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STREAM HYDRAULIC ENGINEERING (MSc)

Thesis Title:-

“Estimation of Reservoir Sediment by using Satellite Remote Sensing”

For Legedadi Dam Reservoir

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science

DECLARATION

I confirm that the research work “Estimation of Reservoir Sediment by using Satellite Remote Sensing for Legedadi Dam Reservoir” is my work. The work has not been presented elsewhere. Where material has been used from other sources it has been properly acknowledged.

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ABSTRACT

Reservoir sedimentation is the gradual accumulation of inward sediments from upstream catchment that has driven the decrease in useful storage volume of the reservoir. Enumerating the reservoir sedimentation amount is vital for improved water resources management. The conventional methods to estimate sediment deposition in a reservoir, such as hydrographic surveys and the inflow-outflow approaches, are bulky, costly, and time-consuming. Further, forecasting of sediment deposition outlines using empirical and numerical methods needs a large quantity of input data and the outcomes are still not inspiring. It is necessary to develop a precise approaches, which need less time and cost-effective. Because of sediment deposition, the water-spread area of a reservoir at different levels keeps on decreasing.

The Satellite Remote Sensing (SRS) method for estimation of reservoir sediment uses the fact, that the water spread area of reservoir at different elevations keeps on decreasing due to the sediment accumulation takes the area of the water. The remote Sensing technique gives us directly the water spread area of the reservoir at a particular elevation on the date of pass of the satellite. This helps us to determine sedimentation over a specified time. By using remote sensing data in combination with a geographic information system and Envi 5.3 software the chronological variation in the water-spread area can be investigated to assess the sediment deposition in a reservoir. The revised capacity of the reservoir for available satellite image and at fluctuation levels was computed using the Simpsons 1/3 Rule formula.

In this paper, a remote sensing method has been tried to estimate sedimentation in Legedadi Dam Reservoir, the reservoir placed on the upper part of Awash Basin, the outflow is joining Akaki river. Multi-date remote sensing data level 1 Landsat 8 and 7 gives the information on the water spread area of the reservoir, which will be used for calculating the sedimentation amount.

The current (2018/19 GC) live storage capacity of Legedadi reservoir estimated using remote sensing approach is 36.087 Mm³ at an elevation of 2465.16 m.a,m,s,l. According to 1979Gc study result the capacity was 41.610 Mm³ at the same level. The loss in reservoir capacity due to sediment deposition for a period of 39 years since the 1979 hydrographic survey to 2018/19 Gc is determined by deducting the 1979 and 2018/19 GC value it gives 5.523 Mm³ which is 13.27 % capacity loss between 2465.16 and 2460.98 m.a,m,s,l. At the live storage zone, Therefore, the result shows that there is a need to give a serious attention for reservoir sedimentation. To protect the reservoir from sedimentation problem we need to protect the upstream and downstream catchment by means of integrated environmental protection.

Keywords: - hydrographic survey; inflow-outflow methods; remote sensing; reservoir sedimentation amount; storage capacity; water-spread area.

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Acronyms

AAWSA- Addis Ababa Water and Sewerage Authority

ENVI- Environmental Visualization Interfere

FRL-Full Reservoir level

FCC-False Color Combination

GeoTIFF -Geographic tagged image file format

GSFC-Goddard Space Flight Center

HSV -High Surface Visualization

ITCZ -inter-tropical convergence zone

MIR-Mid Infrared Radiation

MNDWI- Modified Normalized Difference Water Index

NDWI - Normalized Difference Water Index

OLI-Operational Land Imager

NIR-Near Infrared Radiation

SRS-Satellite Remote Sensing

SWIR-Short Wave Infrared Radiation

TIRS -Thermal Infrared Sensor

TOA-Top of Atmosphere

USGS –United States Geological Survey

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1.0 INTRODUCTION

1.1 Background

Reservoirs are constructed for one or more purposes which include source of water supply, source of irrigation water, source of power, flood prevention and recreation. In other words, reservoirs form part of a basic commodity for the economy and well-being of our society. All reservoirs formed by dams on natural water courses are subject to some degree of sedimentation. The problem confronting the hydraulic engineer is to estimate the rate of sedimentation and the period of time before the sediment will interfere with the useful functions of the reservoir (Jose Luis Lopez.S, 1978 GC) .

In general, the construction of a hydraulic structure such as a dam changes the natural equilibrium of the stream by changing the characteristics of discharge and the sediment transport capability. Under these conditions a natural stream is usually classified into four different phases . The first phase occurs upstream in the watershed ~here soil erosion and degradation takes place. This phase usually originates most of the sediment transported by the stream. The second phase is that part of the river where aggradation and/or degradation is taking place. This part of the system can be considered to be in dynamic balance until changes induced by nature or man's activities alter the natural conditions. The third phase occurs in the reservoir itself where sediment deposition or aggradation takes place. That part of the stream downstream from the dam is further designated as the fourth phase where mostly degradation takes place.(Jose Luis Lopez.S, 1978 GC) .

Sediment particles initiating from erosion processes in the catchment are spread along with the river flow. When the flow of a river is kept in a reservoir, the sediment will deposit in the reservoir and decreases its capacity. Decrease in the storage size of a reservoir beyond the limit will affect the function for which it was planned. Thus Estimation of sediment accumulation becomes very important for the management and operation of such reservoirs.

Sedimentation developments associated with watershed activities, river features, and reservoir design are dropping the water storage capacity and negative impacts on reservoir functionality

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(Bunyasi et al, 2013). It is assessed that 0.5–1% of the existing storage volume in the world is lost each year due to sedimentation (Walling 2006).

This phenomenon of sedimentation, increasingly harming the utility of the reservoir needs attention not only at the project planning phase but also during the operation phase. Depending upon the form of the reservoir, mode of reservoir operation, sediment inflow amount, and grain size distribution, the arriving sediment will be deposited in different places of the reservoir.

These reservoirs need to meet various requirements of the community. After the dam is built the silt-loaded water drifts into the reservoir causing siltation in both Live and dead storage of the reservoir, thus functionality of water storage and benefits from the reservoir are decreased. The life of the reservoir is reduced when the rate of sedimentation is higher than the design rate (Eilander et al, 2014).

Reservoir sedimentation is a serious problem in various portions of the world compromising the valuable lifetime of reservoirs (Andredaki et al., 2015). The exclusion of collected sediments is typically excessive and expensive needs to responsibility (Minear and Kondolf, 2009), whereas instead of this , the building of new reservoirs to balance the loss of reservoir volume from sedimentation is becoming a fewer feasible choice since most reservoirs have already been built at the most appropriate sites (Rashid et al., 2014).

Sediment trapping by reservoirs is now a primary concern for Ethiopians. This has substantial consequences, both for the channels downstream, and for the sustainability of the reservoirs and thus future water supplies. There is growing indication of channel erosion and ecosystem impacts resulting from sediment limitation in downstream of dams.(Yonas Alemshet, 2017GC)

sedimentation surveys of the reservoir must be done. An essential component of water resources planning is a periodic determination of sediment in flow rate, accumulation form, and net storage accessibility. This water resources planning and periodic review will promote optimum utilization. To guarantee reservoir performance requires correct estimation of sediment deposit and distribution in the entire body of the reservoir because reservoirs are national assets that is necessity to be taken care of.

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Analysis of sedimentation has usually been done through direct and indirect approaches. Direct methods contain the real measurement of the volume of sediments accumulations in the reservoir through mostly hydrographic surveys (Vente et al., 2003). Indirect methods contain sediment budgets which include the analysis of the inflow and outflow sediment specimen gathered at gauging stations upstream and downstream of the reservoir, and also several models that have been established to determine sediment yield into reservoirs (Adam et al., 2014; Bronstert et al., 2014; Weerakoon, 2005).

The Satellite Remote Sensing technique for estimations of reservoir sedimentation based on the reality, that the water spread area of reservoir at different levels remains on declining due to the sediment accumulation takes the area of the reservoir. The remote sensing technique gives us the water-spread area of the reservoir at a specific levels on the time of the satellite pass. This supports us to estimate sedimentation over some time. Analysis of data from space platforms can help in reservoir capacity surveys. Multidate satellite remote sensing package deliver data on elevation contour areas directly in the form of water spread. Any decrease in reservoir water spread area at observed water level is shows the sediment accumulation (Shanker, 2004). Thus, by assessing the variations of water-spread areas at different operating stages of the reservoir, the amount of the sediment weight that has accumulated over some period can be evaluated.

For good distribution and functionality of water in a reservoir, knowhow about the sediment accumulation form in different regions of a reservoir is vital. Because of this, organized capacity studies of a reservoir should be done occasionally. Using remote sensing methods, it has become highly effective and suitable to estimate the sedimentation in a reservoir and to evaluate its arrangement and accumulation form. Remote sensing approaches, present data gaining over a long time and wide spectral variety, can deliver synoptic, repetitive, and appropriate data about the sedimentation features in a reservoir. Reservoir water spread area for a specific elevation can be found highly precise from the satellite data. Reduction if any, in the water spread area for a specific Elevation shows accumulation of sediment at that condition. This combined over a series of Elevations using multi-date satellite data allows in estimating volume of storage lost as a result of Sedimentation.

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1.2 Statement of Problem

Sediment accumulation in Legedadi reservoir decrease their live storage size, while the accumulation of suspended solids in Legedadi Reservoir has influence on the fresh water quality thus growing the treatment expenses. Siltation of water has a significant impact on reservoir functions. It decrease the storage capacity and amount of the collected water that in return caused water scarcity. According to AAWSA reports, the cost of water treatment increased from 7.7 million birr in 1993 to 21.4 million birr in 2001 due to the increasing amount of reservoir sedimentation. On the average, the state experiences water treatment cost of 12.6 million birr /year (AAWSA, 2001).

Sedimentation is likely to have consequences both upstream and downstream of a reservoir. Deposition of sediment in the river upstream of the reservoir can increase flood levels. Downstream of a reservoir subjected to sedimentation the sediment equilibrium in the river is disrupted. Since the flow that leaves the reservoir carries little sediment, the bed and banks of the river tend to become eroded. With bed and bank material becoming coarser the resultant changing habitat can have far-reaching consequences.(Tom Jacobsen 1997 GC)

One of the most general environmental impacts of reservoir sediments is the role they play in water quality dynamics, as they act both as sources and sinks of the chemical and organic constituents of reservoir water. Contaminants, in particular such as plant nutrients and toxic pollutants, are of concern here. Both bottom sediment and suspended sediment contribute to these water-quality impacts.

1.3 Objectives of the Study

General Objective

- ❖ The general objective of this study is to Estimate sedimentation of the Legedadi Dam reservoir by using remotely sensed satellite data.

The specific objectives of the study are

- ❖ To show the capability of remotely sensed data to determine reservoir sedimentation.

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- ❖ To determine the volume of sediment deposited in the Legedadi Dam reservoir with in fluctuation period from 2003 GC to 2018/19Gc.
- ❖ To develop the current reservoir capacity curve of the Legedadi Dam reservoir.

1.4 Research Questions

- How much is the sediment deposition rate at the live storage zone of Legedadi reservoir for the available satellite imageries between 1979 and 2018/19 GC.
- What is the indication of revised Elevation Area Capacity curve of Legedadi reservoir.

1.5 Scope of the Study

This study is targeted to estimate the Reservoir Sedimentation of the legedadi dam reservoir. It addresses the determination of sediment deposition by the available satellite images and prepares a revised Elevation – Area – capacity curve for the live storage zone of Legedadi Dam Reservoir.

1.6 Significance of the Study

This study is intended to use by Engineers, Scientists, and Natural Resource Managers as guidance in formulating yearly sediment management plans for reservoirs that makes a reservoir sustainable. Further, The result of this Thesis might also serve as baseline information for those who are interested to conduct further research on reservoir sedimentation using remotely sensed data.

2.0 LITERATURE REVIEW

2.1 General concepts of reservoir sedimentation

Reservoir sedimentation is a gradual accumulation of the incoming sediment load from a river. It is a universal and natural phenomenon. The eroded soil from the upper catchment area is carried into watercourses by flood and storm waters resulting in tremendous sediment movement. Uncontrolled deforestation, forest fires, overgrazing, improper method of digging, and unwise agricultural and land-use practices accelerate soil erosions resulting in a large increase of sediment inflow into streams and ultimately entering into lakes and artificial reservoirs (Ouyang et al., 2010).

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

Sediment particles are originated from the catchment area and river systems. As a river enters the reservoir, its cross-section of inflow is enlarged due to the effect of the backwater curve. Thus, it causes a decrease in flow velocity; subsequently, the sediments carrying capacity of the water is decrease too. The accumulation of sediment in reservoirs creates a variety of problems, such as depletion of storage capacity, increased flood risks, interruption in hydropower generation and downstream river bed degradation; other problems such as degradation of water quality, increased complexity in reservoir operation and maintenance leads a subsequent growth in their associated expenses(Kothyari et al., 2002).

2.2 Erosion and Sedimentation

Soil erosion, soil loss, and sediment produce are terms with distinct meanings in soil erosion processes. Soil erosion is the gross amount of soil driven by drop detachment or runoff. Soil loss

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is the soil moved off a particular slope or field. Sediment yield is the soil loss delivered to a point under evaluation.

The development of soil erosion includes disintegrate, transport, and successive accumulation (Meyer & Wischmeier, 1969). Sediment is apart from the soil surface both by the raindrop effect and by the shearing force of flowing water. The separated sediment is transported downslope mainly by flowing water, while there is a minor quantity of downslope transported by raindrop splash also.

The sediment yield from any drainage system is calculated by averaging the data collected over years. It is, therefore, an average of the results of many different hydrologic events. The sediment yield for each storm or flood will differ, depending on the behavior of the storm occasion and the resulting hydrologic behavior of the floods. High-intensity storms may result sediment produces above the normal, while an equivalent quantity of precipitation happening over a longer period may produce relatively small sediment. During short period of time (days or years), sediment yields may fluctuate greatly because of natural or man-induced accidents. Gathering sediment flow data over a time and periodic reservoir survey data are some resources demanding methods for evaluating sediment yield rates at a catchment level (Silva et al, 2007).

2.3 Reservoir sedimentation in Ethiopia

Reservoirs of Ethiopia, the existing and the new ones, are under similar threat of sedimentation problems (Siyam et al.,2005); (Haregeweyn et al.,2012). Several efforts have been made to estimate sediment yield throughout the world, though few in Ethiopia. Aynekulu et al., (2006) reported that the life of dams in Ethiopia is almost five times shorter than that considered during the design phase. Tamene, (2005) in the Tigray region northern part of Ethiopia studied reservoir siltation and siltation rate on 11 small reservoirs. He found that the annual average amount of capacity loss varies from 0.1 to 7.4% due to the broad difference in environmental variables of catchments. In addition to this, his outcome showed that most of the reservoirs would be filled with sediment in less than 50% of their projected service time.

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Several dams build to accumulate water for irrigation and drinking purposes, were being silted up, when it is during construction (Amare, 2005). There were Sevier sedimentation cases in Ethiopia such as Borkena Dam in Wollo, which expenses \$35 million US dollars in 1991Gc, and Adrako Dam (Ebinat, South Gondar) where the dead storage capacity of the reservoirs silted up before their construction ended (Haregeweyn et al., 2006).

This is an indicator of the circumstance that sedimentation is a challenging problem in the reservoirs of Ethiopia. The existing condition of previously constructed reservoirs showed that a significant portion of their storage capacities is lost due to sedimentation every year. The realization of the objectives was highly affected unless possible mitigation actions are taken throughout the palming, construction, and operation stages.

