2023-02

Preliminary Investigation of Dam site using an integrated method of AHP, GIS, and Multi-Criteria Decision-Analysis in Upper Blue Nile Basin, Ethiopia

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Faculty of Civil and Water Resources Engineering

MSc in Irrigation Engineering and Management

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MSc. Thesis

By

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Supervised by: Fasikaw Atanaw (Ph.D.)

Bahir Dar, Ethiopia

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A Thesis submitted to the Faculty of Civil and Water Resources Engineering , Bahir Dar University in partial fulfillment of the requirements for the degree of Master of Science in Irrigation Engineering and Management in the Faculty of Civil and Water Resources Engineering

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Bahir Dar, Ethiopia

Feb., 2023

Declaration

This is to certify that the thesis entitled "**Preliminary Investigation Dam site using an integrated method of AHP, GIS, and Multi-Criteria Decision-Analysis in Upper Blue Nile Basin, Ethiopia**", submitted in partial fulfillment of the requirements for the degree of Master of Science in Irrigation engineering and management under faculty of Civil and Water Resources Engineering, Bahir Dar Institute of Technology, is a record of original work carried out by myself and has never been submitted toany other institution to get any other degree or certificates. The assistance and help I received during this investigation have been duly acknowledged.

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Approval of thesis for defense result

I hereby confirm that the changes required by the examiners have been carried out and incorporated in the final thesis.

Name of student: Bethlehem Degu Signatures: ________ date March 7, 2023

As members of the board of examiners, we examined this thesis entitled **"Irrigation dam site selection using an integrated method of AHP, GIS, and Multi-Criteria Decision-Analysis in Upper Blue Nile Basin, Ethiopia",** We hereby certify that the thesis is accepted for fulfilling the requirements for the award of the degree of Masters of sciences in "Irrigation Engineering and Management".

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DEDICATED TO

My father Degu Terefe and my advisor Dr. Fasikaw Atanaw

ACKNOWLEDGEMENT

First of all, I would like to praise the Almighty heavenly God for his merciful help and guidance throughout my life.

I would like to express my deepest gratitude, appreciation and acknowledgement to Dr. Fasikaw Atanaw for his excellent way of support, technical advice, valuable comments, and suggestion on every step of my work from the beginning up to the end. I extend my heartfelt thanks for his unreserved guidance, positive attitude, and encouragement throughout my research to do my best in this work. I learned a lot in every step of the research.

I would like also to thank my instructor, Tewodros. Taffesse (PhD) and the staff of the Irrigation Engineering and Management chair of Bahir Dar |Institute Technology who helped me at various stages of my research. I extend my great respect and thanks to Ewenetu Tarekegn and Abatyihun Ashenefe for their support. Abay Basin Authority and ADSWE experts thank you for providing data I requested.

Finally, my special thanks go to my father for his moral support and for believing in me in pursuing this research. My heartfelt thanks go to my family and friends for motivating and strengthening me and for their love and encouragement, without whom this work would not have been completed. I express my deep gratitude to all whose names have not been mentioned individually but helped me differently in my work.

ABSTRACT

The construction of a dam helps address water scarcity in both residential and irrigation. This study uses GIS and AHP Multi-Criteria Decision Analysis to determine suitable dam sites in terms of topographical, hydrological, and environmental factors. In general, from the analysis southern, southwest and central part of the Abay basin werefound to be the densest area with high suitability for constructing dam while northeast and eastern parts were found as low or extremely low suitable area for constructing dam. Accordingly, *26.36%* of the Abay basin is in the highly suitable and very high suitability in which only *0.03%* was very highly suitable; *72.01%* of the Abay basin area was found in the moderate suitability; *1.59%* on low or extremely low suitability. Based on the suitability map, 39 dam sites were proposed with 17 being large, 9 intermediate, and 3 small based on height. The height of dams varies from 12 m to 174 m, width from 165 to 1025 m, storage from 3.16Mm^3 to 8532.4Mm^{3,} and surface area from 0.24 Mm^2 to 148.49 Mm^2. Equations were developed to support future design, such as inundation area, volume, and annual sediment trapped with an accuracy of 50%, 80%, and 90% respectively. These reservoirs improve livelihoods and reduce drought, act as a flood buffer, and recharge groundwater aquifers. They also trap sediment to benefit future generations and reduce flash floods in the high rainy season in Sudan. Some senior researchers in the Blue Nile like Whittington believe that it is economical if dams are built upstream rather than downstream, and more water will be available for downstream users to use, reducing evaporation and seepage losses(Whittington et al., 2004).

These planned reservoirs apart from their use for irrigation, they can trap a lot of sediment (353.7 M. tons/year) that could have been deposited in GERD which reduces the life time of our great dam that will benefit our children and grandchildren economically. These dams help not only in trapping sediment but also harness the flood that inundates Sudan in the high rainy season.

Keywords: GERD, GIS, MCDA, AHP, and Dam Site,

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LIST OF ABBREVIATIONS

ADSWE	Amhara Design and Supervision Work Enterprise
AHP	Analytical Hierarchy Process
ANP	Analytical Network Process
Chirps	Climate Hazards Group InfraRed Precipitation with Stations
CR	Consistency Ratio
DEM	Digital Elevation Model
DD	Drainage Density
DTM	Displacement Tracking Matrix
ET	Evapotranspiration
EACC	Elevation Area Capacity Curve
GERD	Great Ethiopian Renaissance Dam
GIS	Geographic Information System
GLOFs	Glacial Lake outburst floods
HWSD	Harmonized World Soil Database
MCE	Multi-Criteria Assessment
MCDA	Multi-criteria decision analysis evaluation
ML	Machine Learning
MOWR	Ministry of Water Resources, Irrigation, and Energy
PCMS	Pair-Wise Comparison Matrices
RS	Remote Sensing
SRTM	Shuttle Radar Topography Mission
USGS	United State Geographic Survey

1. INTRODUCTION

1.1. Background

Water is a basic human need (Gupta et al., 2020; Haghiabi et al., 2013), and it plays an important role in facilitating geophysical cycles (Smith et al., 2002), regulating microclimates and runoff cycles (Xu et al., 2020; Zhang et al., 2020), and sustaining the life activities of the Earth's organisms (Riley et al., 2018; Smith et al., 2002). Dams, on the other hand, control the hydrology of limited areas on a small scale (Biggs et al., 2017). Dams are man-made or natural barriers that bridge rivers and elevate water levels by restricting or controlling the flow of water. They regulate the geographical distribution pattern of water resources (Zionts, 2016) for soil and water conservation, water supply, irrigation, aquaculture, flood management, and power generation(Bezabih, 2021; Nguyen-Tien et al., 2018) Ethiopia is blessed with abundant natural resources, and water appears to be the most abundant of them all. The country is frequently referred to as the "water roof of East Africa." Ethiopia, blessed with this resource, is putting up a considerable effort to exploit the vast water resources that may be used to support the country's current rapid economic expansion. Dams are structures that completely block a river's valley or drainage system, effectively limiting the river's flow. As a result of the obstruction, storage is created, which can be used for various water resource development or water control purposes. As a result, the dam is the retaining structure, which can be composed of soil, rock, or concrete, and the Reservoir is the retained body of water. Agriculture in Ethiopia is mainly dependent on rainfed systems, and this dependency has put the majority of the Ethiopian population at the mercy of meteorological variability. With increasing meteorological variability due to changing climate, it is highly probable that the rainfed agriculture of Ethiopia will be vulnerable to its effects.

The construction of a dam is an important solution to the problem of water scarcity for both residential and irrigation purposes, which is exacerbated by low rainfall and prolonged dry seasons, which result in droughts. The focus of this work is on locating a suitable dam site for dry season irrigation. The key issue is determining an effective, efficient, and accurate approach for dam site selection, including precise terrain assessment and sufficient information on the chosen site for optimum planning and design. The basin qualities, such as slope, soil, geology, land cover, and catchment, as well as social-economic variables, such as proximity to a road and proximity to a river, must all be taken into account when choosing a good site for an earth dam (Dorfeshan et al., 2014). Slope and the area's physical characteristics are the most influential factors as they determine the inundation behavior of the area under consideration(Saleh Alatawi, 2015). The slope is a crucial determining element in whether dam construction is required to create suitable habitat, and it also determines river energy and velocity, making it strongly linked to flood plain extent and river bank materials (Njiru & Siriba, 2018).

Dam sites are typically chosen using traditional methods such as traditional decision-Analysis techniques or based on political considerations. Remote sensing (RS), geographic information systems (GIS), and Multi-Criteria decision-Analysis (MCDA) tools, on the other hand, have recently emerged as the most appropriate approaches to understanding dam locations. Advances in satellite and computational power have improved the ability to control many hydrologic parameters and terrain aspects in recent years. RS and GIS provide a lot of flexibility when it comes to combining spatial data with advanced numerical, factual, and decision-making strategies including fuzzy logic, analytical hierarchal processes (AHP), weighted overlay analysis, multi-criteria evaluation techniques, and artificial intelligence(Al-Ruzouq et al., 2019).

1.2. Statement of the Problem

Dam site selection is typically done using traditional decision-making procedures or based on based on interest of few people/criteria (Jozaghi et al., 2018). These methods are typically driven by a top-down approach, with limited public participation and a focus on technical and economic factors over environmental and social considerations.

The selection of a dam site involves the consideration of a wide range of criteria, such as topography, hydrology, geology, environmental impact, and social and economic factors. In many cases, the data available for the selection of dam sites is limited or outdated, which can make it difficult to make informed decisions. In addition to that conventional methods of dam selection often rely on subjective judgments and opinions, which can introduce biases into the decision-making process. Conventional methods also lack transparency, making it difficult for stakeholders to understand how decisions are made and why certain sites are selected. Therefore, the conventional selection of dam sites is difficult due to the complexity of decision-making, limited data, subjectivity, stakeholder conflict, and lack of transparency.

The development of computing and information technology has tremendously aided in the determination of competitive solutions in terms of cost, time, and a number of other objective variables. Geographical Information System (GIS) and its hydrology-related applications are a potent tool that significantly contribute to this process. GIS as a computer-based system that can integrate large layers of data and handles attribute data and spatial data with geographic information as a crucial component is a great help in this regard.

The use of such technology as GIS, AHP and MCDA has still remained as a challenge in the lifecycle management of dams in Ethiopia. Hence the integrated use of GIS, AHP and MCDA methods can help to address these challenges, providing a more integrated, objective, and transparent approach to the selection of dam sites.

Economically speaking, if dams are built upstream rather than downstream, there is more water available for downstream users to use, reducing evaporation and seepage losses(Whittington et al., 2004).

This research therefore focuses on the use of multi criteria analysis integrated with GIS, AHP to select suitable area for water inundation /reservoir and selecting the appropriate dam site in the Blue Nile Basin. The dams will be selected considering initially for irrigation but can be used for flood control and trapping sediment for the Great Ethiopian Renaissance Dam (GERD)

1.3. Scope of the Study

This study tries to identify preliminary investigation dam sites using GIS, Analytical Hierarchy Process, and multi-criteria decision-Analysis in the upper Blue Nile Basin in Ethiopia. The work will extend to the determination of the dam axis, developing the reservoir characteristics like Elevation- Area- capacity curve, and mapping and quantifying the inundated areas and determination of accumulated sediment taraped in the reserviours for all the selected dams.

1.4. Significance of the study

Remote sensing (RS) and geographic information systems (GIS) on the other hand, have lately emerged as some of the most effective methods for analyzing dam sites. Advances in satellite and computational power have improved the ability to control a variety of hydrologic parameters and topographical conditions in recent years. Experts can do the field research from their offices, saving time and money and allowing us to assess the project's feasibility and drawbacks. It can reduce costs and increase efficiency, especially in maintenance, vehicle movements, and scheduling calendars with the traditional method of dam site identification.

The thesis will highlight the use of a GIS tool and multi-criteria decision analysis approaches to identify potential dam areas in watersheds, which is useful for delivering optimal water resource spatial distribution patterns for irrigation and other purposes.

The output from the use of GIS, AHP, and MCDM methods in dam selection can provide valuable information for further future works in several ways: For example for, the selection process can serve as a baseline for future monitoring and evaluation of the dam's performance and impact on the environment and communities; The output can be used to support decision-making in future dam-related projects, such as expansion or rehabilitation, as well as in similar projects in other regions.

Therefore, the use of GIS, AHP, and MCDM methods can provide a useful and comprehensive output that can support future dam-related activities and decision-making. By using these methods, the decision-making process can become more transparent, systematic, and objective, leading to a better selection of dam sites with lower risk and higher benefits.

1.5. Objectives

1.5.1 General Objective

The goal of this research is to identify potential preliminary investigation of dam site using GIS, Analytical Hierarchy Process, and multi-criteria decision Analysis in Upper Blue Nile Basin.

1.5.2. Specific Objectives

The specific objectives of the research are:

- To prepare different thematic maps using AHP, MCDA with a weighted overlay on the upper Blue Nile
- To select the appropriate dam axis on the narrow part of the topography and extract the x-section of the dam and associated attributes
- To develop the reservoir characteristics like Elevation-Area- capacity curve and mapping and quantifying the inundated areas, dam height, width, catchment area and Develop equations relating dam height with reservoir capacity, dam height with inundation area and reservoir capacity with annual sediment trapped for the Upper Blue Nile reservoirs

1.6. Research Questions

- What are the the most influential factors for dam selection and their weights?
- What is the process for selecting the appropriate dam axis on the narrow part of the topography and extracting the cross-section of the dam and associated attributes?
- What are the methods used to develop the reservoir characteristics such as the Elevation-Area-Capacity curve, mapping and quantifying the inundated areas, dam height, width, and catchment area?
- What kind of equations can be developed to relate dam height with reservoir capacity, dam height with inundation area, and reservoir capacity with annual sediment trapped for the Upper Blue Nile reservoirs?
- What kind of relations can we develop from extracted information?

2. LITERATURE REVIEW

2.1. General

Dams are man-made or naturally occurring barriers that control or block water flow to cross rivers and raise water levels. They control the spatial distribution of water resources for soil and water conservation, water supply, irrigation, and other purposes. Aquaculture, flood management, and electricity generation are all important aspects of the industry. Dams are necessary for hydraulic projects, however, not all dam construction processes follow a systematic and rigorous decision-making process. Because of anthropogenic and political factors, the technological aspects of the problem are still being disregarded. Reasonable siting solutions are cost-effective and take into account the ecological and energy balance (Baban, S. M. J., & Wan-Yusof, 2003). Multi-purpose dams facilitate human life by purveying water for household purposes, irrigation activities, hydropower generation, and reducing flood risk (Yilma & Awulachew, 2009).

