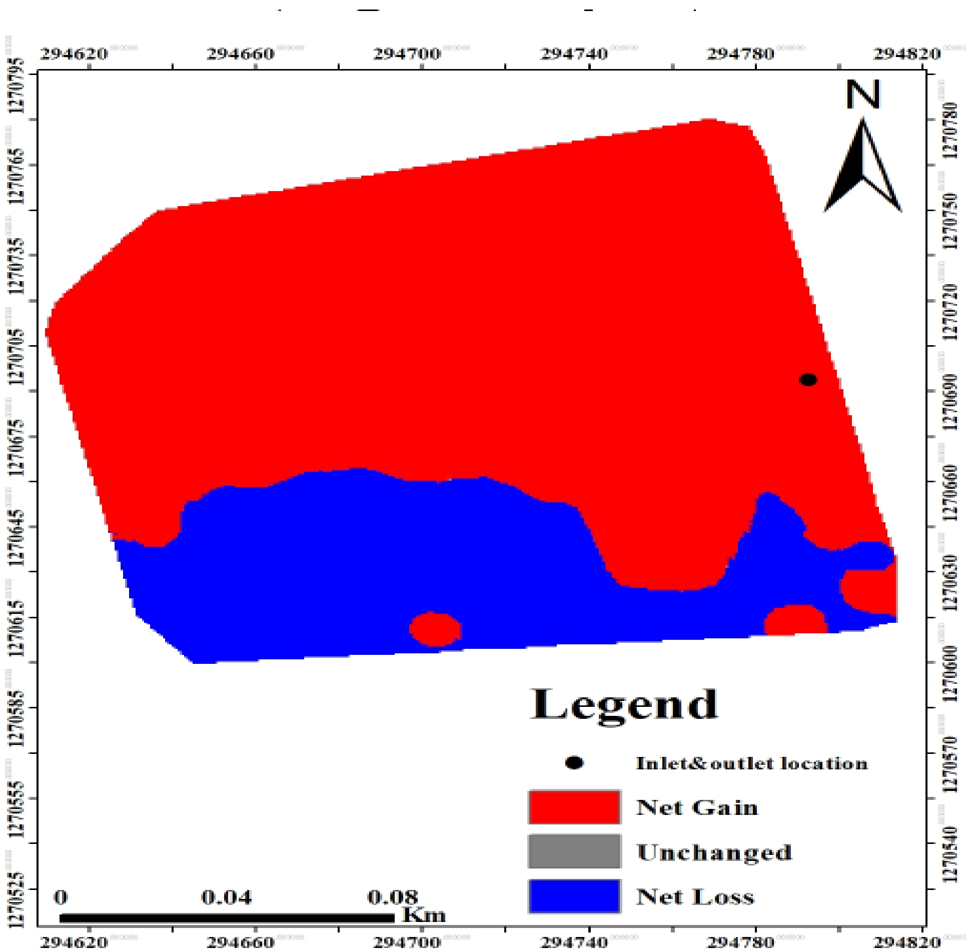


Figure 4-18: Net gain and loss of Teleta NSR sediment volume map

4.6. Analysis of Sediment Core Samples in the Three NSRs

A total of twelve undisturbed reservoirs sediment core samples were collected and analyzed for dry bulk density in Laboratory. The results are presented in Appendex-1. Dry density of sediment deposition is used to convert reservoir sediment volume to mass (Verstraeten and Poesen, 2001). The mean dry bulk densities for the Tagel , Adbra and Teleta night storage reservoirs were found to be 1236.5, 1236.75and 1228.5kg/m^3 respectively with a range of 1000-1350 kg/ m^3. (Haregeweyn et al., 2006) reported mean dry bulk density of 1010.18 – 1420 kg/m^3 for different reservoirs in northern Ethiopia. The dry bulk density value estimated in the present study has the same order of magnitude with previous one. Generally the lower dry density occur in the vicinity of the dam axis and the higher dry density of sediment occur in the inlet part of the reservoirs.

4.7. Estimation of Life of the Three NSRs

The life of a reservoir is affected by the silting rate in a reservoir that is directly influenced by the sediment produced in the catchment and the amount of sediment trapped by the reservoir.

To estimate life of the reservoirs the bathymetric survey results were used. Loss of the initial storage capacity is estimated to obtain remaining useful life of the reservoirs.

The depositional conditions or sedimentation rates of Koga Night Storage Reservoirs are different from ordinary storage reservoirs because they are not provided with dead storage space. Therefore the formula of this useful life of night storage simply total storage divided by annual sediment volume.

The design period of each Koga night storage reservoirs is 50 years.

The Life for each of NSRs is computed as a total storage divided by annual sediment volume used Eq.3.1

Tagel NSR Life= $\frac{32296}{655} = 49\ years$

Adbra NSR Life= $\frac{36902}{114\ 7.5} = 32\ years$

Teleta NSR Life= $\frac{36294}{1106.9} = 32\ years$

Each of the NSRs has maximum storage capacity at the beginning of the estimated life and zero storage at end of the life. The estimated life could be reduced due to absence of appropriate soil conservation practice in the catchment of the reservoirs.