2.4 Principles of Sediment Transport

Sediment is fragmental material, typically formed by the physical and chemical breakup of rocks from the earth's crust. Such particles range in size from large boulders to colloidal size fragments and differ in shape from rounded to angular. They also differ in specific gravity and mineral configuration, the predominant material presence is quartz. Once the sediment particles are separate, they may either be transported by gravity, wind, or/and water. When the carrying object is water, it is called fluvial or marine sediment transport. The progress of moving and removing from their original basis or stationary place is called erosion.

2.5 Methods for Estimating Reservoir Sedimentation

Depending upon the form of the reservoir, means of reservoir operation, sediment inflow rates, and grain size distribution, the inward sediment will be accumulated in different regions of the reservoir. Systematic assessment of sedimentation throughout the operation phase is vital to have up-to-date knowledge of the sedimentation process going on in the reservoir and to plan reservoir operation for best utilization of water. Determination of sediment accumulation becomes very useful for the management and operation of a reservoir. Some of the methods presently in use for estimating sediment deposition in reservoirs are : - a) Empirical and Mathematical models for sediment deposition and distribution. b) Analytical models for computation of sediment deposition

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and delta formation, c) Stream Flow Analysis for sediment and water inflow/outflow measurements, d) Hydrographic/bathymetric surveys for direct measurement of sediment deposition and e) Satellite Remote Sensing (SRS) techniques which use satellite imageries.

2.6 Remote Sensing

Remote Sensing means, "obtaining evidence about an object, area or Phenomenon without coming in direct connection with it." i.e. by some remote means. If we go by this sense of Remote Sensing, then several issues would be coming under Remote Sensor, e.g. Seismographs, fathometer, etc. The science of obtaining information about the earth using devices that are remote to the earth's surface, usually from aircraft or satellites. Devices may use visible light, infrared, or radar to get data. Remote sensing gives the capability to detect and gather data for large areas comparatively quick and is a good source of data for GIS. (Source: digital map).

2.6.1 Types of Remote Sensing

Remote sensing can be either passive or active. ACTIVE schemes have their own basis of energy (such as RADAR), while the PASSIVE schemes depend upon an exterior basis of light (such as SUN) or self-release for remote sensing

a) Active Remote Sensing

Remote sensing methods provide their own source of electromagnetic radiation to illuminate the terrain.

Active Remote Sensing Instruments

Each active sensor in remote sensing directs its signal to the object and then checks the response the received quantity. The majority of instruments employ microwaves meanwhile they are comparatively resistant to weather situations. Active remote sensing systems vary by what they carry (light or waves) and what they regulate (e.g., distance, height, atmospheric conditions, etc.).

b) Passive Remote Sensing

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Passive sensors in remote sensing do not streamline energy of their own to the researched object or surface, unlike active ones. Passive remote sensing rely on natural energy (sunrays) bounded by the focus. For this reason, it can be applied only with proper sunlight; otherwise, there will be nothing to reflect. Remote sensing of energy naturally reflected or radiated from the terrain.

2.6.2 Land Sat 8

The task of the Landsat Program is to deliver continuous gaining of moderate-resolution multispectral data of the Earth's surface on a global basis.

The Landsat 8 mission purpose is to deliver timely, high-quality visible and infrared images of all landmass and near-coastal areas on the Earth, frequently refreshing an existing Landsat database. Data input into the system is adequately reliable with currently archived data in terms of gaining geometry, calibration, coverage, and spectral features to permit for comparison of global and regional variation discovery and characterization.

As with all Landsat data, products are available at no cost to the user. Available data can be viewed through several interfaces:

- ✓ **Earth Explorer**
- ✓ **Global Visualization Viewer**
- ✓ **Landsat Look Viewer**

2.6.2.1 Applications of Landsat 8 Data

Landsat data are used by government, commercial, industrial, civilian, military, and educational communities through the United States and around the globe. The data support a wide variety of purpose in such areas as global change research, agriculture, forestry, geology, resource management, geography, mapping, water quality, and coastal studies.

Table 2.1 Applications of Landsat 8 Bands

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Spectral bands	Wavelength (micrometer)	Resolution (meters)	Functions
Band 1 - coastal/aerosol	0.43-0.45	30	Increased coastal zone observations
Band 2 - blue	0.45-0.51	30	For mapping coastal water areas, differentiating between soil and vegetation, forest type mapping, and detecting cultural features.
Band 3 - green	0.53-0.59	30	Emphasizes peak vegetation, which is useful for assessing plant vigor
Band 4 - red	0.64-0.67	30	Emphasizes vegetation slopes
Band 5 - NIR	0.85-0.88	30	Is especially responsive to the amount of vegetation biomass present in a scene. For crop identification and emphasizes soil/crop and land/water contrasts

Band 8 - panchromatic	0.5-0.68	15	For sharpening multispectral images
Band 9 - cirrus	1.36-1.38	30	For detecting cirrus clouds
Band 10 - TIRS 1	10.60-11.19	100	
Band 11 - TIRS 2	11.50-12.51	100	Same as band 10

2.6.2.2 Operational Land Imager (OLI)

The OLI sensor, which has a five year design life, is similar in design to the Advanced Land Imager (ALI) that was included on Earth Observing 1 (EO-1) and represents important technological progress over L7's ETM+ sensor. Instruments on earlier Landsat satellites employed oscillating mirrors to sweep the detectors' Field of View (FOV) across the swath width ("whiskbroom"), but OLI instead uses long linear detector arrays with thousands of detectors per spectral band. Sensors aligned across the instrument's focal planes gather imagery in a "push-broom" way, resulting in a more sensitive tool with less moving parts. OLI has a 4-mirror telescope, and data generated by

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OLI are quantized to 12 bits, compared to the 8-bit data produced by the TM and ETM+ sensor. stated in Landsat 8 data users Handbook.(LSDS-1574 Version 5.0).

2.6.2.3 Thermal Infrared Sensor (TIRS)

Like OLI, TIRS is a push-broom detector engaging a focal plane with extended arrays of photosensitive sensors. TIRS uses Quantum Well Infrared Photodetectors (QWIPs) to measure longwave Thermal Infrared (TIR) energy emitted by the Earth's surface, the intensity of which is a function of surface temperature. The TIRS QWIPs are sensitive to dual thermal infrared wavelength bands, allowing separation of the temperature of the Earth's surface from that of the atmosphere. QWIPs' design works on sophisticated ideas of quantum mechanics. Gallium arsenide semiconductor chips trap electrons in an energy state 'well' until the electrons are elevated to a higher state by thermal infrared light of a certain wavelength. The elevated electrons create an electrical signal that can be read out, recorded, translated to physical units, and used to create a digital image. . stated in Landsat 8 data users Handbook.(LSDS-1574 Version 5.0).

2.6.3 Landsat 7

L7 was launched in 1999 and performed nominally until the Enhanced Thematic Mapper Plus (ETM+) sensor's Scan Line Corrector (SLC) failed in May 2003. Since that point, L7 has continued to amass useful image data within the "SLC-off" mode. All L7 SLC-off data are of the identical high radiometric and geometric quality as data collected before to the SLC failure.

2.6.3.1 Enhanced Thematic Mapper Plus (ETM+)

Landsat 7's sensor - the ETM+ (see Figure 2-5) - was built by Santa Barbara Remote Sensing (SBRS). The sensor is a derivative of the TM engineered for Landsat 4 and Landsat 5, but is more closely related to the ETM that was lost during the Landsat 6 launch failure. The primary performance-related enhancements of the ETM+ over the TM are the addition of two gain ranges, the panchromatic band (Band 8), the improved spatial resolution for the thermal band (Band 6), and the addition of two solar calibrators. Reflected energy from the Earth's surface energy passes through a number of major ETM+ subsystems.

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Band	Wavelength (μm)	Example Applications
1	0.45–0.52 (Blue)	Coastal water mapping: bathymetry & quality Ocean phytoplankton & sediment mapping
2	0.52–0.60 (Green)	Atmosphere: pollution & haze detection Chlorophyll reflectance peak Vegetation species mapping Vegetation stress
3	0.63–0.69 (Red)	Chlorophyll absorption Plant species differentiation Biomass content
4	0.76–0.90 (NIR)	Vegetation species & stress Biomass content Soil moisture
5	1.55–1.75 (SWIR)	Vegetation-soil delineation Urban area mapping Snow-cloud differentiation
6	10.4–12.5 (TIR)	Vegetation stress analysis Soil moisture & evapotranspiration mapping Surface temperature mapping
7	2.08–2.35 (SWIR)	Geology: mineral and rock type mapping Water-body delineation Vegetation moisture content mapping
8	0.50–0.90 (15-m PAN)	Medium-scale topographic mapping Image sharpening Snow-cover classification

Table 2.2 applications of the Landsat-7 ETM+ bands (from principle of remote sensing Text book)

2.6.4 Reflectance Characteristics of Earth's Cover types in Remote sensing imageries

The spectral characteristics of the three main earth surface features in the land sat imageries are:

Water: The majority of the radiation incident upon the water is not reflected but is either absorbed or transmitted. Longer visible wavelengths and near-infrared radiation is captivated more by water than by the visible wavelengths. Thus water appearances blue or blue-green due to high reflectance at these shorter wavelengths and darker if observed at red or near-infrared wavelengths. The issues that influence the variability in reflectivity of a water body are depth of water, materials within the water, and surface roughness of the water.

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Vegetation: The spectral characteristics of vegetation vary with wavelength. Plant color in leaves named chlorophyll highly detects radiation in the red and blue wavelengths but reflects the green wavelength. The inner structure of healthy leaves responds as a diffuse reflector of near-infrared wavelengths. Measurement and monitoring the near-infrared reflectance is one way that experts know how healthy specific vegetation may be.

Soil: The majority of radiation incident on a soil surface is either reflected or absorbed and little is transmitted. The behaviors of soil that find its reflectance characters are its moisture content, organic matter content, texture, structure, and iron oxide content. The soil curve shows fewer peak and valley differences. The occurrence of moisture in soil reduces its reflectance.

2.6.5 Limitations of Satellite Remote Sensing

- ✚ The Remote Sensing based capacity estimation works between FRL and the minimum water level in the reservoir only. Thus changes can be estimated only in this zone of the reservoir. For the capacity estimation below the minimum water level in the reservoir, another method like a hydrographic survey is to be conducted.
- ✚ Availability of cloud-free dates through reservoir operation period is the problem.
- ✚ Remote Sensing approach gives precise determination for fan-shaped reservoir where there is a significant variation in water-spread area for increasing variation in water level.

2.7 ENVI (Environmental Visualization Interfere)

ENVI image analysis software is used by GIS experts, remote sensing researchers, and image experts to capture meaningful data from imagery to overcome well conclusions. ENVI can be organized and recovered from the computers, in the cloud, and on mobile tablets, and can be modified through an API to encounter precise scheme necessities (L3HARRISgeospatial). ENVI answers combine the newest spectral image analysis and image processing product with an in-built, accessible package help to get expressive data from imagery (whether it is panchromatic, LiDAR, SAR, multispectral or hyperspectral imagery). ENVI's algorithms have been scientifically proven, are easy to use, and are tightly integrated with the ArcGIS platform from Esri(Wikipedia/Harrisgeospatial).

2.8 Estimation of Reservoir Sedimentation

The water level in a reservoir is probably to be close the full reservoir level (FRL) by the end of the monsoon period (September/October) before it progressively reduces to lower stages near to the end of the declination sequence (May/June). Due to accumulation of sediments in the reservoir, the water-spread area at an elevation retains on decreasing. By means of the remote sensing method, the water-spread area can be estimated at varies reservoir elevation and a revised elevation-capacity curve can be made. By comparing the original and revised elevation-capacity curves, the quantity of volume lost to sedimentation can be determined. With the accessibility of high-resolution satellite data, volume studies of reservoirs by remote sensing approach are receives credit and appreciation. The reservoir capacity between two consecutive levels is computed using the prismoidal formula and a revised elevation capacity table is generated. Comparison of revised and original elevation-capacity tables gives the capacity loss due to sedimentation in various zones of the reservoir.

The volume of deposit represents a loss of storage capacity which reduces the efficiency of a reservoir to regulate flow. The distribution of deposits determines the relative impact of trapped sediments on the usable storage as well as the prospect of flushing it. The useful lifetime of the reservoir can be determined by estimating the rate of sedimentation which ultimately reduces the storage capacity of the reservoir. This capacity loss of reservoir will affect adversely the planning for long-term utilization of storage of reservoir for irrigation, urban water supply, and flood mitigation. Some of the methods presently in use for estimation/ prediction of sediment deposition in the reservoir are:

1. Stream measurements (sediment rating curve)
2. hydrographic surveys
3. Empirical methods
4. Mathematical models
5. Satellite Remote Sensing

❖ Stream Measurements (Sediment Rating Curve)

Estimation of Reservoir Sediment

Sediment rating curve describes the average relation between water discharge and suspended sediment concentration. A relationship between discharge and concentration can be developed which, although exhibiting scatter, will allow the mean sediment yield to be determined on the basis of discharge history (Morris & Fan, 1998). Although apparently simple in concept, critical evaluation of the data, careful application of the technique, and appreciation of its limitations are required if the approach is to be used effectively (Walling, 1977). Most river loads estimated by this method have been underestimated and the degree of underestimation increases with the degree of scatter about the rating curve and can reach 50% (Walling, 1977).

❖ Hydrographic Surveys (Bathymetry)

A complete hydrographic survey of the reservoir provides the most accurate data of the reservoir bottom, the sediment accumulation, and the present reservoir capacity. However, a complete reservoir survey can be expensive which may limit the possibility and frequency of reservoir surveys. This especially applies to large reservoirs. Evaluation of reservoir sediment deposition usually involves extensive field data collection requiring significant time and resources to complete. The survey technology has changed significantly over recent decades with the dramatic increase in speed of data acquiring and computer system processing. This has significantly reduced the field collection and analysis time while resulting in higher accuracy.

❖ Mathematical Models

Mathematical analysis of sedimentation transients is based on the premise that the dynamic action of flow acting through sediment transport is the driving force and sediment deposit (or scour) takes place due to the spatial variations in the transport rate. As the sediment transients move at a much small rate compared to the celerity of water waves, the discharge can be considered to be steady during the time interval used to compute scour deposition [e.g., (Mahmood, Yevjevich, & Miller, 1975).

❖ Satellite Remote Sensing

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This method provides data acquisition over a long time period and for a broad spectral range which can be considered superior to conventional methods of data acquisition. Spatial, spectral and temporal attributes of Remote Sensing data provide invaluable and timely synoptic information regarding changes in water spread area of reservoir after deposition of sediments over a period of time at particular elevation and hence by comparing the revised storage capacity at different date of satellite pass at various elevations with the original storage capacity at year of impoundment, the reservoir capacity loss can be estimated using satellite data.

Empirical methods and Mathematical models are the methods for the prediction of reservoir sedimentation and are normally used during the planning stage. The remaining three methods are used for monitoring sedimentation during the operation stage. The streamflow analysis method needs daily measurements of water and sediment flows upstream and downstream of the reservoir right from the day of reservoir impoundment. The hydrographic surveys for reservoirs in a hilly region with thick vegetation within and around reservoirs pose great difficulties despite high-tech systems. Even with such modern systems, surveys of large fan shape reservoirs require a period of 12 to 18 months or more. Apart from the time factor, these hydrographic surveys are not cost-effective and therefore cannot be carried out regularly at shorter intervals for purpose of monitoring reservoir sedimentation.