The suitable site of hydro-projects has the least pessimistic environmental impacts (Ledec & Quintero, 2003). Therefore, site suitability analysis for the construction of the dam is crucial (Ramakrishnan et al., 2009) by considering geographical properties like downstream conditions (Wen et al., 2020), lakes(Zhou et al., 2019) , and geological hazards (Chen et al., 2011; Niu et al., 2007). Water is one of the essential components of all human activities and supports life(Araujo et al., 2006). The distribution of water has been uneven and further disturb by global variability in climate (Dai, 2016a). Snow and glaciers melting due to the temperature rise have increased the discharge of rivers and the frequency of Glacial Lake outburst floods (GLOFs). Similarly, variation in the amount and spatial pattern of rainfall has further intensified the magnitude and frequency of floods in the areas which receive more precipitation and drought in arid regions(Ali et al., 2017) .

To avoid such a disaster and for the sake of development, dams provide a sustainable amount of benefits to humanity, such as flood risk mitigation, agriculture, and hydropower production (Bizzi et al., 2012; Hecht et al., 2019).

Remote sensing (RS), geographic information systems (GIS), and machine learning (ML) techniques, on the other hand, have lately emerged as some of the most effective methods for analyzing dam sites. Advances in satellite and computational power have improved the ability to control a variety of hydrologic parameters and topographical conditions in recent years. RS and GIS combine spatial data with advanced numerical, factual, and decision-making procedures such as fuzzy logic, analytical hierarchal processes (AHP), Boolean logic, weighted overlay analysis, multi-criteria evaluation techniques, and artificial intelligence (Li et al., 2020).

Dams' economic benefits surpass their disadvantages and expenses, offering a compelling cause for their construction around the world. One of the most difficult and contentious decisions in water supply management is determining the appropriate location for a dam (A. Noori et al., 2018). A good site selection can improve the security of a region's reservoir and groundwater regeneration, whereas a bad site selection can have the opposite effect.

Dams are responsible for bringing larger areas under agriculture and allowed in the green revolution with high-yielding crops and fertilizer application a few decades ago, ensuring food security in the face of an ever-increasing population. Water consumed more than ET demands, on the other hand, enters the system as surface or groundwater, but with quality degradation due to fertilizers and pesticides, as well as minerals taken from soils (Schultz, 2002)

consumer of storage..

2.2. Factors for Suitable Dam Site Location

According to Othman et al., (2020) analyzed the factors in different papers before making a decision on the selection of factors, and concluded that 70% used land use, soil type, slope, sedimentation, and CN grid; 20–40% used elevation, drainage networks, distance to lineaments, lithology, distance to faults, tectonic zone, distance to villages, distance to roads, and distance to towns; and less than 10% of the articles used distance to materials, total dissolved solids (TDS), evapotranspiration, and depression volume. Nevertheless, rainfall, slope, land use, geological lithology, and soil type are all important factors in different siting scenarios. From the literature review, experts' judgment, and most importantly available data seven of those criteria were selected to identify potential sites for dams. Those are slope, land use/land cover, soil type, precipitation, stream order/drainage density, geology and TWI was selected criteria or factors for investigation of suitability dam site.

*Table 2-1**:** Selected criteria. (Njiru & Siriba, 2018)*

Factor	Explanation based on expert's opinion
Slope (Topography)	The gentle the slope the better
Geology	Stronger foundations are preferred for dam construction
Soil type	The lower the soil infiltration rate, the better
Land Cover	Land cover prone to soil erosion is less conducive for dam
Drainage density	The highly and nearer stream order of the dam to the river
TWI	The highly TWI better
rainfall	The highly rainfall better

Table 2-1 shows the various aspects and accompanying criteria that are used to evaluate the selection of a suitable dam construction location. Following that, each of the elements is discussed below.

A) DEM

DEM data can be retrieved from the following websites:

1. United States Geological Survey (USGS) Earth Explorer website: https://earthexplorer.usgs.gov/
2. NASA's SRTM Mission Website: https://lpdaac.usgs.gov/dataset_discovery/measures/measures_products_table/srtm_90_v4.
3. Viewfinder Panoramas: http://www.viewfinderpanoramas.org/dem[3].html

These websites provide access to SRTM data in various formats, such as Geo TIFF, ASCII, or IMG. The data used in this study is retrieved from the Earth Explorer website.

The SRTM Digital Elevation Model (DEM) with 30m resolution has been used for to generate drainage density, elevation and slope maps for dam suitability analyses in the research region.

B) Topographic Wetness Index(TWI|)

Topographic factors reflect important topographic features that directly determine whether a dam can find a suitable or optimal location TWI describes the spatial pattern (location and size) of saturated areas affected by watershed-scale hydrologic processes, and characterizes the proportional relationship between moisture and contributing areas(Pourali et al., 2016) . In contrast, the Topographic Wetness Index (TWI) is an immediate solution, allowing rapid ascertainment of the distribution of overland flash-flood-prone areas in a given study site. The TWI is determined using a spatially distributed conceptual model which can be used in a Geographical Information System (GIS) environment. The TWI describes the location and size for saturated area subject to overland flow (Wimmer et al., 2019). The TWI was developed by (Beven & Kirkby, 1979) as a part of the runoff model in TOPMODEL. Due to the ease of implementation of the TWI, simple physically-based principles, less dependent on user inputs and representing a consistent approach to the parameterization of water movement (Hjerdt et al., 2004), have become widely used in modelling hydrological processes, biological processes, vegetation patterns, and studies in forests (Sørensen et al., 2006). The TWI formula takes on the form of Eq. 1 below:

$$TwI = LN\left(\frac{\alpha}{TAN\beta}\right) \qquad \text{Equation 1}$$

Equation 1: Original form of the TWI formula(Beven & Kirkby, 1979) In Eq. 1, W is the TWI index, a is equal to the upslope catchment area divided by the contour length along with the flow pathway, and tanβ shows the steepest downslope direction. The index describes the impact parameters of slope on the hydrological processes. In terms of a specific catchment, TWI describes the water trend accumulating at a given point and the local slope indicates the effect of gravitational forces on water movement.

C) Slope

The slope has an impact on dam safety since steep slopes increase the risk of landslides and put additional pressure on foundations (Njiru & Siriba, 2018). Elevation and slope are the main criteria reflecting topographic characteristics. It is generally accepted that areas of moderate elevation are more suitable for dam construction, while lower and higher elevations show weak suitability (A. M. Noori et al., 2019; Othman et al., 2020); however, researchers differ in their views on the suitability of steep versus moderate slopes for dam construction. (Othman et al., 2020) argued that steepness is the main factor influencing dam siting, with smooth land being more suitable for dam construction than steep slopes, as did (Buraihi & Shariff, 2015). As the slope increases, so does the risk of landslides and the pressure on building foundations (Dai, 2016a; Njiru & Siriba, 2018). Al-Ruzouq et al., (2019) concluded that water velocity is proportional to slope and that a slope of less than 5% has a positive effect on soil and water conservation in reservoirs, while (Jha et al., 2014) argued that the slope should be less than 15 °.

Slope can be described in two different ways. One is the degree of slope, which is used in this study and indicates the angle between the ground surface and the horizontal plane. The other one is the percentage slope which indicates the percentage ratio of elevation change to horizontal distance change. Slope can be generated according to DEM using the Pythagorean Theorem. For constructing a dam, different slope thresholds have been chosen in previous studies such as less than 10 percent which equals 5.71 degrees (Singh et al., 2009), and less than 3 percent which equals 1.72 degrees (Saleh Alatawi, 2015). In research on watershed resource prioritization, the slope is categorized as gently sloping (5 degrees), moderately to steeply sloping (5 to 18 degrees), and steep to very steep sloping (more than 18 degrees) (Adinarayana et al., 1995).

D) Geological Factors

Geological circumstances influence not only the character of formations but also the materials that can be used to build dams(Lashkaripour & Ghafoori, 2002). Competent rock foundations, which include igneous rocks such as granite, offer relatively good resistance to erosion, filtration, and pressure (Njiru & Siriba, 2018). A site with an impermeable geological/dam foundation and no leakage is one of the most significant factors, as it allows for easy construction and a guaranteed firm structure(Mati et al., 2006). The amount of water that can permeate is affected by the type of soil. Foundations of fine-grained, water-resistant soils, including clay soils and their combinations(Zhan et al., 2003), are recommended for dam building(Biswas, 1968). Among various natural factors that affect dam construction, none are more important than the geological ones(Lashkaripour & Ghafoori, 2002). In a summary of dam performance statistics, foundation problems are found to be the most common causes of dam failure(Hencher, 2020) (Shao, Z., Jahangir, Z., Yasir, Q. M., & Atta-Ur-rahman, 2020). Competent rock foundations are rocks with relatively high resistance to erosion, percolation, and pressure (US Army Corps of Engineers 2005). For a desirable foundation, igneous rocks such as granite; metamorphic rocks such as quartzite; sedimentary rocks such as thick-bedded sandstones, flat-lying sandstones, and limestones are among the most satisfactory materials (NShellum, C. J., & Trudnak, 2005).

The geological conditions of the dam site are critical and directly affect the safety and stability of the project. The geological foundation of the site also affects the dam type(Biswas, 1968) and dam construction materials(Lashkaripour & Ghafoori, 2002; Njiru & Siriba, 2018). The site should have impermeable geology, a dam foundation, and no leakage; for example, southwest China is a typical karst landscape region, and the lithology directly affects whether the water will "leak away" after the dam is built (Zhang et al., 2014). Geological-related indicators include geology/lithology, tectonic zones, distance to faults, and distance to lineaments. Lithology is the most important geological factor (Jozaghi et al., 2018), which was used 68% of the time, with which the influence of faults and tectonic lines are considered. Different epochs form ground rock units representing different conditions of stability and degrees of pressure resistance (Othman et al., 2020).

E) Land use land cover

The land cover of an area shows the present use and pattern of the land, as well as the value of that usage about the population and the current development(Ajin et al., 2013). Changes in land use and vegetation often have an impact on the water cycle, with the density of plant cover and the shape of plant species playing a role (Ghoraba, 2015). An ideal dam site should have a catchment area that is not too small to prevent the dam from filling, nor too large to necessitate the installation of an expensive spillway(Zhan et al., 2003). The size of the drainage basin within the area or the catchment areas guides this. The dam site should be easily accessible so that the requisite population can be economically connected(Zavadskas et al., 2014).

F) River network and stream discharge drainage density

Drainage networks are areas of land from which all surface water converges and be transported to other locations through fluvial process. For selecting location for constructing dams, it is necessary to have drainage networks extracted. The river network provides the essential runoff for the dams, and different river network classes indicate different runoff volumes when the rivers are upstream tributaries and downstream main stems. River network density reflects the water resources in the region, and a higher river network density shows better diversion capacity in the face of floods, while river network density and flood volume show a positive correlation trend(Rahmati et al., 2019) . The river network rank indirectly reflects the runoff volume, where higher-order rivers have higher runoff volume.

Drainage networks are areas of land from which all surface water converges and be transported to other locations through the fluvial process for selecting a location for constructing dams, it is necessary to have drainage networks extracted. The basic idea of the popular drainage networks extraction method comes from 1984 By using digital elevation data as input, F. O'Callaghan and M. Mark proposed an effective method for extracting drainage networks in their work (Mark et al., 1984), the proposed method consists of a sequence of procedures, which contains elevation smoothing (optional), flow direction assignment, drainage feature assignment, drainage basin labeling, interior pit removal, drainage accumulation, drainage feature assignment, and channel link recovery.

2.3. Integration of GIS and AHP

Despite its capacity in spatial analysis, GIS alone does not have the capabilities to integrate all decision aspects linked to land suitability assessment. It should instead be used in conjunction with other evaluation and assessment tools, such as the AHP, Multi-Criteria Decision Analysis approaches.

According to (Özkan et al., 2019), AHP Multi-Criteria Decision Analysis has functionalities and characteristics that make it a suitable approach. These functionalities and characteristics include the ability to handle decisions involving subjective judgments, multiple decision makers, and, most importantly, the ability to provide consistent measures of preference. Dorfeshan et al., (2014) define AHP Multi-Criteria Decision Analysis as an approach based on three analysis principles: binary comparison, summarizing, prioritizing, and selecting. It is used within GIS to establish the weights for the selected criteria, and it can deal with contradictory judgments. The method is based on the creation of a series of Pair-wise Comparison Matrices (PCMs), which are used to compare all of the criteria. Aziz et al., (2016) provided a scale of 1 to 9 for PCM elements. These values represent the number of times one element is more important than another. The weight estimate is then calculated, which is subsequently utilized to calculate the consistency ratio (CR) of the pair-wise comparisons. PCM consists of a consistency check in which judgment errors are discovered and a consistency ratio is generated, as detailed by(Al-shabeeb, 2016). If the CR value is larger than 0.10, certain pair-wise values must be reviewed, and the operation must be repeated until the desired CR value of less than 0.10 is reached. Overlay analysis is then done to get the overall summation of the weight of each contributing factor. After then, overlay analysis is used to calculate the total weight of each contributing factor. In a GIS environment, the overlay inputs include all contributing factor layers normalized to a common scale. The chosen weight is multiplied by each input raster. It then combines all of the input raster to create the final suitability.

2.4. Elevation-Area- Capacity-Curves

Area-capacity curves are of the most important physical characteristics of reservoirs. These curves are used for reservoir flood routing, dam operation, determination of water surface area and capacity corresponding to each elevation, reservoir classification and prediction of sediment distribution in reservoirs. As a result, obtaining the area-capacity equations has great significance from a practical point of view (Haghiabi et al., 2013). Besides this, these relations are site specific, and are usually derived from a detailed bathymetry map. To be able to assess the sedimentation rate or to determine sustainable water withdrawal rates, the Elevation-Area-volume or stage curve relationships provide invaluable information. The reservoir depth-area-volume relationship is important information for water resource planning and management, hydrology and modeling. However, it is laborious, time consuming and costly to obtain them, specifically in areas with large number of this infrastructures.

The elevation-area capacity curve (EACC) is an important tool in the design and operation of dams and reservoirs, and its development has several important benefits, including:

Water storage capacity: The EACC is used to determine the water storage capacity of the reservoir as a function of the water elevation or water level. This information is crucial for planning and managing the water resources of the reservoir, including flood control, irrigation, water supply, hydropower, recreation, and environmental management.

Flood control: The EACC is used to determine the flood storage capacity of the reservoir, which is the amount of water that can be stored during a flood event to reduce downstream flood peaks and prevent damage to communities and infrastructure.

Irrigation and water supply: The EACC is used to determine the usable water storage capacity of the reservoir, which is the amount of water that can be withdrawn for irrigation, domestic, industrial, and other uses, without compromising the flood control and environmental objectives.

Hydropower generation: The EACC is used to calculate the head (difference in water level) and flow rate of water that can be generated by a hydropower plant, which depends on the available water storage in the reservoir.

Environmental management: The EACC is used to monitor and manage the environmental impacts of the reservoir, such as water quality, sedimentation, and downstream flow regimes, as well as to assess the potential impacts of climate change and variability on the reservoir operation and performance.

