ADDIS ABABA UNIVERSITY AAIT DEPARTEMENT OF CIVIL ENGINEERING

ASSESSMENT OF SEDIMENTATION IN GILGEL GIBE 1 RESERVOIR PROJECT USING REMOTELY SENSED DATA

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Stream of Hydraulic Engineering

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DECLARATION

I, the undersigned declare that the project comprises my own work. In compliance with internationally accepted practices, I have dually acknowledged and refereed all materials used in this work. I understand that non-adherence to the principles of academic honesty and integrity, misrepresentation/ fabrication of any idea/data/fact/source will constitute sufficient ground for disciplinary action by the university and can also evoke penal action from the sources which have not been properly cited or acknowledged.

Signature……………..

Yonas Alemshet

Date……….

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ABSTRACT

A reservoir is an integral component of a water resources system. Periodic evaluation of the sediment deposition pattern and assessment of available storage capacity of reservoirs is an important aspect of water resources management. The conventional techniques of quantification of sediment deposition in a reservoir, such as hydrographic surveys and the inflow-outflow methods, are cumbersome, costly and time consuming. Further, prediction of sediment deposition profiles using empirical and numerical methods requires a large amount of input data and the results are still not encouraging. There is a need for developing simple methods, which require less time and are cost effective. Due to sedimentation, the water-spread area of a reservoir at various elevations keeps on decreasing. Remote sensing, through its spatial, spectral and temporal attributes, provides synoptic and repetitive information on the water-spread area of a reservoir. By use of remote sensing data in conjunction with a geographic information system, and Envi software the temporal change in water-spread area can be analyzed to evaluate the sediment deposition in a reservoir.

In this study, a remote sensing approach has been attempted for assessment sedimentation in Gilgel Gibe 1 hydropower Reservoir, the reservoir located on the upper parts of the Gilgel Gibe catchment. Multi date remote sensing data (Landsat 8) provided the information on the water-spread area of the reservoir, which was used for computing the sedimentation rate. The revised capacity of the reservoir between maximum and minimum levels was computed using the Trapezoidal formula.

The current capacity of Gebi 1 reservoir estimated using remote sensing techniques becomes 809.216 Mm3. The original capacity during planning was 827.439 Mm3 at the same level, the loss in reservoir gross capacity due to sediment deposition for a period of 27 years since the construction of the dam in 1990 to 2017 was determined to be 18.223 Mm3 which translate to 2.2 % gross capacity loss. The specific sediment yield over Gibe 1 was calculated to be 204.147 tones / km2 / year. The result of the sedimentation analysis is typical of medium reservoirs. The sedimentation results or Gibe 1 reservoir using the remote sensing approach for 2017 are comparable with the sedimentation results from the 2013 Swat model and hydrological survey method (during planning and design phase) . The results further confirm the applicability of remote sensing for sedimentation analysis for medium reservoirs in Gibe 1. Assuming a uniform sedimentation rate, current trends suggest that Gibe 1 reservoir may be filled up in the next sixty eight years from 2017, however the useful capacity of the reservoir may be lost in much less time.

Key words: - inflow-outflow methods; reservoir sedimentation rate; storage capacity; reservoir; remote sensing; hydrographic survey; water-spread area, water identification.

NOMENCLATURE

CCA -Cloud Cover Assessment

DN-Digital Number

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

SWIR-Short Wave Infrared Radiation

TIRS -Thermal Infrared Sensor

TOA-Top of Atmosphere

USGS –United States Geological Survey

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1 INTRODUCTION

1.1 Background

Reservoirs of large and medium size were built under various plan periods and others are under construction. These reservoir need to meet various requirements of the community. After the dam is built the silt-laden water flows into the reservoir causing siltation in both Live and dead storage of the reservoir, thus utilizable water storage and benefits from the reservoir are reduced. Life of the reservoir is reduced when the rate of sedimentation is higher than the design rate (Eilander et al, 2014).

Sediment particles originating from erosion processes in the catchment are propagated along with the river flow. When the flow of a river is stored in a reservoir, the sediment settles in the reservoir and reduces its capacity. Reduction in the storage capacity of a reservoir beyond a limit hampers the purpose for which it was designed. Thus assessment of sediment deposition becomes very important for the management and operation of such reservoirs. Some conventional methods, such as hydrographic survey and inflow-outflow approaches, are used for estimation of sediment deposition in a reservoir, but these methods are cumbersome, time consuming and expensive. There is a need for developing simple methods, which require less time and are cost effective. In this study, a remote-sensing approach has been attempted for assessment of sedimentation of Gilgel Gibe 1 Reservoir project, located in the south-western part of Ethiopia, in Oromia Regional state. Multi date remote sensing data provided the information on the water-spread area of the reservoir, which was used for computing the sedimentation rate. The revised capacity of the reservoir between maximum and minimum levels was computed using the trapezoidal formula.

Reservoir sedimentation is a natural phenomenon. The soil erosion is a natural process occurs in stream Gilgel Gibe 1 project Reservoir and in the river basin system. Such eroded soil settles down in the storage of reservoirs reducing the utilizable capacity. So, over a period of time, the entire reservoir faces a loss of storage potential because of silt load. So to overcome the threat of sedimentation one needs to have knowledge about net storage available in the reservoir excluding the silt volume as well as irrigation scheduling. To determine net or live storage, regular periodic sedimentation surveys of reservoir must be done. An integral element of water resources planning is periodic measurement of sediment in flow rate, deposition pattern and net storage availability. 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 need to be taken care.

Sediment trapping by reservoirs is now of primary concern for Ethiopian. This has significant consequences, both for the channels downstream, and for the sustainability of the reservoirs and thus future water supplies. There is increasing evidence of channel erosion and ecosystem impacts resulting from sediment starvation downstream of dams.

For proper allocation and management of water in Gilgel Gibe 1 project reservoir, knowledge about the sediment deposition pattern in various zones of a reservoir is essential. In view of this, systematic capacity surveys of a reservoir should be conducted periodically. Using the remote sensing techniques, it has become very efficient and convenient to quantify the sedimentation in a reservoir and to assess its distribution and deposition pattern. Remote sensing technology,

Offering data acquisition over a long period of time and broad spectral range, can provide synoptic, repetitive and timely information regarding the sedimentation characteristics in a reservoir. Reservoir water spread area for a particular elevation can be obtained very accurately from the satellite data. Reduction if any, in the water spread area for a particular Elevation indicates deposition of sediment at that level. This integrated over a range of Elevations using multi-date satellite data enables in computing volume of storage lost due to Sedimentation.

The Satellite Remote Sensing (SRS) method for assessment of reservoir sedimentation uses the fact, that the water spread area of reservoir at various elevations keeps on decreasing due to sedimentation. 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 estimate sedimentation over a period of time. This thesis describes assessment of sedimentation carried out for the Gilgel Gibe 1 project reservoir. The Elevation capacity curve of year 1990 G.c, when actual impoundment was started, is used as a base for sedimentation assessment for the year 2017 E.c. The results of remote sensing survey for the period 2009 are compared with the deposition pattern of

Gilgel Gibe 1 reservoir with the standard types of deposition pattern as per Area trapezoidal formula.

Water spread area in each image was calculated in Envi software by multiplying the number of water pixels and the pixel area. Isolated water pixels noted around the reservoir and along the tributary rivers were not considered to be part of the reservoir. Finally water spread area for each reduced reservoir level was obtained by averaging water spread area for that level from the two methods used. Reservoir water storage capacity between consecutive levels was calculated using the trapezoidal formula. This method is used because to make similar with the method used in previous method.

1.2 Statement of the problem

Dams interrupt by continuity of sediment deposition through reservoirs, resulting in loss of reservoir storage and reduced usable life of reservoir. With the acceleration of new dam construction in Ethiopia, these impacts are increasingly widespread. There are proven techniques to calculate sediment deposition through or around reservoirs, to preserve reservoir capacity and to minimize downstream impacts, but they are not applied in many situations where they would be effective. This paper indicates reservoir sediments deposition managing on Gilgel Gibe 1 reservoirs.

1.3 Objectives of the study and Research question

1.3.1 General Objectives:-

The main objective of this study is to assess the sedimentation of Gilgel Gibe 1 project reservoir using remotely sensed satellite data.

1.3.2 The Specific objectives:-

- To show the capability of remotely sensed data to determine reservoir sedimentation.
- To determine the volume of sediment deposited in Gilgel Gibe 1 project reservoir from 1982-2009.
- To develop the current reservoir capacity curve of Gilgel Gibe 1 project reservoir.

- To compare the results which done by other methods which help to predict reservoir sedimentation such as Hydrographic survey and swat model and recommend the best.

1.4 Significance of the study

In Ethiopia, there are many reservoirs under construction and many other are being designed for the development of the country by the Federal and Regional government. The country has experienced low reservoir sedimentation control and management due to many reasons for many decades. However, most of the projects have experienced sediment problem.

The findings of the this thesis may help for Gilgel Gibe 1 Reservoir management authority (ELPA) to take appropriate measure to reduce erosion from the catchment Area and sedimentation problem of the Reservoir and to adapt appropriate generation of power based on the current revised reservoir capacity.

This indicate that there is a need to have a good understanding of reservoir sediment problem for ongoing projects and currently working projects to overcome the consequence of sediment problem. Therefore, this research will develop or contribute better understanding to the efforts working towards attaining storage capacity of a reservoir purpose for which it was designed. Sediment deposition becomes very important for the management and operation of such reservoir.

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.

1.5 Scope of the study

The study will focus on assessment of reservoir sedimentation on Gilgibe Gibe 1 hydropower project for capacity estimation based between FRL and the Minimum water level in the reservoir only. Thus changes can be estimated only in this Zone of reservoir and Availability of cloud free dates through reservoir operation period is the problem, hence data from different Months was selected. Hydropower generation for sustainable development, that is, to meet the needs of the present without compromising the ability to meet the needs of future generations. We recommend that all dams be designed and operated so that they continue to provide benefits to future generations.

2 Review of Literature

2.1 Reservoir Sedimentation

2.1.1 Storage loss

Reservoir sedimentation is responsible for water resources management. All sorts of Structures are concerned including large dams, fill or concrete dams, river barrages, power Plants, locks, impounding dams and dykes. The aim to create reservoirs is storing water; Other matters are carried along by the water and are usually deposited there. Other applications of reservoirs are water supply, irrigation, energy & flood control. The reservoir can have its capacity decreased due to sediment deposition over the years. In an extreme case, this may result in the reservoir becomes filled up with sediments, and the water flows over land again. A natural reservoir silts up more or less rapidly. In actual fact, reservoirs may completely fill with sediments even within just a few years, whereas natural lakes may remain as stable features of the landscape for as much as 10'000 or 20'000 years after they were formed. Dam construction investment on other side gets reduces the value or even nullified due to reservoir sedimentation. The use for which a reservoir was built can be sustainable or represent a renewable source of energy only where sedimentation is controlled by adequate management, for which suitable measures should be devised. Lasting use of reservoirs in terms of water resources management involves the need for sedimentation.

Sedimentation causes the loss of approximately 0.4 to 2.0% of the world reservoir volume annually (Hasan et al., 2011; Issa et al., 2015), while sediment deposition rate varies from 0.1 to 2.3% for large dams worldwide (Rashid et al., 2015). However depending on the nature of the catchment, small reservoirs in semi-arid to arid areas experience much higher levels of sediment deposition., sediment load exceed the normal design limits in many reservoirs.