Comparatively, the use of satellite imageries offers a cost and time-effective alternative for monitoring purposes. Moreover, remote sensing techniques, offering data acquisition over a long time period and broad spectral range, are superior to conventional methods. It is highly cost-effective, easy to use, and requires lesser data and time in the analysis as compared to other methods. The advantage of satellite data over conventional sampling procedures includes repetitive coverage of a given area every three to four days, availability of synoptic view which is unobtainable by conventional methods, and almost instantaneous spatial data over the areas of interest. More accurate data about the water spread area of a reservoir on a given date could be collected instantaneously which is practically impossible even with high-tech survey systems. These advantages have led to the development of remote sensing techniques in the study of reservoir sedimentation.

2.9 RESERVOIR ELEVATION-AREA-CAPACITY CURVE

Reservoir elevation-area capacity is significant for planning and operation purposes. The distribution of the deposits should be estimated to allow the determination of the extent to which different allocations of the storage are affected by sediment accumulation. The distribution pattern in a reservoir depends on many factors such as the valley slope, length of the reservoir, particle size in suspended sediment, capacity inflow ratio, and the most important of all the reservoir operation.

The original reservoir elevation-area-capacity curve at a dam site can be prepared from the existing topographical maps. The incremental volume between any two contour elevations and live capacity of the reservoir is calculated using the formula,

$$\Delta V_i = \Delta h(A_i + A_{i+1} + \sqrt{A_i A_{i+1}})/3$$

$$V_i = \sum_{k=1}^i \Delta V_k$$

$$Y_a = \sum_{i=1}^{N-1} \Delta V_i$$

Where

ΔV_i = Volume between contour elevations i and $i+1$, Δh = Contour interval, A_i = Area at contour elevation i , A_{i+1} = Area at contour elevation $i+1$, Y_a = Live capacity of reservoir, and N = Number of contour elevations.

2.10 Previous studies performed in Estimation of Reservoir Sediment by using satellite Remote Sensing

The use of Remote sensing approach to determine the amount of sediment deposition in the live storage zone of the reservoir is time saving and cost effective approach than the other method it is also mentioned by previous research work.

2.10.1 Assessment of Sedimentation in Gilgel Gibe 1 Reservoir, Ethiopia

The higher sedimentation rate obtained using remote sensing data can be explained on the basis of accuracy in the determination of water spread area and the mixing of water pixels with the land around the periphery of the reservoir. The application of remote sensing techniques for estimating

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the sedimentation rate in the Gibe 1 reservoir shows that the average sedimentation rate for 27 years (1990-2017GC) is $0.675 \text{ Mm}^3/\text{year}$, whereas ground observations through hydrographic survey provided a sedimentation rate of $0.845 \text{ Mm}^3/\text{year}$ for the period of (1990-2017GC).

The comparison of the result from the two different approach showed that the estimated deposition rate ranged $0.675\text{-}0.845 \text{ Mm}^3/\text{year}$. For the subsequent prediction of the reservoir deposition, a mean value of 0.17 taking into consideration a safety factor 0.2 for predicting the reservoir sedimentation empirical area reduction method can be used. This study is applied only once in 27 years, it should be applied with in some interval.

Sedimentation results for 2017GC from remote sensing techniques that are comparable with 1990GC hydrographic survey further confirms the applicability of remote sensing for sedimentation analysis for medium reservoirs. Reservoir play an important role for the generation of power, and should be regularly monitored for sedimentation to ensure that corrective measures are taken in time. The results also show that sedimentation rates in Gibe 1 reservoir are comparable with sedimentation rates recorded within the country and region. Corrective measures have to be put in place to ensure that the useful life of reservoir in not compromised in the near future.

2.10.2 Assessment of Reservoir Sedimentation Using Remote Sensing Satellite Imageries for Srisailam Reservoir, India.

This paper describes assessment of sedimentation carried out for the Srisailam Reservoir using Remote Sensing satellite imageries. The area capacity curve of year the 1976GC, when actual impoundment was started, is used as a base for sedimentation assessment for the year 2004. The results of Remote Sensing survey for the period 2001-04 are compared with the deposition pattern of Srisailam Reservoir with the standard types of deposition pattern as per Area Reduction Method suggested by Borland and Miller. The sediment index computed considering total sediment deposition since 1976 to 2004 comes to around $543.84 \text{ t/m}^2/\text{year}$ which is lower than the rates suggested by Garde & Kothari.

The comparison of deposition pattern of Srisailam Reservoir with the standard types of deposition pattern suggested by Borland and Miller indicated that the sediment deposition pattern in Srisailam Reservoir also followed Type-I in 2004. The data indicates that a definite relationship exists between the reservoir shape and the percentage of sediment accumulated in various depths since its impoundment.

2.10.3 Sedimentation Study In A Reservoir Using Remote Sensing Technique for Vaigai Reservoir, India.

The present study describes the evaluation of sedimentation carried out for Vaigai reservoir situated in Tamil Nadu, India. Vaigai reservoir nourishes the inhabitants through water storage and

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supply for irrigation and water power. Nowadays, capacity loss occurs in the reservoir due to sedimentation. As it is highly tedious and uneconomical to do hydrographic surveys, the frequentness in finding the sediment yield becomes impossible. But the recent application of remote sensing and GIS technologies in the field of Civil Engineering make it possible. The Satellite Remote Sensing (SRS) method for prediction of reservoir sedimentation uses directly the water-spread area of the reservoir at a particular elevation on the date of pass of the satellite. With known area and the difference in level of water, the capacity and thereby the loss in capacity of the reservoir due to sedimentation can also be estimated. This paper illustrates the prediction of sedimentation at Vaigai reservoir using remote sensing and ArcGIS.

The net sediment deposition of the reservoir from the year of inception (i.e) 1958 to 2012 is 32.164 Mm³ . It is clear that for various elevations, there is change in capacity for different years. Therefore it is understood that definite relationship exists between reservoir shape and the sediment accumulation at various depths since its impoundment. As per the present study, average annual silting rate of vaigai reservoir is increasing day by day and it is 16.512% in 2012. High sedimentation rates were observed where there is steep slope and high rain fall which indicates that sedimentation rate is highly dependent on slope factor and rain fall intensity. If desilting is proposed the approximate cost will be Rs.238 crores whereas for the construction of new dam, the cost will be Rs.1460 crores. So, the cost of desilting is only 16.20% of the cost of construction of new dam. Hence, to reduce soil erosion, urban development authorities must take environmental preservation measures into account.

2.10.4 Estimation of Sedimentation Rate of a Reservoir using Remote Sensing Data: a case study of Tehri Reservoir, India.

Due to sedimentation in the reservoir, the elevation (stage) changes with time and with it the water spread area of a reservoir also changes. An adaptive technique was applied for extracting of water-spread area of the reservoir at any particular elevation by using multi dated satellite imageries (LANDSAT5 TM) and SRTM DEM. This facilitates to estimate sedimentation over a period of time. The revised capacity of the reservoir between maximum and minimum levels was computed using the trapezoidal formula.

The application of remote sensing techniques for estimating the sedimentation rate in the Tehri Reservoir, built on Bhagirathi River in the Himalayas in the state of Uttarakhand, led to the result that the average sedimentation rate for 5 years (2006-2011GC) (from the date of commissioning of the dam, 2006GC till the date of study, 2011GC) is 11.02 Mm³ year⁻¹. However, there are some limitations in the estimation of results by remote sensing method. In this study, remote sensing techniques give the information on the capacities only in the water elevation fluctuation zone, which generally lies in the live zone of the reservoir, and hence the sedimentation gradient in live zone can only be calculated. Below this, in the dead load zone, the information on the capacity reduction due to sedimentation could be taken from the hydrographic survey conducted at the dam

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site, as the scope of estimation of sedimentation using satellite imagery is restricted only to water fluctuation zones. This method is widely accepted for reservoir sedimentation rate, so the result of the study is also accepted.

2.10.5 Assessment of reservoir sedimentation using remote sensing and recommendations for desilting Patratu Reservoir, India.

The sedimentation assessment was carried out using satellite data and reservoir water level data from 2006 to 2012. Water spread area was analyzed from satellite data. The Normalized Difference Water Index (NDWI) has been used to delineate open water features and to enhance the presence of water surface in satellite imagery of the Patratu Reservoir. Water spread area of the reservoir at a particular elevation on the date of the passing of the satellite was used to develop an elevation-area curve.

From the satellite remote sensing survey of Patratu Reservoir, it was found that the live storage capacity of the reservoir was reduced to 89.96 hm³ from 101.95 hm³ showing an 11.76% loss in its original capacity. On the basis of analysis of a SRS survey, the sedimentation rate in the Patratu Reservoir seems to be on the higher side. Moreover in order to get true picture of sediment deposition in the reservoir, an integrated survey by carrying out a hydrographic survey below MDDL and multispectral analysis from MDDL to FRL would be more appropriate. Manual and mechanical digging combined with flushing is recommended for desilting of the Patratu Reservoir.

The study recommends that Satellite-based reservoir sedimentation study of the Patratu Reservoir revealed that the amount of silting which has occurred in the live storage zone is about 12 hm³. It is proposed to de-silt the reservoir by adopting some measures like Mechanical/manual excavation, transportation and dumping of the excavated material to low lying areas downstream of the dam and the distance of transportation shall be about 1 km. It is assumed that 50% of the 12 hm³ silt deposit shall be excavated and transported to the downstream by dumpers. Manual excavation work will provide employment to the local workforce and Mechanical/manual excavation, dredging of the material to deeper portion near sluices (within the reservoir) for hydraulic flushing during flood period. It is assumed that 50% of the 12 hm³ silt deposit shall be excavated and hydraulically flushed through the sluices.

2.10.6 Assessment of Reservoir Sedimentation using RS and GIS techniques - A case study of Kabini Reservoir, Karnataka, India.

This study illustrates the assessment of reservoir sedimentation using RS and GIS. The area capacity curve of the year 1974 (impoundment) is now used as a base for sedimentation assessment for the year 2013-14. This will help us to evaluate sedimentation over a period of time. In this study, digital processing is carried out using the ERDAS image processing software. The Normalized Difference Water Index has been used to delineate open water features and to improve the presence of water surface in satellite imagery of the Kabini Reservoir. The water spread area

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of the reservoir at a particular elevation on the date of the passing of the satellite is used to develop an elevation-area curve. Then a linear interpolation/ extrapolation technique has been used to estimate the water spread area of the Kabini Reservoir at various elevations. Further, these areas were used to compute the live storage capacity of the reservoir between two elevations by using the Prizmoidal formula.

SRS survey could be done for the available imageries of the live storage zone only which covers only 49.75% part of Gross storage while 50.25% part remained not assessed. Thus giving sedimentation rate for whole storage on the basis of analysis of 49.75 % volume will not be appropriate, Therefore It would be appropriate if hydrographic surveys are conducted at longer intervals and the remote sensing based sedimentation surveys are carried out at shorter intervals, so as to give more accurate sedimentation deposition volume and rate with an integrated system. The revised capacity of the reservoir is then compared with the original capacity of the year 1974 so as to give the loss in capacity from 1974 to 2014 i.e. in 40years. It was found that the capacity was reduced to 552.64Mm³ from 523.928Mm³ showing 5.20 % of loss in capacity of the total gross storage in 40 years. The rate of sedimentation was estimated as 0.718Mm³year⁻¹ considering total catchments of 2142 km².

2.10.7 Assessment of Reservoir Sedimentation in Chhattisgarh State Using Remote Sensing and GIS, India.

GIS & Remote sensing technique is used in present work to compute the loss of storage capacity and sedimentation in Murrumsilli reservoir situated in dhamtari district, Chhattisgarh state, India. The ten images have been geo-referenced by using Survey of India topo-sheets so that they can be superimposed and associate with the latitude and longitude and the geographical area also can be found out directly in sq. m. After geo-referencing, ten images have been slice to small sizes to display the water spread area of the reservoir and its surroundings. The visible region of the spectrum (0.4-0.7 urn) shows the transmittance of water significant and the absorption and reflectance are low. The absorption of water swift in the near-IR band, where both the reflectance and transmittance will low. The normalized difference water index (NDWI) has been used to identify the water pixels in the images. Several scenes of Linear Image Self Scanning (LISS III) digital data of Indian Remote Sensing (IRS) satellite IRS-1D/P6 have been imported and normalized difference water index (NDWI), image rationing and slicing techniques have been implemented to detect the water and non-water pixels from the images using Integrated Land and Water Information System 3.0 (ILWIS 3.0), a GIS software. The revised water spread area at various elevations has been computed which will provides the revised capacity of the reservoir. Using revised water spread areas, the revised cumulative capacity and percentage loss in gross storage at different levels have been computed.. Final results obtained by study shows that in Murrumsilli reservoir total deposition of sedimentation is found to be 29.956 MCM and percentage loss of capacity is equals to 18.37 % from 1923 to 2015. It also shows that rate of sediment deposit are about 0.32 MCM/year.

2.10.8 Sedimentation Study of Hirakud Reservoir through Remote Sensing Techniques

Any reduction in water spread area at a specified elevation over a time period is indicative of sediment deposition at this level. Raw digital satellite data contain geometric distortions due to instability of the satellite platforms, altitude & attitude variations and earth rotation. In order for remote sensing data to be useful for resource and environmental users it must be having same scale and projection properties as that of a map. Registration is the related technique of geometric correction in which coordinates of the image can be transformed according to the referenced topographic map so that image and map has the same scale and projection properties. This when integrated over a range of water stages helps in computing volume of storage lost through sedimentation.

This study relates to estimation of capacity loss due to sedimentation of Hirakud reservoir, located in Orissa, India. Satellite data of 5 optimal dates corresponding to various water stages from minimum to maximum draw down levels were used in estimating the water spread areas. Simple ratioed (NIR/RED) image were generated to identify the water pixels and then verifying the standard FCC. The non-water pixels were then identified with the ratioed (GREEN/NIR) image and removed to have the total water spread. The water spread area on different satellite overpass dates and corresponding elevations were then used to find the total reservoir storage capacity with the help of Elevation area curve. After determination of reservoir water spread for different data sets, the elevations corresponding to the satellite over pass dates are determined. The Reservoir Level Monitoring System provides this data over NICNET (Mehta, 2000).

The Reservoir capacity between two successive elevations were calculated using the cone formula (Murthy, 1968). Dead, live and gross storage capacities from 1957 to 1989 is observed that the annual rate of capacity loss from the year 1957 to 1982 is 59.15 M.Cu.m., 1957 to 1986 is 51.39 and 1957 to 1989 is 61.05 M.Cu.m. since the year of impoundment in 1957 to 1989, the year of SRS survey. The capacity loss of 1953.70 M.Cu.m.(24.10 percent) from 1957 to 1989. Annual rate of siltation is found to be 61.05 M.Cu.m, since impoundment of reservoir in 1957 to 1989. The project had been carried out in 1999. However, in view of excellent results obtained through this approach, the exercise may be replaced with the latest satellite data.

2.10.9 Assessment of sedimentation in Pong and Bhakra reservoirs in Himachal Pradesh, India, using geospatial technique

In this study, a remote sensing data based digital image processing technique was used to assess the sedimentation in Pong and Bhakra reservoirs, located in foothill of Western Himalayas, India. Seven dates of IRS-(P6) LISS-III satellite data from maximum to minimum reservoir level were used to assess temporal and spatial patterns of reservoirs. Geometric and radiometric correction. The identification of the water pixels in terms of water spread area by using a band rationing technique was performed with the help of ERDAS IMAGIN 9.3 software . Since the size of each scene was very large, the reservoir area and its surrounding was separated out from the full scene

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of all the imageries. This was done through a utility tool named area of interest (AOI). The water spread areas of the reservoirs were assessed by using a band rationing technique i.e. Normalized Difference Water Index (NDWI). Furthermore, the revised capacities of the reservoirs between minimum and maximum levels were computed using the trapezoidal formula.