Safety and risk management: The EACC is used to assess the safety and stability of the dam and reservoir, including the potential for overtopping, seepage, landslides, and other hazards, and to develop emergency action plans to mitigate and manage risks.

2.5. Development of relationship between depth, area, and volume

Water Storage Capacity: The volume of water in a reservoir is directly proportional to the water depth and the area of the reservoir. By understanding this relationship, water managers can determine the maximum amount of water that can be stored in a reservoir and how it changes with changes in water depth.

Flood Control: Reservoirs can be used to store excess water during periods of high runoff and then release it during periods of low runoff. By understanding the relationship between depth, area, and volume, water managers can estimate how much water can be stored in a reservoir during a flood and how quickly it can be released to control the flood peak.

Hydropower Generation: Hydroelectric power plants use the energy stored in falling water to generate electricity. By understanding the relationship between depth, area, and volume, water managers can determine the amount of water that is available for hydropower generation and how it changes with changes in water depth.

Water Quality Management: The water depth in a reservoir can affect the water temperature, stratification, and mixing patterns. By understanding the relationship between depth, area, and volume, water managers can predict how changes in water depth will affect water quality and manage it accordingly.

Its importance in several aspects of dam engineering and management, inDesign and planning: The volume-depth curve is used to determine the optimal design of the dam, including the height, crest length, and spillway capacity, based on the desired water storage capacity and the environmental, economic, and social constraints.

Flood control: The volume-depth curve is used to calculate the flood storage capacity of the reservoir, which is the amount of water that can be stored during a flood event to reduce downstream flood peaks and prevent damage to communities and infrastructure.

Irrigation and water supply: The volume-depth curve is used to determine the usable water storage capacity of the reservoir, which is the amount of water that can be withdrawn for irrigation, domestic, industrial, and other uses, without compromising the flood control and environmental objectives.

Hydropower generation: The volume-depth curve is used to calculate the head (difference in water level) and flow rate of water that can be generated by a hydropower plant, which depends on the available water storage in the reservoir.

Environmental management: The volume-depth curve is used to monitor and manage the environmental impacts of the reservoir, such as water quality, sedimentation, and downstream flow regimes, as well as to assess the potential impacts of climate change and variability on the reservoir operation and performance.

Overall, the relationship between the reservoir depth and the reservoir volume curve is crucial for water resource planning, hydrology, and modeling and for the effective and sustainable operation and management of dams and reservoirs.

2.6. Role of trap efficiency for estimation of reservoir sedimentation

Reservoir sedimentation is a great problem in all over the world, because it reduces the reservoir capacity by accumulation of sediments coming from watersheds. Therefore, managing and minimizing this problem is essential; hence, knowledge on the amount of sediments accumulated in a reservoir and addressing different methods for estimation is very important. There are several methods to estimate the amount of sediments accumulated in reservoirs, one of these methods is trap efficiency method proposed by Brune (1953) and developed by Gill, 1979; dendy, 1974; Heinemann, 1981; Jothiprakash and Garg, 2008 and it is the best method. This method used to estimate the amount of sediments accumulated in a reservoirs by estimating the trap efficiency using the reservoir capacity-inflow ratio. Trap efficiency is a key factor in estimating reservoir sedimentation, as it measures the effectiveness of the dam and reservoir in trapping and retaining sediment carried by the river. The role of trap efficiency in estimating reservoir sedimentation is as follows: Sediment trapping: The trap efficiency represents the fraction of the total sediment load carried by the river that is trapped and retained in the reservoir, as opposed to being transported downstream. The higher the trap efficiency, the more sediment is retained in the reservoir and the lower the rate of sedimentation. It can be used for Sediment budget: The trap efficiency is used to calculate the sediment budget of the reservoir, which is the balance between the sediment inflow and outflow from the reservoir. The sediment budget is used to estimate the sedimentation rate and the sediment accumulation in the reservoir over time. It is also used for design and planning: The trap efficiency is used in the design and planning of dams and reservoirs, to determine the optimal size, shape, and operating conditions of the reservoir, based on the sediment load and the desired water storage capacity. The trap efficiency also influences the design of the spillway, the outlet works, and the sediment flushing systems of the reservoir, which are used to regulate and manage the sediment in the reservoir. The trap efficiency is used to monitor and manage the sedimentation in the reservoir over time, to ensure the safe and sustainable operation of the dam and reservoir, and to prevent or mitigate the impacts of sedimentation on the water quality, the water supply, the hydropower generation, and the environment.

Overall, trap efficiency is a critical factor in estimating reservoir sedimentation, as it provides important information on the sediment trapping and retention capacity of the dam and reservoir, and guides the design, operation, and management of the reservoir to ensure its long-term viability and sustainability.

However, determining the inflow to the reservoir is difficult, because it needs upstream gauging stations for every reservoir, but installing gauging stations at upstream of every reservoir is difficult, especially for developing countries because of its high cost. Therefore, indicating another mechanism, which will easily estimate the amount of trapped sediment in the reservoir with low cost and easily available data, is very important.

The trap efficiency of all the dams is estimated after the capacity of all the dams is estimated from the Elevation-Area-Capacity and the yield/inflow is estimated from annual dependable rainfall of Chirps. We used CHIRPS because of unavailability of time series annual rainfall data for the selected watersheds.

3. MATERIALS AND METHODOLOGY

3.1. Study Area Description

The Abay Basin in Ethiopia is located between 7° 40' N and 12° 51' N latitude and 34°25' E and 39° 49' E longitude in the northwestern part of the country. With a surface size of 199,812 square kilometers, the basin is the second largest in the world. In terms of a variety of criteria, the river basin is regarded as Ethiopia's most significant river basin. It covers 60 percent of Amhara, 40 % of Oromiya, and 95 percent of Benishangul-Gumuz regional states, accounting for 20 percent of the country's territory. It is bordered on the north by the Tekeze basin, on the east and south by the Awash basin, on the south by the Omo-Gibe basin, and on the west by the Baro-Akobo basin. To the north of the basin is Lake Tana, the country's largest freshwater lake. Based on the basin's principal rivers, the Abay River and its tributaries, the basin is divided into 16 sub-basins (See Fig.1 below).

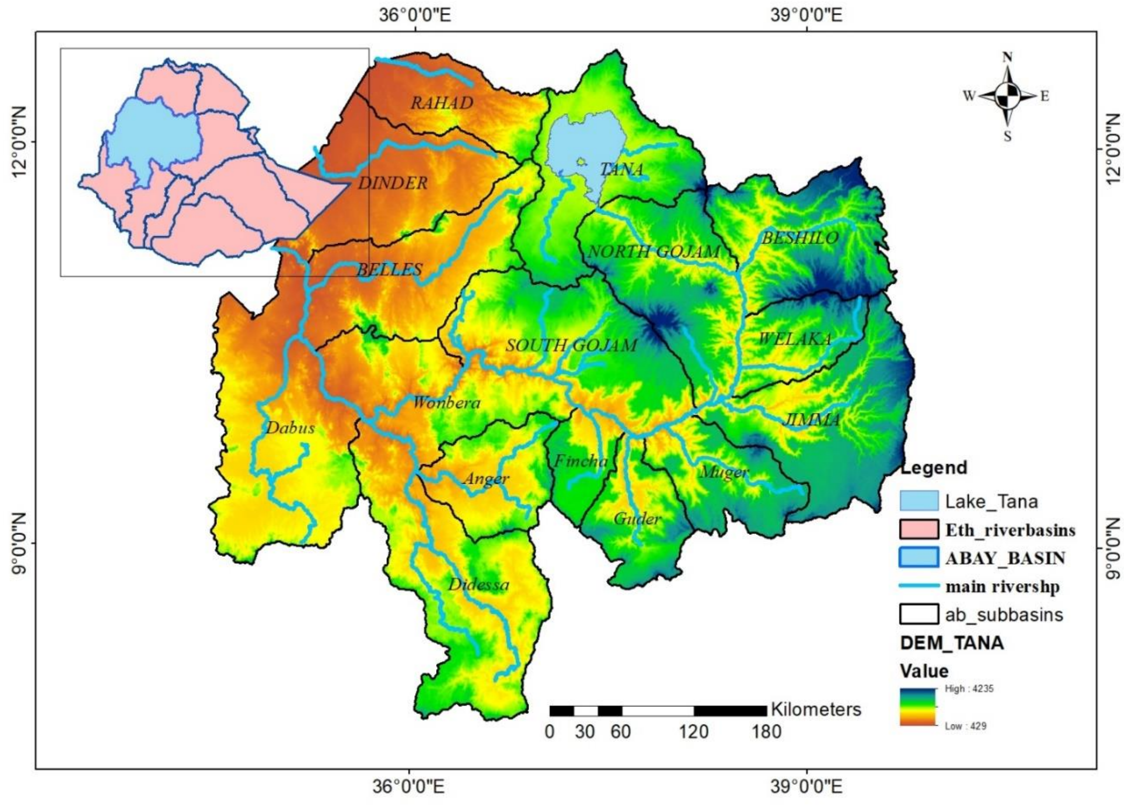


Figure 3-1: Location of the study area

3.2. Methodology

3.2.1. Collection of data and information

The overall methodology of this research is shown in below to find suitable sites for dam construction, various types of data were collected

Table 3-1: Various types of data

Data type	Source	Spatial resolution (m)
Digital Elevation Model (DEM)	United States Geological Survey (USGS) SRTM	30
Land use land cover	(USGS) Esri_2020_Land_Cover_V2 Image Server	30
Soil	Abay basin Authority	30
GEOLOGY	Abay basin Authority	30
Rainfall	Chirps (KNMI Netherlands) http://climexp.knmi.nl/	30
Ethiopian Administrative Boundary	https://gadm.org/download_country.html	30
Master plan Dams	Abay Basin Authority	

from different sources. Satellite Imagery (Landsat 8 OLI) was downloaded from the USGS ESRI 2021 website which has 10 m spatial resolution. Images taken on 2021 were pre-processed, processed, and then post-processed to produce the land use and land cover map of the study and the data were mosaicked and resample to 30m spatial resolution area. In this study, ArcGIS software was used to produce other maps. Digital Elevation Model (DEM, 30 m × 30 m) was extracted from USGS, ArcGIS10.3 is used for processing imagery datasets including DEM, soil, geological layer, land cover, precipitation and products from these datasets. Excel 2013 is used for simple statistical analysis and creation of tables and histograms. DEM was used to extract the drainage network, elevation, TWI and slope of the study area. Collection of data and information to achieve the objectives of the study different input data that were used for suitability analysis of the dam site include physical (Slope, TWI (Topography), precipitation, geology, soil type, drainage density, land cover is just a few of the characteristics that influenced dam site selection. were collected from an online source and different governmental and nongovernmental offices. These suitability factors were selected from other factors by considering literature and expert opinion on irrigation potential assessment. Materials used to effectively execute the research included ArcGIS10.3 and EXCEL.

3.2.2. Methods of Data Analysis

Following the collection of all relevant data from various data sources, further analyses were conducted for each physical land suitability aspect to assess the suitability of the indicated area for site dam. Based on the literature review, this study selected 7 criteria. for the determination of suitable areas for dam construction: rainfall, slope, drainage density, soil texture, geology, TWI and land use land cover. Hydrological parameters such as stream network flow accumulation, elevation, TWI and slope were derived from the DEM using ArcGIS 10.3 software and using excel. The altitude map was derived from the DEM of the study area. The identification of suitable sites for dam site identification was done by using GIS in combination with a multi-criteria evaluation system (MCE). It consists of four steps:

I. Selection of criteria and prepare a spatial dataset
II. Classification of the suitability level of each criterion
III. GIS analysis and generation of suitability maps for dam site
IV. Site identification to propose dam site structures
V. Determine the dam axis, developing the reservoir characteristics like Elevation-Area- capacity curve and mapping and quantifying the inundated areas, dam height, and width etc.

3.2.3. Criteria selection and suitability Analysis

Potential dam suitability sites were identified by integrating different criteria that are expected to have influence for site selection and used to identify potential locations for dam site. According to Al-Ruzouq et al., (2019) Nine layers were developed for the study area: precipitation, DSD, geomorphology, geology, CN, total dissolved solid, elevation, slope and major fractures. Many processing techniques and statistical algorithms were utilized in a spatial context to develop these thematic layers. The next subsection presents details about each thematic layer , Based on Dai, (2016b) studies, for specific conditions of Bortala region, and data availability, *6(six)* criteria were considered as main factors including: level of drainage network, precipitation amount, topographic conditions (slope), soil type, land cover, and resistance of geological layer(Shao, Jahangir, & Yasir, 2020).

Considering the differences in the natural environment, social environment, and goal, (Wang, Y., Tian, Y., & Cao, Y. (2021).)observed that the selection of components amongst dams exhibited certain similarities and features after reviewing a significant number of studies. Future site selection studies can benefit from having a reference for the types and frequency of criteria in various articles. Advanced information regarding the application of modern study factors is crucial. For instance, (Othman et al., 2020) examined the factors in various papers before choosing the factors to be used and found that 70% of the articles used land use, soil type, slope, sedimentation, and CN grid; 20–40% used elevation; distance to lineaments; lithology; distance to faults; tectonic zone; distance to villages; distance to roads; and distance to towns; and less than 10% used distance to materials and total dissolved solids. However, in various siting scenarios, rainfall, slope, land use, geological lithology, and soil type are all significant variables. Seven of those criteria were chosen to identify possible dam locations based on the literature, the opinions of experts, and most crucially, based on readily data availability. These include geology, TWI, slope, soil type, rainfall, stream order/drainage density, and land use/land cover.

3.2.4. Dam Site Suitability Analysis

The dam suitability is done using an overlay analysis in ArcMap. The procedure consists of several significant stages, 1st generation of thematic raster layers of all the selection criteria; 2nd reclassification of all layers; 3rd assigning weightage; 4th overlay analysis; 5th proposing and selection of dam sites ; 6th validate the suitability map .For this study, rainfall map of the area was download from CHIRPS KNMI(http://climexp.knmi.nl/). The drainage maps have been prepared using the line densityanalysis tool in Arc GIS 10.3 and the geological, soil and land use thematic maps wereprepared using Arc GIS 10.3. The slope, TWI, elevation, and drainage densitywere derived from 30m resolution DEM was obtained from USGS and used as input data in ArcGIS to delineate watersheds and to derive slope maps of the study area for irrigation suitability analysis. All the steps are discuses in flowchart Figure 3-2.