The planning and design of a reservoir require the accurate prediction of erosion, sediment Transport and deposition in the reservoir. For existing reservoirs, more and wider knowledge is still needed to better understand and solve the sedimentation problem, and hence improve Reservoir operation. (Annandale, G. W. (1987), Reservoir Sedimentation, Elsevier, New York)

Reservoir sedimentation is a process that has been going on since a dam is build. It is a consequence of decreases in the velocity of flowing water because of increased cross-sectional area through which it passes. The decrease in velocity leads to sediment deposition at the bottom of the reservoir under the action of gravity. It eventually starts to influence the reservoir capacity and the river morphology. The siltation of the reservoir could hinder the usage of the dam and interfere with the functionality of the reservoir. With the sediments taking up space in the reservoir, the storage capacity of the reservoir is decreasing. If the sediments settle all the way towards the dam structure, the hydropower installation can be influenced by the sedimentation process as well. Also, the navigability of the river can be negatively influenced due to the fact that the river morphology is changing. It has an effect on the ecology too, since the continuous river flow is interrupted and fragile ecological equilibriums will be disturbed.

2.1.2 Life Expectancy

Life expectancy is the useful life span of a reservoir for beneficial water use. The life span of the reservoir on the catchment characteristics, inflows and reservoir properties.

In planning dams, reservoir sustainability and downstream impacts should be analyzed over a sufficiently long temporal scale (300 years or more) to capture long-term impacts, and a spatial scale much larger than reservoir and its immediate environs should be adopted. The upstream river basin should be analyzed for its sediment production, with respect to additional dams, and other changes. Downstream impacts to the river sediment balance should be an integral part of the analysis of dams, and extending downstream far enough to incorporate the limit of impacts, including the coastal zone where appropriate.

For purposes of dam design and operation the recommended adoption of a life-cycle management approach of a design life. Planning and economic studies for reservoirs are commonly based on a design life of only 50 years [Morris and Fan, 1998], which effectively makes it difficult to manage sedimentation problems during and after that period. A 50-year design life is the economic norm, because all costs and benefits are usually calculated to represent present values. The costs are then compared to the benefits using a market-based discount rate. Because any benefits farther than 50 years in the future, when reduced to a present value, are extremely low, and additional capital costs to manage sedimentation well into future generations are not "economically justified." This means, most dams do not have large, low-level outlets that could be used to manage sediment both during a traditional design life and well beyond. To the extent that sedimentation has been considered, it has most commonly been addressed by provision of a sediment storage pool within the reservoir's dead storage, commonly designed to accommodate 100 years worth of sedimentation [Morris and Fan, 1998]. However, with adequate maintenance and management of sedimentation, the usable life of a reservoir can be extended for a much longer period [Palmieri et al., 2003]

If traditional cost–benefit analysis practice is to be continued, assigning the correct value to implementation of reservoir sedimentation management approaches to preserve reservoir storage space requires application of the Hotelling Rule, which says that for the maximum good of current and future generations, the price of exhaustible resources should increase at the rate of interest, to maximize the value of the resource stock over time [Solow, 1974]. Hotelling was responding to the problem of natural resources that were priced "too cheap for the good of future generations that...are being selfishly exploited at too rapid a rate" [Hotelling, 1931]. Given that good reservoir sites are limited and many already used, reservoir storage space should be viewed as an exhaustible resource in cases where reservoir sedimentation management is not implemented. However, if reservoir sedimentation management is incorporated an integral part of the design, operation, and management of a dam and reservoir, the reservoir storage space can be viewed as a renewable resource. The decision as to whether reservoir sedimentation management should be implemented or not, i.e., whether the reservoir is viewed as an exhaustible or a renewable resource, has significant implications for the economic analysis of dam and reservoir projects [Annandale, 2013]. Thus, sustainable development of dams and their reservoirs requires close attention to either preventing sediment deposition or removing deposited sediment from reservoirs.

2.1.3 Sediment management plan

Both suspended and bed load sediments are important to river systems. Not only do reservoirs trap different grain sizes with different efficiencies, it is important to understand downstream sediment impacts and to plan for them. The transport characteristics, trapping potential, and downstream impacts of fine and coarse sediment are quite distinct, and should be considered separately. For example, gravels are trapped with 100% efficiency in most reservoirs, commonly leading to gravel deficits downstream, and it is rare that gravels can be sluiced or flushed except in small reservoirs. Sluicing and flushing work best with finer grained sediments, which in any event, are usually the vast majority of sediment. In all cases, it is essential that the caliber of sediment coming into a reservoir be known to effectively design for it.

It is useful to distinguish between coarse and fine sediments, both in their role in river systems and their susceptibility to being trapped by reservoirs. Coarse sediment (gravel and sand) can be viewed as forming the "architecture" of most riverbeds, as the material constitutes the channel bed and often banks. Moreover, many geomorphic features that serve as important habitats, such as riffles, are composed of coarse sediments (gravels, cobbles). Downstream of dams, reduced supply of coarse sediment has resulted in channel incision and consequent effects on bridges and other infrastructure, and degradation of aquatic habitat quality, including loss of gravels needed by spawning salmon [Kondolf, 1995].

Fine-grained sediment (silt and clay) is important for the structure of some riverine forms, such as vertically accreted floodplains and estuarine mud flats, but it also plays important roles distinct from coarse sediment, such as a source of turbidity, and its role in transporting nutrients and contaminants adsorbed onto clay particles. Anthropically increased loads of fine sediment (e.g., rom land disturbance) can cause problems of increased turbidity in the water column and sedimentation in river channels, estuaries, and harbors [Owens et al., 2005], and deposition of fine-grained sediment in streambed gravels can affect salmon spawning habitat [Kondolf, 2000] and aquatic habitats generally [Wood and Armitage, 1997]. Loss of a river's natural fine-grained sediment load can have a range of negative impacts, as the native species in a river are, by definition, adapted to the natural conditions. Construction Dam dramatically reduced turbidity and summer water temperatures in the downstream reaches, providing excellent habitat for exotic rainbow trout but nearly extirpating the native fish species [Schmidt et al., 1998]

2.2 REMOTE SENSING

Remote Sensing means "obtaining information about an object, area or Phenomenon without coming in direct contact with it." i.e. by some remote means. If we go by this meaning of Remote Sensing, then a number of things would be coming under Remote Sensor, e.g. Seismographs, fathometer etc.

The science of acquiring information about the earth using instruments which are remote to the earth's surface, usually from aircraft or satellites. Instruments may use visible light, infrared or radar to obtain data. Remote sensing offers the ability to observe and collect data for large areas relatively quickly, and is an important source of data for GIS. (Source: digimap)

Remote sensing by other means has been in use like without coming in direct contact with the focus of earthquake, seismograph can measure the intensity of earthquake. Likewise without Coming in contact with the ocean floor, fathometer can measure its depth. However, modern Remote Sensing acquires information about earth’s land and water surfaces by using reflected or emitted electromagnetic energy.

From the following definitions, we can have a better understanding about Remote Sensing: According to White (1977), “Remote Sensing includes all methods of obtaining pictures or Other forms of electromagnetic records of Earth’s surface from a distance, and the treatment and processing of the picture data” Remote Sensing then in the widest sense is concerned with detecting and recording electromagnetic radiation from the target areas in the field of view of the sensor instrument. This radiation may have originated directly from separate components of the target area, it may be solar energy reflected from them; or it may be reflections of energy transmitted to the target area from the sensor itself.

According to American Society of Photogrammetry, Remote Sensing imagery is acquired With a sensor such as electronic scanning, using radiations outside the normal visual range of the film and camera- microwave, radar, thermal, infra-red, ultraviolet, as well as multispectral, special techniques are applied to process and interpret remote sensing imagery for the purpose of producing conventional maps, thematic maps, resource surveys, etc. in the fields of agriculture, archaeology, forestry, geography, geology and others.

According to James B. Compel, “Remote Sensing is the practice of deriving information about the earth’s land and water surfaces using images acquired from an overhead Perspective, using electromagnetic radiation in one or more regions of the electromagnetic Spectrum, Reflected or emitted from the earth’s surface.

2.2.1 Principle of Remote Sensing

Detection and discrimination of objects or surface features means detecting and recording of radiant energy reflected or emitted by objects or surface material. Different objects return different amount of energy in different bands of the electromagnetic spectrum, incident upon it. This depends on the property of material (structural, chemical, and physical), surface roughness, angle of incidence, intensity, and wavelength of radiant energy.

The Remote Sensing is basically a multi-disciplinary science which includes a combination of various disciplines such as optics, spectroscopy, photography, computer, electronics and telecommunication, satellite launching etc. All these technologies are integrated to act as one complete system in itself, known as Remote Sensing System. There are a number of stages in a Remote Sensing process, and each of them is important for successful operation.

2.2.2 Stages in Remote Sensing

- Emission of electromagnetic radiation, or EMR (sun/self- emission)
- Transmission of energy from the source to the surface of the earth, as well as absorption and scattering
- Interaction of EMR with the earth's surface: reflection and emission
- Transmission of energy from the surface to the remote sensor
- Sensor data output.

2.2.3 Types of Remote Sensing

Remote sensing can be either passive or active. ACTIVE systems have their own source of energy (such as RADAR) whereas the PASSIVE systems depend upon external source of illumination (such as SUN) or self-emission for remote sensing.

i. Active Remote Sensing

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

ii. Passive Remote Sensing

Remote sensing of energy naturally reflected or radiated from the terrain

2.2.4 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:

Vegetation: The spectral characteristics of vegetation vary with wavelength. Plant pigment in leaves called chlorophyll strongly absorbs radiation in the red and blue wavelengths but reflects green wavelength. The internal structure of healthy leaves acts as diffuse reflector of near infrared wavelengths. Measuring and monitoring the near infrared reflectance is one way that scientists determine how healthy particular vegetation may be.

Water: Majority of the radiation incident upon water is not reflected but is either absorbed or transmitted. Longer visible wavelengths and near infrared radiation is absorbed more by water than by the visible wavelengths. Thus water looks blue or blue green due to stronger reflectance at these shorter wavelengths and darker if viewed at red or near infrared wavelengths. The factors that affect the variability in reflectance of a water body are depth of water, materials within water and surface roughness of water.

Soil: The majority of radiation incident on a soil surface is either reflected or absorbed and little is transmitted. The characteristics of soil that determine its reflectance properties are its moisture content, organic matter content, texture, structure and iron oxide content. The soil curve shows less peak and valley variations. The presence of moisture in soil decreases its reflectance.

By measuring the energy that is reflected by targets on earth's surface over a variety of different wavelengths, we can build up a spectral signature for that object. And by comparing the response pattern of different features may be able to distinguish between them, which may not be able to do if only compare them at one wavelength. For example, Water and Vegetation reflect somewhat similarly in the visible wavelength but not in the infrared

2.3 LAND SAT 8

The mission of the Landsat Program is to provide repetitive acquisition of moderate-resolution multispectral data of the Earth's surface on a global basis. The Landsat 8. observatory offers these features:

- **Data Continuity**: Landsat 8 is the latest in a continuous series of land remote sensing satellites.
- **Global Survey Mission**: Landsat 8 data systematically builds and periodically refreshes a global archive of sun-lit, substantially cloud-free images of the Earth's landmass.
- **Free Standard Data Products**: Landsat 8 data products are available through the USGS EROS Center at no charge.
- **Radiometric and Geometric Calibration**: Data from the two sensors, the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS), are calibrated to better than 5% uncertainty in terms of top-of-atmosphere reflectance or absolute spectral radiance, and having an absolute geodetic accuracy better than 65 meters circular error at 90% confidence (CE 90).
- **Responsive Delivery**: Automated request processing systems provide products electronically within 48 hours of order (normally much faster).

The Landsat 8 mission objective is to provide timely, high quality visible and infrared images of all landmass and near-coastal areas on the Earth, continually refreshing an existing Landsat database. Data input into the system is sufficiently consistent with currently archived data in terms of acquisition geometry, calibration, coverage and spectral characteristics to allow for comparison of global and regional change detection and characterization.