From the analysis, it has been observed that the live storage capacity of Pong Reservoir, due to sedimentation, was estimated as 632.84 Mm³ in last 35 years (1974–2009), whereas it was determined as 802.34 Mm³ for Bhakra reservoir in the span of 46 years (1963–2009). Further, the sedimentation rate in the Pong reservoir was calculated as 18.08 Mm³/year, while for the Bhakra reservoir it was 17.46 Mm³/year. These sedimentation rates are comparable with the hydrographic survey analysis. In order to determine the useful life of a reservoir, it is essential to periodically assess sedimentation rate and volume in the reservoir. To sustain the reservoir's capacity, the precise knowledge of the sedimentation processes, sources of sedimentation and causes of soil erosion in the catchment is essential. The remedial measures can be undertaken well in advance; and reservoir operation schedules can be planned for optimum utilization of water. However, there are some limitations in the remote sensing based approach, i.e. remote sensing technique gives the information of the capacities only in the water level fluctuation zone, which generally lies in the live zone of the reservoir. Below this zone, i.e. in the dead load zone, the information of the capacity could be taken only from the most recently conducted hydrographic survey.

2.10.10 Reservoir Sedimentation Assessment Through Remote Sensing and Hydrological Modelling, Jayakwadi Reservoir.

This study assessed Jayakwadi reservoir sedimentation using Landsat 8 OLI satellite data combined with ancillary data. Multi-date remotely sensed data were used to produce the water spread area of the reservoir, which was applied to compute the sedimentation rate. The revised live storage capacity of the reservoir between maximum and minimum levels observed under the period of analysis (2015–2017) was assessed utilizing the trapezoidal formula.

The revised live storage capacity is assessed as 1942.258 against the designed capacity of 2170.935 Mm³ at full reservoir level. The total loss of reservoir capacity due to the sediment deposition during the period of 41 years (1975–2017) was estimated as 228.677 Mm³ (10.53%) which provided the average sedimentation rate of 5.58 Mm³ year⁻¹. As this technique also provides the capacity of the reservoir at the different elevation on the date of the satellite pass, the revised elevation–capacity curve was also developed. The sedimentation analysis usually provides the volume of sediment deposited and rate of the deposition. However, the interest of the reservoir authorities and water resources planner's lies in sub-watershed-wise sediment yield, and the critical sub-watersheds upstream reservoir requires conservation, etc. Therefore, in the present study, Soil and Water Assessment Tool (SWAT) was used for the estimation of sediment yield of the reservoir. The average annual sediment yield obtained from the SWAT model using 36 years of data (1979–2014) was 13.144 Mm³ year⁻¹ with the density of the soil (loamy and clay) of

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1.44 ton m⁻³. The findings revealed that the rate of sedimentation obtained from the remote sensing-based methods is in agreement with the results of the hydrographic survey.

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3. MATERIALS AND METHODS

3.1 Description of Study Area

3.1.1 Location

The Legedadi reservoir, located in east of Addis Ababa about 25 km, was constructed in 1967Gc. The purpose of the reservoir was to supply drinking water for the city of Addis Ababa. In 1999 Dire dam, with a capacity of 19 MCM, was commissioned to supplement water supply by Legedadi reservoir in order to meet the increasing water demand of the city. According to 2010 GC study the inflow average annual sediment rate is 183,000 m³/year. The reservoir catchment area exists in Oromia Regional State under the administration of North-Western Shoa Zone in Aleltu Bereh district administration, Sendafa town. The catchment area has a total area of 234 km² and the catchment is bounded by latitude 9° 01' N – 9° 13' N and longitude 38° 60' E - 39° 07' E. Legedadi dam is administered by Addis Ababa Water and Sewerage Authority.

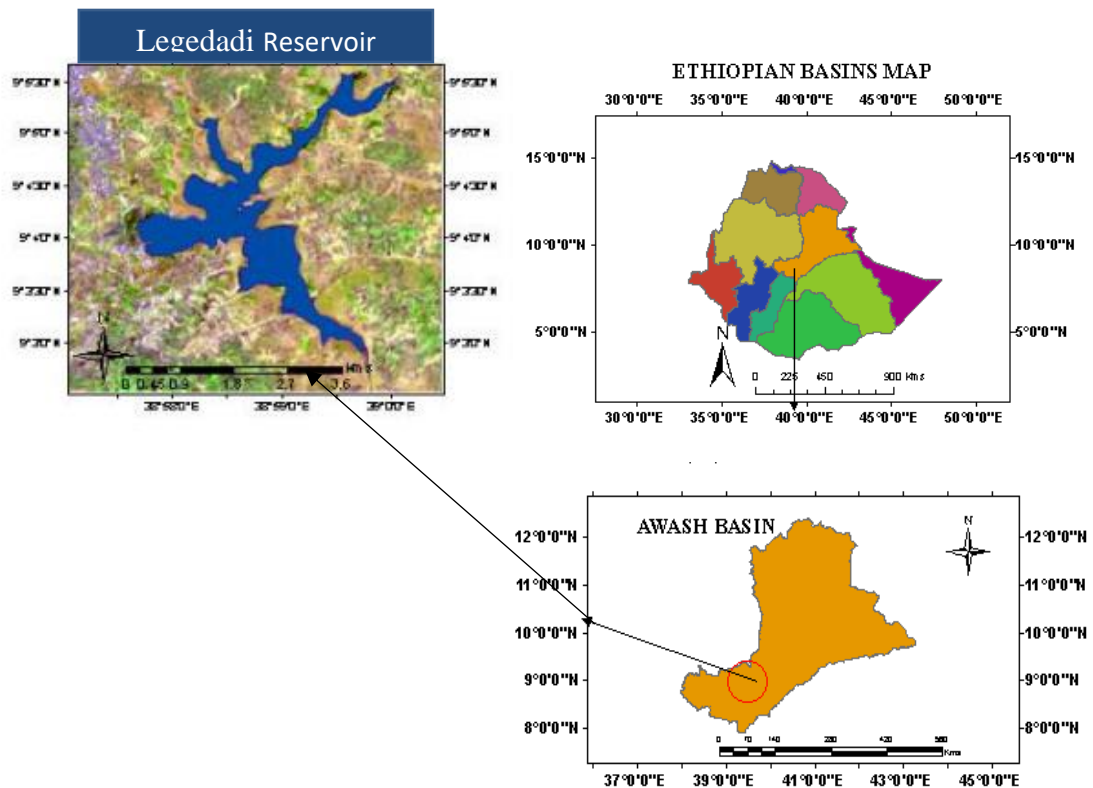


Figure 3.1 study area location Map

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3.2 Data Type

3.2.1 Topographical Data

The topographical map is needed for to avoid any geometrical distortion in the satellite imageries and its prepared by using Surfer software to start the process with satellite imageries. In this study, the satellite imageries were georeferenced and geometrically corrected by Ground Control Point (GCP), in UTM Adindan Zone 37 N WGS 84 in the system because all images are level 1 Landsat 7 and 8. The prepared topographic map is shown below

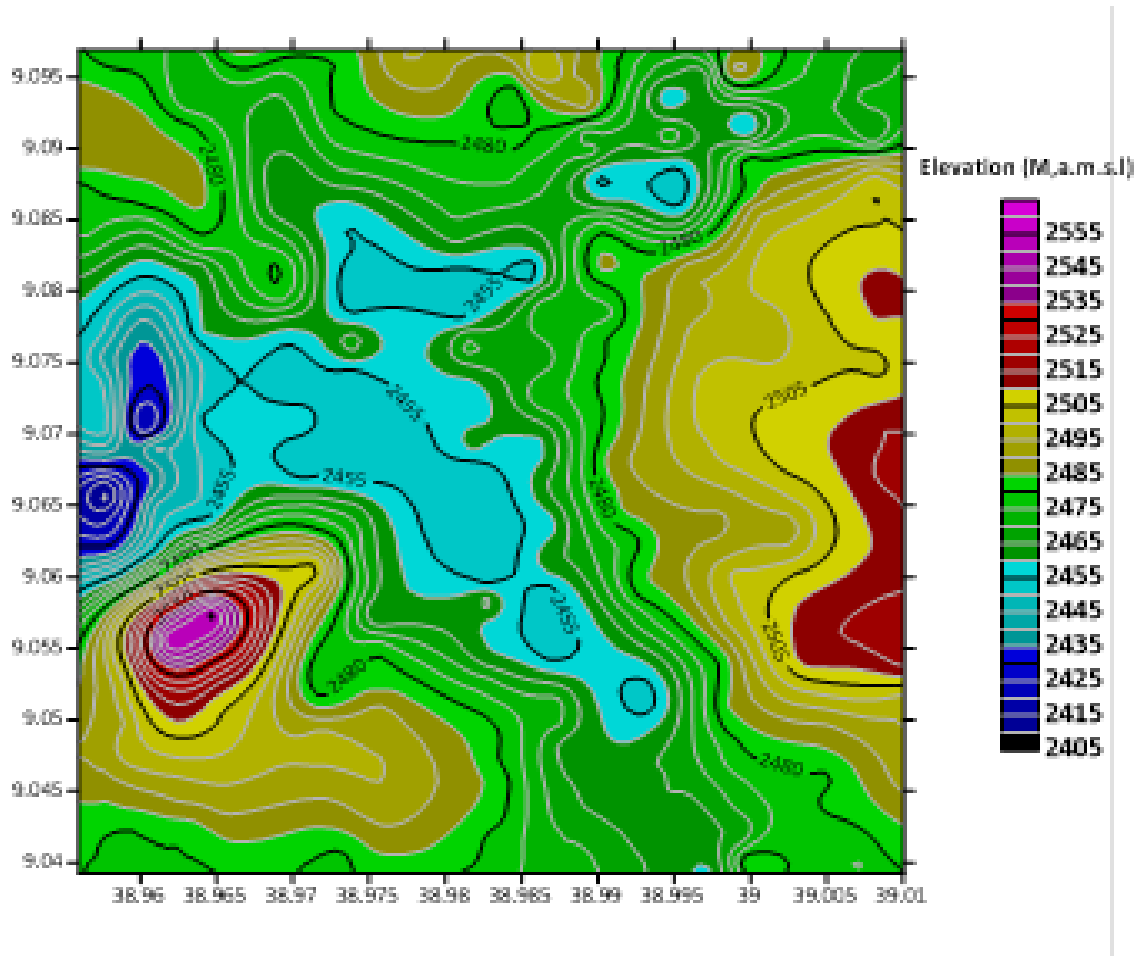


Figure 3.2 Topographic Map of Legedadi Reservoir

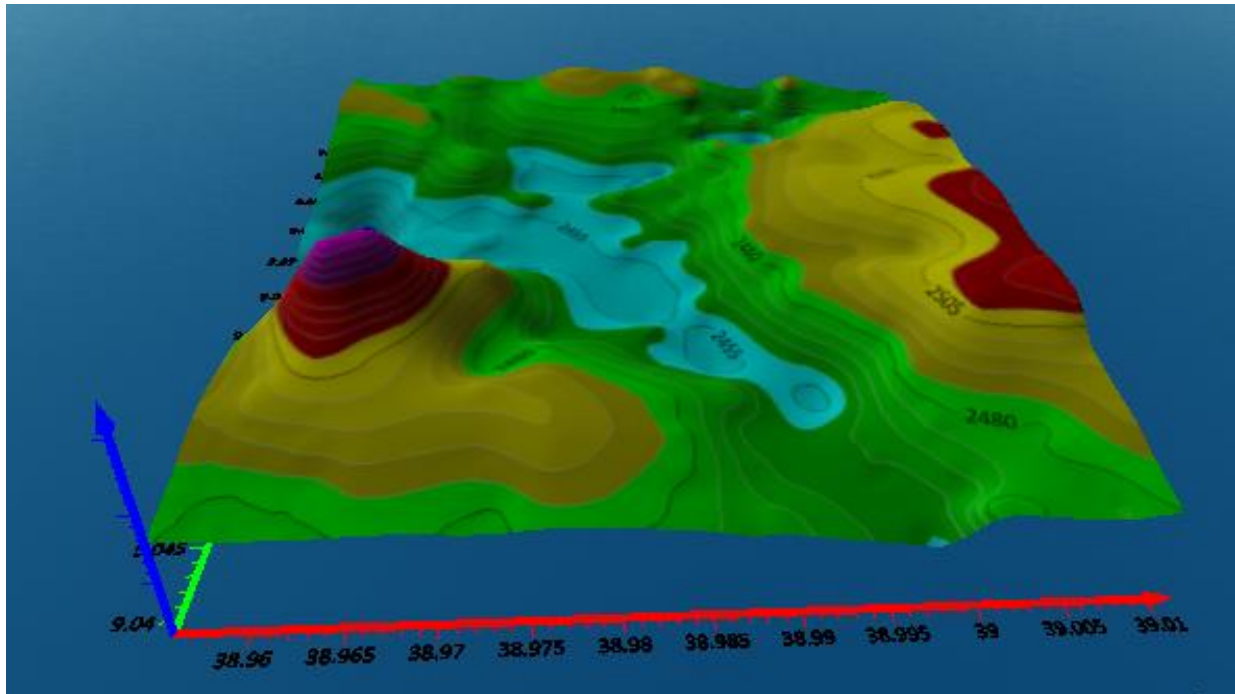


Figure 3.3 3 D Map of Legedadi Reservoir

3.2.2 Field Data

Daily observed water level (Elevation) data for Legedadi Dam reservoir, Taken from Addis Ababa Water and Sewerage Authority. For a specific period of 2003 Gc to 2018/19 GC And the 2010 Gc Elevation-Area-Capacity data is taken from the institute (AAWSA).

3.2.3 Satellite data

The useful information taken from remote sensing data is the water spread area at different dates of the satellite pass over the reservoir area. The selection of suitable periods for a study is a vital step in the estimation of reservoir sedimentation using satellite remote sensing data. Therefore, it is recommended to use the remote sensing data of such a period when there is maximum variation in the elevation of the reservoir water surface and accordingly, the water spread area. for this study, cloud-free images were available for six consecutive months from 2003 to 2019 GC.

3.3 Methodology

The water level in a reservoir is likely to be near the full reservoir level (FRL) by the end of the monsoon season (September/October) before it gradually depletes to lower levels towards the end of the drawdown cycle (May/June). Due to deposition of sediments in the reservoir, the water-spread area at an elevation keeps on decreasing. Using the remote sensing approach, the water-spread area can be determined at different reservoir levels and a revised elevation-capacity curve can be prepared. By comparing the original and revised elevation-capacity curves, the amount of capacity lost to sedimentation can be assessed.

For the Estimations of the volume of sediments deposited in the reservoir, the basic information taken from the satellite data is the water spread area of the reservoir at different water surface elevations to be compared with the 1979 GC reservoir area. With the deposition of sediments in the reservoir, the water spread area at any elevation gradually keeps on decreasing due to sedimentation deposited in the reservoir. Greater depositions of sediments at an elevation cause a greater decrease in the area of water spread or reservoir. Revised contour areas, after the deposition of sediments, can be taken as the continuous water-spread area of the reservoir having an elevation of water surface in the reservoir at the time of satellite pass.

3.3.1 Digital Image Processing

- **Layer Stacking and Radiometric correction**

Accurate geometry ensures that Land data pixels are aligned and the data can be used easily in time series analysis. Landsat Level-1 data products were georeferenced and geometrically corrected by Ground Control Point (GCP), in UTM Adindan Zone 37 N WGS 84 in the system. After the above task is done in the system, needs to carry-out layer stacking of all imageries/bands. Radiometric correction is done to calibrate the pixel values and/ correct for errors in the values. The process improves the interpretability and quality of remote sensed data. This task is done by ENVI 5.3 Software package.