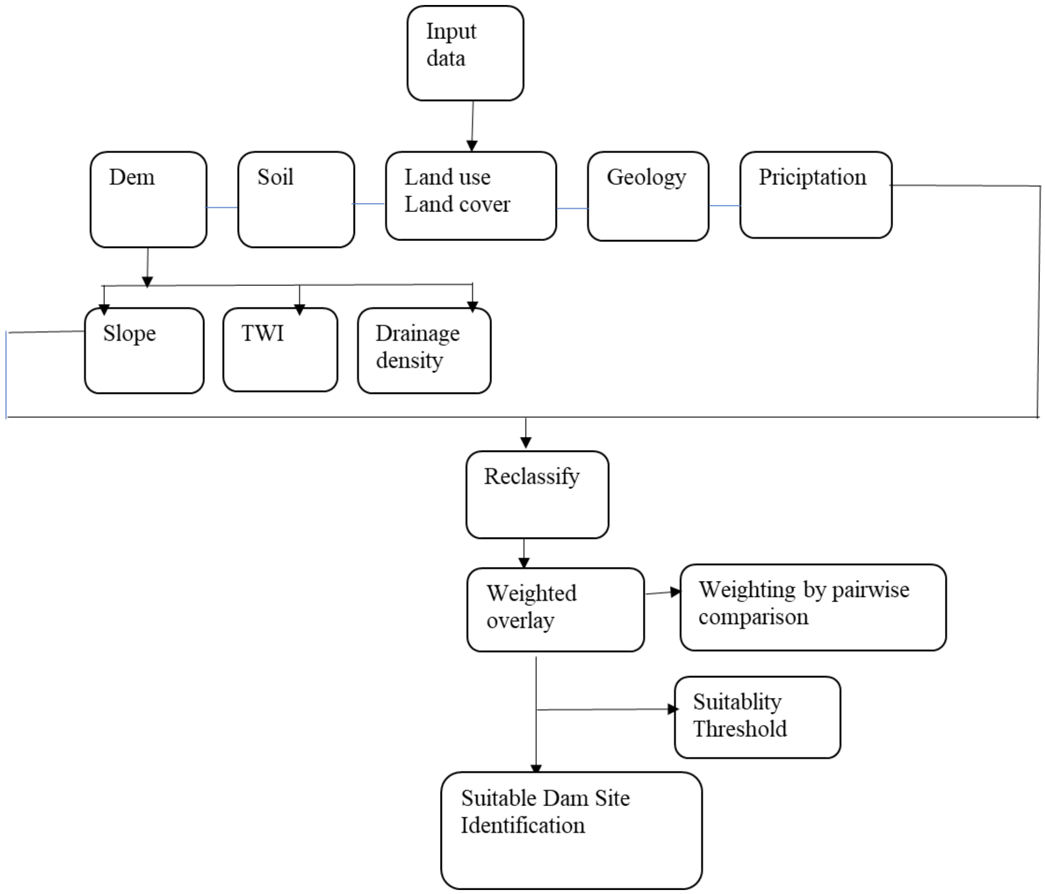


Figure 3-2: Flow chart of this study area

3.2.5. Thematic Layer

Thematic layers were classified as indicated Scores (S) is assigned to each class according to the order of the influence of the class on dam site susceptibility. Assigned S values of 1–5 was adopted, where S = 1, 2, 3, 4, 5 imply very least, less, medium, high, very high dam suitability, respectively. The score values of all thematic layer classes are also shown in below tables.

3.2.5.1. Precipitation (Rainfall) Analysis

Chirps (Climate Hazards Group InfraRed Precipitation with Stations) is a dataset that provides rainfall information for data scarce regions. It is created by combining satellite data with ground-based rainfall measurements to produce a more accurate rainfall estimate. This dataset can be useful for planning reservoirs in data scarce regions as it provides information on the amount and distribution of rainfall, which is crucial in determining the water supply for a reservoir. CHIRPS data can help decision makers in these regions make informed decisions on the design, capacity, and operation of the reservoir, ensuring that it meets the water needs of the community. We used CHIRPs data without bias correction because we are doing preliminary investigation of dam site .

For the Abay basin, an average of 42 years annual distributed data in (mm) from 1981 to 2022 is analyzed, and downloaded from KNMI site using google earth engine. This data is used for the dam site selection as one factor for MCDA.

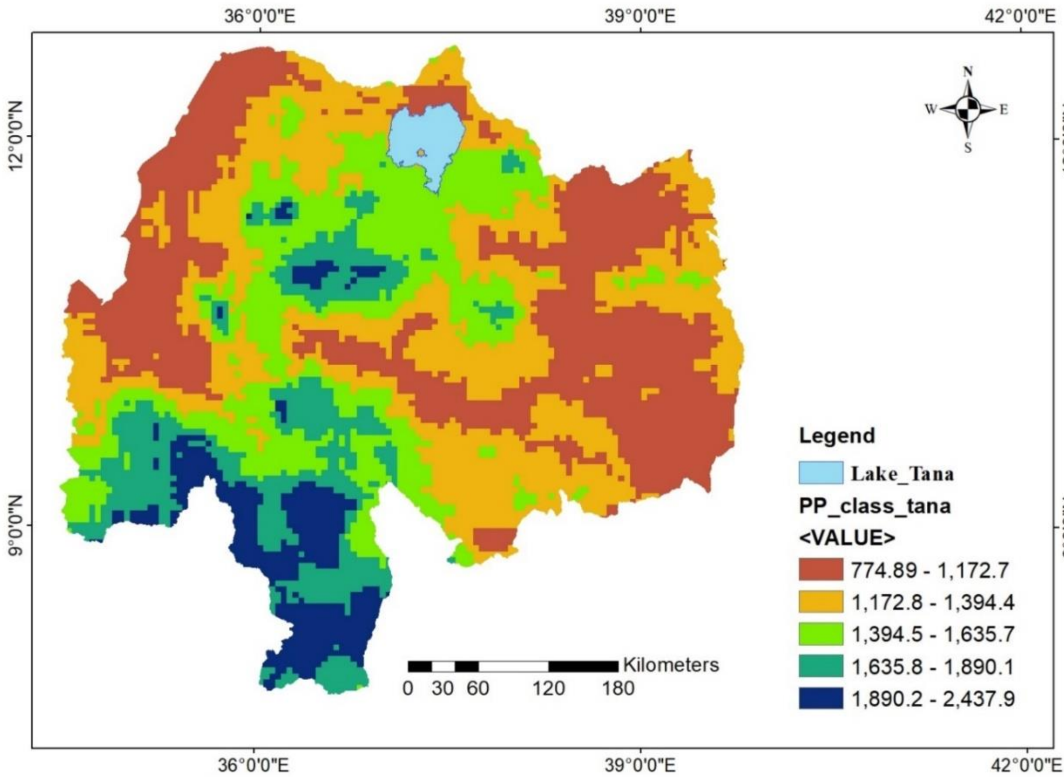


Figure 3-3: Precipitation class analysis

Table 3-2_2: Precipitation class frame work

precipitation	Value	suitability class
<774.88	1	Least
774.88-1000	2	Less
1000-1200	3	Moderate
1200-1831.7	4	High
1831.7-2437.9	5	Very High

A classification is carried out to make individual values into categories related to preferential level of constructing dam on.The classes indicate the average annual precipitation in the level of less than 774.88mm, 774.88mm – 1000 mm, 1000 mm – 1200 mm, 1200 mm – 1831.669 mm and 1831.669 mm – 2437.88 mm.

3.2.5.2. Drainage Density (DD)

Drainage density plays an important role in flooding, such that a decrease in drainage density often results in decreasing flood volumes (Moore & Wilson, 1992). In addition, DD affects the magnitude of peak flow by changing the concentration time; therefore, it can provide useful information for site selection of dams. DD is the total length of streams of all orders divided by the area of the drainage basin and indicates the closeness of the spacing of channels (Jamali et al., 2014). A major indicator of percolation rate is lithology, which determines the quality of a drainage network. The structure of a drainage network helps gauge the characteristics of a water holding zone (Jamali et al., 2014) .The suitability of locating a dam site is directly proportional to the drainage density because of its relationship with surface runoff and permeability. A high drainage density indicates a high prospect of groundwater and increased suitability for locating a dam site (Pandey et al., 2011) . The drainage streams and basins should also be mapped for preparing the drainage density raster layer. In this study, drainage density was calculated using the line density tool in ArcGIS10.3 software.

Table 3-3: Drainage density class

Drainage density	Preference Value	Suitability class
0.37-0.54	5	Very High
0.28-0.37	4	High
0.21-0.28	3	Moderate
0.13-0.21	2	Less
0.003-0.13	1	Least

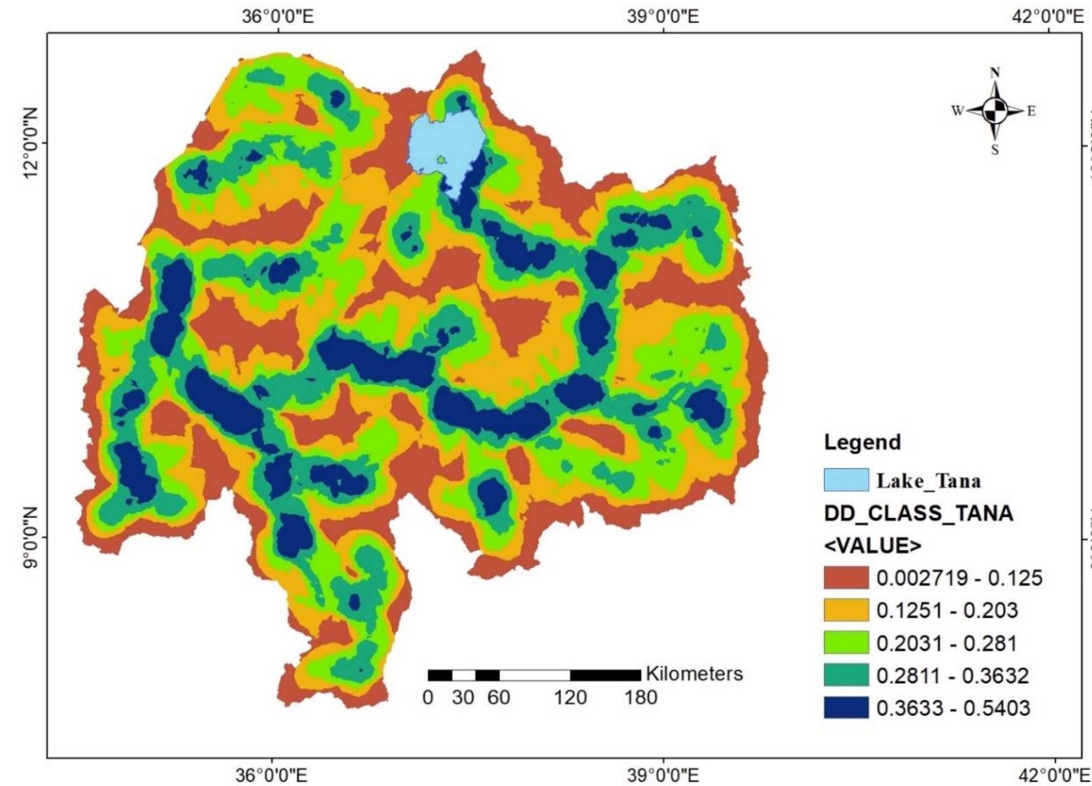


Figure 3-4: Drainage Density class

3.2.5.3. TWI CLASS ANAIYSIS

The TWI is a topo-hydrological factor proposed by (Beven & Kirkby, 1979) and is often used to quantify topographic control on hydrological processes(Michielsen et al., 2016). The TWI controls the spatial pattern of saturated areas that directly affect hydrological processes at the watershed scale. Manual mapping of soil moisture patterns is often labor intensive, costly, and not feasible at large scales. The TWI provides an alternative for understanding the spatial pattern of wetness and upslope contributing areas (Mokarrama & Hojati, 2018). It is a function of both the slope and the upstream contributing area. The hydrological response of the study area in the form of a topographic wetness index (TWI) was calculated in ArcGIS by dividing flow accumulation by slope (in radians). TWI is commonly used to quantify topographic control on hydrological processes and was first presented by (Beven & Kirkby, 1979) and the index is based on a digital elevation model

.

$where$ α = the cumulative upslope area draining through a point (per unit contour length) and tanβ = the slope angle at that point. The index communicates the water accumulation in the catchment in terms of the slope of the terrain (i.e., α) and the movement of the water down the slope in terms of the hydraulic gradient (i.e., tanβ). TWI can quantify the effect of topography on runoff generation and serves as a physically based index for approximating zones of surface saturation and the spatial distribution of soil water (Quinn et al., 1995). TWI describes the spatial pattern (location and size) of saturated areas affected by watershed-scale hydrologic processes, and characterizes the proportional relationship between moisture and contributing areas (Pourali et al., 2016). The procedure for TWI is indicated as a figurative representation in appendix-5: Figure 3-5..

Table 3-4: TWI class analysis framework

TWI	Value	suitability class
14.7-29.4	5	Very High
10.9-14.7	4	High
8.1-10.9	3	Moderate
6.3-8.1	2	Less
2.0-6.3	1	Least

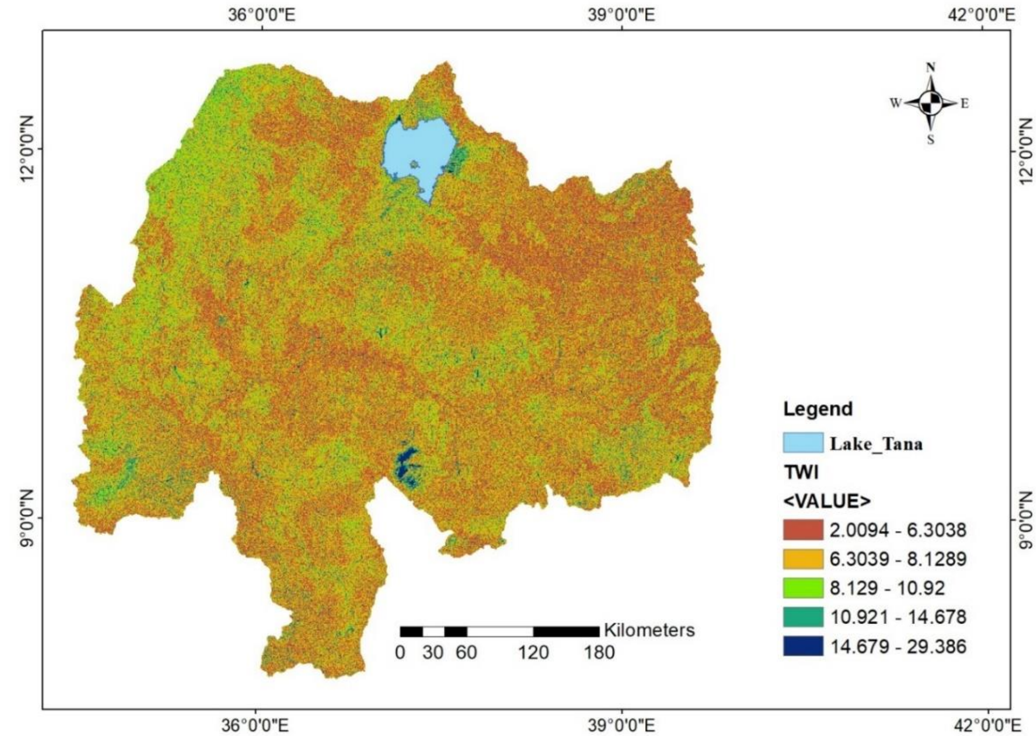


Figure 3-5: TWI Class Analysis

3.2.5.4. Slope class analysis

Soil types can be classified according to soil texture, which leads to different rates of soil infiltration and, thus, different effects on the runoff volume. Sufficiently water-resistant fine-grained foundations, clays, and clay mixtures are recommended (Biswas, 1968; Zhang et al., 2014). The water velocity of surface and groundwater is affected by the slope degree parameter, the greater the chance of water accumulation, the lower the slope. A slope map was also generated using the DEM at a resolution of 30 meters, similar to the elevation map. The slope has a direct relationship with water velocity. The projected dam's water holding capacity requires a slope of less than 8 degree.