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

- Earth Explorer

- Global Visualization Viewer
- Landsat Look Viewer

2.3.1 Observatory Overview

The Landsat 8 observatory is designed for a 705 km, sun-synchronous orbit, with a 16-day repeat cycle, completely orbiting the Earth every 98.9 minutes. S-Band is used for commanding and housekeeping telemetry operations while X-Band is used for instrument data downlink. A 3.14 terabit Solid State Recorder (SSR) brings back an unprecedented number of images to the USGS EROS Center archive.

Landsat 8 carries a two-sensor payload: the Operational Land Imager (OLI), built by the Ball Aerospace & Technologies Corporation; and the Thermal Infrared Sensor (TIRS), built by the NASA Goddard Space Flight Center (GSFC). Both the OLI and TIRS sensors simultaneously image every scene, but are capable of independent use should a problem in either sensor arise. In normal operation the sensors view the Earth at nadir on the sun synchronous WRS-2 orbital path, but special collections may be scheduled off-nadir. Both sensors offer technical advancements over earlier Landsat instruments. The spacecraft with its two integrated sensors is referred to as the Landsat 8 observatory.

Table 2-1 OLI and TIRS Spectral Bands

Land 8 OLI and TIRS Bands		
Spectral bands	**Resolution (meters)**	**Wavelength (micrometers)**
Band 1	30m Coastal/Aerosols	0.43-.451
Band 2	30m Blue	0.452-0.512

Land 8 OLI and TIRS Bands		
Spectral bands	**Resolution (meters)**	**Wavelength (micrometers)**
Band 3	30m Green	0.533-0.59
Band 4	30m Red	0.636-0.673
Band 5	30m NIR	0.851-0.879
Band 6	30m SWIR-1	1.566-1.651
Band 7	30m SWIR-2	2.107-2.294
Band 8	15m pan	0.503-0.676
Band 9	30m Cirrus	1.363-0.676
Band 10	100m TIR-1	10.6-11.19
Band 11	100m TIR-2	11.5-12.51

Source: - tool: *http://landsat.usgs.gov/tools_spectralViewer.php*.

The OLI sensor collects image data for nine shortwave spectral bands over a 185 km swath with a 30 m spatial resolution for all bands except the 15 m panchromatic band. The widths of several OLI bands are refined to avoid atmospheric absorption features within ETM+ bands. OLI has stringent radiometric performance requirements and is required to produce data calibrated to an uncertainty of less than 5% in terms of absolute, at-aperture spectral radiance and to an uncertainty of less than 3% in terms of top-of-atmosphere spectral reflectance for each of the spectral bands.

2.3.2 Thermal Infrared Sensor (TIRS)

TIRS is also a push broom sensor employing a focal plane with long arrays of photosensitive detectors. TIRS measure long wave thermal infrared energy emitted by the Earth's surface, the intensity of which is a function of surface temperature. The TIRS are sensitive to two thermal infrared wavelength bands, enabling separation of the temperature of the Earth's surface from that of the atmosphere. The elevated electrons create an electrical signal that can be read out, recorded, translated to physical units, and used to create a digital image.

2.3.3 Applications of Landsat 8 Data

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

Table 2-2:-OLI and TIRS band designations and use of bands

Spectral bands	**Wavelength (micrometers**	**Resolution (meters)**	**Use**
Band 1–coastal/aerosol	0.43–0.45	30	I Increased coastal zone observations.
Band 2–blue	0.45-0.51	30	This band is useful 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

Spectral bands	Wavelength (micrometers	Resolution (meters)	Use
Band 5–NIR	0.85–0.88	30	This band is especially responsive to the amount of vegetation biomass present in a scene. It is useful for crop identification and emphasizes soil/crop and land/water contrasts
Band 8–panchromatic	0.50–0.68	15	Useful in 'sharpening' multispectral images
Band 9–cirrus	1.36–1.38	30	Useful in 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

Source: - tool: *http://landsat.usgs.gov/tools_spectralViewer.php*.

2.3.4 Land sat 8 Level-1 Processing System

The Level-1 processing algorithms include the following:

- Ancillary data processing
- L8 sensor / platform geometric model creation
- Sensor LOS generation and projection
- Output space / input space correction grid generation
- Systematic, terrain-corrected image resampling
- Geometric model precision correction using ground control
- Precision, terrain-corrected image resampling

Ancillary Data

The L8 OLI and TIRS geometric correction algorithms are applied to the wideband (data contained in Level-0R (raw) or 1R (radio metrically corrected) products.

Data Products

One of the goals of L8 is the provision of high-quality, standard data products. About 400 scenes per day are imaged globally and returned to the United States archive. All of these scenes are processed to a Level-1 standard product and made available for downloading over the Internet at no cost to users.

The L1T available to users is a radio metrically and geometrically corrected image. Inputs from both the sensors and the spacecraft are used, as well as GCPs and DEMs. The result is a geometrically rectified product free from distortions related to the sensor (e.g., view angle effects), satellite (e.g., attitude deviations from nominal), and Earth (e.g. rotation, curvature, relief). The image is also radio metrically corrected to remove relative detector differences, dark current bias, and some artifacts. The Level-1 image is presented in units of DNs, which can be easily rescaled to spectral radiance or TOA reflectance.

Product Components

A complete L1 product consists of 13 files, including the 11 band images, a product-specific metadata file, and a Quality Assessment (QA) image. The image files are all 16-bit GeoTIFF images. The OLI bands are Bands 1-9. The TIRS bands are designated as Bands 10 and 11.

The QA image is a 16-bit mask, which marks clouds, fill data, and some land cover types. The metadata (MTL) file contains identifying parameters for the scene, along with the spatial extent of the scene and the processing parameters used to generate the Level-1 product. This file is a human-readable text file in ODL format

Product Format

The product delivered to L8 data users is packaged as Geographic tagged image file format (GeoTIFF) (a standard, public-domain image format based on Adobe's TIFF) and is a self-describing format developed to exchange raster images. The GeoTIFF format includes geographic or cartographic information embedded within the imagery that can be used to position the image in a geographic information display. Each L8 band is presented as a 16-bit grayscale image. Specifically, GeoTIFF defines a set of TIFF tags, which describes cartographic and geodetic information associated with geographic TIFF imagery. GeoTIFF is a means for tying a raster image to a known model space or map projection and for describing those projections. A metadata format provides geographic information to associate with the image data. However, the TIFF file structure allows both the metadata and the image data to be encoded into the same file.

Cloud Cover Assessment (CCA)

The L8 CCA system uses multiple algorithms to detect clouds in scene data. Each CCA algorithm creates its own pixel mask that labels clouds, cirrus, and other classification types. The separate pixel masks are then merged together into the final L1 quality band.

The separate masks are merged together via a weighted voting mechanism. Each algorithm is assigned weights for every class (cloud, cirrus, water, and snow / ice), which indicates how accurate that algorithm is expected to be when classifying that type of target. These weights are defined in the CPF. Then, for each pixel, the confidence value in each mask is used to sum the algorithm weights together.

2.4 Digital image processing

2.4.1 Image file formats

BSQ (Band Sequential Format):

- Each line of the data followed immediately by the next line in the same spectral band. This format is optimal for spatial (X, Y) access of any part of a single spectral band. Good for multispectral images
- Band sequential (BSQ) format stores information for the image one band at a time. In other words, data for all pixels for band 1 is stored first, then data for all pixels for band 2, and so on.

BIP (Band Interleaved by Pixel Format):

- The first pixel for all bands in sequential order, followed by the second pixel for all bands, followed by the third pixel for all bands, etc., interleaved up to the number of pixels. This format provides optimum performance for spectral (Z) access of the image data. Good for hyper spectral images.
- Band interleaved by pixel (BIP) data is similar to BIL data, except that the data for each pixel is written band by band. For example, with the same three-band image, the data for bands 1, 2 and 3 are written for the first pixel in column 1; the data for bands 1, 2 and 3 are written for the first pixel in column 2; and so on

BIL (Band Interleaved by Line Format):

- The first line of the first band followed by the first line of the second band, followed by the first line of the third band, interleaved up to the number of bands. Subsequent lines for each band are interleaved in similar fashion. This format provides a compromise in performance between spatial and spectral processing and is the recommended file format for most ENVI processing tasks. Good for images with 20-60 bands.
- Band interleaved by line (BIL) data stores pixel information band by band for each line, or row, of the image. For example, given a three-band image, all three bands of data are written for row 1, all three bands of data are written for row 2, and so on, until the total number of rows in the image is reached.

2.4.2 Image processing –Correction

I. Radiometric Correction

As any image involves radio metrical errors as well as geometric errors, these error should be corrected. Is to avoid radiometric errors or distortion while geometric correction is to remove geometric distortion

When the emitted or reflected electromagnetic energy is observed by sensor on board an aircraft or spacecraft, the observed energy does not coincide with the energy emitted or reflected from the same object observed from a short distance. This is due to the sun azimuth and elevation, atmospheric condition such as fog or aerosols, sensors response etc... Which influence the observed energy .there for, in order to obtain the real irradiance or reflectance, those radiometric distortion must be corrected.

Radiometric correction is classified into radiometric correction of effects due to sensor sensitivity and radiometric correction for sun sun angle and topography

Radiometric correction of effects due to sensor sensitivity (Absolute Correction in Envi software)

In the case of optical sensor, with the use of a lens, a fringe area in the corner will be darker as compared with the central area. This is called **vignetting**. Vignetting can be expressed by cosn β where β is the angle of ray with respect to optical axis is dependent on the lens characteristics,

Radiometric correction for sun angle and topography

- Sun spot :-

  The solar radiation will be reflected diffusively onto the ground surface, which results in lighter areas in image.it is called sun spot. The sun spot together with vignetting effects cab be corrected by estimating a shading curve.
- Shading:-

The shading effect due to topographic relief can be corrected using the angle between the solar radiation direction and normal to the ground surface.

Perform calibration of Landsat 8 OLI/TIRS data with ENVI’s Landsat Calibration Too

II. Geometric correction (Layer stacking)

Is undertaken to avoid geometric distortion from a distorted image and is achieved by establishing the relationship between coordinate system and geographic coordinate system using calibration data of the sensor, measured data of position and altitude, ground control point's atmospheric condition

Systematic correction

When the geometric reference data or the geometry of sensor are given or measured, the geometry distortion can be theoretically or systematically avoided. This systematic correction is sufficient to remove all errors in water surface area.

Nonsystematic correction

Polynomial to transform from a geographic coordinate system to an image coordinate system, or vice versa ,will be determined with given coordinate of ground control point using the least square method. The accuracy depends on the order of the polynomial and the number and distribution of ground control point

Combined method

Firstly the systematic method is applied, the residual errors will be reduced using lower order polynomial usually the goal of geometric correction is to obtain an error within plus or minus one pixel of its true position.

III. Atmospheric correction (in Envi software)

The solar radiation is absorbed or scattered by the atmosphere during transmission to the ground surface while the reflected or emitted radiation from the target is also absorbed or scattered by the atmosphere before it reaches a sensor. The ground surface receive not only the direct solar radiation but also skylight or scattered radiation from the atmosphere. A sensor will receive not only the direct reflected or emitted radiation from a target, but also the scattered radiation from a target and scattered radiation from the atmosphere, which is called path radiance or atmospheric correction is used to remove these effects

The atmospherics correction method is classified into:-

- **The method using the radiactive transfer equation**
- **The method with ground truth data**

The method using the radio transfer equation

An approximate solution is usually determined for the radiative transfer equation, for atmospheric correction, aerosols density in the visible and near infrared region and water vapor density in the thermal infrared region should be estimated. Because these values cannot be determined from image data, a rigorous solution cannot be determined.