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The study includes the bathymetric assessment of the reservoir sedimentation. It assessed the capacity loss, sediment distribution, life and deposited sediment mass of Koga NSRs.

The work included several activity such as survey of topography, making of map of initial reservoir area, measuring dry sediment bulk density of deposited sediment and estimation of deposited sediment mass.

The main objective of this study to determine the changes in reservoirs volume due to sedimentation in koga night storage reservoirs was fulfilled. Computations were made on ArcGIS software using TIN map of the reservoirs based on original topographic data and bathymetry survey data. Data analysis showed that in eight years of operation period storage capacity of the Tagel,Adbra and Teleta NSR decreased by 5240, 9180 and 8855m^3 which are about 16.2,24.8 and 24.4% of total volumes respectively. The average rate of sedimentation is estimated to be 655, 1147.5and 1106.9m^3/year giving 2.1, 3.1and 3.04 % of annual rate of capacity loss of the Tagel ,Adbra and Teleta NSRs respectively.

At the current rate of sedimentation the useful life of Tagel, Adbra and Teleta NSR volumes are decreased by 16.2, 24.8 and 24.4% of their capacity respectively. The result indicates the need for planning and implementing of sediment removal from the NSRs. Koga catchment indirectly affects the NSRs through its influence on sedimentation of the main reservoir since the NSRs get water from main reservoir. Therefore soil erosion control measures should be under taken at the catchment. Sediment inflow to the reservoirs can also be reduced by introducing land use change from ordinary crop cultivation to development of perennial crops and grass strip for sediment trap.

5.2 Recommendation

To extend life of the night storage reservoirs and efficiently achieve the purpose for which constructed reduction of sediment inflow hereby recommended.

- Removal accumulated sediment by various techniques such as flushing mechanically or by labor force.
- For the Koga night storage reservoirs provide bathymetry equipment like echo sounding, hand held GPS, boat to monitor sedimentation regularly and to improve reservoir operation and sediment management.
- To inform the water user of the downstream people the reduction of the capacity of night storage reservoirs because of sedimentation. This will be helped properly use water.

6. REFERANCE and APPENDIX

6.1. REFERANCE

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6.2. APPENDIX

APPENDIX -1

Laboratory analysis bulk –density core sampling

Name	Code	Wet soil+ Container mass (gm)	Dry soil mass + container (gm)	Mass of Container (gm)	Volume of container (cm^3)	Mass of moist Soil (gm)	Mass of dry soil (gm)	Soil water Content (gm)	Soil dry Bulk density kg/m^3	Moist soil Bulk Density kg/m^3
TELETA NSR	02	260.4	198	96.9	85	163.5	101.1	0.61	1189	1923
	04	269.7	208	96.9	85	172.8	111.1	0.55	1307	2032
	05	261.6	202.3	96.9	85	164.7	105.4	0.56	1240	1937
	13	255.3	197.1	96.9	85	158.4	100.2	0.58	1178	1863
Sub average									**1228.5**	
TAGEL NSR	60	253.9	193.2	96.9	85	157	96.3	0.63	1132	1847
	19	265.9	205.6	96.9	85	169	108.7	0.55	1278	1988
	21	259.4	194	96.9	85	162.5	97.1	0.67	1142	1911
	03	274.8	215.4	96.9	85	177.9	118.5	0.5	1394	2092
Sub average									**1236.5**	
ADBRA NSR	01	284.5	222.1	96.9	85	187.6	125.2	0.49	1472	2207
	77.4	250.3	190.9	96.9	85	153.4	94	0.63	1105	1804
	24	261.9	195.4	96.9	85	165	98.5	0.67	1158	1941
	14	259.4	200	96.9	85	162.5	103.1	0.57	1212	1911
Sub average									**1236.75**	

APPENDIX-2

Data quality assurance measurement table

1	2	3	4	5	6	7
No	X_Coordinate	Y_Coordinate	Echo sounder Reading(m)	Tape measurement (m)	5-4	6^2
1	295257	1262844	1.8	1.9	0.1	0.01
2	285164	1262908	1.7	1.7	0	0
3	295184	1262879	1.7	1.7	0	0
4	295179	1262851	1.7	1.72	0.02	0.0004
5	295199	1262940	1.6	1.61	0.01	0.0001
6	295159	1262912	1.6	1.6	0	0
7	295159	1262858	1.6	1.6	0	0
8	295197	1262850	1.6	1.63	0.03	0.0009
9	295199	1262843	1.6	1.62	0.02	0.0004
10	295185	1262831	1.6	1.61	0.01	0.0001
11	295266	1262843	1.6	1.62	0.02	0.0004
12	295181	1262934	1.5	1.53	0.03	0.0009
						0.0132/12 =(0.0011)^0.5
	RMSE					**0.0332**