Estimation of Reservoir Sediment

- **Atmospheric correction**

Is the process of removing the effects of the atmosphere on the reflectance values of images taken by satellite or airborne sensors. Atmospheric effects in optical remote sensing are significant and complex, dramatically changing the spectral nature of the radiation reaching the remote sensor. In this study atmospheric correction is done by using FLAASH method instead of DOS approach due to the accuracy of the methods.

- **Sub-setting and Enhancement**

To extract, clip or cut only a part from the entire image needs to be displayed or processed to convey the information or to represent the whole.

Therefore, it becomes necessary to extract the area of interest from the images. This task is done with in ENVI_ Resize option by using the reservoir coordinates.

3.3.2 Software's used in this study

This section includes different software and interfaces with their purposes and sources.

The listed software and interface in these sections were played a great role in this thesis based on their importance, purpose, and availability.

Table 3.1 Software's used in this Study

Name	Purpose	Source
ENVI/IDL 5.3	To make corrections To extract water body To prepare thematic map	Getintopc/premium package
GIS 10.5	To prepare location map To determine water spread area	Getintopc/premium package
Get Data Graph Digitizer	To get numerical data from graph	Student version
Surfer Golden 2018	To prepare Topographical Map	Getintopc/premium package

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Microsoft Word 2016	For documentation	Getintopc/premium package
Microsoft Excel 2016	To prepare graphs and tables	Getintopc/premium package

3.4 Methods

The useful Life of reservoir can be determined by estimating rate of sedimentation which ultimately reduces the storage capacity of reservoir. This capacity loss of reservoir will affect adversely the planning for long term utilization of storage of reservoir for irrigation, urban water supply and flood mitigation. Some of methods presently in use for estimation/ prediction of sediment deposition in reservoir are:

- Stream measurements (sediment rating curve)
- hydrographic surveys
- Empirical methods
- Mathematical models
- Satellite Remote Sensing

❖ **Sediment rating curve** describes the average relation between water discharge and suspended sediment concentration. A relationship between discharge and concentration can be developed which, although exhibiting scatter, will allow the mean sediment yield to be determined on the basis of discharge history (Morris & Fan, 1998).

❖ **Hydrographic Surveys** are Surveys of sediment deposition rate in reservoirs can give accurate estimate of sediment yield from upstream the reservoir if trap efficiency is known. Considering reservoir sediment problem, reservoir surveys are necessary to get more realistic data regarding the rate of siltation to provide reliable criteria for studying the implications of annual loss of storage over a definite period of time.

Estimation of Reservoir Sediment

- ❖ **Mathematical Models** are Mathematical analysis of sedimentation transients is based on the premise that the dynamic action of flow acting through sediment transport is the driving force and sediment deposit (or scour) takes place due to the spatial variations in the transport rate.
- ❖ **Satellite Remote Sensing (SRS)** technique offers data acquisition over a long time period and for a broad spectral range which can be considered superior to conventional methods of data acquisition. Spatial, spectral and temporal attributes of Remote Sensing data provide invaluable and timely synoptic information regarding changes in water spread area of reservoir after deposition of sediments over a period of time at particular elevation and hence by comparing the revised storage capacity at different date of satellite pass at various elevations with the original storage capacity at year of impoundment, the reservoir capacity loss can be estimated using satellite data.

Using the Landsat 7 and 8 level 1 satellite data and the image interpretation techniques, the water spread area of the reservoir at the instant of the satellite overpass can be determined. The water surface elevation in the reservoir corresponding to the date of imagery and the time of satellite pass can be obtained from AAWSA. In this way, the revised contour areas at different elevations can be calculated and the revised elevation- area curve can be prepared.

The reduction in reservoir capacity between consecutive contour levels can be computed using the Simpson 1/3 rule or prismoidal formula. The overall reduction in capacity between the lowest and the highest observed water levels can be obtained by adding the reduced capacity at all levels. It is important to mention here that the number of sediment deposits below the lowest observed water level cannot be determined using remote sensing techniques. A survey for the area within the lowest observed water spread area can be carried out. It is also important to emphasize here that for the optimum and careful operation of the reservoir, the zone of interest of sedimentation analysis is only the live storage of the reservoir. Since the reservoir hardly goes below the minimum draw-down level; the interest mainly lies in knowing the loss of capacity and the pattern of sediment deposition within the live storage.

3.4.1 Import and visualization (Band combination)

The data of Landsat 7 ETM+ and Landsat 8 TIRS OLI images for the year 2003 GC to 2019 GC for some interval were downloaded from the USGS Earth Explorer platform. The data were processed and analyzed using ENVI/IDL 5.3 software package. Before all the combination is applied the layer stacking task is should be applied for the available images. For band combination we have a true color combination and false color combination. For true combination use 4.3.2 for landsat-8 and 3.2.1 for landsat-7. In false color combination use 6.5.4 for landsat-8 and 5.4.3 for landsat-7.

3.4.2 Image Classification

3.4.2.1 Supervised Image Classification

Landsat imagery bands corresponding to the blue, green, red, and near-infrared (NIR) wavelengths of the electromagnetic spectrum were selected and combined into a multiband image using layer stacking in ENVI 5.3 software. The area covering of Legedadai Dam Reservoir and surrounding areas were extracted by masking from the multi-band images using image sub-setting. A false-color composite with a band combination of NIR, Red, and Green in the (Red; Green; Blue) format was adopted prior to image the classification. They adopted false-color composite enhances visualization of vegetation pixels with a red color and water pixels with dark pixels. A supervised maximum likelihood classification algorithm was used for image classification as it had a good separation of water pixels.

3.4.3 Water Spread Area Estimation

By using the ENVI package, the water index method, water pixels will be identified by calculating the band ratio of Green/Near-Infrared for normalized difference water index (NDWI) and Green/Short Wave Infrared for Modified Normalized Water Index (MNDWI) to be very low compared to DN values in the Green band. MNDWI is the most appropriate for water mapping. The water body has strong absorbability and low radiation in the range from visible to infrared wavelengths. The index uses the green and short wave infrared bands of remote sensing images based on phenomena. Values of water bodies are larger than 0. vegetation has much smaller values,

Estimation of Reservoir Sediment

which results in distinguishing vegetation from water bodies easier. Built-up features have positive values between zero and 0.1. therefore, the range of MNDWI is between -1 and 1, the water body pixel value is greater than 0.1.

3.4.3.1 Modified Normalized Difference Water Index

The NDWI is modified by substituting the MIR band for the NIR band to avoid the mixed up water with buildup areas (Xu, 2006). The modified NDWI (MNDWI) can be expressed as follows

$$\text{MNDW} = \frac{\text{Green} - \text{MIR}}{\text{Green} + \text{MIR}}$$

Rewrite as these for to put in the ENVI Software **(float(b2)-float(b5))/(float(b2)+float(b5))**

Where: Green is band 3 for landsat-8 and band 2 for landsat-7.

MIR is a middle infrared band for landsat-8 it is band 6 and for landsat-7 its band 5.

The computation of the MNDWI will produce three results:

Water will have greater positive values than in the NDWI as it absorbs more MIR light than NIR light.

Soil and vegetation will still have negative values as soil reflects MIR light more than NIR light and the vegetation reflects MIR light still more than green light.

Estimation of Reservoir Sediment

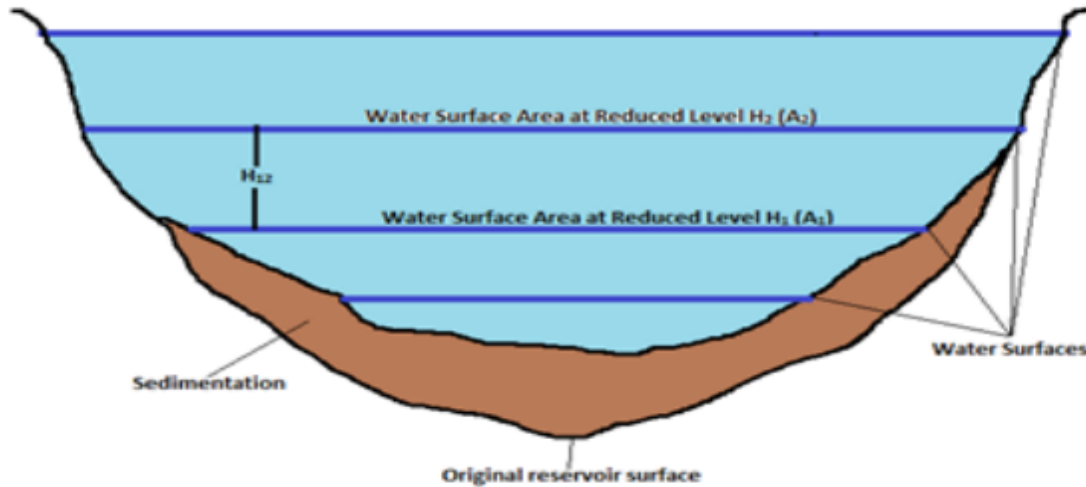


Figure 3.4 Sketch of the reservoir sedimentation and effects on reservoir water surfaces areas.

3.4.4 Calculation of Revised Reservoir Capacity and Sedimentation

The water spread area in each image was calculated in ENVI 5.3 software package and GIS by multiplying the number of water pixels and one-pixel area (30×30). Isolated water pixels noted around the reservoir and along the tributary rivers were not considered to be part of the reservoir this task is done by extracting tool in ENVI package of Resize option with the coordinate of the reservoir area. Reservoir water storage capacity between consecutive levels was calculated using the Prismoidal (Simpsons 1/3 rule) formula. The prismoidal formula was adapted because it was used during the reservoir and design phase to calculate the reservoir capacity and to have similarities during calculation.

$$V_{12} = \frac{H_{12}}{3} (A_1 + A_2 + \sqrt{A_1 * A_2}).$$

Where

V12 is the volume of water present in the dam between two consecutive water levels taken as H1 and H2. H12 is the difference in water levels between consecutive water level H1 and H2. A1 and A2 are spread area at water level H1 and H2 respectively.

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3.4.5 Reservoir Elevation-Area-Capacity Curve

Reservoir elevation-area capacity is important for planning and operation purposes. The 2003/04, 2007/08, 2011/12 and 2018/19 GC reservoir Elevation-Area-Capacity curves for live storage can be prepared from the calculated results of Area and Volume integrated with Elevation data corresponding with the results.

3.4.6 Research Framework

This section includes the whole study framework for Legedadi Dam Reservoir Sediment Estimation. It contains detailed descriptions to represents this study. The step listed in this framework is only representing the general steps that were passed through and did not include minor steps undertaken in methods due to the wideness of the study.

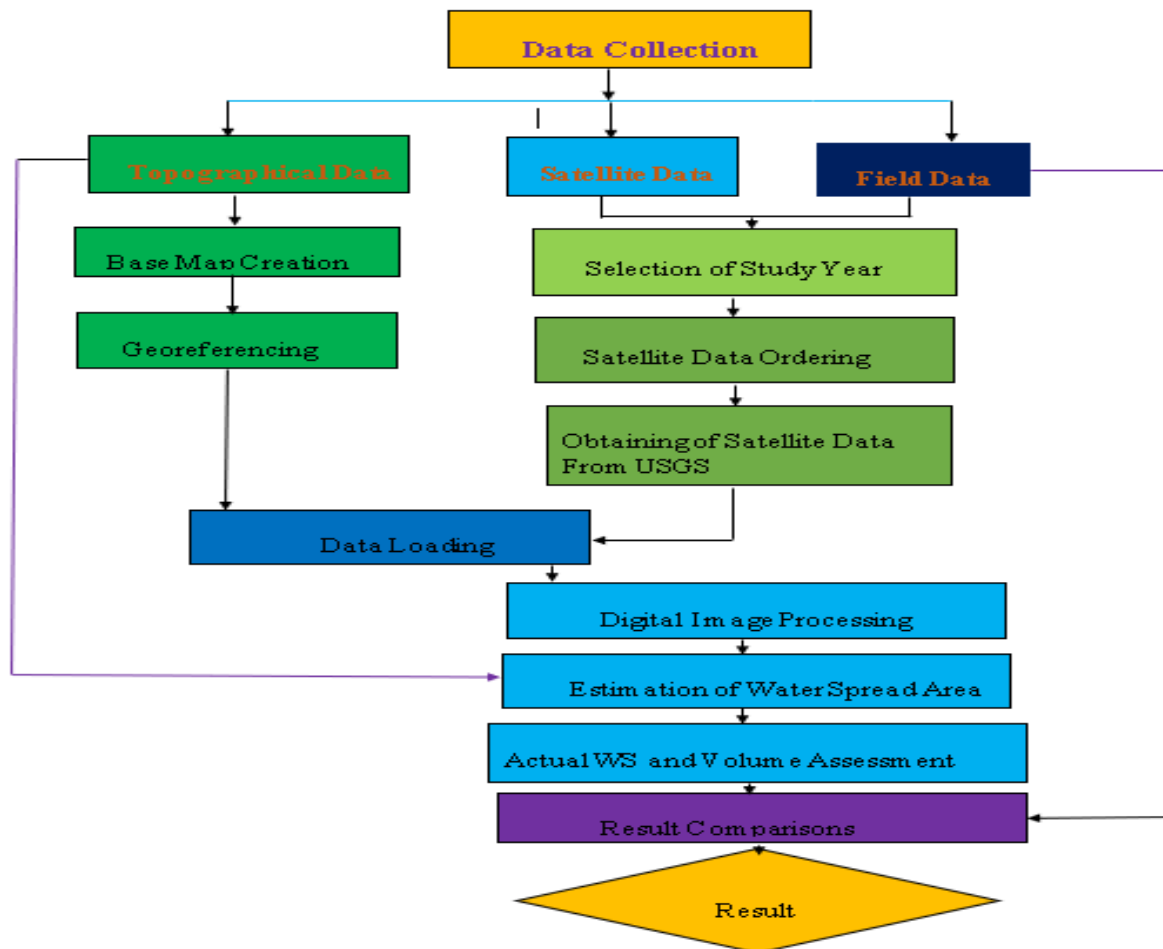


Figure 3. 5 Conceptual Framework of the research

Estimation of Reservoir Sediment

4 RESULT AND DISCUSSION

4.1 Water Spread Area Results

Estimated water spread areas for different dates (dates of satellite pass) of 2003 to 2018/19 GC for some interval year is obtained by digital analysis of satellite data corresponding to different elevations for the available cloud-free satellite imageries are shown below.

By using $(\text{float}(b2)-\text{float}(b5))/(\text{float}(b2)+\text{float}(b5))$ this expression in ENVI (Band Math) package, we can separate the water pixel with that of vegetation and soil pixel value.