The method with ground truth data

Those targets with known or measured reflectance will be identified in the image. Atmospheric correction can be made Conversion of DNs to Physical Units

2.5 DIGITAL IMAGE PROCESSING FOR DELINEATION OF WATER AND LAND BOUNDARY

For delineating the land and Water pixels following methods were adopted for a better accuracy

2.5.1 Generation of contours

Contours of equal intensity (lines of equal digital numbers) were generated on the image. Contours which show probable water – land delineation were extracted and edited based on Digital Number (DN) of various bands. The contour satisfying the condition DN NIR<DNR<DNG at maximum number of pixels on the contour, is considered as final contour giving delineation representing water spread area at that particular elevation. This final contour is then further edited for corrections.

2.5.2 Thresholding technique

After analyzing the histogram of the image, the ranges of NIR band for land/water boundary demarcation were identified. The NIR image was threshold into two to three ranges. First range contained all confirmed water pixels and a mask was created, second and third range contained pixels at the land/water boundary and at the tail portions of the water-spread extending into river course and masks were created. These range masks were evaluated for the correctness of range limits by consulting FCC. In most of the cases, the criterion for 7 thresholding the image could not give satisfactory results in identifying the correct water pixels due to shallow depth of water at some of the locations along the periphery and at the tail portion of the reservoir. Hence, actual water pixels in these two range masks were estimated by including thresholding of RED band data and further applying the condition of reflectivity property of water for NIR and RED band. (The reflectivity of water in NIR band is smaller than RED band and hence the DN values of NIR band will be smaller than DN values of RED band for water). The total reservoir water spread area was estimated by adding the water spread masks under the different range masks. For finer delineation of water and land boundary by Thresholding Technique, following two criteria were adopted.

2.5.3 Water Index (WI) Method

The water pixels are identified by taking band ratio of Green/Near Infrared. Since the maximum absorptance of electromagnetic radiation by water is in the Near Infrared (NIR) spectral region, the DN value of water pixel in NIR band is appreciably less than the DN values of Green spectral region, which is having high reflectance value. This ratio separates the water body from soil/vegetation quite distinctly. Normalized Water index

2.5.4 Normalized water index (NDWI)

The Normalized Difference Water Index (NDWI) was first proposed by (McFeeters, 1996) to detect surface waters in wetland environments and to allow for the measurement of surface water extent. The NDWI is calculated using Equation

$$NDWI = \frac{Green - NIR}{Green + NIR}$$

Where Green is a green band for landsat-8 band 3, and NIR is a near infrared band 5 for Landsat-8

NDWI is designed to

- ✓ Maximize reflectance of water by using green wavelengths;
- ✓ Minimize the low reflectance of NIR by water features; and
- ✓ Take advantage of the high reflectance of NIR by vegetation and soil features.

(McFeeters, 1996) asserted that values of NDWI greater than zero are assumed to represent water surfaces, while values less than, or equal, to zero are assumed to be non-water surfaces. Values of NDWI were calculated from landsat-8 satellite image in the ENVI 5.4 software Raster or in ArcGIS® 10.4.

2.5.5 Modified Normalized Difference Water Index (NDWI) Method

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

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

Where MIR is a middle infrared band for landsat-8 it is band 6.

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.

Consequently, compared with the NDWI, the contrast between water and built-up land of the MNDWI will be considerably enlarged owing to increasing values of water feature and decreasing values of built-up land from positive down to negative. The greater enhancement of water in the MNDWI-image will result in more accurate extraction of open water features as the built-up land, soil and vegetation all negative values and thus is notably suppressed and even removed.

“The condition used to separate the water pixels from the other pixels is as follows: “If NDWI is positive and if the DN value of NIR band is less than the DN value of Red band and the Green band (NIR < Red < Green), only then the pixel must be classified as water”.

(McFeeters, 1996) asserted that values of NDWI greater than zero are assumed to represent water surfaces, while values less than, or equal 1(black color), to zero are assumed to be non-water surfaces (white color). Values of NDWI were calculated from landsat-8 satellite image in the ENVI 5.4 software Raster or in ArcGIS® 10.1.

2.5.6 IMAGE CLASSIFICATION IN ENVI SOFTWARE

The overall objective of image classification is to automatically categorize all pixels in an image into land cover classes or themes. Normally, multispectral data are used to perform the classification, and the spectral pattern present within the data for each pixel is used as numerical basis for categorization. That is, different feature types manifest different combination of DNs based on their inherent spectral reflectance and emittance properties.

The term classifier refers loosely to a computer program (ENVI software) that implements a specific procedure for image classification. From these alternatives the analyst must select the classifier that will best accomplish a specific task. At present it is not possible to state that a given classifier is "best" for all situations because characteristics of each image and the circumstances for each study vary so greatly. Therefore, it is essential that understands the alternative strategies for image classification.

Classification mainly follow two approaches: unsupervised and supervised. The unsupervised approach attempts spectral grouping that may have an unclear meaning from the user's point of view. Having established these, the analyst then tries to associate an information class with each group. The unsupervised approach is often referred to as 94 Digital Image Processing clustering and results in statistics that are for spectral, statistical clusters. In the supervised approach to classification, the image analyst supervises the pixel categorization process by specifying to the computer algorithm; numerical descriptors of the various land cover types present in the scene. To do this, representative sample sites of known cover types, called training areas or training sites, are used to compile a numerical interpretation key that describes the spectral attributes for each feature type of interest. Each pixel in the data set is then compared numerically to each category in the interpretation key and labeled with the name of the category it looks most like. In the supervised approach defines useful information categories and then examines their spectral separability whereas in the unsupervised approach determines spectrally separable classes and then defines their informational utility.

It has been found that in areas of complex terrain, the unsupervised approach is preferable to the supervised one. In such conditions if the supervised approach is used, have difficulty in selecting training sites because of the variability of spectral response within each class. Consequently, a prior ground data collection can be very time consuming. Also, the supervised approach is subjective in the sense that the to classify information categories, which are often composed of several spectral classes whereas spectrally distinguishable classes will be revealed by the unsupervised approach, and hence ground data collection requirements may be reduced. Additionally, the unsupervised approach has the potential advantage of revealing discriminable classes unknown from previous work. However, when definition of representative training areas is possible and statistical information classes show a close correspondence, the results of supervised classification will be superior to unsupervised classification.

Unsupervised classification

Unsupervised classification do not utilize training data as the basis for classification. Rather, this family of classifiers involves algorithms that examine the unknown pixels in an image and aggregate them into a number of classes based on the natural groupings or clusters present in the image values. It performs very well in cases where the values within a given cover type are close together in the measurement space, data in different classes are comparatively well separated.

The classes that result from unsupervised classification are spectral classes because they are based solely on the natural groupings in the image values, the identity of the spectral classes will not be initially known. The analyst must compare the classified data with some form of reference data (such as larger scale imagery or maps) to determine the identity and informational value of the spectral classes. In the supervised approach we define useful information categories and then examine their spectral separability; in the unsupervised approach determine spectrally separable classes and then define their informational utility.

There are numerous clustering algorithms that can be used to determine the natural spectral groupings present in data set. One common form of clustering, called the "K-means" approach also called as ISODATA (Interaction Self-Organizing Data Analysis Technique) accepts from the number of clusters to be located in the data. The algorithm then arbitrarily "seeds", or locates, that number of cluster centers in the multidimensional measurement space. Each pixel in the image is then assigned to the cluster whose arbitrary mean vector is closest. After all pixels have been classified in this manner, revised mean vectors for each of the clusters are computed.

The revised means are then used as the basis of reclassification of the image data. The procedure continues until there is no significant change in the location of class mean vectors between successive iterations of the algorithm. Once this point is reached, the analyst determines the land cover identity of each spectral class. Because the K-means approach is iterative, it is computationally intensive. Therefore, it is often applied only to image sub-areas rather than to full scenes.

Supervised classification

Supervised classification can be defined normally as the process of samples of known identity to classify pixels of unknown identity. Samples of known identity are those pixels located within training areas. Pixels located within these areas term the training samples used to guide the classification algorithm to assigning specific spectral values to appropriate informational class.

The basic steps involved in a typical supervised classification procedure are:-

- The training stage
- Feature selection
- Selection of appropriate classification algorithm
- Post classification smootTraining
- Accuracy assessment

Training data

Training fields are areas of known identity delineated on the digital image, usually by specifying the corner points of a rectangular or polygonal area using line and column numbers within the coordinate system of the digital image, know the correct class for each area. Usually it begins by assembling maps and aerial photographs of the area to be classified. The objective is to identify a set of pixels that accurately represents spectral variation present within each information region.

Select the Appropriate Classification Algorithm

Various supervised classification algorithms may be used to assign an unknown pixel to one of a number of classes. The choice of a particular classifier or decision rule depends on the nature of the input data and the desired output. Parametric classification algorithms assume that the observed measurement vectors Xc for each class in each spectral band during the training phase of the supervised classification are Gaussian in nature; that is, they are normally distributed. Non-parametric classification algorithms make no such assumption. Among the most frequently used classification algorithms are the parallelepiped, minimum distance, and maximum likelihood decision rules Parallelepiped Classification Algorithm.

Parallelepiped Classification Algorithm

This is a widely used decision rule based on simple Boolean and logic. Training data in n spectral bands are used in performing the classification. Brightness values from each pixel of the multispectral imagery are used to produce an n-dimensional mean vector, Mc = (µck1, µc2, µc3, ... µcn) with µck being the mean value of the training data obtained for class c in band k out of m possible classes, as previously defined. Sck is the standard deviation of the training data class c of band k out of m possible classes.

The decision boundaries form an n-dimensional parallelepiped in feature space. If the pixel value lies above the lower threshold and below the high threshold for all n bands evaluated, it is assigned to an unclassified category. Although it is only possible to analyze visually up to three dimensions, as described in the section on computer graphic feature analysis, it is possible to create an n-dimensional parallelepiped for classification purposes.

The parallelepiped algorithm is a computationally efficient method of classifying remote sensor data. Unfortunately, because some parallelepipeds overlap, it is possible that an unknown candidate pixel might satisfy the criteria of more than one class. In such cases it is usually assigned to the first class for which it meets all criteria. A more elegant solution is to take this pixel that can be assigned to more than one class and use a minimum distance to means decision rule to assign it to just one class.

Parallelepiped classification uses a simple decision rule to classify multispectral data. The decision boundaries form an n-dimensional parallelepiped classification in the image data space. The dimensions of the parallelepiped classification are defined based upon a standard deviation threshold from the mean of each selected class. If a pixel value lies above the low threshold and below the high threshold for all n bands being classified, it is assigned to that class. If the pixel value falls in multiple classes, ENVI Classic assigns the pixel to the last class matched. Areas that do not fall within any of the parallelepiped classification are designated as unclassified.

2.5.7 Minimum Distance to Means Classification Algorithm

The minimum distance classification uses the mean vectors of each ROI and calculates the Euclidean distance from each unknown pixel to the mean vector for each class. All pixels are classified to the closest ROI class unless the user specifies standard deviation or distance thresholds, in which case some pixels may be unclassified if they do not meet the selected criteria.

This decision rule is computationally simple and commonly used. When used properly it can result in classification accuracy comparable to other more computationally intensive algorithms, such as the maximum likelihood algorithm. Like the parallelepiped algorithm, it requires that the user provide the mean vectors for each class in each hand µck from the training data. To perform a minimum distance classification, a program must calculate the distance to each mean vector, µck from each unknown pixel (BVijk). It is possible to calculate this distance using Euclidean distance based on the Pythagorean Theorem.

The computation of the Euclidean distance from point to the mean of Class-1 measured in band relies on the equation 98 Digital Image Processing

$$Dist = SQRT \{(BV_{ijk} - \mu_{ck})^{2} + (BV_{ijl} - \mu_{cl})\ 2\}$$

Where μ_{ck} and μ_{cl} represent the mean vectors for class c measured in bands k and l.

Many minimum-distance algorithms let the analyst specify a distance or threshold from the class means beyond which a pixel will not be assigned to a category even though it is nearest to the mean of that category.