APPENDIX-3

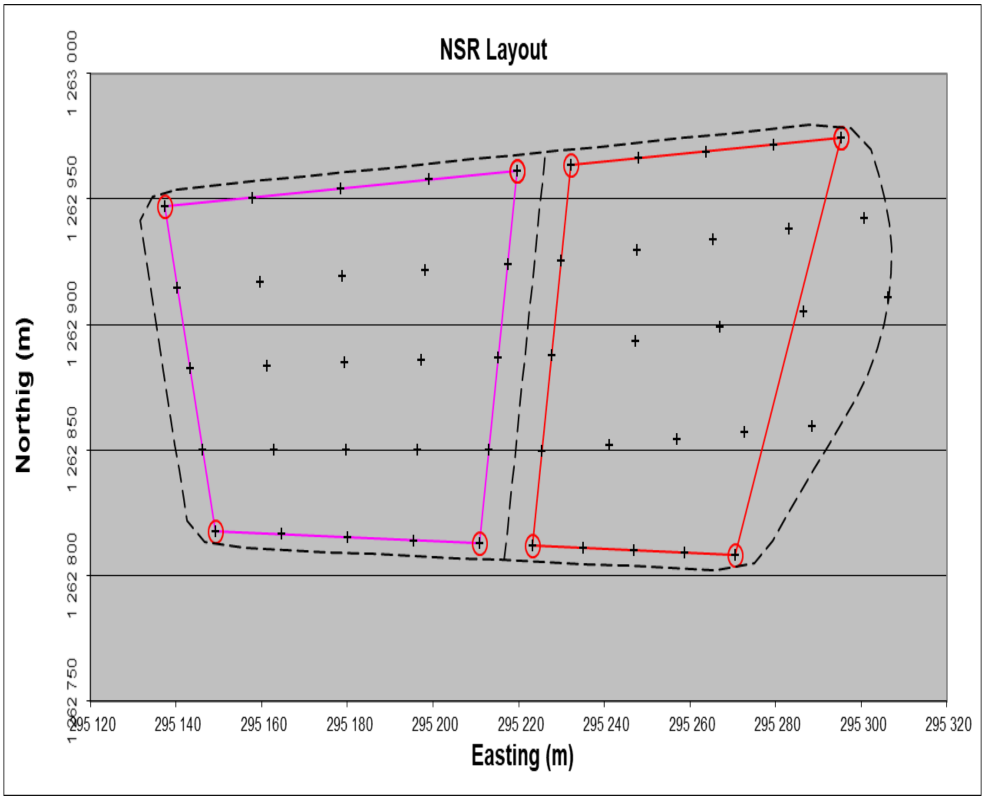
Water released from main reservoir throughout 8 years from 2004 to 2012 E.

	Monthly flow from main reservoir (m^3 10^6)							
Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
2004	-	1.6	10.4	19.2	20.4	7.77	10	-
2005	0.905	10.34	9.326	22.84	9.22	11.6	5.038	0.062775
2006	0.38	3.56	45.9	-	0.619	10.59	3.617	-
2007	0.168	7.136	14.228	18.246	18.3	9.72	4.478	-
2008		2.089	8.2	9.6	10.2	4.3	1.7	-
2009	0.6	5.3	13.7	15.6	16.9	14.7	3.9	0.864
2010	0.2	6.4	14.7	17.3	16.2	10.6	5.1	3.09
2011	2.2	5.9	15.9	17.2	16.7	12.7	6.2	1.4
2012	1.05	4.96	12.7	14.9				