The water velocity of surface and groundwater is affected by the slope, the greater the chance of water accumulation, the lower the slope. The lower slope values indicate the flatter terrain (gentle slope) and higherslope values correspond to steeper terrain. A slope map was also generated using the DEM at a resolution of 30 meters, similar to the elevation map. In this study slope map is in degree that is produced from STRM DEM with 30m resolution Figure 3-6 based on FAO and (Shao, Jahangir, & Yasir, 2020) classification varies from 0 to 78 using the "Spatial Analysis Slope" tool in ArcGIS.

Table 3-5: Slope class analysis frame work

Slope (degree)	Value	suitability class
<8	5	Very High
8-15	4	High
15-30	3	Moderate
30-45	2	Less
>45	1	Least

Source: (Shao, Jahangir, Yasir, et al., 2020)

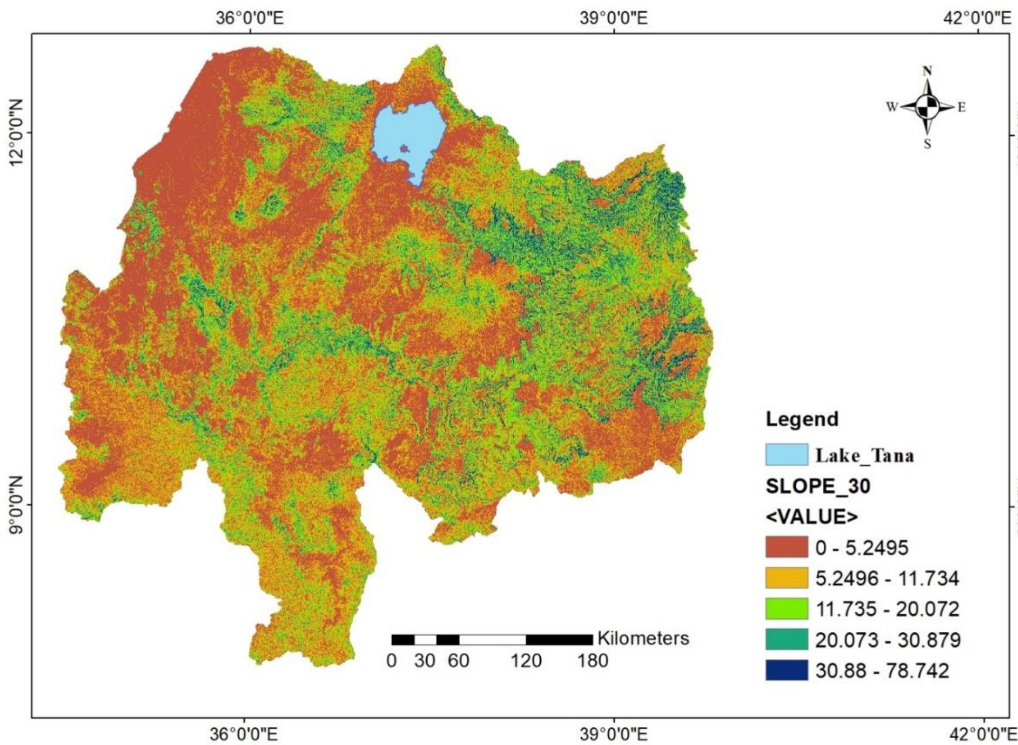


Figure 3-6: Slope class analysis

3.2.5.5. Geological Data

Competent rock foundations are rocks with relatively high resistance to erosion, percolation and pressure(NShellum, C. J., & Trudnak, 2005). For a desirable foundation, igneous rocks such as granite; metamorphic rocks such as quartzite; sedimentary rocks such as thick-bedded sandstones, flat-lying sandstones, and limestones are among the most satisfactory materials(Baban, S. M. J., & Wan-Yusof, 2003). In this study the geology of the research region is collected from the Ethiopian geological mapping Agency. According to (Othman et al., 2020) the characteristics of different classes of rocks, which can stand for the preference of constructing for earthen a dam the geology is classified geological data is reclassified from *11* classes into 5 classes Amba Abia Basalt very high suitable, Undifferentiated Lower Complex high suitability, Adigrate Sand Stone moderate suitable, Alluvium less suitable, and Lake least.

Table 3-6 : Geology class framework (Shao, Jahangir, Yasir, et al., 2020)

Geology	Value	suitability class
Amba Aiba Basalts/Termaber Basalts (2)/Ashangi Basalts/Lake/Basalts related to volcanic center (2)/Posttectonic granites/Amba Al	5	Very High
Undifferentiated Lower Complex/Tsaliet & Tambien Group clastics/Syntectonic granites/Syntectonic granodiorites & diorites/Alcali	4	High
Adigrate Sandstone/Amba Aradam Sandstone (1)/Antalo Sandstone/Ultra- basic rock/Abbai Beds/Laterite on Adigrate Sandston	3	Moderate
Alluvium/Lacustrine deposites	2	less
Marsh soil, colluvium	1	Least

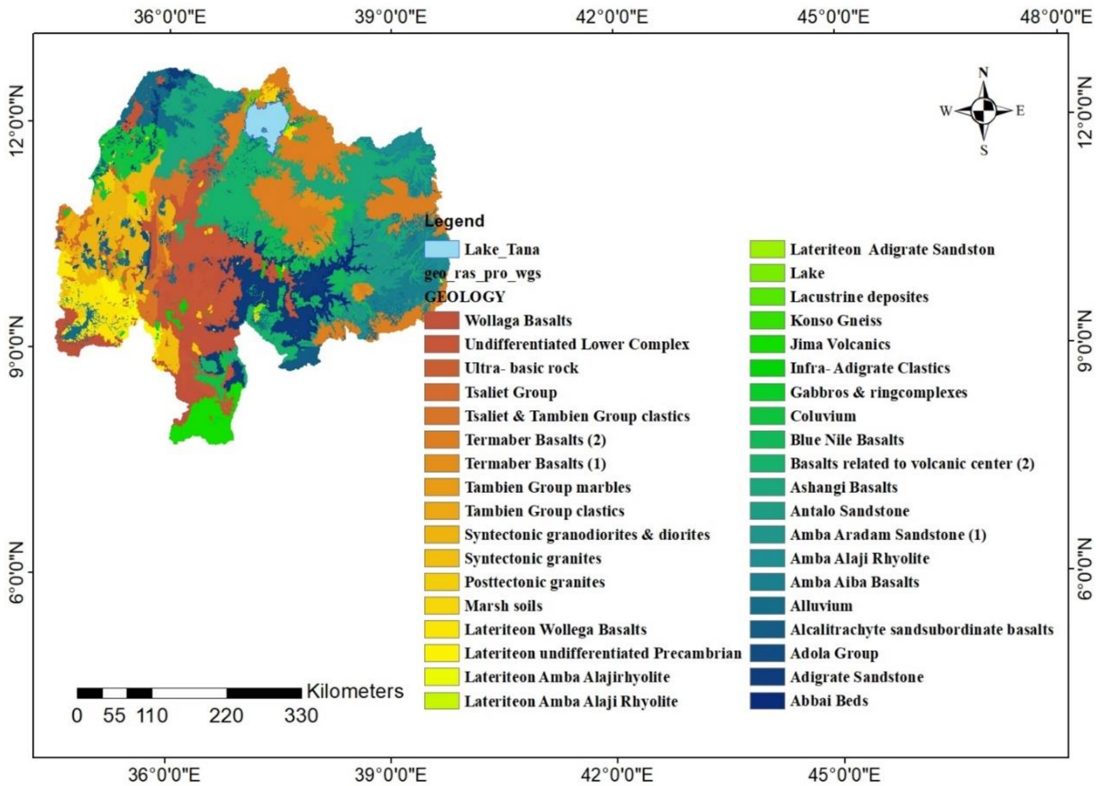


Figure 3-7: Geology class analysis

3.2.5.6. Land Cover Data

Land cover plays several roles in dam site selection. Firstly, land cover greatly modifies the effect of rainfall which gives the land cover a place in influencing soil erosion(Adinarayana et al., 1995), and a high soil erosion area makes a weak foundation for constructing a dam(NShellum, C. J., & Trudnak, 2005). On the other hand, constructing a dam leads to the expropriation of land which has different economical costs according to land cover type (NShellum, C. J., & Trudnak, 2005). In this study, land use land cover download from USGS Esri_2020_Land_Cover_V2 Image Server with resolution 10m using tool in ArcGIS and reclassified from 9 classes into 5 classes, as show in table 3.7 andFigure 3-8, Land-use type is the most important factor for suitability analysis and is used to decide which area is most suitable for a dam during planning.

Table 3-7: Land use land cover class framework

Land Use Land Cover	Value	suitability class
Water/ Bare Ground	5	Very High
Flooded Vegetation/ Range Land	4	High
Trees	3	Moderate
Crops	2	Less
Built Area/ Clouds	1	Least

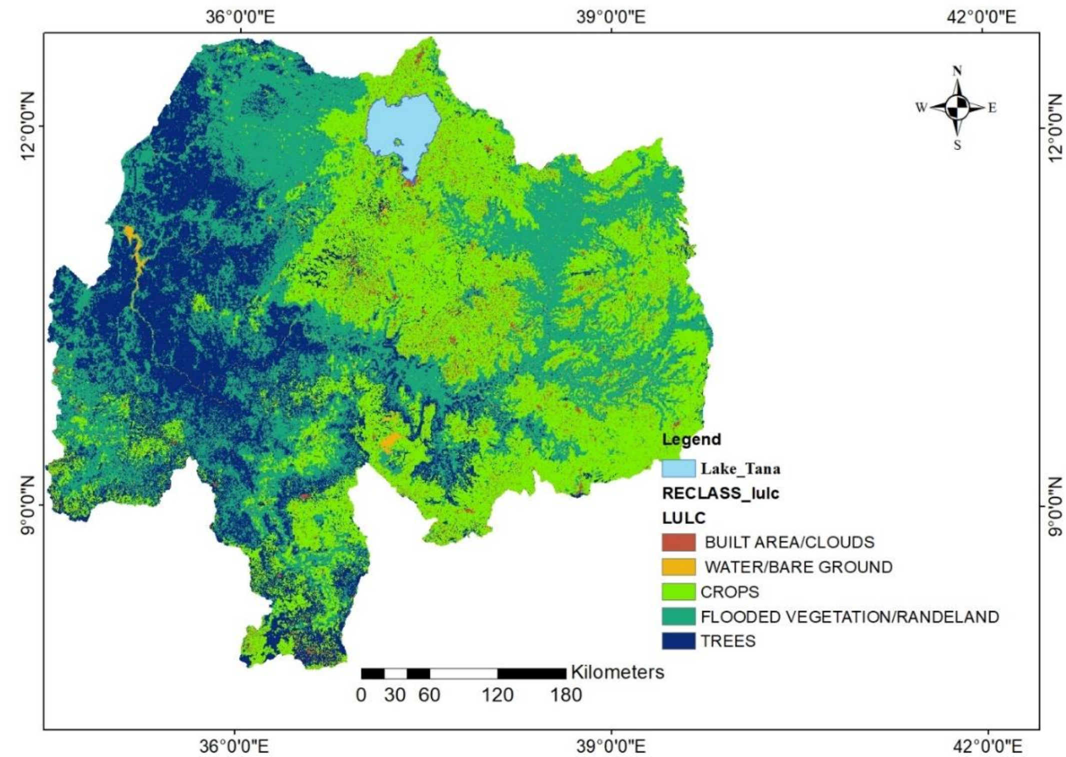


Figure 3-8: Land use land cover class analysis

3.2.5.7. Soil Data

Soil is a very important factor in the suitability assessment of irrigation. Soil properties or data maps of the study area are obtained from

the FAO soil digital map of the world. The FAO harmonized soil map which is highly detailed and informative has been compared and reconciled with the existing literature from the Ethiopian soil database.

Soil types can be classified according to soil texture, which leads to different rates of soil infiltration since they have different effects on the runoff volume.

Table 3-8: Soil suitability framework

Soil	Preference Value	suitability class
Clay/Heavy Clay	5	Very High
Clay Loam/ Loam	4	High
Loam Sand	3	moderate
Sandy Loam	2	less/ least

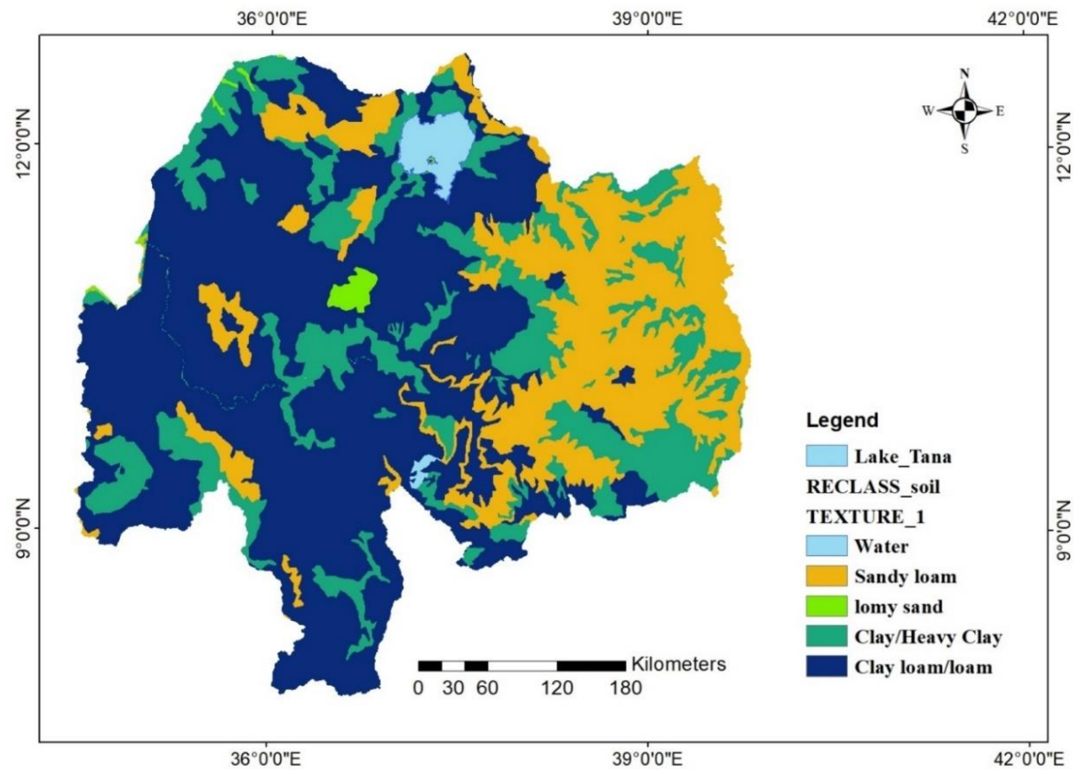


Figure 3-9: Soil class analysis

3.3. Methods for Dam Siting

Dam siting methods based on suitability evaluation models can be employed in GIS. To establish the spatial area of a suitable dam geological, topographical and hydrological other site selection considerations are used to determine its suitability. Geographic information systems (GIS), and multi-criteria decision-Analysis (MCDA) approaches are frequently utilized in the suitability assessment process because they are overlay analyses by nature and have the advantage of being simple and straightforward to apply.