2.5.8 Maximum Likelihood Classification Algorithm

Maximum likelihood classification assumes that the statistics for each class in each band are normally distributed and calculates the probability that a given pixel belongs to a specific class.

Unless a probability threshold is selected, all pixels are classified. Each pixel is assigned to the class that has the highest probability (i.e., the maximum likelihood)

The maximum likelihood decision rule assigns each pixel having pattern measurements or features X to the class c whose units are most probable or likely to have given rise to feature vector x. It assumes that the training data statistics for each class in each band are normally distributed, that is, Gaussian. In other words, training data with bi-or trimodal histograms in a single band are not ideal. In such cases, the individual modes probably represent individual classes that should be trained upon individually and labeled as separate classes. This would then produce unimodal, Gaussian training class statistics that would fulfil the normal distribution requirement.

The Bayes's decision rule is identical to the maximum likelihood decision rule that it does not assume that each class has equal probabilities. A priori probabilities have been used successfully as a way of incorporating the effects of relief and other terrain characteristics in improving classification accuracy. The maximum likelihood and Bayes's classification require many more computations per pixel than either the parallelepiped or minimum-distance classification algorithms. They do not always produce superior results.

2.5.9 Classification Accuracy Assessment

Quantitatively assessing classification accuracy requires the collection of some in situ data or a priori knowledge about some parts of the terrain which can then be compared with the remote sensing derived classification map. Thus to assess classification accuracy it is necessary to compare two classification maps 1) the remote sensing derived map, and 2) assumed true map (in fact it may contain some error). The assumed true map may be derived from in situ investigation or quite often from the interpretation of remotely sensed data obtained at a larger scale or higher resolution.

2.5.10 LIMITATIONS OF THE 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 reservoir. For the capacity estimation below minimum water level in reservoir, other method like hydrographic survey is to be conducted.

- Availability of cloud free dates through reservoir operation period is the problem. Hence data from different year was selected
- Remote Sensing technique gives accurate estimation for fan shaped reservoir where there is a considerable change in water-spread area for incremental change in water level
- Another source of general error lies in the identification of tail end of reservoir particularly, in rainy season

2.6 Reservoir Sedimentation Estimation

The engineering interest in reservoir sedimentation primarily concerns three physical aspects: total volume of trapped sediment; spatial distribution of deposit volume and, sediment load carried by flow releases including its particle size distribution. The volume of deposit represents loss of storage capacity which reduces the efficiency of a reservoir to regulate flow. The distribution of deposit determines the relative impact of trapped sediments on the usable storage as well as the prospect of flushing it. The sediment load carried by flow releases is the potential source of abrasion damage to power turbines and outlet works.

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:

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

5. Satellite Remote Sensing

2.6.1 Stream Measurements (Sediment Rating Curve)

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).

The most commonly used mathematical rating curve is power function (Morris & Fan, 1998; Walling, 1977)

$$Cs = aQ^b$$

Cs is sediment concentration in mg/l, Q is water discharge in m3/s, a and b are coefficients. A suspended sediment rating curve is usually presented in one form of the two basic forms, either as a suspended sediment concentration/stream flow or a suspended sediment discharge/stream flow relationship (Morris & Fan, 1998; Walling, 1977). The latter is the product of both concentration and discharge and it produces a better fit than the original data set. A logarithmic plot is commonly used in both cases (Walling, 1977). A regression equation minimizes the sum of squared deviation from log transformed data, which introduces bias that underestimates the concentration or load at any discharge (Morris & Fan, 1998).

The relationship between discharge and sediment concentration or discharge and sediment load for a particular stream is not a fixed parameter but can considerably vary from one storm to another depending on factors including the intensity and areal distribution of the rainfall, and changes in the sediment supply (Morris & Fan, 1998). To avoid poor relationship between water discharge and sediment discharge separate curves may be developed for winter and summer, fine and course, falling and rising stages of discharge and different ranges of discharge (Morris & Fan, 1998; Walling, 1977).

2.6.2 Hydrographic Surveys

Survey 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. Sediment surveys not only determine the volumetric loss but also provide other valuable information such as sediment distribution in a reservoir and changes in the stream channel in relation to transport and deposition (Vanoni, 2006).

Generally, reservoir survey can be the most accurate means of estimating total sediment yield at a reservoir provided that reservoirs within the study area are monitored frequently. Frequency of monitoring however is determined by amount of annual sediment deposition and budget availability.

2.6.3 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.

2.6.4 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.

Empirical methods and Mathematical models are the methods for prediction of reservoir sedimentation and are normally used during planning stage. Remaining three methods are used for monitoring of sedimentation during operation stage. Stream flow analysis method needs daily measurements of water and sediment flows at upstream and downstream of reservoir right from the day of reservoir impoundment. The hydrographic surveys for reservoirs in hilly region with thick vegetation within and around reservoir pose great difficulties in spite of 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 time factor, these hydrographic surveys are not cost effective and therefore cannot be carried out regularly at shorter intervals for purpose of monitoring of reservoir sedimentation.

Comparatively, use of satellite imageries offers a cost and time effective alternative for monitoring purpose. Moreover remote sensing technique, 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 it requires lesser data and time in analysis as compared to other methods. The advantage of satellite data over conventional sampling procedures include 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 water spread area of reservoir on a given date could be collected instantaneously which is practically impossible even with high-tech survey systems. These advantages have led to development of remote sensing technique in study of reservoir sedimentation.

3 Methodology

3.1 DESCRIPTION OF THE STUDY AREA

3.1.1 Location and environmental setting of the study area

The reservoir located in the upper parts of the Gilgel Gibe catchment. The study area has altitudes ranging between 1000 and 1800 m.a.s.l., and is bounded by latitude 7°29′30″–7°26′00″ N and longitude 37°30′30″–37°53′00″ E.(According to the geological map of Ethiopia). However, the spatial occurrence of the different geological materials is very complex and heterogeneous and not known in detail. The major soil types in the study area are Nitisols, Acrisols and Vertisols (FAO-Unesco, 1974). The annual rainfall of the Gilgel gibe catchment varies from a minimum of 1300mm near the confluence with the great gibe river, to a maximum of about 1800mm in the Utubo and fego mountains with annual average of is 1624 mm. the 60% of the total amount of annual rainfall occurs between June and September (National Meteorological Agency of Ethiopia, 2009), 30% from February to May and only 10% between October to January. The rainfall pattern in the catchment is distributed over only one season with an average of 20.5°C in April, the warmest month and 17.7°C in December, the coldest month (National Meteorological Agency of Ethiopia, 2008).

The basin is largely comprises of cultivated land. In general terms, the Gilgel Gibe basin is characterized by wet climate, influenced by the ITCZ (inter-tropical convergence zone)

3.1.2 Gilgel gibe reservoir

Gilgel Gibe-1 reservoir is situated in the south-western part of Ethiopia. The reservoir water purely for hydropower generation, with an installed capacity of 180 Mw, aimed to increase energy and power supply to the national grid. This reservoir is designed for a live storage

Of 657 million m^3 and a dead storage of 182 million m^3 water. It operates at reservoir water levels between 1653 and 1671 m.a.s.l. And has an average inflow of 50 M^3/S (feasibility study 1982.Pietrangeli and Pallavicini 2007).The catchment area of the Gilgel Gibe reservoir is about 51.25 km2 at its confluence with the great Gibe River and about 42.25 km^2 at the dam site. The

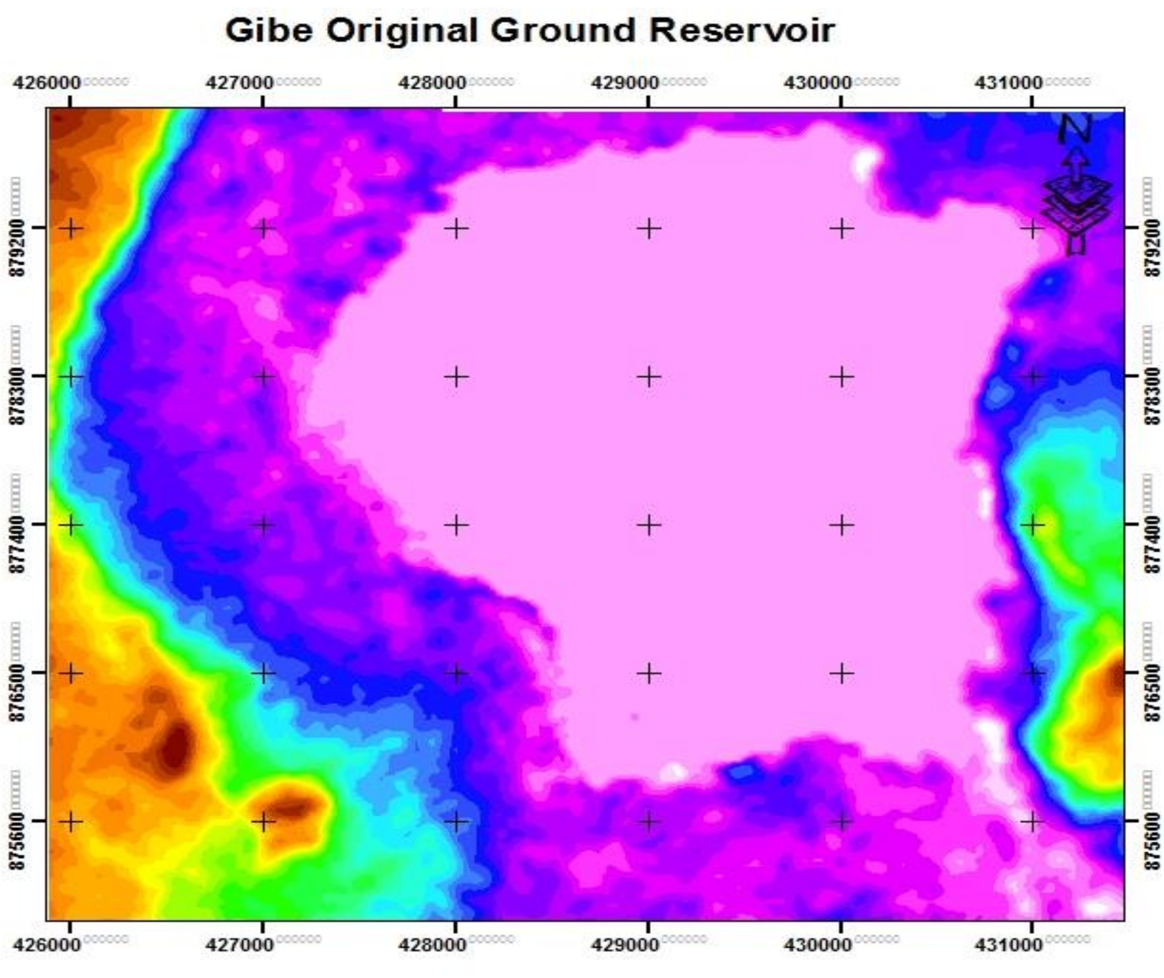
Area is generally characterized by high relief hills and mountains with an average elevation of about 1,700 m above mean sea level.

3.2 Data Type

3.2.1 Topographical Data

The topographical map details were taken from ministry of water resource.this data utilized to prepare a base map prior to start the process with a satellite imageries.

Figure 3-1 Gibe original ground reservoir



3.2.2 Field Data

Maximum, minimum and Daily observed water level data for Gilgel Gibe one reservoir for the period from September ,2016 to April or May 2017 was obtained from ELPA(Utility authority of Ethiopian Hydropower operation).The observed data ranged from reservoir reduced level of 1658.5m to 1671.00m at rreservoir full supply level.

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3.2.3 Satellite data

The only useful information extracted from remote sensing data is the water spread area at different dates of the pass of the satellite over the reservoir area. Selection of appropriate periods for analysis is an important step in the study of reservoir sedimentation assessment using remote sensing data. Therefore, it is imperative to use the remote sensing data of such a period when there is maximum variation in the elevation of the reservoir water surface and consequently, the water spread area.