Where; b2 = Green band

b5 = SWIR (Short Wave Infrared) or NIR (Near Infrared)

Table 4.1(a) Water Spread Area for Oct 2003 GC at elevation of 2465.60 m,a.m.s.l

OID	Value	Count	Area_km2
▶ 0	1	9459	8.5131
1	2	19686	17.7174
2	3	10813	9.7317
3	4	2061	1.8549
4	5	5845	5.2605

Area = No of water pixel * one pixel Area

$$= 5845 * (30\text{m} * 30\text{m}) / 10^6 = 5.26 \text{ km}^2$$

Table 4.1(b) Water Spread Area for Dec 2003 GC at elevation of 2464.14 m,a.m.s.l

OID	Value	Count	Area_km2
▶ 0	1	18630	16.767
1	2	15949	14.3541
2	3	8683	7.8147
3	5	5001	4.5009

Table 4.1(c) Water Spread Area for Feb 2004 GC at elevation of 2462.64 m,a.m.s.l

OID	Value	Count	Area_km2
▶ 0	1	23137	20.8233
1	2	18828	16.9452
2	3	10952	9.8568
3	4	123	0.1107
4	5	4248	3.8232

Estimation of Reservoir Sediment

Table 4.1 (d) Water Spread Area for May 2004 GC at elevation of 2459.97 m,a.m.s.l

OID	Value	Count	Area_km2
0	1	22502	20.2518
1	2	14787	13.3083
2	3	7062	6.3558
3	4	533	0.4797
4	5	3276	2.9484

Table 4.2 (a) Water Spread Area for 06 Oct 2007 GC at elevation of 2465.90 m,a.m.s.l

OID	Value	Count	Area_km2
0	0	1	0.0009
1	1	23907	21.5163
2	2	23701	21.3309
3	3	3329	2.9961
4	4	371	0.3339
5	5	5979	5.3811

Area = No of water pixel * one pixel Area
 = 5979 * (30m*30m)/ 10⁶ = 5.38 km²

Table 4.2 (b) Water Spread Area for 22 Oct 2007 GC
 at elevation of 2465.55 m,a.m.s.l

OID	Value	Count	Area_km2
0	0	1	0.0009
1	1	17107	15.3963
2	2	25396	22.8564
3	3	9098	8.1882
4	4	69	0.0621
5	5	5617	5.0553

Table 4.2 (c) Water Spread Area for Dec 2007 GC
 at elevation of 2464.50 m,a.m.s.l

OID	Value	Count	Area_km2
0	0	2	0.0018
1	1	20503	18.4527
2	2	20374	18.3366
3	3	10488	9.4392
4	4	798	0.7182
5	5	5123	4.6107

Table 4.2 (d) Water Spread Area for Jan 2008 GC
 at elevation of 2463.76 m,a.m.s.l

OID	Value	Count	Area_km2
0	0	1	0.0009
1	1	29565	26.6085
2	2	22103	19.8927
3	3	1000	0.9
4	5	4619	4.1571

Table 4.2 (e) Water Spread Area for May 2008 GC
 at elevation of 2459.75 m,a.m.s.l

OID	Value	Count	Area_km2
0	1	19163	17.2467
1	2	20028	18.0252
2	3	12497	11.2473
3	4	2595	2.3355
4	5	3005	2.7045

Estimation of Reservoir Sediment

Table 4.3 (a) Water Spread Area for 01 Oct 2011 GC at elevation of 2465.82 m,a.m.s.l

OID	Value	Count	Area_km2
0	0	1	0.0009
1	1	17107	15.3963
2	2	25396	22.8564
3	3	9098	8.1882
4	4	69	0.0621
5	5	5617	5.0553

Area = No of water pixel * one pixel Area

$$= 5617 * (30m*30m)/ 10^6 = 5.06 \text{ km}^2$$

Table 4.3 (b) Water Spread Area for Nov 2011 GC

at elevation of 2465.45 m,a.m.s.l

OID	Value	Count	Area_km2
0	1	20896	18.8064
1	2	20228	18.2052
2	3	10861	9.7749
3	4	3	0.0027
4	5	5300	4.77

Table 4.3 (c) Water Spread Area for Dec 2011 GC

at elevation of 2463.90 m,a.m.s.l

OID	Value	Count	Area_km2
0	0	1	0.0009
1	1	21745	19.5705
2	2	19534	17.5806
3	3	11105	9.9945
4	4	240	0.216
5	5	4663	4.1967

Table 4.3 (d) Water Spread Area for Jan 2012 GC

at elevation of 2463.48 m,a.m.s.l

OID	Value	Count	Area_km2
0	1	20257	18.2313
1	2	20409	18.3681
2	3	11853	10.6677
3	4	229	0.2061
4	5	4540	4.086

Table 4.3 (e) Water Spread Area for Feb 2012 GC

at elevation of 2462.18 m,a.m.s.l

OID	Value	Count	Area_km2
0	1	18948	17.0532
1	2	21991	19.7919
2	3	11993	10.7937
3	4	536	0.4824
4	5	3820	3.438

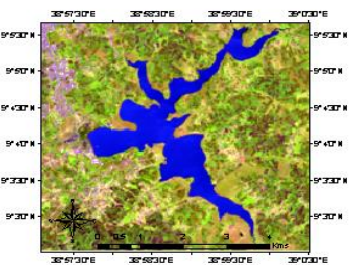
Table 4.3 (f) Water Spread Area for May 2012 GC at elevation of 2457.70 m,a.m.s.l

OID	Value	Count	Area_km2
0	1	24046	21.6414
1	2	20076	18.0684
2	3	10322	9.2898
3	4	682	0.6138
4	5	2162	1.9458

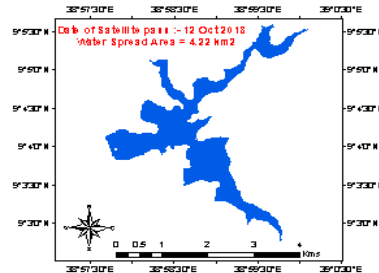
Estimation of Reservoir Sediment

Thematic map of the area is shown below for different period:-

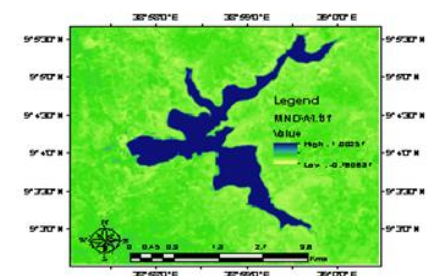
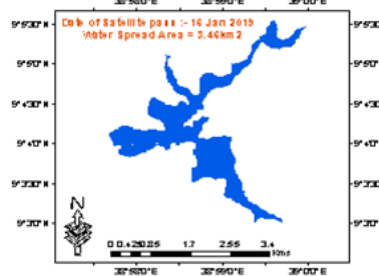
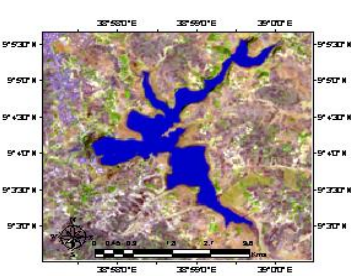
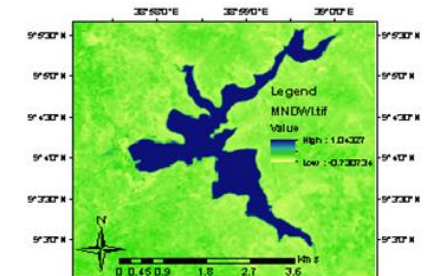
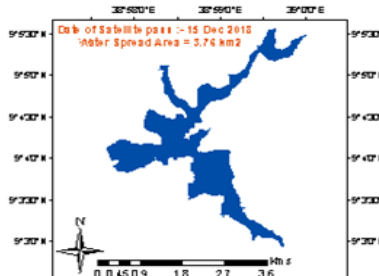
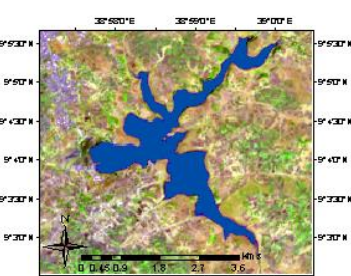
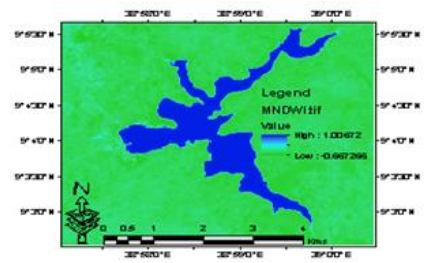
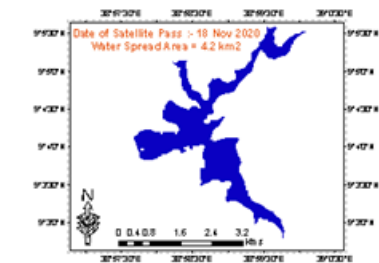
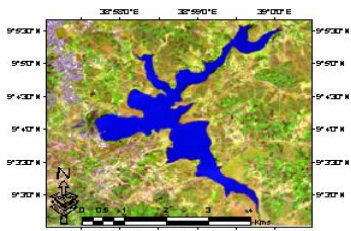
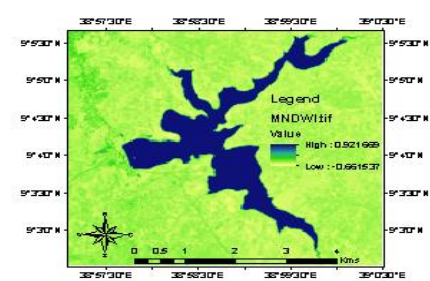
a. False color composite



b. Water Spread Area



c. MNDWI



Estimation of Reservoir Sediment

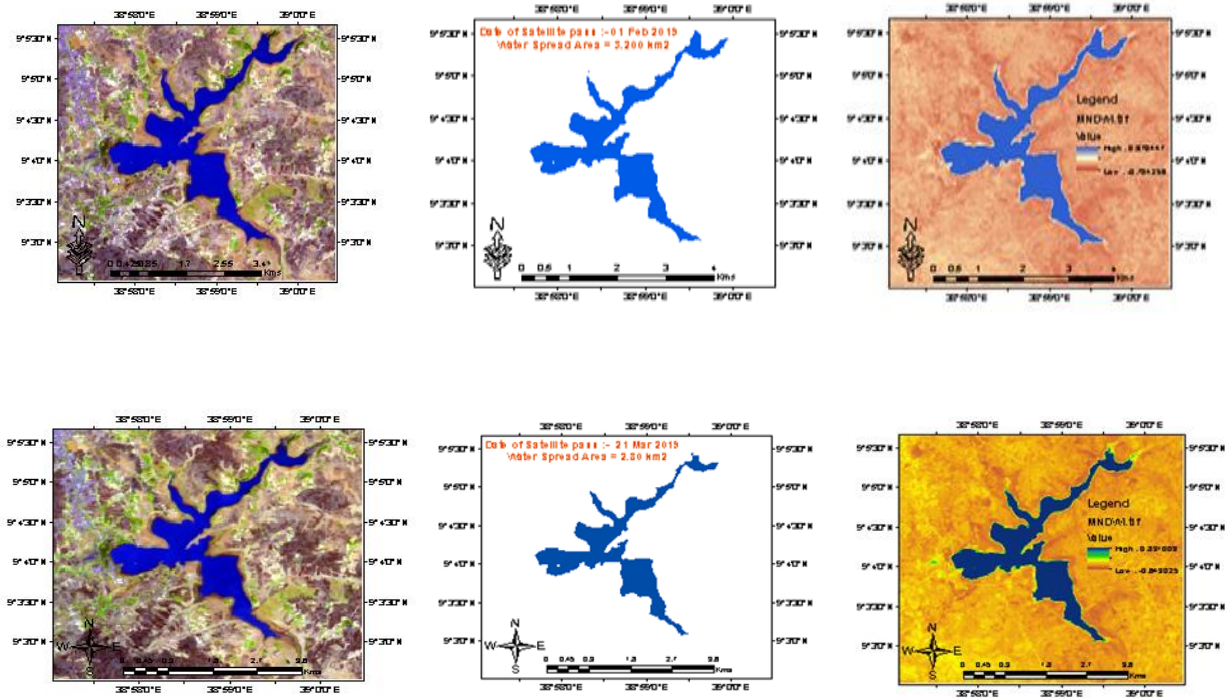


Figure 4.1: (a) False-color composite of Legedadi Reservoir, (b) extracted water spread areas of Legedadi Reservoir, and (c) MNDWI map of Legedadi Reservoir.

4.2 Estimation of Reservoir Capacity For Live Storage Zone

The capacity of the reservoir for different periods estimated by Simpsons 1/3 formula. The calculated result is shown below-

Table 4.4 Calculation of sediment deposition in Legedadi Reservoir using remote sensing for the year (2003/04 GC) in the Live Storage Zone.

Date of Satellite Pass(GC)	Observed WL (m,a.m.s.l)	Cumulative Capacity (Mm3)			Sediment deposition (Mm3) 2003/04
		HS1979	HS 1998	SRS 2003/04	
11- Oct 2003	2465.60	44.70	43.10	41.62	3.08
14-Dec 2003	2464.14	37.50	35.98	34.52	2.98

Estimation of Reservoir Sediment

16-Feb 2004	2462.64	31.21	29.70	28.28	2.93
06- May 2004	2459.97	22.15	20.65	19.27	2.88

The data we need to calculate the capacity is Elevation data corresponding with the satellite passing date (cloud free available images) taken from AAWSA and the area extracted from satellite images. The capacity is determined by using simpsons 1/3 rule formula as shown below:

$$\Delta V_i = \Delta h \left(A_i + A_{i+1} + \sqrt{A_i A_{i+1}} \right) / 3$$

Where

ΔV_i = Volume between contour elevations i and i+1, Δh = Elevation difference, A_i = Area at Contour elevation i, A_{i+1} = Area at contour elevation i+1.

Sample Volume calculation

$$\begin{aligned} V1 &= (2465.60 - 2464.14) * (5.26 \text{ km}^2 - 4.51 \text{ km}^2 + \sqrt{5.26 \times 4.51}) \\ &= 7.10 \text{ Mm}^3 \text{ individual volume between two elevations} \end{aligned}$$

$$V2 = 6.24 \text{ Mm}^3$$

$$V3 = 9.01 \text{ Mm}^3$$

Then the cumulative capacity becomes

According to AAWSA report from 1979 GC to 2010 GC average siltation per year is 0.12 MCM.

For the year 1979 GC to 2003 GC it becomes 24 years x 0.12 = 2.88 MCM Capacity loss,

Therefore the volume become 22.15 – 2.88 = 19.27 MCM in 2003/04 GC at an elevation of 2459.97 m,a.m.s.l.

$$19.27 + 9.01 = 28.28 \text{ Mm}^3$$

$$28.28 + 6.24 = 34.52 \text{ Mm}^3$$

$$34.52 + 7.10 = 41.62 \text{ Mm}^3$$

Estimation of Reservoir Sediment

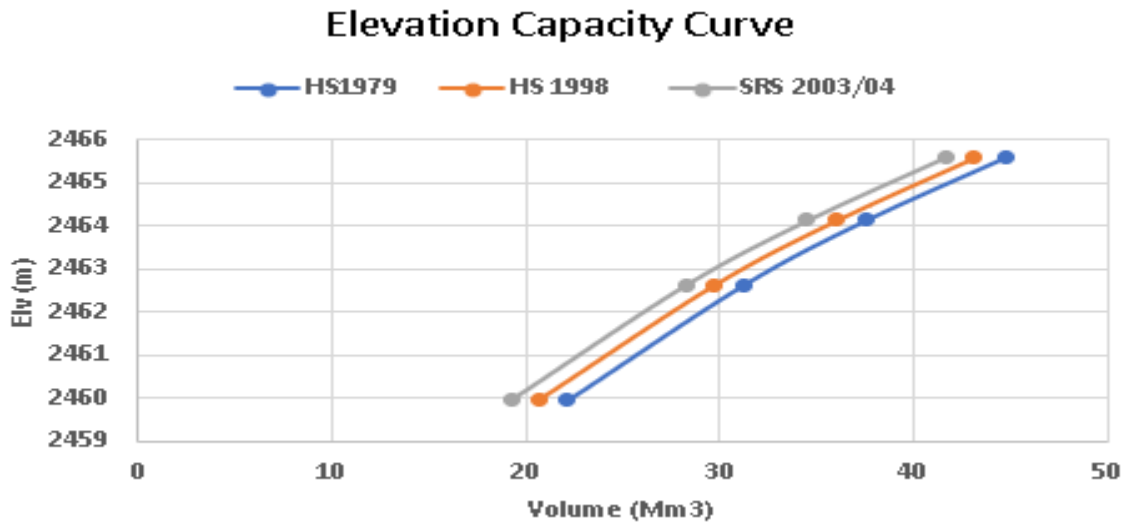


Figure 4.2 Reservoir Elevation Capacity curve for the year in Live Storage Zone.