3.3.1. GIS analysis and generation of suitability maps for dam site

Multi-criteria decision analysis (MCDA) is a systematic and comprehensive process used to evaluate and rank alternative solutions to a complex decision problem based on multiple and often conflicting criteria. MCDA involves a series of steps to help decision-makers identify, weight, and evaluate the relative importance of different criteria, and to use this information to rank the alternatives and select the best solution The steps involved in MCDA typically include:

Problem definition: The problem must be clearly defined and the objectives must be identified. Criteria identification: All the relevant criteria that should be considered in the decision must be identified. These criteria can be either quantitative or qualitative.

Criteria weighting: The criteria must be ranked and assigned a weight to indicate their relative importance. This weighting process is typically based on a combination of expert judgment, stakeholder input, and statistical methods. Alternative evaluation: The alternatives are evaluated against each criterion and a score is assigned for each alternative based on how well it meets the criteria.

Alternative ranking: The alternatives are ranked based on the total score, with the alternative with the highest score considered the best.

Final decision: The final decision is made based on the results of the MCDA. The decision-maker must consider the trade-offs between the different criteria and make a choice that best meets the objectives.

Because of the complexity of reality, making decisions in the actual world can be difficult at times. Multi-Criteria Decision Analysis (MCDA) is one of the available options. It refers to making judgments in the presence of many criteria that are frequently in conflict with one another (Zavadskas et al., 2014).

The suitability map of dams developed by combining different thematic layers by using the GIS-based MCDA technique. MCDA is a powerful methodology to provide a flexible way of combining many factors and it is possible to assign weight andrankings of criteria. The present weight influence of each criterion was assigned to identify the significance of criteria for dam suitability. To assign the weight of the criteria, the pair-wise comparison called the Analytical Hierarchy Process (AHP) developed by (Saaty, 1977) was used. AHP is a system of Multi Criteria Evaluation that is instigated within GIS, that defines weights for the criteria based on a given condition. AHP was first developed by (Saaty, 1977) for assigning the criteria weights The pairwise comparison matrices involve the comparison of each factor against all other factors in pairs to determine which of all the criteria has higher importance. (Saaty, 1977) recommends a scale from 1 to 9, where the rate of 1 show that the criteria are equally important and a rate of 9 indicates that the criterion under consideration is extremely important compared to each other of all the criteria.

3.3.2. Analytical Hierarchy Process (AHP)

To investigate multi-criteria decision issues, AHP technique employs simple and traditional advancing hypotheses. Nonetheless, the AHP allows for certain variations that should not exceed a certain limit (Halefom & Teshome, 2019). It is a parameter analysis on a pair-by-pair basis: Using paired analysis and a relative relevance scale, the weights of each parameter are established. Defining a hierarchy of objectives, criteria, and alternatives; recognizing a hierarchy of objectives, criteria, and alternatives; and constructing a hierarchy of objectives, criteria, and alternatives are the three elements of the AHP technique. An integration uses the pairwise comparison result as a measure of relative value at all levels of the hierarchy (Saaty, 1988, 2010). One of the most commonly used MCDA strategies is the Analytical Hierarchy Process (AHP), which is a simple and effective decision-Analysis process. The principal components of the normalized matrix reflecting the parameter weights is calculated after the pairwise matrix has been normalized.

3.3.2.1. Pairwise comparison

pairwise comparison is applied to all criteria using the fundamental scale shown in Table 3-9 which was proposed as part of AHP (Saaty, 2010). The intensity of importance is assigned to criteria i when compared to criteria j and the reciprocal value is assigned to criteria j as the intensity of importance. When a comparison between all possible criteria pairs is done, the weight of criteria i, which is used in the later analysis for suitability analysis, is calculated using *equation 2* (Saaty, 2010).

$$Wi = \sum_{j=1}^{n} p_{ij} / (\sum_{i=1}^{n} \sum_{j=1}^{n} p_{ij}) \qquad \textit{Equation 2}$$

In which P_{ij} indicates relative importance in pairwise comparison of criteria *i* comparing to criteria *j*.

Table 3-9 : Pair-wise comparison scale and definition(Saaty, 2010)

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective.
3	Somewhat more important	Experience and judgment slightly favor one over the other
5	Much more important	Experience and judgment strongly favor one over the other.
7	Very Much more important	Experience and judgment very strongly favor one over the other. Its importance is demonstrated in practice
9	Absolutely more important	The Evidence favoring one over the other is of the highest possible validity.
2, 4, 6, 8	When Intermediate values	compromise is needed

3.3.2.2. Evaluation of matrix consistency

These values represent the number of times one element is more important than another. The weight estimate is then calculated, which is subsequently utilized to calculate the consistency ratio (CR) of the pair-wise comparisons. PCM consists of a consistency check in which judgment errors are discovered and a consistency ratio is generated, as detailed by(Al-shabeeb, 2016). If the CR value is larger than 0.10, certain pair-wise values must be reviewed, and the operation must be repeated until the desired CR value of less than 0.10 is reached. Overlay analysis is then done to get the overall summation of the weight of each contributing factor. After then, overlay analysis is used to calculate the total weight of each contributing factor. In a GIS environment, the overlay inputs include all contributing factor layers normalized to a common scale. The chosen weight is multiplied by each input raster. It then combines all of the input rasters to create the final suitability map.

The consistency ratio (CR) was calculated according to (Saaty, 2010) and the acceptable CR value is up to 10% based on (Saaty, 2010).

$CR = CI/RI$ Equation 3

Where: - CR = consistency ratio, CI = consistency index, and RI = consistency index of randomly generated matrix

The consistency ratio was used to check the consistency of the pairwise matrix. To check strength the of the pairwise comparison matrix, apply Saaty (1990) gave a measure of consistency, called the consistency index (CI), as deviation or degree of consistency computed using the following formula: -

$$CI = \frac{\lambda max - n}{n-1}$$ *Equation 4*

However, eigenvalues (λmax) were determined by averaging criteria ratio (weighted sum value/criteria weight). Where n is the number of criteria. Finally, Consistency Ratio (CR) was calculated, which is a measure of consistency of the pairwise comparison matrix that determined in Equation 4. Saaty (1980) recommended that, for matrices with CR rating greater than 0.1, the process is repeated until the desired value of CR <10%.

Table 3-10: Random index value (Saaty, 1977)

No of criteria	RI value
1	0
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41

3.3.3. Weighted Overlay Analysis

The weighted overlay is a technique for combining several inputs into a single analysis by using a single measuring scale of values. To tackle geographic problems, GIS is widely utilized to assess several factors. For example, determining the ideal irrigation dam site requires considering factors such as land cover, slope, soil, and distance from a water source(Yang et al., 2003). Weighted overlay analysis prioritizes the influence of these factor values using a 1 to 9 by 1 evaluation scale. A value of 1 indicates the least appropriate factor in an evaluation, while a value of 9 indicates the most appropriate element. Weighted overlay simply takes integer raster's as input to find suitable irrigation dam site areas, such as a raster of land cover/use, soil types, slope, and Euclidean distance output (Janssen & Rietveld, 1990). For this study various thematic maps such as drainage density, land use land cover, slope,rainfall, soil, geology and TWI are prepared by using GIS and remote sensing tools. DEM is used to develop slope, TWI and drainage density map and geomorphology maps while the Landsat data are used to prepare the line ament map. Aggregation of all criterion layers is performed to find suitability maps using a weighted overlay tool in the ArcGIS.

3.4. Choosing possible inundation area of reservoir area

Many studies have started with topographic features and designed programs to automatically obtain target dam locations [(Petheram et al., 2017; Teschemacher et al., 2020; Wimmer et al., 2019)]. The upstream location of dams is usually depressed terrain. The larger water capacity sites are the most recommended due to their narrow formation of contour troughs and ridges or valley shape allowing for various dam options. Wide contours mostly lead to a very big dam which is not economical in most cases. As most of the studies[(Dai, 2016b; Jamali et al., 2013; Padmavathy et al., 1993; S, 2016; Saleh Alatawi, 2015; Wang, Y., Tian, Y., & Cao, Y. (2021). Wang, P., Casner, R. G., Nair, Wang, Y., Tian, Y., & Cao, 2021; Yi et al., 2010)] involved stream and surface water as an essential parameter to determine potential sites for the dam as adequate water is vital, which has to be stored and utilized for many purposes. However, the suitability map results were still all over the area, which is not satisfactory. This research is an effort to improve dam site identification analysis and elaborates on the different results based different criteria. For every proposed possible dam,15 *meters* interval contour layer is generated for convince of use by our choice and limitation of computer capacity to generate low contours from DEM and the base contour is selected from narrow section of the dam axis. The contour is selected and exported for further analysis Tools in ArcGIS.

3.4.1. Determination of reservoir catchment area

The catchment area of a reservoir is the area of land that contributes runoff to the reservoir and is therefore an important factor in determining the yield of the reservoir. There are several reasons why catchment area is important for the yield of a reservoir:

1. Runoff generation: The catchment area is responsible for generating runoff that contributes to the inflow into the reservoir. A larger catchment area generally means more runoff and higher inflow into the reservoir, leading to a higher yield.
2. Water quality: The catchment area can also affect the water quality of the reservoir. If the catchment area contains pollutants, they can enter the reservoir and impact its water quality. Therefore, it is important to manage the catchment area to reduce the impact of pollutants on the reservoir.
3. Evaporation: The size of the catchment area also affects the amount of evaporation from the reservoir surface. A larger catchment area means a larger surface area exposed to the sun, leading to higher evaporation rates and lower yield.
4. Groundwater recharge: The catchment area can also impact the groundwater resources in the region, either through recharge or discharge. A well-managed catchment area can help to maintain the balance of the groundwater resources and support the long-term yield of the reservoir.

In summary, the catchment area plays a crucial role in determining the yield of a reservoir by affecting runoff generation, water quality, evaporation, and groundwater recharge. Understanding the catchment area and managing it effectively can help to improve the yield and sustainability of the reservoir. Hydrological tools in the Spatial Analysis Tools are used to generate the watershed using the dam location as an outlet point to measure the catchment area.(Hagos et al., 2022).

Here are the steps followed to delineate the watershed area of a reservoir using ArcMap:

1. Add the DEM into ArcMap: You can import the DEM into ArcMap as a raster layer and display it in the data frame.
2. Fill sinks in the DEM: In some cases, the DEM might contain sinks which prevent the flow of water. Fill the sinks in the DEM using the "Fill" tool in the "Spatial Analyst" toolbox.
3. Flow direction: Create a flow direction surface from the filled DEM using the "Flow Direction" tool in the "Spatial Analyst" toolbox.
4. Flow accumulation: Create a flow accumulation raster from the flow direction surface using the "Flow Accumulation" tool in the "Spatial Analyst" toolbox.
5. Delineate the watershed: Determine the outlet point for the reservoir and use the "Watershed" tool in the "Spatial Analyst" toolbox to delineate the watershed area. The outlet point will serve as the pour point for the analysis.
6. Create the final map: Finally, you can display the delineated watershed on a map
7. Calculate the area of watershed

3.5. Validation of the dam site suitability map

Researchers are using different models to find viable dam sites all over the world, but it is crucial to properly validate the output of the models using actual ground conditions or recorded observations. It may be desirable to validate the model results with existing dams in the basin when assessing the suitability of a dam site (Odiji et al., 2007). The validation was done by comparing the result of suitable dam from existing proposed and constructed dam in the basin. The result of suitable dam from that the area of suitable dam but the data or the area selected for validation is the result was extracted by existing dam area coverage. As a result, in this dam site suitability study, the outcomes of the modeling employed are contrasted with those from the location of an existing dam and reservoir was utilized are contrasted with those from the location of an already-built dam and reservoir that was carefully selected and constructed. As seen in the very high, high, and moderately acceptable dam site locations from the model's generated output were used to build an existing dam in the basin.

3.6. Development of reservoir Elevation-Area-Capacity curve

The development of the elevation-area capacity curve is crucial for the effective and sustainable operation and management of dams and reservoirs(Rodrigues & Liebe, 2013). The reservoir elevation-area-capacity curve of a dam site can be prepared from the available topographical maps were generated from DEM based on the selected dam axis. The incremental volume between any two contour elevations and live capacity of reservoir are calculated using the following formula in ArcMap,

$$\Delta V_i = \Delta h(A_i + A_{i+1} + \sqrt{A_i A_{i+1}})/3 \quad \textit{Equation 5: (1)}$$

$$V_i = \sum_{k=1}^{i} \Delta V_K \quad \textit{Equation 6: (2)}$$

$$Ya = \sum_{i=1}^{N-1} \Delta V_i \quad \textit{Equation 7: (3)}$$

where ΔVi = Volume between contour elevations i and i+1, Δh = Contour interval, Ai = Area at contour elevation i, Ai+1 = Area at contour elevation 1+i, Ya = Live capacity of reservoir, and N = Number of contour elevations.

The development of a reservoir Elevation-Area-Capacity (E-A-C) relationship is a process used to determine the relationship between the storage capacity of a reservoir, its surface area and the water level (elevation) within it. This information is used to manage the storage and release of water in the reservoir, to meet various demands such as irrigation, hydropower generation, flood control, and water supply.

The E-A-C relationship is typically established through field surveys. The field surveys involve measuring the elevation and area of the reservoir at various levels. However, in this research the capacity of ArcMap tools is applied. The data obtained from DEM then used to construct the E-A-C relationship, which is usually presented in the form of a graph or table.