The multispectral data of satellite, Landsat 8 sensor (OLI and TIRS) were available for the period of analysis and were used in this study. The data were obtained using Global Visualization Viewer interface, on the US Geological Survey (USGS) platform. The GIBE Reservoir water spread area was covered in one scene of Path 169 and Row 55 of the satellite this obtained (from EO-1 and Landsat archived on USGS server). Based on the status and availability of remote sensing data and the time spacing between the satellite data's, eight scenes were obtained for the following dates of pass. Oct 11/2016,Nov 30/2016,Dec 15/2016,Jan 17/2017,Feb 18/2017,Mar 06/2017,Apr 22/2017. The water levels on these days were obtained from ELPA (Ethiopian Electric power Authority).

It needs to be mentioned that for the year (2016-17), the sedimentation assessment was restricted to (1658.5-1670.5 m) zone of the reservoir only. For most year of the operation of the dam the reservoir level varies within or around this range and our main concern is to quantify the sedimentation rate and assess the sediment deposition pattern in the zone of operation.

Table 3-1:-date pass of satellite and reservoir water level those days

SI .NO	Date of Satellite Pass	Reservoir Water Level above mean sea level(m	Satellite & sensor	Path/Row	Remark
1	Oct 11/2016	1672.12	Landsat-8 OLI	169/55	Above FRL
2	Nov 30/2016	1671.8	Landsat-8 OLI	169/55	Above FRL
3		1670	Landsat-8 OLI	169/55	FRL
4	Dec 15/2016	1668.235	Landsat-8 OLI	169/55	Below FRL
5	Jan 17/2017	1666.58	Landsat-8 OLI	169/55	Below FRL
6	Feb 18/2017	1663.95	Landsat-8 OLI	169/55	Below FRL
7	Mar 06/2017	1661.6	Landsat-8 OLI	169/55	Below FRL
8	Apr 22/2017	1658.4	Landsat-8 OLI	169/55	Below FRL

3.3 General

For the quantification of volume of sediments deposited in the reservoir, the basic information extracted from the satellite data is the water spread area of the reservoir at different water surface elevations to be compared with the original reservoir area. The original contours areas at different elevations and the original elevation-area-capacity curves at the dam site can be obtained from the original capacity survey, which are carried out during the planning and design phase of the dam. With the deposition of sediments in the reservoir, the water spread area at any elevation gradually keeps on decreasing due sedimentation deposited in the reservoir. Greater depositions of sediments at an elevation cause 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 speared area of the reservoir having elevation of water surface in the reservoir at the time of satellite pass. Using the land sat 8 satellite data and the image interpretation techniques, the water spread area of the reservoir at the instant of 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 the authority which lead the power station. 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 trapezoidal, mid area 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 amount of sediments deposits below the lowest observed water level cannot be determined using the remote sensing techniques. Hence, the volume of reservoir below the lowest level is assumed to be the same before and after sedimentation. Survey for the area within the lowest observed water spread area can be carried out. It is also important to emphasis here that for the purpose of optimum and judicious operation of 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.

Digital images have some major advantages over paper or film (analogue) images: they Take up less storage space, perfect copies can be created time and time again, they can be Reduced or enlarged at the push of a button, cartographic errors can easily be removed, and Most important of all – digital images can be processed using statistics, to enhance, Analyses and classify their features. For these reasons, digital techniques are superior and are gaining recognition now-a-days. In this study, digital analysis was carried out for identifying the water pixels and determining the water spread area

3.3.1 Processing of Remote Sensing Data

In this study The DEM data was used to generate the original reservoir area of Gilgel gibe 1 hydro power and using Global mapper 15 In order to identify the original reservoir area of the catchment. This represents the study Area of Interest where assessment of sedimentation was done. Water spread area was analyzed from the downloaded Landsat 8 images. Prior to water spread area analysis all the images were geometrically corrected (location on the surface of the earth) the Universal Transverse Mercator (UTM) projection and GPS (Global Position Systems an earth centered, earth fixed terrestrial reference system. Geo -referencing was done using the nearest neighbor resampling method using ground truth data obtained from the catchment using a hand held GPS receiver (this data was received from ELPA) and from Google Earth by using the layer stacking ENVI 5.4 software.

3.3.2 Import and visualization ((Band combination)

The data of landsat-8 images for one year 2016-17 were downloaded from Global Visualization Viewer interface, on the US Geological Survey (USGS) platform. The data were processed and analyzed using HSV (high surface visualization) ENVI 5.4 and. Every landsat-8 image was having 11 different bands characterized as below that can be used for different purpose.

Initially, a false color composite of band 4, 3 and 2, 6, 5 and 3 or 6, 5, and 2 combination was prepared and visualized Using Envi 5.4 software. The pixels representing water spread area which is water quality. Turbid water gives bright blue and clear water gives dark blue. Except at the periphery of the reservoir were quite distinct and selected and represented the reservoir area and clear in the FCC.

3.3.3 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 5.4 software (processing and analysis tools help to extract meaning full information to make better decision). The Gibe 1 reservoir area covering and surroundings areas were extracted by masking from the multiband images using image sub-setting. A false color composite with band combination of NIR, MIR and Green in the (Red; Green, Blue or

Band 6,5, and 2) format was adopted prior to image classification. The adopted false color composite enhances visualization of vegetation pixels with a thistle color and water pixels with dark blue pixels. Supervised maximum likelihood classification algorithm was used for image classification as it had a good separation of water pixels. The images were classified into three classes (water; vegetation and other). The producer and user accuracy for the water class for all classified images were all above 85%.

3.3.4 Water index method

Using the water index method (Rathore etal, 2006), water pixels were identified by calculating the band ratio of Green/Near Infrared to be very low compared to DN values in the Green band (This was done by ENVI 5.4 software).The ratio distinctly separates water bodies from soil and vegetation with very bright pixels. The WI image was then reclassified to show water pixels as a separate class by assigning the value 1 for water pixels and 0 for the remaining area which is not covered by water.

3.4 Calculation of Revised Reservoir Capacity and Sedimentation

Water spread area in each image was calculated in ENVI 5.4 by multiplying the number of water pixels and the 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. Reservoir water storage capacity between consecutive levels was calculated using the trapezoidal formula. Trapezoidal formula was adapted because it was used during the reservoir planning and design phase to calculate the reservoir capacity and to have similarity during calculation. As follows

$$V_{12}=\frac{H12}{3}\left(A1 + A2 + \sqrt{A1 * A2}\right) \qquad \text{Eq(2)}$$

$$Y_a = \sum_{i=1}^{N-1} \Delta V_i \qquad \text{Eq(3)}$$

Where V_{12} is the volume of water present in the dam between two consecutive water levels taken as H_1 and H_2. H_{12} is the difference in water levels between consecutive water level H_1 and H_2. A_1 and A_2 are spread area at water level H_1 and H_2 respectively and Y_a = Live capacity of reservoir, and Storage capacities between consecutive levels were summed up to arrive at the revised capacity at the full supply level.

3.5 RESERVOIR ELEVATION- CAPACITY CURVE

Reservoir elevation-area-capacity is important for planning and operation purposes. The original and current reservoir elevation-capacity curve at dam site can be prepared from the available calculated.

4 RESULT AND DISCUSSION

The reservoir area false color combination and delineated water areas are shown in Figs 6.1-6.8 the following pictures for each date of satellite passes.

SATELLITE IMAGERY WATER SPREAD AREA

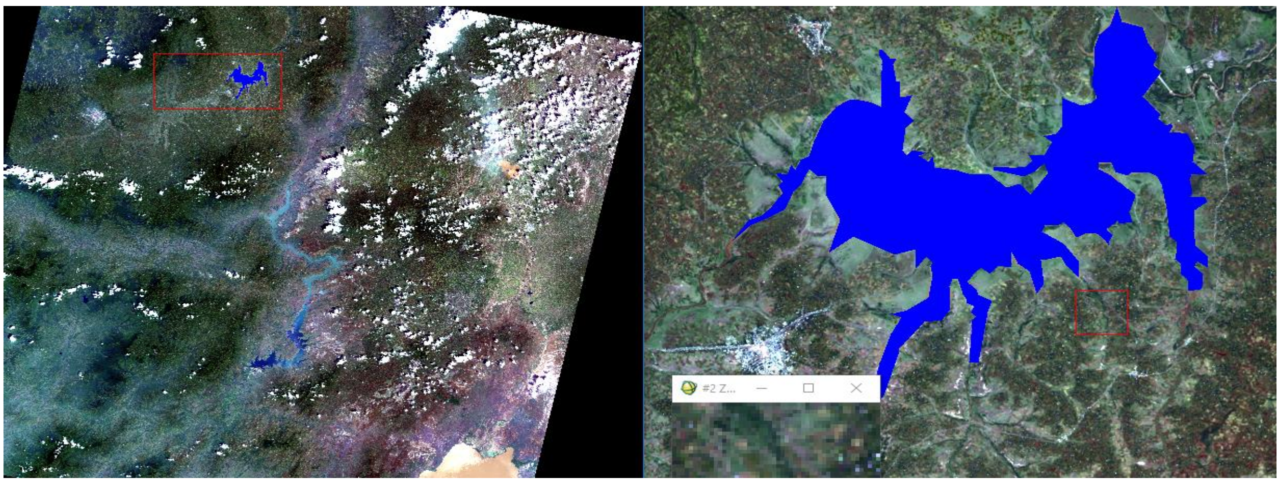


Figure 4-1:-Extracted Water Spread Area of GEBI 1 Reservoir = 50.043 K.M2 on Oct 11/2016 WATER LEVEL=1672.5

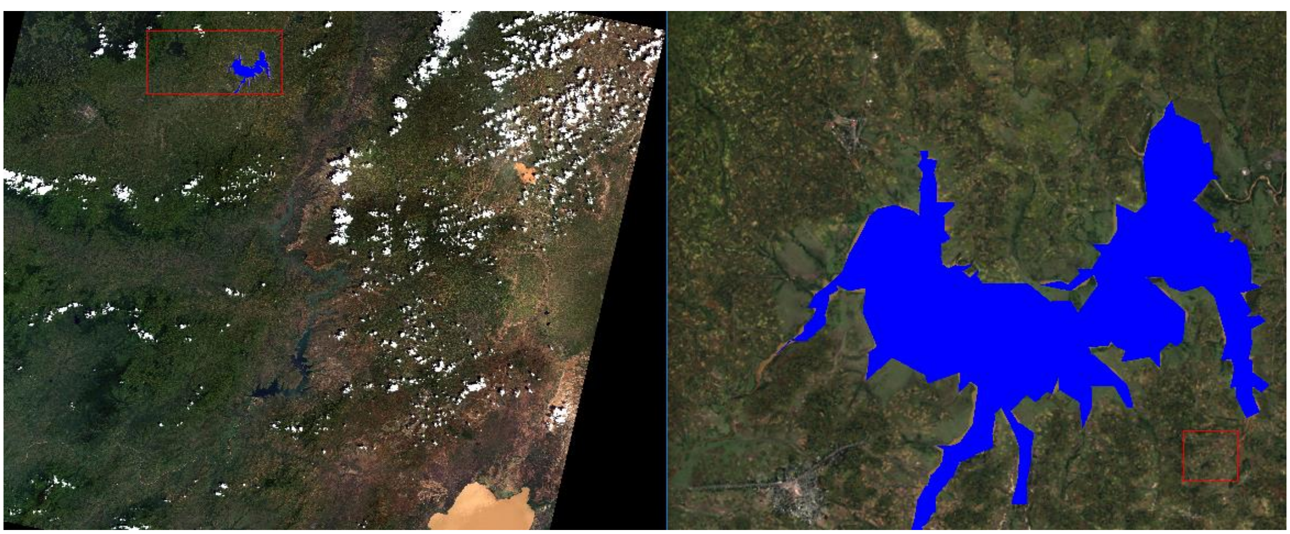


Figure 4-2:- Extracted Water Spread Area of GEBI Reservoir = 48.893K.m2 Nov 28 on WATER LEVEL= 1671.8