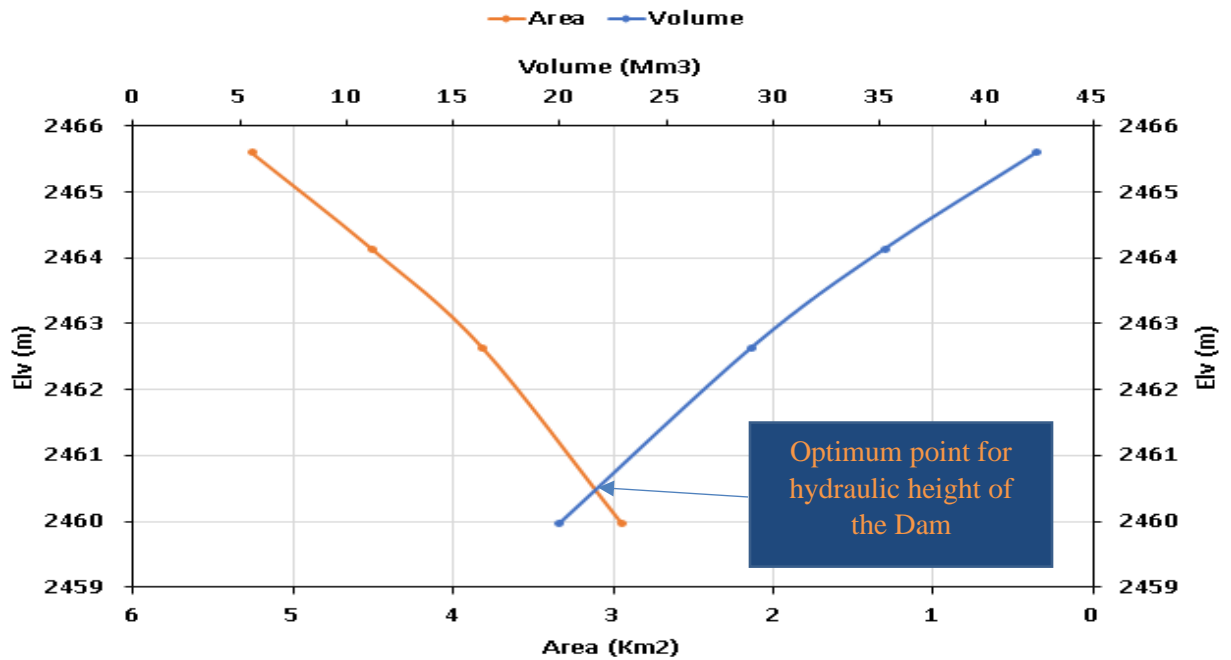


Figure 4.3 Reservoir Elevation-Area-Capacity curve for the year 2003/04 GC in Live Storage Zone.

Estimation of Reservoir Sediment

The water spread area of the Legedadi Reservoir was calculated using satellite data and the volume is calculated by using the Prismoidal formula, the revised capacity between the maximum (2465.60 m a.m.s.l) and minimum (2459.97m a.m.s.l) observed levels were obtained.

The difference between the 1979 Gc study by BCEOM and (2003/04) SRS result, estimated cumulative capacity represented the loss of capacity due to sedimentation in the live storage zone of the reservoir. The 2003/04 GC capacity was estimated by using Trapezoidal formula is **41.62 Mm³** at an elevation of 2465.60 m,a.m.s.l. to get the loss in capacity deduct the 2003/04 capacity from 1979 Gc capacity at the elevation of 2465.60 m,a.m.s.l. (**44.7 Mm³**) it becomes **3.08 Mm³** it indicates that the sediment deposition between an elevation of 2465.60 and 2459.97 m,a.m.s.l from 1979 Gc to 2003/04 Gc.

The comparative Elevation-Area-Capacity curves for the above periods are shown in the above figure. Based on the SRS survey the annual sedimentation rate (The loss in live storage capacity) for a given period and elevation is 3.08 Mm³ / 25 years, it becomes **0.123 Mm³/year** for the available satellite imageries. The zone of interest of sedimentation analysis from the operation point of view is the live storage.

Table 4.5 Calculation of sediment deposition in Legedadi Reservoir using remote sensing for the year (2007/08 GC) in the Live Storage Zone.

Date of Satellite Pass(GC)	Observed WL (m,a.m.s.l)	Cumulative Capacity (Mm3)			Sediment deposition (Mm3) 2007/08
		HS 1979	HS 1998	SRS 2007/08	
06-Oct 2007	2465.90	45.71	43.92	42.032	3.68
22-Oct 2007	2465.55	43.86	42.29	40.21	3.65
09-Dec 2007	2464.50	38.70	37.17	35.13	3.57
10-Jan 2008	2463.76	35.40	33.90	31.89	3.51
14- Mar 2008	2461.92	28.25	26.80	24.83	3.42
17- May 2008	2459.75	21.45	19.98	18.09	3.36

Estimation of Reservoir Sediment

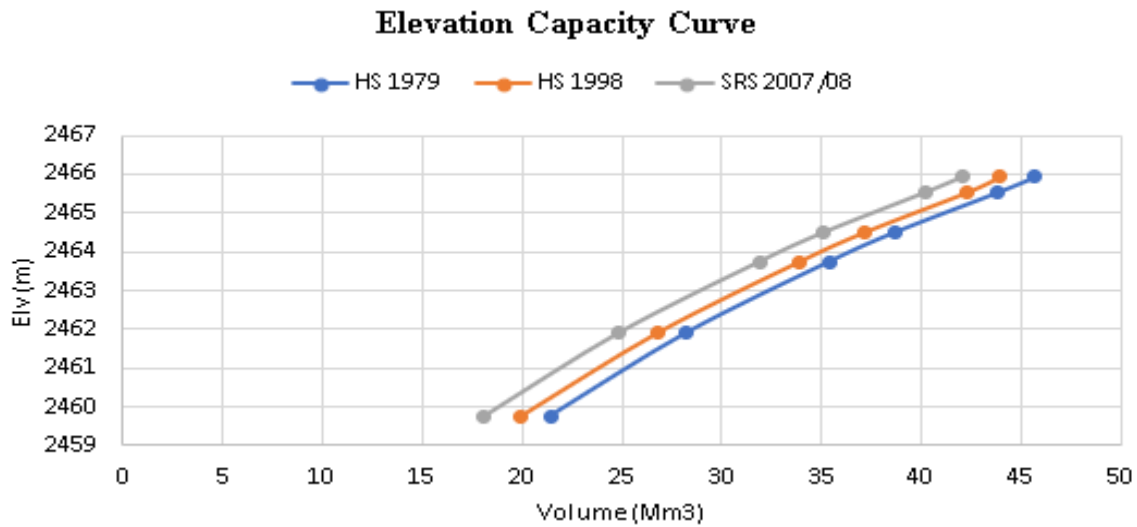


Figure 4.4 Reservoir Elevation Capacity curve for the year in Live Storage Zone.

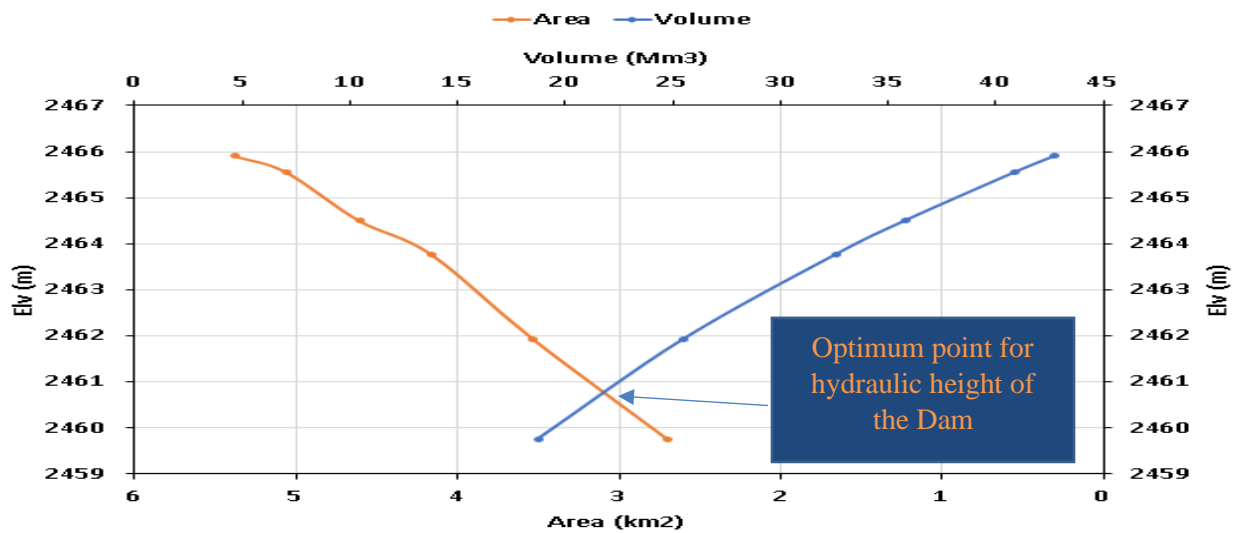


Figure 4.5 Reservoir Elevation-Area-Capacity curve for the year 2007/08 GC in Live Storage Zone.

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The difference between the 1979 Gc study by BCEOM and (2007/08) SRS result, estimated cumulative capacity represented the loss of capacity due to sedimentation in the live zone of the reservoir. The 2007/08 GC capacity was estimated by using Trapezodal formula is **42.032 Mm³** at an elevation of 2465.90 m,a.m.s.l. to get the loss in capacity deduct the 2007/08 capacity from 1979 Gc capacity at the elevation of 2465.90 m,a.m.s.l. **45.71 Mm³** it becomes **3.68 Mm³** it indicates that the sediment deposition between an elevation of 2465.90 and 2459.75 m,a.m.s.l from 1979 Gc to 2007/08 Gc.

The comparative Elevation-Area-Capacity curves for the above periods are shown in the above figure. Based on the SRS survey the annual sedimentation rate (The loss in live storage capacity) for a given period and elevation is 3.68 Mm³ / 29 years it becomes **0.126 Mm³ /year** for the available satellite imageries. The zone of interest of sedimentation analysis from the operation point of view is the live storage.

Table 4.6 Calculation of sediment deposition in Legedadi Reservoir using remote sensing for the year (2011/12 GC) in the Live Storage Zone.

Date of Satellite Pass(GC)	Observed WL (m,a.m.s.l)	Cumulative Capacity (Mm3)			Sediment deposition (Mm3) 2011/12
		HS 1979	HS 1998	SRS 2011/12	
01-Oct 2011	2465.82	45.02	43.30	41.210	3.81
18 -Nov 2011	2465.45	43.13	41.40	39.395	3.785
20- Dec 2011	2463.90	36.12	34.40	32.410	3.710
05 -Jan 2012	2463.48	34.40	32.65	30.705	3.695
22-Feb 2012	2462.18	29.45	27.7	25.810	3.640
28- May 2012	2457.70	16.56	15.65	13.04	3.520

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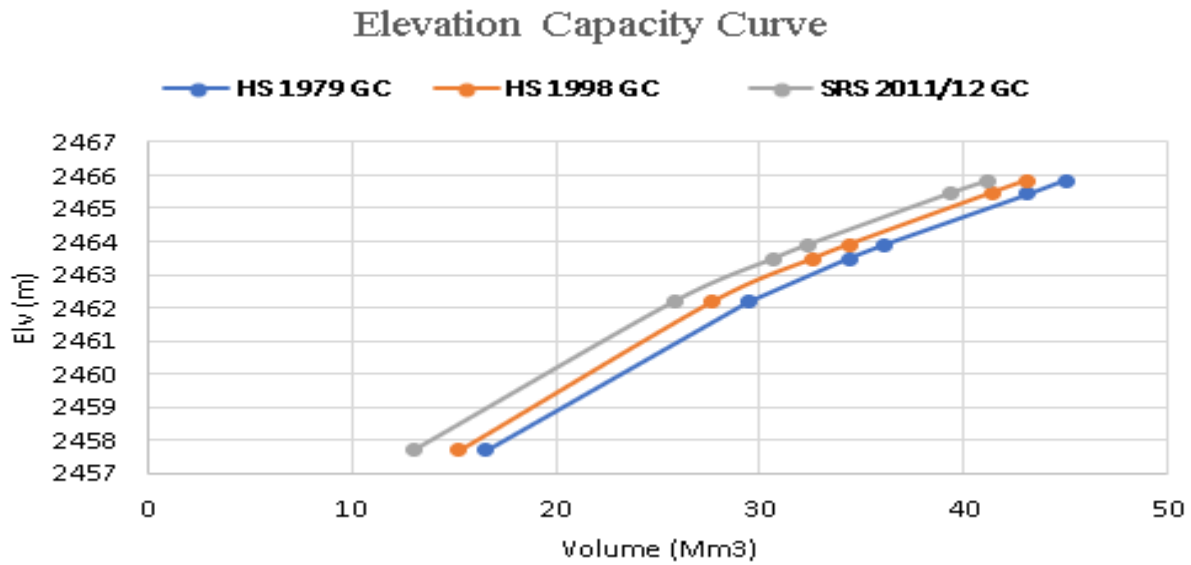


Figure 4.6 Reservoir Elevation Capacity curve for the year in Live Storage Zone.

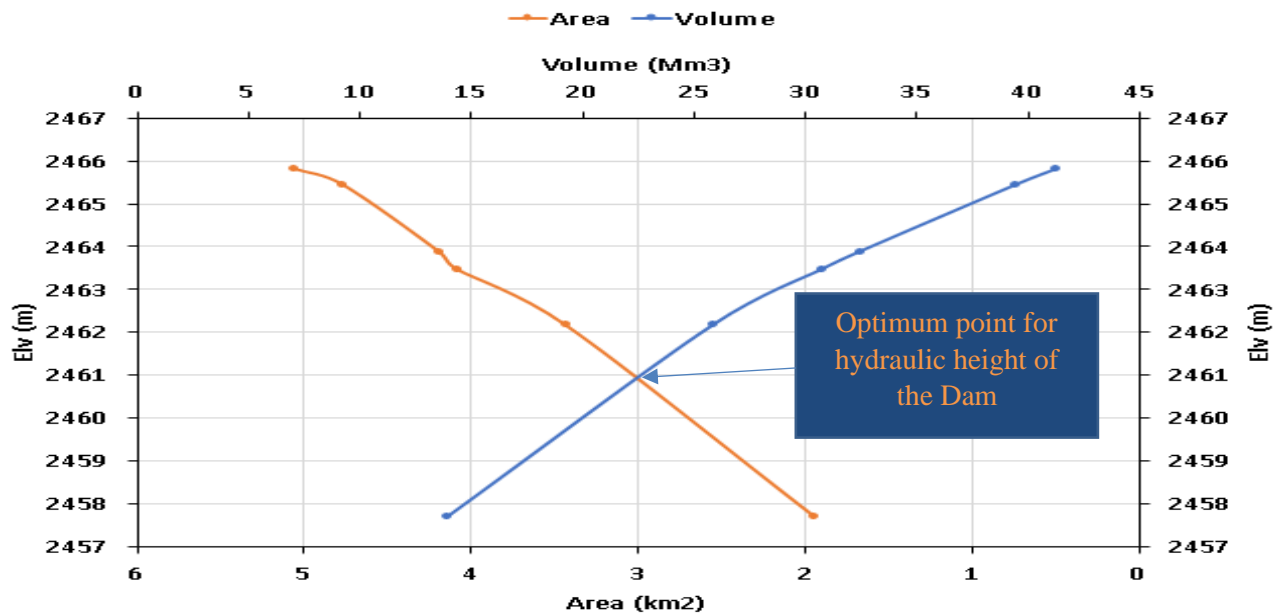


Figure 4.7 Reservoir Elevation-Area-Capacity curve for the year 2011/12 GC in Live Storage Zone.