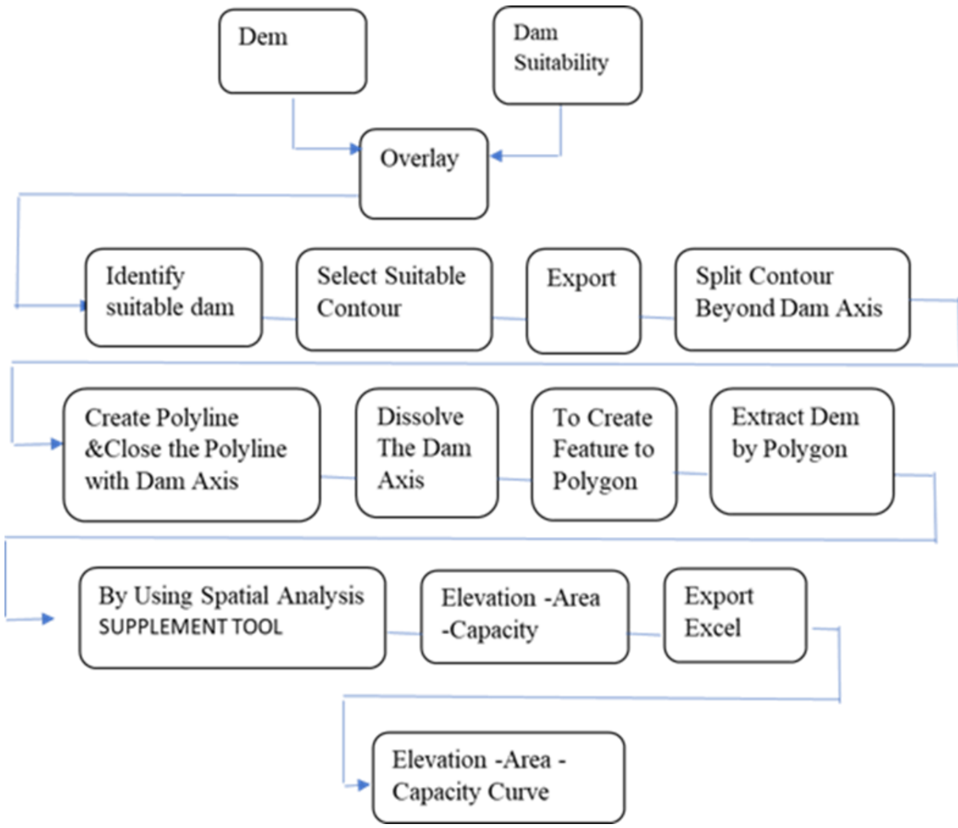


Figure 3-10: Flow chat of selected suitable dam elevation- area-capacity generation

3.7. Development of Profile of proposed dams

Profile of proposed dams were generated from DEM based on the selected dam axis. The dam axis is divided in to equal interval and the elevation from the DEM are extracted using ArcMap tools. The extracted elevation at each interval is exported to excel and preparing profile figures and determining the height/ depth and width of dam is determined. The procedure followed as shown in *Figure 3-11*.

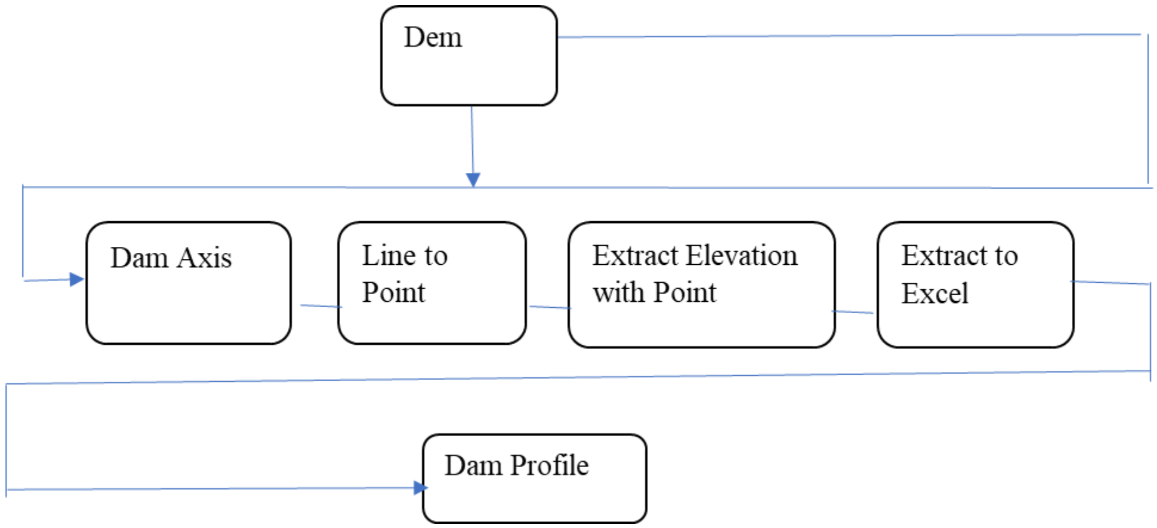


Figure 3-11: Flow chart dam profile creation

3.8. Classification of selected dams

Proposed sites for dam construction were obtained from the suitability map with medium and large size. The height, length, storage capacity, and basin area of the selected dams were considered. Appropriate locations for the dams were searched using drainage networks and contour lines per 15 m interval. The storage capacity of the dam was estimated using the ArcGIS 10.3 tools. :Dam Classification Source (Ren et al., 2017)shows that dams can be classified as small, medium, or large. The present study identified only intermediate and large potential dams. Table 9 illustrates the different types of dams according to size and height. The standard classified dams in terms of their height, their storage capacity, and the dam breaking risk. Different flood control standards for spillway are shown in Table 3-11.

Table 3-11:Dam Classification Source (Ren et al., 2017)

Classification	Storage ($10^6\ m^3$)	Dam Height (m)
Large	>61.70	>30
Medium	1.23~31.70	12~30
Small	0.6~1.23	8~12

3.9. Development of relationship between depth, area, and volume

The relationship between depth, area, and volume in a reservoir is critical for water resource planning, managing hydrology, and modeling (Rodrigues & Liebe, (2013)). It is laborious, time consuming and costly to obtain them. However, it has advantages for different purposes:

3.10. Administrative Location of selected dams

Dams were selected based on the criteria set for selection and using overlaying the final suitability map with the 15m contour generated from the DEM. The selection was mainly based on the availability of a suitable constricted abutment for the dam axis. To locate the dams in the administrative regions the shape file of all the dams was overplayed with the administrative shape file. The generated file from the overlay analysis was summarized with the administrative zones and regions.

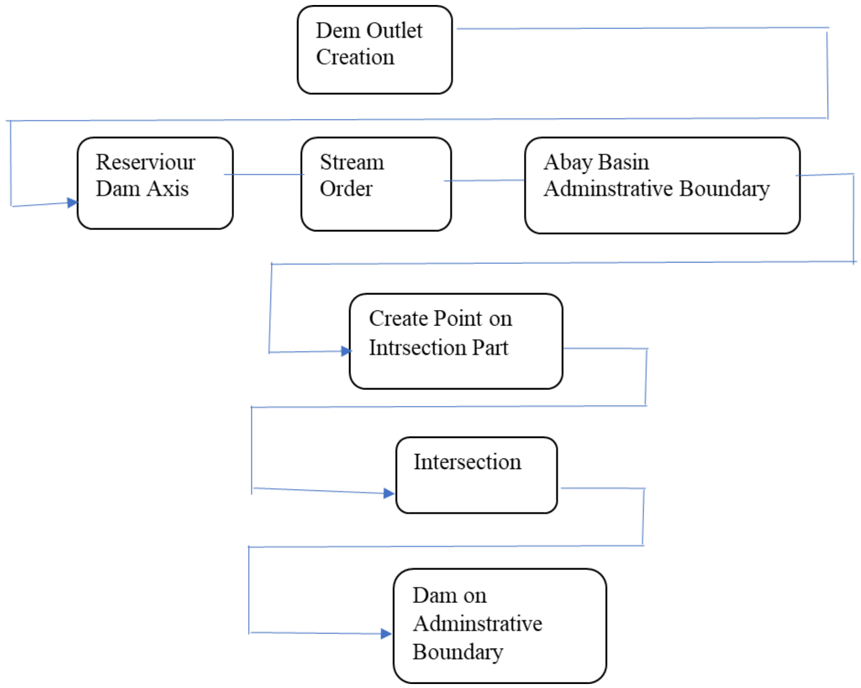


Figure 3-12: Flow chart dam on administrative boundary creation

3.11. Hydrological data analysis

3.11.1. Computing Dependable Catchment Yield

The dependable yield, corresponding to a given dependability percentage p, is detained from the past available data of the last 42 years data download from CHIRPS for daily rainfall. The annual rainfall data of the reservoir catchment is generally used for this purpose, since such long runoff data is rarely available. The rainfall data of the past years is therefore used to get the dependable rainfall value corresponding to the given dependability percentage p. This dependable rainfall value is then converted into the dependable runoff value by using an empirical equation connecting the yearly rainfall with the yearly runoff.

Here we used exceedance probability between rainfall (R) and percent of time the rainfall is equaled or exceeded (P), and is of the type shown inequ.8.

$$P_p = 100 * \frac{m}{N+1} \qquad \textit{Equation 8}$$

where m is the order no. of that rainfall (or class value) PP = percentage probability of the rainfall magnitude being equaled or exceeded. The ordinate R at any percentage probability p (such as 80%), i.e., R, will represent the rainfall magnitude that will be available for 80% of the year, and is hence termed as 80% dependable rainfall (Q80)(S K. Garg,1976). Since, all the reservoirs are without inflow gauging stations upstream of reservoirs, the currently evaluated method would offer a superior estimation the rainfall that will further be translated into an inflow which will later help for trap efficiency estimation. This problem involves preparing the inflow data from rainfall data that is changed using an empirical equation of Inglis.

Inglis formula.

Inglis derived his formula for catchments of West Maharashtra State of India. He divided the areas as ghat areas (Sahyadri ranges) where rainfall is 200 cm or more; and non ghat areas where rainfall is less than 200 cm. his formulas are;

(a) For ghat areas, with rainfall (P) equaling or exceeding 200 cm:

$$Yield = (0.85P - 30.48)cm$$ *Equation 9*

where P is the rainfall in cm

this is the easiest way and all the rainfall data less than 200cm to determine

3.11.2. Trap efficiency calculation

3.11.2.1. Capacity-Inflow Method (Brune's Curve):

This method is probably the most widely used method for estimating the trap efficiency of reservoirs. Brune's curves were drawn based on data from 44 normal ponded reservoirs in the United States. Brune plotted Teagainst the reservoir (C/I) ratio. The graph plotted by Brune has three curves consisting of one median and two envelop curves as shown in the Figure 8-5. Brune developed an empirical relationship between trap efficiency and the ratio of reservoir capacity to mean annual inflow, both in the same quantities. (Gill, 1979) developed empirical Eqs. 10 to 12 and shoew the graph appendix-6:Figure 8-5 which provided a very close fit to the three curves proposed by Brune.

i) Primarily Highly Flocculated and Coarse-Grained Sediment:

$$\boldsymbol{T_{eff}} = \frac{(\frac{C}{I})\hat{}2}{0.994701\left(\frac{C}{I}\right)^{2} + 0.006297\left(\frac{C}{I}\right) + 0.3*10\hat{}-5}$$ *Equation 10*

(ii) Median Curve (for medium sediments):

$$T_{eff} = \frac{(\frac{C}{I})}{0.012+1.02(\frac{C}{I})} \qquad \textit{Equation 11}$$

(iii) Primarily Colloidal and Dispersed Fine-grained Sediments:

$$T_{eff} = \frac{(\frac{C}{I})^3}{1.02655\left(\frac{C}{I}\right)^3+0.02621\left(\frac{C}{I}\right)^2-0.133*10^{-3}\left(\frac{C}{I}\right)+0.1*10^{-5}} \qquad \textit{Equation 12}$$

Where L is the reservoir length, C is the reservoir capacity and I is the reservoir inflows

3.11.3. Volume of Sediment in the reservoirs

According to Sultana & Sultana, (2019) Brune's method of trap efficiency is used to estimate the accumulated sediment in a reservoir. The basic steps to calculate the accumulated sediment using Brune's cure of trap efficiency are as follows: Determine the inflow and capacity of the reservoir volume Calculate the Capacity / Inflow Ratio (CI ratio) Calculate trap efficiency using Eq 10-12. The accumulated sediment in the reservoir is estimated by the following equation:

Accumulated sediment = trap efficiency * inflow volume * average suspended sediment concentration

The main source of sediment load in the Nile basin is the Blue Nile Watershed, which comes from the Ethiopian highlands. The growth of water resources in the Nile basin is under danger due to soil erosion upstream and the consequent downstream sedimentation. The Blue Nile Basin's yearly average sediment loss along the Sudanese border is 7 t/ ha/yr (Betrie et al., 2011; Steenhuis et al., 2013).

4. RESULTS AND DISCUSSION

4.1. Criterion layer maps

The following thematic maps were essential to identify potential sites for dam in the area:

4.1.1. Precipitation

According to the predicted annual precipitation data map in

Figure 3-3: the spatial distribution of mean annual rainfall in the study area which was obtained with google earth engine method was varied from 774mm to 2437.9mm. precipitation map was reclassified into five suitability classes as very highly suitable, highly suitable, moderately suitable, less suitable, and least suitable for dam site. The general distribution trend is low in eastern and western north Abay basin and high in central part of Abay basin, Southern and central north basin.