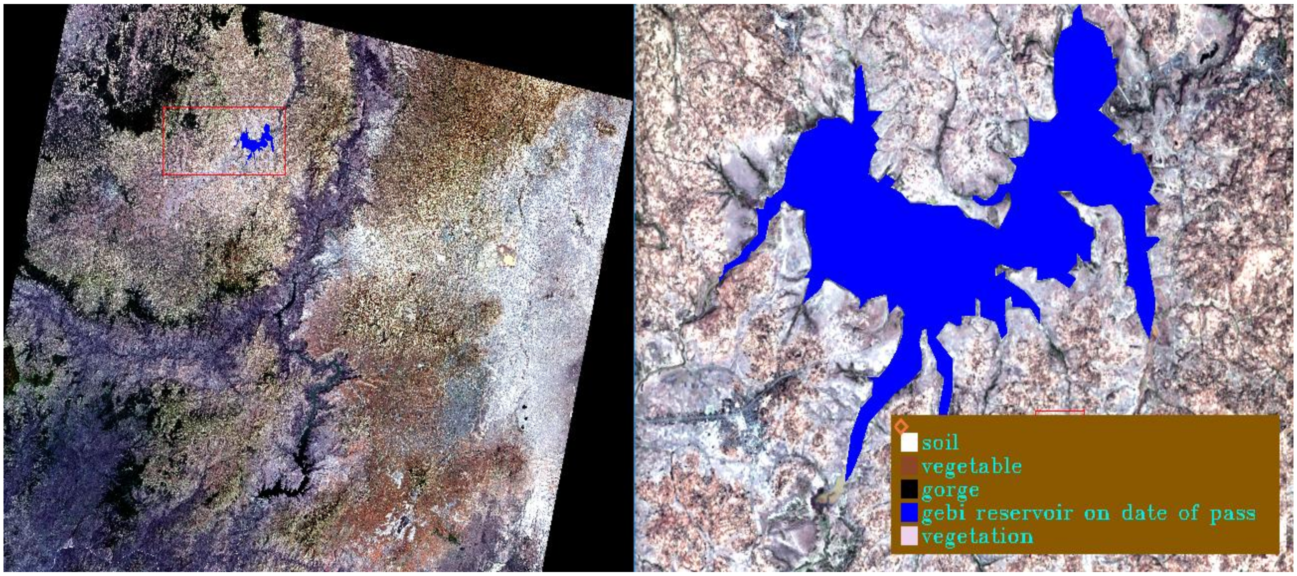


Figure 4-3:-Extracted Water Spread Area of Gebi 1 Reservoir =47.047k.m2 on Dec 14/2017 Water Level = 1668.235

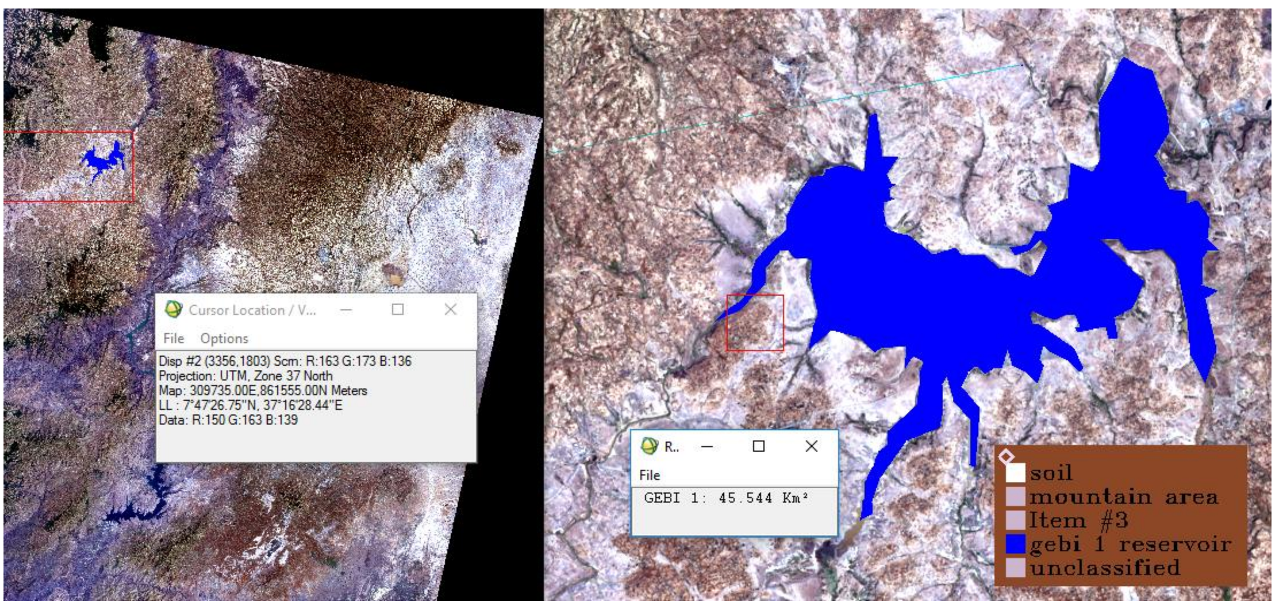


Figure 4-4:-Extracted Water Spread Area of GEBI Reservoir on Jan=45.544 K.m2 Water Level = 166.58

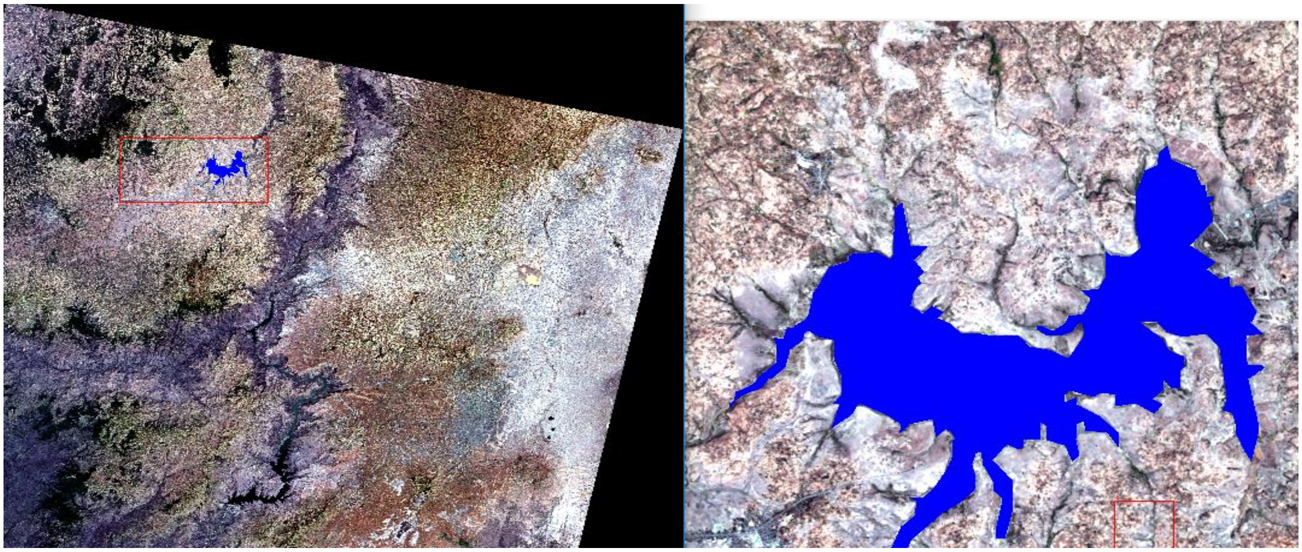


Figure 4-5:-Extracted Water Spread Area of GEBI Reservoir on Feb =45.023 K.m2 Water Level = 1663.95

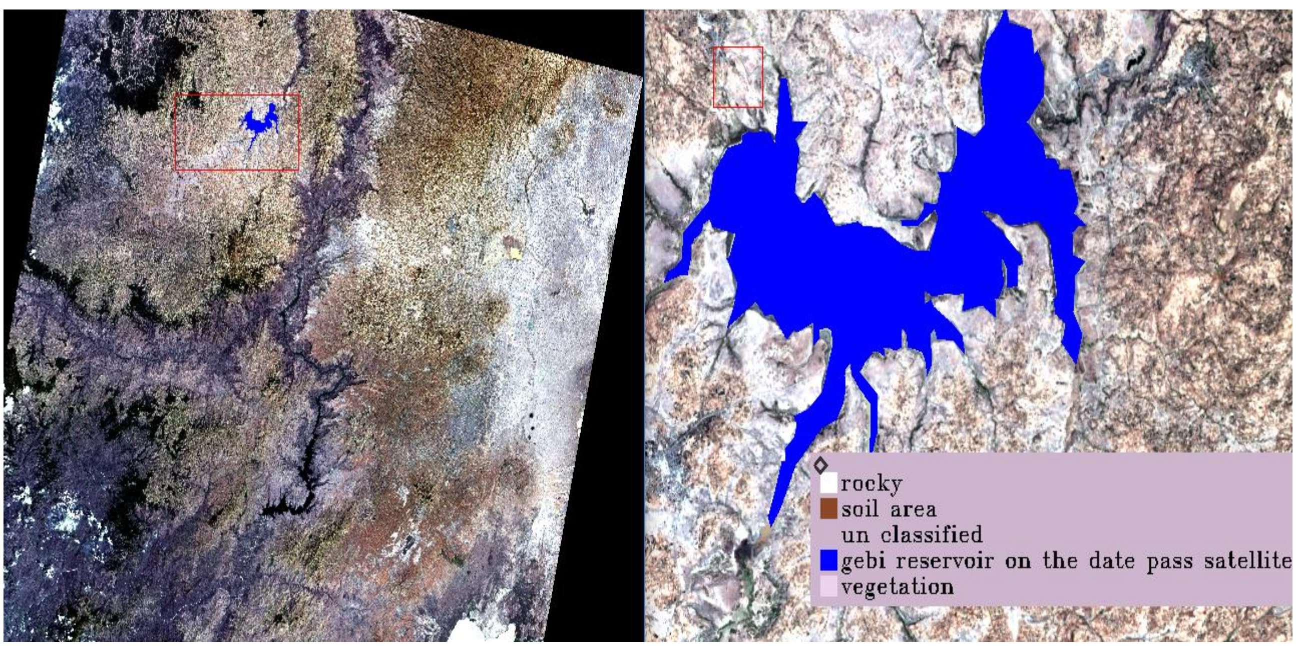


Figure 4-6:-Extracted Water Spread Area of GEBI 1 Reservoir on Mar=44.543 Water Level =1661.6