APPENDIX-4

Design layout (original data) of three night storage reservoirs

Design layout of Tagel NSR (original data) and its point data

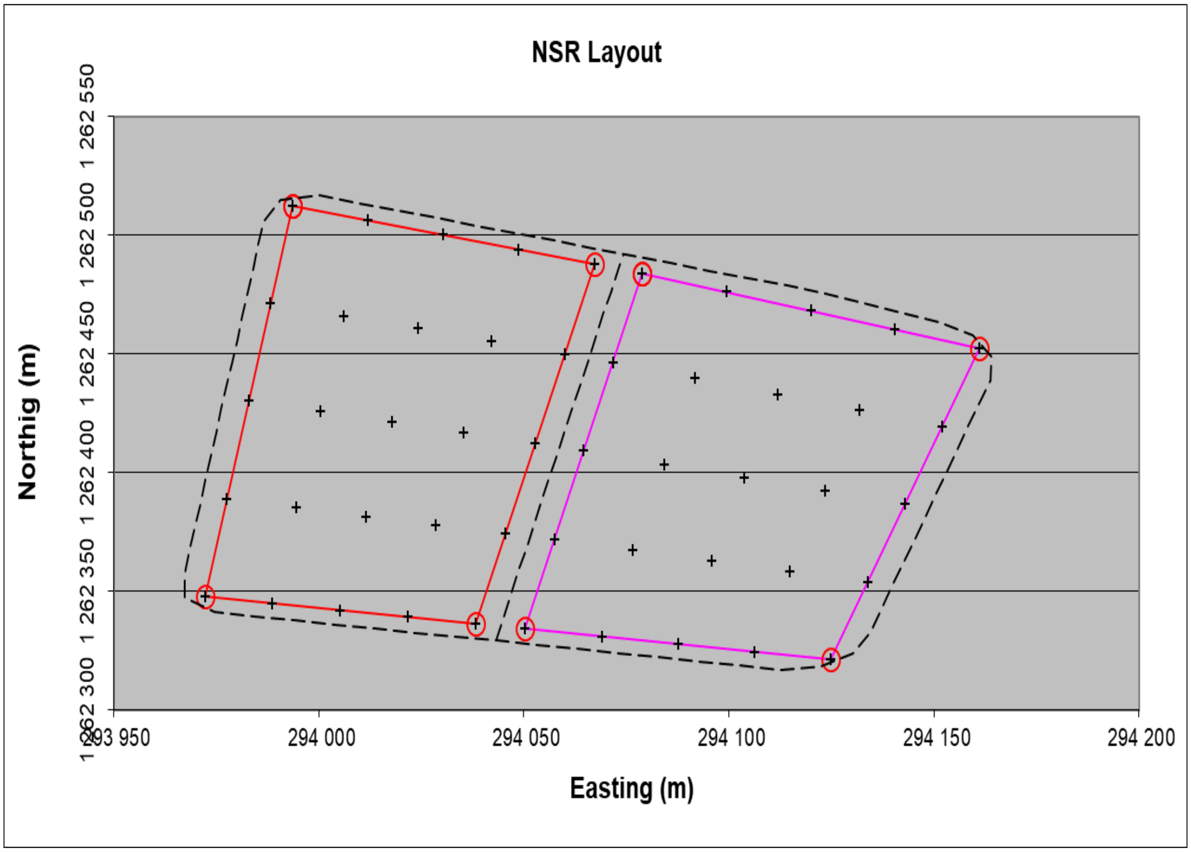


Easting(m)	Northing(m)	Elevation(m)			
295164.56	1262816.61	1991.4	295258.75	1262809.02	1993.47
295179.99	1262815.37	1992.23	295246.9	1262809.97	1993.49
295210.84	1262812.88	1992.35	295288.4	1262859.48	1993.51
295195.41	1262814.12	1992.41	295223.2	1262811.08	1993.51
295149.13	1262817.85	1992.41	295306.19	1262910.9	1993.59
295213.03	1262849.98	1992.57	295235.05	1262810.93	1993.65
295162.88	1262850.11	1992.58	295300.71	1262942.6	1993.66
295146.16	1262850.15	1992.63	295295.22	1262974.36	1993.74
295176.6	1262850.07	1992.77	295272.66	1262857.06	1993.77
295143.19	1262882.45	1992.86	295225.44	1262849.78	1993.77
295196.31	1262850.02	1992.88	295286.56	1262905.09	1993.79
295179.21	1262884.77	1992.94	295256.92	1262854.63	1993.83

295161.2	1262883.61	1992.95	295283.01	1262938.36	1993.87
295197.21	1262885.92	1993.01	295266.94	1262899.29	1993.97
295215.22	1262887.08	1993.05	295279.46	1262971.63	1994.01
295140.23	1262914.75	1993.1	295265.31	1262934.1	1994.08
295159.52	1262917.11	1993.12	295241.18	1262852.2	1994.08
295198.12	1262921.83	1993.18	295247.92	1262966.18	1994.12
295217.41	1262924.18	1993.19	295247.31	1262893.48	1994.12
295178.85	1262919.47	1993.2	295229.91	1262925.56	1994.13
295219.6	1262961.29	1993.24	295268.69	1262968.91	1994.19
295157.84	1262950.61	1993.26	295247.61	1262929.83	1994.26
295137.26	1262947.05	1993.3	295227.68	1262887.67	1994.8
295178.43	1262954.17	1993.31	295232.15	1262963.46	1994.89
295199.02	1262957.73	1993.33			
295270.6	1262808.06	1993.35			