The difference between the 1979 Gc study by BCEOM and 2011/12 SRS result, estimated cumulative capacity represented the loss of capacity due to sedimentation in the live zone of the

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reservoir. The 2011/12 GC capacity was estimated by using Trapezoidal formula is **41.210 Mm³** at an elevation of 2465.82 m,a.m.s.l. to get the loss in capacity deduct the 2011/12 capacity from 1979 Gc capacity at the elevation of 2465.82 m,a.m.s.l. **45.02 Mm³** it becomes **3.81 Mm³** it indicates that the sediment deposition between an elevation of 2465.82 and 2457.70 m,a.m.s.l from 1979 Gc to 2011/12 Gc.

The comparative Elevation-Area-Capacity curves for the above periods are shown in the above figure. Based on the SRS survey the annual sedimentation rate (The loss in live storage capacity) for a given period and elevation is **0.128 Mm³ /year** for the available satellite imageries. The zone of interest of sedimentation analysis from the operation point of view is the live storage.

Table 4.7 Calculation of sediment deposition in Legedadi Reservoir using remote sensing for the year (2018/19 GC) in the Live Storage Zone.

Date of Satellite Pass(GC)	Observed WL (m,a.m.s.l)	Cumulative Capacity (Mm3)				Sediment deposition (Mm3) 2018/19
		HS 1979	HS 1998	HS 2010	SRS 2018/19	
12-Oct 2018	2465.16	41.61	39.45	37.15	36.087	5.523
13 -Nov 2018	2464.44	38.30	36.56	33.92	32.950	5.35
15- Dec 2018	2463.67	35.11	33.19	30.77	29.854	5.256
16 -Jan 2019	2462.84	31.89	30.18	27.65	26.740	5.15
01-Feb 2019	2462.39	30.05	28.21	26.05	25.180	4.87
21- Mar 2019	2460.98	25.45	23.65	21.60	20.770	4.68

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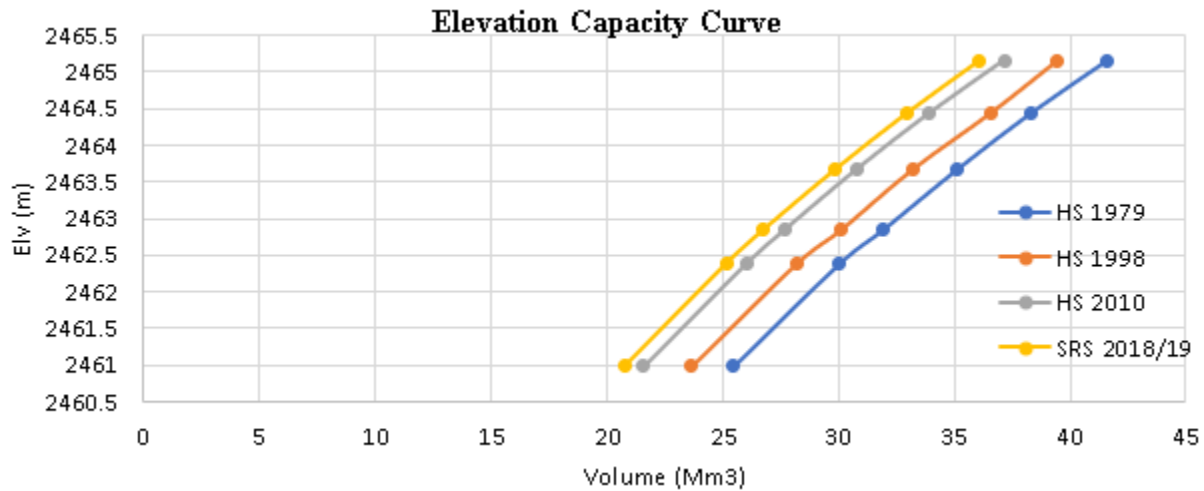


Figure 4.8 Reservoir Elevation Capacity curve for the year in Live Storage Zone.

The difference between the 1979 Gc study by BCEOM and (2018/19) SRS result, estimated cumulative capacity represented the loss of capacity due to sedimentation in the live zone of the reservoir. The 2018/19 GC capacity was estimated by using Trapezoidal formula is **36.087 Mm³** at an elevation of 2465.16 m,a.m.s.l. to get the loss in capacity deduct the 2018/19 capacity from 1979 Gc capacity at the elevation of 2465.16 m,a.m.s.l. **41.61 Mm³** it becomes **5.523 Mm³** it indicates that the sediment deposition between an elevation of 2465.16 and 2460.98 m,a.m.s.l from 1979 Gc to 2018/19 Gc.

The comparative Elevation-Area-Capacity curves for the above periods are shown in the above figure. Based on the SRS survey the annual sedimentation rate (The loss in live storage capacity) for a given period and elevation is **0.142 Mm³ /year** for the available satellite imageries. The zone of interest of sedimentation analysis from the operation point of view is the live storage.

The first bathymetric survey of Legedadi reservoir was carried out in 1979 by BCEOM. The survey was performed using an ELAC type LAZ 7I hydrographic echo-sounder which is an analogue system that records data on paper. A bathymetric map, at a scale of 1:1000 with contour interval of 1 meter was prepared. The bathymetric map of the reservoir was digitized by TAHAL but the digitized map is not available for the present study.

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The objectives of this study were to determine reservoir sedimentation by means of satellite remote sensing approach. As conclusions are provided in each chapter, only the main conclusions will be given here.

- Reservoir sedimentation in many regions seriously affects the development and operation of reservoirs.
- Existing methods like conventional methods, such as hydrographic(bathymetry) surveys, are laborious, costly and time-consuming. For these reasons, the hydrographic surveys of reservoirs are normally conducted at a frequency of 5-15 years, though the recommended frequency is every five years. Remote sensing techniques can be used as a cost- and time effective tool to estimate capacity loss.
- The water spread area of the Legedadi Reservoir was calculated using satellite data and the volume is calculated by using the Prismoidal formula, the revised capacity between the maximum and minimum observed water levels were obtained. The 2003/04 GC capacity was estimated by using Trapezoidal formula is 41.62 Mm³ at an elevation of 2465.60 m,a.m.s.l. to get the loss in capacity deduct the 2003/04 capacity from 1979 Gc capacity at the elevation of 2465.60 m,a.m.s.l. 44.7 Mm³ it becomes 3.08 Mm³ The loss in live storage capacity for a given period and elevation is 3.08 Mm³ / 25 years, it becomes 0.123 Mm³ /year. The 2007/08 GC capacity is 42.032 Mm³ at an elevation of 2465.90 m,a.m.s.l. and the 1979 Gc capacity was 45.71 Mm³,the loss in capacity between the 2007/08 and 1979 Gc is 3.68 Mm³, The loss in live storage capacity for a given period and elevation is 0.126 Mm³ /year. The 2011/12 GC capacity is 41.210 Mm³ at an elevation of 2465.82 m,a.m.s.l. and the 1979 Gc capacity was 45.02 Mm³,the loss in capacity between the 2011/12 and 1979 Gc is 3.81 Mm³, The loss in live storage capacity for a given period and elevation is 0.128 Mm³ /year.
- The current (2018/19) capacity of Legedadi reservoir estimated using remote sensing approach is 36.087 Mm³ at an elevation of 2465.16 m.a,m,s,l. According to 1979Gc study

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result the capacity was 41.610 Mm³ at the same level. The loss in reservoir capacity due to sediment deposition for a period of 39 years since the 1979 hydrographic survey to 2018/19 Gc was determined to be 5.523 Mm³ which is 13.27 % capacity loss between 2465.16 and 2460.98 m.a,m,s,l. At the live storage zone,

- Remote sensing techniques can be used as a cost and time effective tool to estimate capacity loss. The main limitation of the remote sensing based method is that the revised capacity below the deepest observed and overhead the maximum observed reservoir water levels couldn't be estimated.
- It is only possible to calculate the sedimentation amount within the zone of variation of reservoir water level. From the viewpoint of service of the reservoir, this limitation is not very important, meanwhile, the reservoir level exceptional to falls under the minimum drawdown reservoir level in usual years, the interest mostly lies in analyzing the revised capacity and the sediment accumulation characteristics within the live storage zone.
- Precision in the determination of water pixels, mainly at the tail end of a reservoir, affects the correctness of estimation of sediment by means of remote sensing.
- The remote sensing approach enables a fast and rationally precise determination of live storage capacity loss because of sedimentation. Keeping in view the time and cost involved in hydrographic surveys.

5.2 Recommendations

Some recommendations regarding with estimation of reservoir sediment by using satellite remote sensing is:-

- ❖ Given the extent and magnitude of reservoir sedimentation, it is clear that this study only can provide a small piece of knowledge. The topic that is studied is of such a kind that few answers are final. Therefore, there is room for more work not only within the scope this thesis, but also as an extension of it.
- ❖ In order to get true picture of sediment deposition in the reservoir, an integrated survey by carrying out a hydrographic survey below MDDL and multispectral analysis from MDDL to FRL would be more appropriate.
- ❖ The satellites of higher spatial resolution are now available and the data of these must be utilized to increase the accuracy of the water-spread area determination.
- ❖ Remote sensing images can be chosen at closer time intervals so that the revised water-spread area may be obtained at smaller elevation intervals, thereby increasing the accuracy of sedimentation assessment.
- ❖ The satellite remote sensing approach is effective if we apply in too small to medium reservoir, it is essential because most of the time small or medium reservoirs are utilized for urban area for the usage of drinking water supply, so there a need to apply cost effective and time saving approach like satellite remote sensing to investigate the sedimentation condition with in the reservoir in a short time interval.
- ❖ The results of this study should be taken as a reference for further studies on the impact of sediment on a reservoir operation in Legedadi reservoir periodically and to inform, water resource companies, and other interested contributors to make effective and economically feasible plans for sustainable future reservoir operation and sediment management.
- ❖ To protect the reservoir from sedimentation problem we should be implement land management methods, particularly integrated watershed managements the upstream and downstream parts of the reservoir and by periodic assessment of the reservoir appearance.

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- ❖ AAWSA should be work towards to investigate sediment deposition with in short period of interval by means of satellite remote sensing approach.

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ANNEXES

Appendices A: **Elevation-Volume-Area table for Legedadi Reservoir in 2010 Gc from AAWSA.**

Level, masl	Volume, MCM	Area, Sq.km	Remark
2437	0.011	0.019	
2438	0.045	0.049	
2439	0.108	0.078	
2440	0.205	0.113	
2441	0.335	0.151	
2442	0.507	0.195	
2443	0.724	0.236	
2444	0.984	0.29	
2445	1.312	0.365	
2446	1.711	0.433	Intake Level III
2447	2.176	0.499	
2448	2.711	0.571	
2449	3.316	0.637	
2450	3.986	0.702	
2451	4.719	0.766	
2452	5.521	0.851	
2453	6.446	1.003	Intake Level II
2454	7.534	1.18	
2455	8.816	1.388	
2456	10.309	1.598	
2457	12.017	1.824	
2458	13.971	2.087	
2459	16.191	2.364	
2460	18.725	2.718	Intake Level I
2461	21.628	3.087	
2462	24.903	3.463	
2463	28.562	3.86	
2464	32.628	4.277	
2465	37.139	4.76	
2466	42.175	5.324	Maximum Water Level

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Appendices B: The 1979 Gc Elevation-Volume data table for Legedadi Reservoir traced by Getdata Graph Digitizer from AAWSA Prepared in Graph Form

Elevation (m.a,m,s,l)	Cumulative Capacity,(m3)
2,466.01	45.9E+6
2,465.80	44.9E+6
2,465.58	44.0E+6
2,465.26	42.3E+6
2,465.15	41.6E+0
2,464.93	40.5E+6
2,464.72	39.9E+6
2,464.61	39.3E+6
2,464.50	38.7E+6
2,464.39	38.0E+6
2,464.18	37.1E+6
2,463.96	36.2E+6
2,463.64	35.1E+6
2,463.42	34.2E+6
2,463.21	33.1E+6
2,462.88	32.3E+6
2,462.67	31.3E+6
2,462.56	30.5E+6
2,462.35	29.9E+6
2,461.91	28.7E+6
2,461.70	27.7E+6
2,461.48	26.7E+6
2,461.05	25.5E+6
2,460.84	24.8E+6
2,460.51	23.9E+6
2,460.19	22.9E+6
2,459.87	21.9E+6
2,459.54	20.9E+6
2,459.22	20.1E+6
2,458.89	19.1E+6
2,458.46	18.1E+6

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2,458.03	17.1E+6
2,457.60	16.1E+6
2,456.95	14.9E+6
2,456.42	13.9E+6
2,455.88	12.9E+6
2,455.23	12.1E+6
2,454.69	11.2E+6
2,454.26	10.4E+6
2,454.04	10.1E+6
2,453.40	9.3E+6
2,452.75	8.4E+6
2,451.89	7.4E+6
2,451.13	6.7E+6
2,450.49	6.0E+6
2,450.05	5.6E+6
2,449.08	4.9E+6
2,448.44	4.4E+6
2,447.57	3.8E+6
2,446.60	3.2E+6
2,445.85	2.7E+6
2,444.88	2.2E+6
2,444.12	1.8E+6
2,443.05	1.4E+6
2,442.08	1.1E+6
2,441.11	7.97E+05
2,440.13	5.98E+05
2,439.06	3.98E+05
2,438.19	2.99E+05

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Appendices C: The 1998 Gc Elevation-Volume data table for Legedadi Reservoir traced by Getdata Graph Digitizer From AAWSA Prepared In Graph Form

Elevation (m.a,m,s,l)	Cumulative Capacity (m3)
2,466.01	43.7E+6
2,465.80	42.4E+6
2,465.47	41.2E+6
2,465.26	40.0E+6
2,464.93	38.9E+6
2,464.72	37.5E+6
2,464.29	36.0E+6
2,463.96	34.4E+6
2,463.64	33.2E+6
2,463.21	31.7E+6
2,462.99	30.5E+6
2,462.78	29.8E+6
2,462.56	28.7E+6
2,462.13	27.6E+6
2,461.81	26.4E+6
2,461.48	25.2E+6
2,461.16	23.9E+6
2,460.62	22.3E+6
2,460.08	20.8E+6
2,459.54	19.3E+6
2,458.89	17.6E+6
2,458.36	16.2E+6
2,457.49	14.5E+6
2,456.85	13.1E+6
2,456.09	11.7E+6
2,455.44	10.5E+6
2,455.12	10.1E+6
2,454.58	9.4E+6
2,453.94	8.5E+6
2,453.18	7.5E+6
2,452.53	6.8E+6
2,451.89	6.1E+6
2,451.24	5.5E+6

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2,450.59	5.1E+6
2,449.84	4.5E+6
2,449.19	4.0E+6
2,448.44	3.5E+6
2,447.68	3.0E+6
2,446.93	2.5E+6
2,446.17	2.1E+6
2,445.42	1.8E+6
2,444.77	1.5E+6
2,444.02	1.2E+6
2,443.37	1.1E+6
2,442.40	8.96E+05
2,441.43	5.98E+05
2,440.78	4.98E+05

Appendices D: **Elevation-Volume graph for three different period Hydrographic survey**