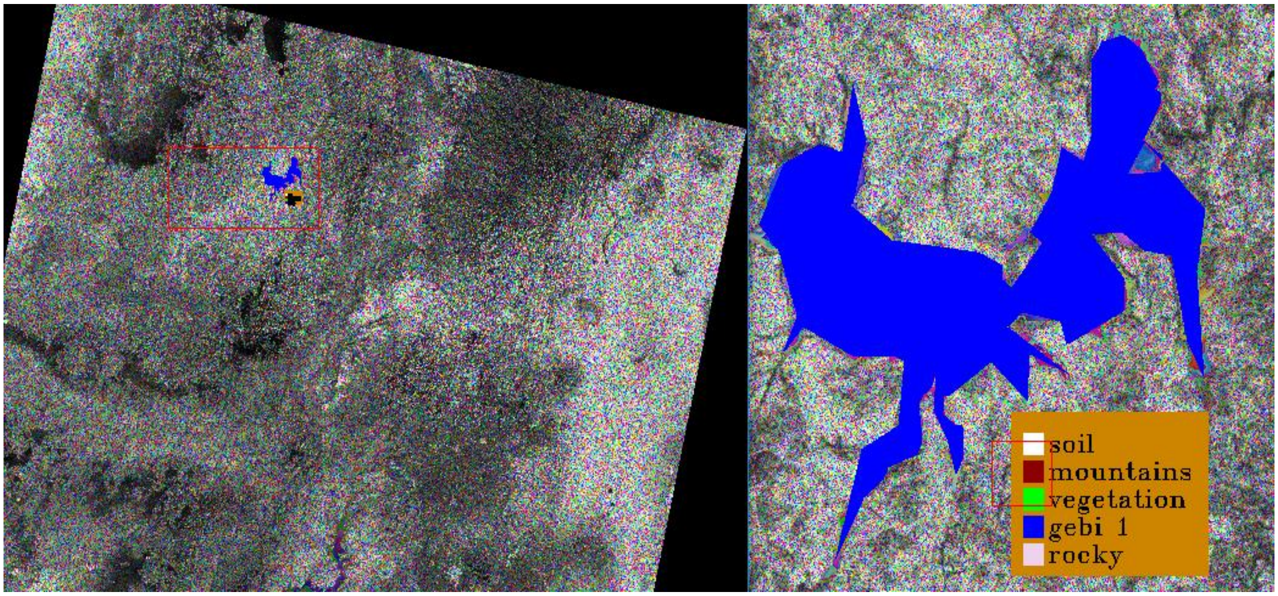


Figure 4-7:-Extracted Water Spread Area of GEBI 1 Reservoir on Apr = 43.825 Water Level =1658.4

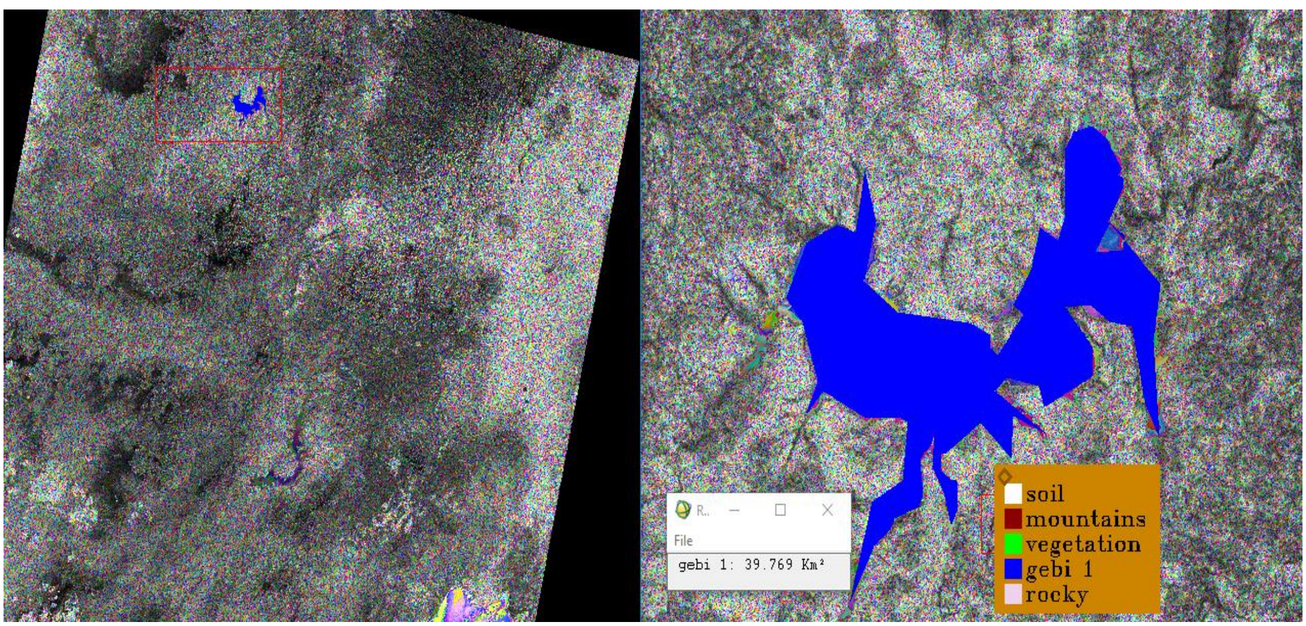


Figure 4-8:-Extracted Water Spread Area of GEBI 1 Reservoir on May = 39.769 Water Level =1656.56

The water-spread area of the reservoir was calculated using remotely sensed data. The difference in volume between two consecutive levels was calculated using the Trapezoidal formula and is given in Table 4.1. In the present study, the cumulative revised capacity of the reservoir at the observed lowest level (1656.56) was assumed to be the same as the original cumulative capacity (182Mm3) at this elevation.

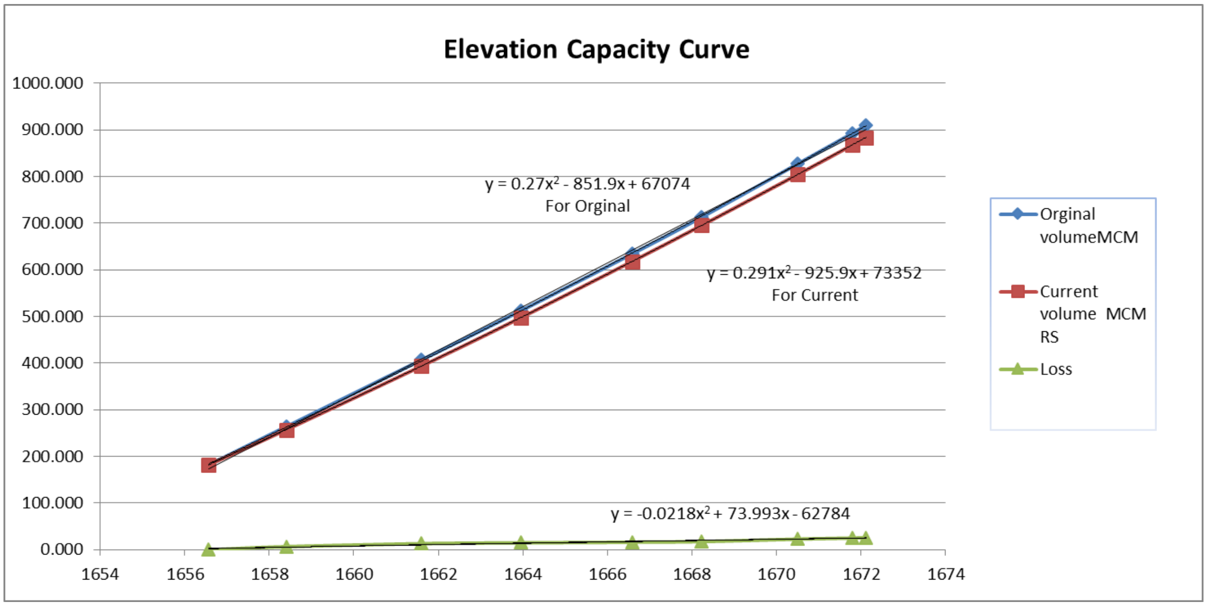
Table 4-1:- Assessment of sediment deposition in Gebi 1 hrdro power reservoir using remote sensing (RS) for the year (2016-2017)

Date of satellite pass	Reservoir Elevation a.m.s.l m	Original Area (KM2)	Original vol-ume MCM	Current Area(KM2) RS	Current volume MCM RS
Oct 11/2016	1672.12	53.251	910.401	50.403	884.208
Nov 28/2016	1671.8	52.62	893.462	49.32	868.253
FRL	1670.5	52.251	827.439	48.65	804.622
Dec 14/2016	1668.235	48.35	713.537	47.42	695.825
Jan 15/2017	1666.58	47.321	634.371	46.5	618.107
Feb 16/2017 Thursday	1663.95	45.316	512.562	45.12	497.631
Mar 04/2017	1661.6	44.51	407.018	43.21	393.852
Apr 21/2017	1658.4	44.86	264.027	42.12	257.328
May 07/2017 Saturday	1656.56	44.3	182	39.769	182

The difference between the original and estimated cumulative capacity represented the loss of capacity due to sedimentation in the live zone of the reservoir. Table 4.1 presents the volume at different dates used to calculate the sediment deposition in the reservoir. The current capacity was estimated using remote sensing techniques (809.216Mm3) was subtracted from the original capacity (827.439 Mm3) at the same level. The loss in capacity (18.223 Mm3) was attributed to the sediment deposition in the zone of study, i.e. between 1672.12 m and 1656.56 m of the reservoir from 1990-2017 G.C. Thus, the average rate of loss of capacity is computed to be 0.675 Mm^3/year for the "live zone" using remote sensing data. A comparison of the cumulative original and revised capacities obtained using remote sensing technique for the year 2017 is shown in Fig. 4.9-.The difference between the curves at any level represents the loss of capacity due to sedimentation at that level from

Fig 4.9:- Elevation capacity curves for Gibe one Reservoir

Volume (Mm3)



Elevation (m.s.l)

5 CONCLUSION

The application of remote sensing techniques for estimating the sedimentation rate in the Gibe 1 reservoir shows that the average sedimentation rate for 27 years (1990-2017) is 0.675 Mm^3 year-1, whereas ground observations through hydrographic survey provided a sedimentation rate of. 0.845Mm^3 year-1 for the period of (1990-2017). 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 use of remote sensing technique enables a fast and reasonably accurate estimation of live storage capacity loss due to sedimentation. Keeping in view the time and cost involved in hydrographic surveys, it is recommended that hydrographic surveys may be conducted at longer intervals and the remote sensing based sedimentation surveys may be carried out at shorter intervals, so that both surveys complement one another. However, there are some limitations in the remote sensing data collection method. For example, remote sensing techniques give the information on 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 on the capacity could be taken from the most recently conducted hydrographic survey or the original planning reservoir capacity. In general estimation of sedimentation by remote sensing technique is highly sensitive to water spread area determination, water level information, original elevation area capacity and accuracy in identification of water pixels.

The comparison of the result from the two different approach showed that the estimated deposition rate ranged 0.675-0.845Mm/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.

Sedimentation results for 2017 from remote sensing techniques that are comparable with 1990 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.

6 RECOMENDATION

The recommendations achieved in this study relate to the remote sensing method to assessment of sedimentation:-

- Availability of satellite data are very crucial for Periodic evaluation of sediment deposition pattern and assessment of available storage capacity of reservoir future development of water Resource management in the reservoir. Hence, the result of SRS method will contribute to solving the challenge of water management problem of the study area.
- Certainly, more accurate results would be obtained in case of considering uncertainties such as inflow-outflow method and hydrological survey method to assess sediment effect on reservoir, Hence, the results of this study should be taken as a reference for further studies on the impact sediment on hydropower generation Gibe reservoir periodically.
- It provides a good understanding for operation how to enhance hydropower energy productions, which can potentially be applied in the decision making process to further develop additional projects.
- It suggests new operation rule, and reservoir a guide curves to improve the operation of Gibe reservoirs as well as to solve some of the problem of flooding in the downstream of reservoir.
- Provide new operational guidelines that can predict the future water elevations, release decision and tractable model that can offer daily power production.
- The outputs of the study results are specifically intended to inform, water resource managers, and other interested stakeholders to make effective and economically viable plans for sustainable future development in the Gibe River Basin.
- Finally, recommends the main findings of this thesis to apply elevation capacity curves for modification of the existing system or the consideration of it for the newly planning and operation of dams and reservoirs based on the feasible results on reservoir operation.

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