APPENDIX-5

Design layout of Adbra NSR (original data) and its point data

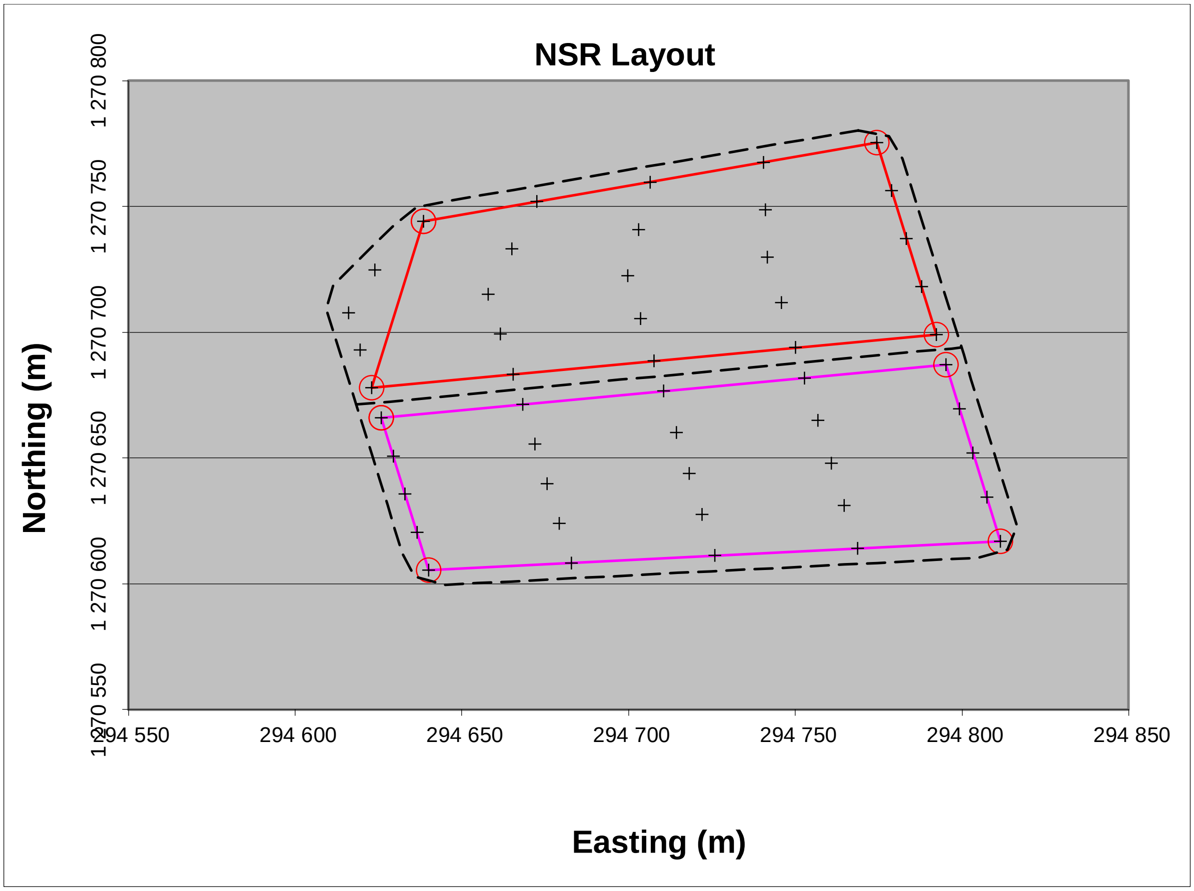


Easting(m)	Northing(m)	elevation(m)			
293993.56	1262512.34	1986.675	294078.91	1262484	1985.605
294011.96	1262506.23	1986.113	294099.43	1262476.05	1985.859
294030.36	1262500.12	1985.711	294119.95	1262468.1	1985.955
294048.76	1262494.01	1985.199	294140.47	1262460.16	1986.006
294067.16	1262487.9	1985.302	294161	1262452.21	1986.04
293988.22	1262471.2	1984.7	294071.76	1262446.52	1985.581
294006.14	1262465.9	1984.71	294091.81	1262439.75	1985.667
294024.07	1262460.59	1984.785	294111.87	1262432.97	1985.78
294042	1262455.29	1984.972	294131.92	1262426.19	1985.848
294059.93	1262449.98	1985.438	294151.98	1262419.41	1985.916
293982.87	1262430.06	1983.4	294064.61	1262409.05	1985.477
294000.33	1262425.56	1984.5	294084.2	1262403.44	1985.475
294017.78	1262421.06	1984.497	294103.79	1262397.83	1985.556

294035.24	1262416.56	1984.541	294123.37	1262392.23	1985.793
294052.7	1262412.06	1985.118	294142.96	1262386.62	1985.995
293977.53	1262388.98	1984.434	294057.47	1262371.57	1985.1
293994.51	1262385.23	1984.446	294076.59	1262367.14	1985.341
294011.5	1262381.53	1984.541	294095.7	1262362.7	1985.497
294028.48	1262377.83	1984.624	294117.82	1262358.26	1985.791
294045.46	1262374.14	1984.656	294133.94	1262353.83	1985.893
293972.18	1262347.78	1984.649	294050.32	1262334.1	1984.795
293988.7	1262344.89	1984.65	294068.97	1262330.83	1985.041
294005.21	1262342	1984.71	294087.62	1262327.56	1985.236
294021.72	1262339.11	1984.744	294106.27	1262324.3	1985.491
294038.23	1262336.21	1984.772	294124.92	1262321.03	1985.631

APPENDIX-6

Design layout of Teleta NSR (original data) and its point data



Easting(m)	Northing(m)	Elevation(m)
294638.58	1270744.16	1905.66
294672.54	1270751.93	1905.41
294706.51	1270759.7	1905.18
294740.47	1270767.46	1905.01
294774.43	1270775.23	1903.4
294623.82	1270724.83	1905.71
294665.09	1270733.18	1905.69
294703.07	1270740.87	1905.61
294741.01	1270748.54	1905.21
294778.9	1270756.21	1904.97
294616.07	1270707.69	1905.86
294657.89	1270715.06	1905.87
294699.71	1270722.44	1905.74
294661.62	1270699.16	1905.91
294703.69	1270705.5	1905.79
294745.76	1270711.84	1905.64
294787.82	1270718.17	1905.46
294623.04	1270677.96	1906.19
294665.35	1270683.26	1906.01
294707.67	1270688.56	1905.92
294749.98	1270693.86	1905.74
294792.29	1270699.15	1905.58
294625.87	1270665.94	1906.35
294668.18	1270671.23	1906.18
294710.49	1270676.53	1906.04
294752.8	1270681.83	1905.82
294795.11	1270687.13	1905.69

294741.54	1270729.82	1905.5	294629.42	1270650.8	1906.52
294783.36	1270737.19	1905.27	294671.87	1270655.5	1906.34
294619.55	1270692.83	1906.01	294714.32	1270660.19	1906.26
294632.97	1270635.67	1906.64	294756.77	1270664.89	1905.98
294675.56	1270639.76	1906.43	294799.23	1270669.59	1905.89
294718.16	1270643.86	1906.38	294764.73	1270631.02	1906.22
294760.75	1270647.96	1906.13	294807.46	1270634.51	1906.27
294803.34	1270652.05	1906.09	294640.08	1270605.4	1907.415
294636.52	1270620.53	1906.76	294682.95	1270608.29	1906.71
294679.26	1270624.03	1906.58	294725.83	1270611.19	1906.5
294721.99	1270627.52	1906.43	294768.7	1270614.08	1906.37
294811.58	1270616.98	1906.46			

APPENDIX-7

Bathymetry survey data for three night storage reservoirs (not including boundary data)

Tagel NSR bathymetry data

Easting(m)	Northing(m)	Elevation(m)			
			295193	1262816	1993.55
295257	1262844	1993.53	295248	1262887	1993.55
295244	1262845	1993.53	295285	1262858	1993.55
295164	1262908	1993.53	295229	1262857	1993.54
295181	1262884	1993.53	295245	1262953	1993.53
295168	1262817	1993.53	295293	1262954	1993.55
295260	1262828	1993.54	295231	1262923	1993.58
295270	1262857	1993.54	295258	1262873	1993.58
295166	1262895	1993.54	295163	1262844	1993.55
295249	1262829	1993.54	295162	1262870	1993.55
295237	1262830	1993.53	295184	1262897	1993.55
295159	1262858	1993.54	295145	1262916	1993.54
295185	1262831	1993.53	295178	1262921	1993.54
295266	1262843	1993.56	295216	1262925	1993.54
295181	1262910	1993.55	295162	1262938	1993.54
295193	1262859	1993.56	295188	1262943	1993.54
295200	1262833	1993.54	295190	1262952	1993.54
295156	1262817	1993.56	295170	1262950	1993.54
295200	1262936	1993.56	295144	1262926	1993.55
295228	1262832	1993.58	295147	1262903	1993.56
295147	1262843	1993.54	295149	1262882	1993.56
295207	1262847	1993.63	295149	1262859	1993.54
295176	1262871	1993.55	295216	1262889	1993.54
295181	1262934	1993.56	295211	1262913	1993.54
295168	1262930	1993.56	295236	1262847	1993.56
295198	1262885	1993.56	295231	1262873	1993.56
295166	1262832	1993.56	295271	1262941	1993.55
295249	1262875	1993.56	295278	1262968	1993.56
295270	1262873	1993.56	295244	1262964	1993.56
295263	1262909	1993.55	295176	1262858	1993.54
295244	1262910	1993.55	295205	1262955	1993.56
295248	1262941	1993.56	295227	1262816	1993.56
295295	1262941	1993.56	295231	1262909	1993.54
295263	1262965	1993.56	295276	1262828	1993.56

295193	1262913	1993.53	295248	1262860	1993.58
295164	1262884	1993.53	295231	1262962	1993.58
295265	1262954	1993.57	295290	1262886	1993.6
295249	1262925	1993.55	295283	1262913	1993.6
295295	1262926	1993.56	295269	1262886	1993.6
295293	1262898	1993.55	295246	1262897	1993.6
295187	1262846	1993.58	295258	1262857	1993.6
295149	1262871	1993.57	295204	1262860	1993.6
295197	1262898	1993.54	295148	1262892	1993.6
295213	1262901	1993.54	295198	1262925	1993.6
295166	1262917	1993.55	295204	1262944	1993.6
295143	1262936	1993.55	295268	1262897	1993.6
295231	1262950	1993.6	295271	1262812	1993.7
295222	1262959	1993.6	295238	1262813	1993.7
295149	1262946	1993.6	295298	1262910	1993.7
295181	1262817	1993.6	295230	1262897	1993.7
295205	1262816	1993.6	295200	1262873	1993.7
295214	1262837	1993.6	295218	1262947	1993.7
295215	1262864	1993.6	295276	1262925	1993.8
295219	1262936	1993.6	295154	1262828	1993.9
295284	1262873	1993.6	295214	1262816	1993.9
295234	1262939	1993.6	295255	1262815	1993.9
295298	1262968	1993.6	295227.68	1262887.67	1994.89
295278	1262842	1993.6			

Adebera bathymetry data

Easting(m)	Northing(m)	Elevation(m)	293997	1262389	1985.388
294137	1262385	1985.075	294012	1262411	1985.388
294049	1262472	1985.188	294009	1262454	1985.388
294060	1262434	1985.288	294020	1262454	1985.388
294049	1262434	1985.288	294039	1262450	1985.388
294031	1262433	1985.288	293990	1262479	1985.388
294020	1262432	1985.288	294008	1262472	1985.388
294051	1262389	1985.288	294088	1262430	1985.388
294036	1262370	1985.288	294105	1262401	1985.388
294026	1262349	1985.288	294122	1262397	1985.388
294000	1262356	1985.288	294102	1262354	1985.388
293991	1262358	1985.288	293984	1262401	1985.388
294074	1262375	1985.288	293997	1262400	1985.388
294049	1262411	1985.288	294078	1262361	1985.45
294031	1262410	1985.288	294044	1262370	1985.488
294057	1262447	1985.288	293980	1262357	1985.488
294040	1262475	1985.288	293989	1262349	1985.488
294055	1262458	1985.288	294063	1262336	1985.488
294040	1262460	1985.288	294071	1262334	1985.488
294100	1262427	1985.34	294078	1262332	1985.488
294116	1262422	1985.34	294112	1262336	1985.488
294123	1262349	1985.36	294098	1262341	1985.488
294128	1262374	1985.37	294084	1262344	1985.488
293995	1262457	1985.37	294076	1262348	1985.488
293995	1262494	1985.388	294111	1262388	1985.488
294039	1262433	1985.388	294102	1262391	1985.488
294008	1262433	1985.388	294073	1262400	1985.488
293985	1262415	1985.388	294092	1262414	1985.488
293996	1262412	1985.388	294099	1262412	1985.488
293980	1262372	1985.388	294108	1262411	1985.488
293998	1262371	1985.388	294124	1262409	1985.488
294011	1262371	1985.388	294103	1262440	1985.488
294017	1262352	1985.388	294093	1262443	1985.488
294069	1262349	1985.388	294092	1262463	1985.488
294081	1262373	1985.388	294102	1262458	1985.488

294130	1262386	1985.388	294091	1262368	1985.488
294088	1262396	1985.388	294104	1262366	1985.488
294119	1262435	1985.388	294115	1262364	1985.488
294025	1262369	1985.388	294136	1262364	1985.488
293979	1262389	1985.388	294121	1262452	1985.488
294144	1262443	1985.488	294131	1262449	1985.488
294140	1262406	1985.488	293988	1262425	1985.62
294139	1262461	1985.488	294113	1262352	1985.64
294072	1262433	1985.488	294072	1262360	1985.65
294071	1262408	1985.488	294111	1262378	1985.65
294126	1262349	1985.488	294047	1262399	1985.65
294085	1262383	1985.488	294008	1262443	1985.65
294007	1262423	1985.488	294058	1262364	1985.67
294083	1262406	1985.49	294051	1262422	1985.68
294130	1262420	1985.53	294050	1262493	1985.688
294149	1262416	1985.54	294038	1262497	1985.688
294137	1262395	1985.58	294026	1262500	1985.688
294061	1262387	1985.58	294012	1262505	1985.688
294068	1262389	1985.58	294003	1262506	1985.688
294099	1262380	1985.58	294045	1262350	1985.688
294066	1262489	1985.588	294034	1262348	1985.688
293993	1262434	1985.588	294016	1262343	1985.688
294005	1262344	1985.588	294088	1262331	1985.688
294027	1262342	1985.588	294100	1262328	1985.688
294060	1262337	1985.588	294127	1262335	1985.688
294118	1262327	1985.588	294064	1262378	1985.688
294072	1262417	1985.588	294080	1262464	1985.688
294080	1262445	1985.588	294024	1262481	1985.688
294109	1262458	1985.588	294119	1262335	1985.688
294156	1262452	1985.588	294125	1262364	1985.688
294153	1262455	1985.588	294034	1262388	1985.788
294146	1262458	1985.588	294025	1262389	1985.788
294103	1262477	1985.588	294109	1262327	1985.788
294037	1262340	1985.588	294155	1262427	1985.788
294057	1262351	1985.588	294125	1262468	1985.788
294104	1262338	1985.588	294113	1262474	1985.788
294038	1262442	1985.59	294013	1262389	1985.788
294086	1262356	1985.62	294032	1262479	1985.788
294024	1262420	1985.62	294154	1262440	1985.788

294017	1262468	1985.88	294031	1262400	1985.788
293998	1262475	1985.88	294011	1262400	1985.788
294020	1262443	1985.88	293988	1262461	1985.88
294031	1262421	1985.88	294029	1262465	1985.88
294002	1262490	1985.888	293989	1262447	1985.88
294012	1262485	1985.888	294056	1262468	1985.888
294043	1262388	1985.888	294079	1262483	1985.888
294135	1262432	1985.888	294077	1262417	1985.988
294133	1262464	1985.888	294083	1262416	1985.988
294094	1262479	1985.888	293993	1262512	1986.675

Teleta bathymetry data

Easting(m)	Northing(m)	Elevation(m)	294677	1270737	1906.22
294785	1270647	1906.015	294686	1270708	1906.22
294783	1270655	1906.015	294705	1270718	1906.22
294783	1270663	1906.015	294714	1270751	1906.22
294782	1270670	1906.015	294719	1270742	1906.22
294755	1270618	1906.015	294723	1270737	1906.22
294704	1270652	1906.015	294727	1270729	1906.22
294704	1270643	1906.015	294758	1270750	1906.22
294683	1270654	1906.015	294761	1270740	1906.22
294658	1270714	1906.015	294764	1270729	1906.22
294636	1270717	1906.12	294786	1270737	1906.22
294684	1270721	1906.12	294803	1270668	1906.22
294703	1270727	1906.12	294805	1270650	1906.22
294727	1270718	1906.12	294807	1270642	1906.22
294728	1270710	1906.12	294809	1270634	1906.22
294746	1270694	1906.12	294734	1270665	1906.22
294800	1270677	1906.12	294733	1270675	1906.22
294788	1270623	1906.12	294706	1270659	1906.22
294787	1270631	1906.12	294659	1270627	1906.22
294786	1270640	1906.12	294778	1270682	1906.22
294731	1270621	1906.12	294697	1270739	1906.22
294731	1270629	1906.12	294731	1270613	1906.22
294733	1270636	1906.12	294635	1270723	1906.32
294733	1270643	1906.12	294660	1270685	1906.32
294734	1270650	1906.12	294663	1270692	1906.32
294735	1270607	1906.12	294660	1270702	1906.32
294703	1270633	1906.12	294692	1270691	1906.32
294704	1270623	1906.12	294708	1270756	1906.32
294680	1270616	1906.12	294769	1270717	1906.32
294682	1270625	1906.12	294805	1270658	1906.32
294682	1270632	1906.12	294682	1270607	1906.32

294683	1270639	1906.12	294684	1270647	1906.32
294684	1270661	1906.12	294693	1270752	1906.32
294659	1270654	1906.12	294777	1270701	1906.42
294659	1270647	1906.12	294785	1270729	1906.42
294659	1270638	1906.12	294782	1270757	1906.42
294660	1270619	1906.12	294759	1270679	1906.42
294640	1270708	1906.22	294706	1270668	1906.42
294646	1270697	1906.22	294659	1270661	1906.42
294657	1270727	1906.22	294635	1270664	1906.42
294654	1270740	1906.22	294734	1270658	1906.42
294632	1270683	1906.42	294658	1270667	1906.42
294789	1270615	1906.42	294641	1270615	1906.52
294650	1270685	1906.52	294705	1270676	1906.52
294671	1270749	1906.52	294631	1270734	1906.52
294708	1270699	1906.52	294771	1270772	1906.52
294708	1270708	1906.52	294711	1270690	1906.52
294730	1270694	1906.52	294628	1270693	1906.62
294745	1270702	1906.52	294624	1270704	1906.62
294742	1270715	1906.52	294676	1270743	1906.62
294740	1270728	1906.52	294811	1270623	1906.62
294739	1270739	1906.52	294757	1270653	1906.62
294736	1270750	1906.52	294635	1270654	1906.62
294735	1270758	1906.52	294617	1270715	1906.62
294750	1270767	1906.52	294793	1270700	1906.62
294756	1270762	1906.52	294792	1270710	1906.72
294783	1270745	1906.52	294787	1270721	1906.72
294780	1270762	1906.52	294636	1270642	1906.72
294795	1270686	1906.52	294702	1270612	1906.82
294760	1270672	1906.52	294640	1270605	1907.415
294759	1270663	1906.52			
294755	1270631	1906.52			
294682	1270670	1906.52			

294660	1270609	1906.52
294640	1270625	1906.52
294638	1270632	1906.52
294755	1270641	1906.52

Appendex-8

Digitized Original topography map of koga reservoir (2006)