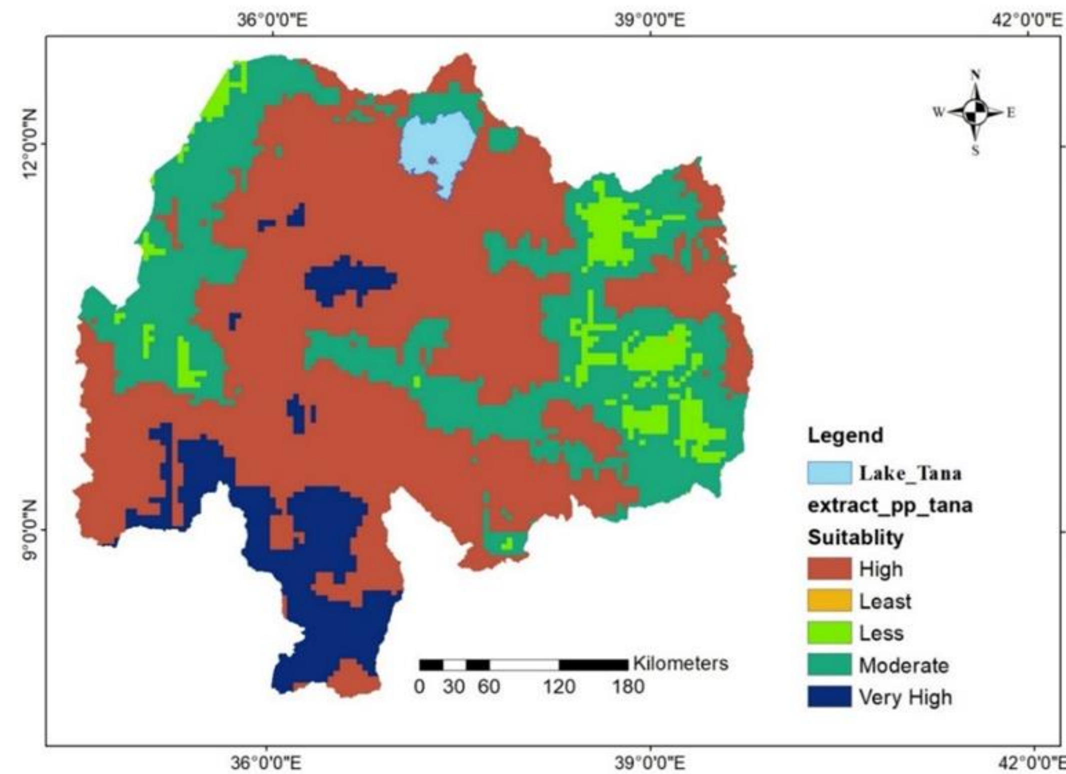


Figure 4-1: Precipitation suitability map of the study area

Table 4-1: Precipitation suitability area percent coverage

Suitability class	Area (%)
Very High	9.9
High	56.1
Moderate	28.8
Less	5.2
Least	0.01

From the analysis result freefall and literature review, the suitability of rainfall in the study area was grouped under the range of very highly suitable to least suitable class units *Figure 4-1*. As a result, a maximum of 0.01% of the study area was not suitable for suitability dam site, this shows that the site contains runoffdepth <774.88mm and the area was exposed for higher loss of water by initial abstraction and infiltration as a result of dense vegetation cover (forest) and soils with low water holding capacity (coarse textured soil). A minimum of 0.3% of the area was covered with a highly suitable class unit of suitability of dam site selection, it implies that theraifall in the area was found >1000mm and the site contains bare-land and fine textured soils (Mugo and Odera 2019). *Figure 4-1*and Table 4-1 the rainfall suitability map and its spatial area coverage.

4.1.2. Drainage Density suitability analysis

Drainage density obtained from the analysis shows that it ranged from 0 to 0.54 km/km^2 in this study. As shown in Figure 3-4. the highest drainage density was found in the central part of the Blue Nile River, whereas the lowest drainage density was found in all parts of the study area. However, moderate and high drainagedensity concentrates in the river line and central part of the study area. By using the analysis result and literature review, the suitability of the area in terms of drainage density, was classified in the range of highly suitable to least suitable class Figure 4-2.

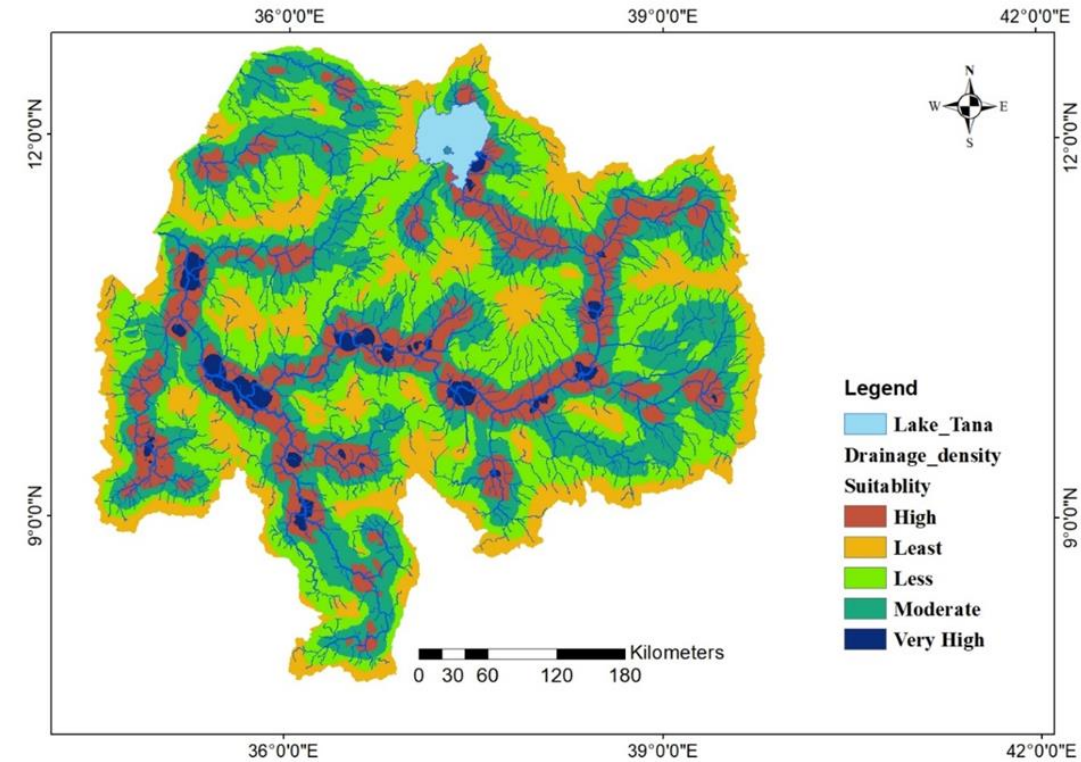


Figure 4-2: Drainage density suitability map of the study area

As indicated in Figure 4-2, the area having blue color signifies an area that has a high drainage density and is rated as higher in suitability for dam site, since an area having higher drainage density is believed to have higher runoff depth by collecting from different tributaries. Light green and yellow color show the area has a low density and which implies the area is not suitable for dam site, since it has less runoff depth potential (Rahmati et al., 2019).

Table 4-2: Drainage density suitability area percent coverage

Suitability class	Area (%)
Very High	2.3
High	16.3
Moderate	28.5
Less	35.5
Least	17.4

4.1.3. Topographic Wetness Index

The hydrological response of the study area in the form of a topographic wetness index (TWI) was calculated in ArcGIS by dividing flow accumulation by slope (in radians). According to Wang et al., (2021) to generate topographic wetness index (TWI) from a Abay basin DEM and reclassified into five suitability classes as very highly suitable, highly suitable, moderately suitable, less suitable, and least suitable for dam site. The highest TWI was found in around Lake Tana and in the southern part of area, whereas the lowest TWI was found in all parts of the study area. in which 2.01 to 6.3 least suitable, 6.3 to 8.13 less suitable, 8.13 to 10.92 moderate suitable, 10.92 to 14.68 high suitable and 14.68 to 29.4 very high suitable.

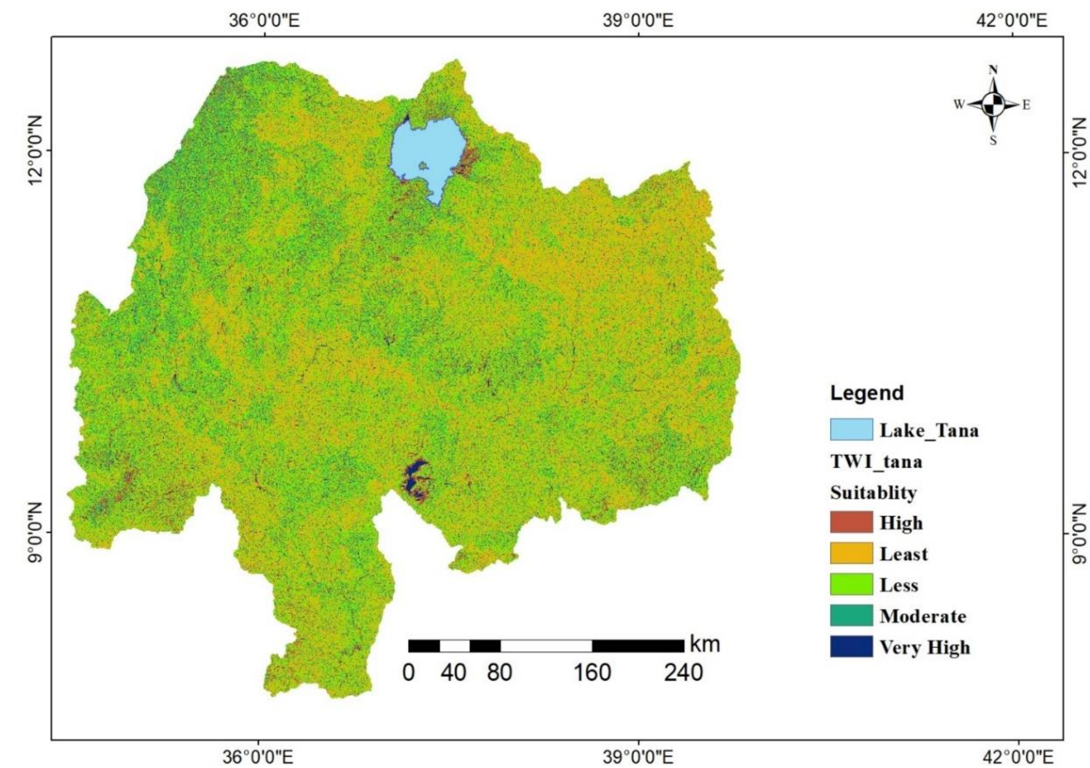


Figure 4-3: TWI suitability map of the study area

Based on *Figure 4-3* and Table 4-3: the information from TWI analysis shows that 2.9% of the TWI in the study area was classified as very highly suitable classes. While, only around 73% of the area was grouped under less and least suitable class.

Table 4-3: TWI suitability area percent coverage

Suitability class	Area (%)
Very High	2.9
High	8.3
Moderate	15.3
Less	40.3
Least	33.2

4.1.4. Slope

The slope of the basin was derived using the ArcGIS 10.3 by spatial analysis tool importing DEM with 30m resolution of the basin downloaded from USGS. The slope derived from the DEM with 30m resolution Based on the analysis result of DEM, the slope of the area ranges from 0 to 78 degree in *Figure 4-4*. the slope is classified into 5 classes, in which Below 8 degrees very high suitable, 8 to 15 high suitable, 15 to 30 moderate suitable, 30 to 45 less suitable, and greater than 45 degrees on the basis of natural breaks classification method. The highest slope gradient was found in central part of the study area and the lowest slope gradient was observed in northeastern and southwestern parts of it.

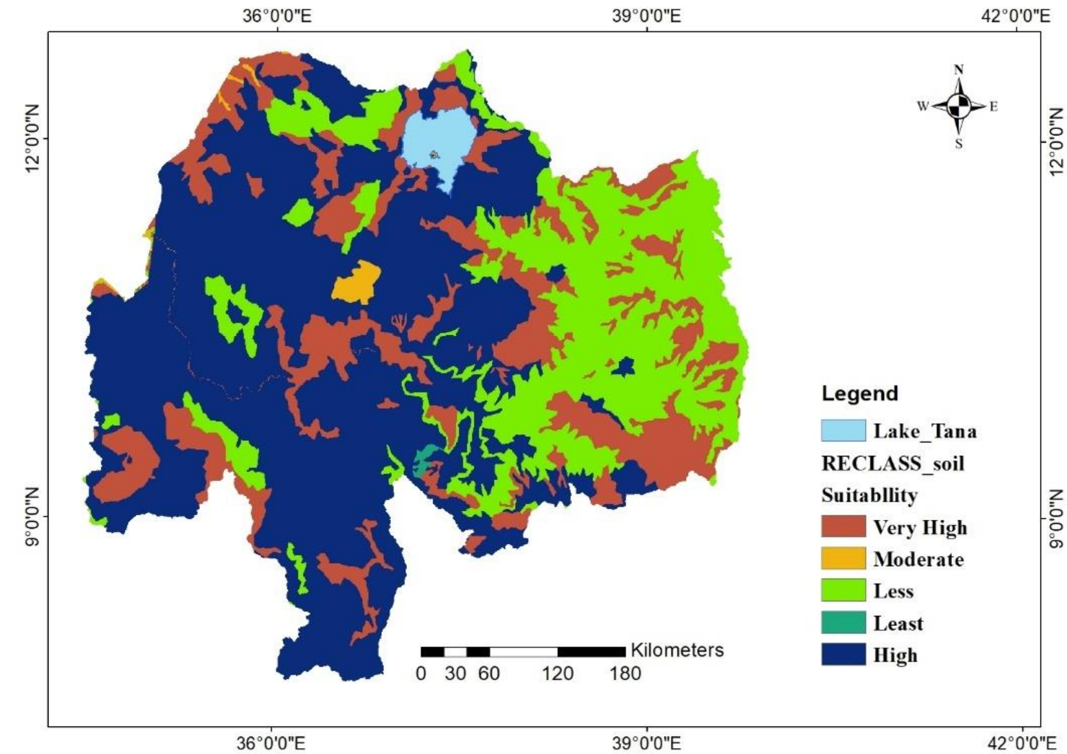


Figure 4-4: Slope suitability map of the study area

As indicated by the literature review Table 3-5, the slope map was reclassified into five suitability classes as very highly suitable, highly suitable, moderately suitable, less suitable, and least suitable for dam site. This implies that, the natural topography of the Abay basin is described as it is the highlands, ragged mountainous areas in the center and eastern part of the basin and the lowlands in the western part of the basin. highly suitable where, the area has a slope of (0 – 8) degree and rated as highly suitable to dam site based on (Shao, Jahangir, & Yasir, 2020)) using the reclassification tool in ArcGIS 10.3 . *Figure 4-4* and Table 4-4 describes the slope suitability level of the study area. As per the analysis result as shown a maximum of 0.3057% of the area was leveled under not suitable class units, since the area has a slope > 45 degree. After the reclassification of the slope of the basin, a slope suitability map of the basin was developed for dam suitability identification.

Table 4-4: Slope suitability area percent coverage

Suitability class	Area (%)
Very High	57.53
High	21.99
Moderate	16.72
Less	3.45
Least	0.3057

4.1.5. Geology

The geological conditions of the dam site are critical and directly affect the safety and stability of the project. The geological foundation of the site also affects the dam type(Biswas, 1968) and dam construction materials(Lashkaripour & Ghafoori, 2002; Njiru & Siriba, 2018) . According to those literature the geology layer has been obtained from Abay basin authority shapefile format. to the preference for constructing a dam, Water/ Bare Ground, Flooded Vegetation/ Rande Land, Trees, Built Area/ Clouds, and Crops cover of the basin, and of the basin is covered by Trees. Built Area/ Clouds cover of the basin from the total Flooded Vegetation/ Rande Land cover of the basin, and the rest of the basin is covered with Water/ Bare Ground Figure 3-7 .

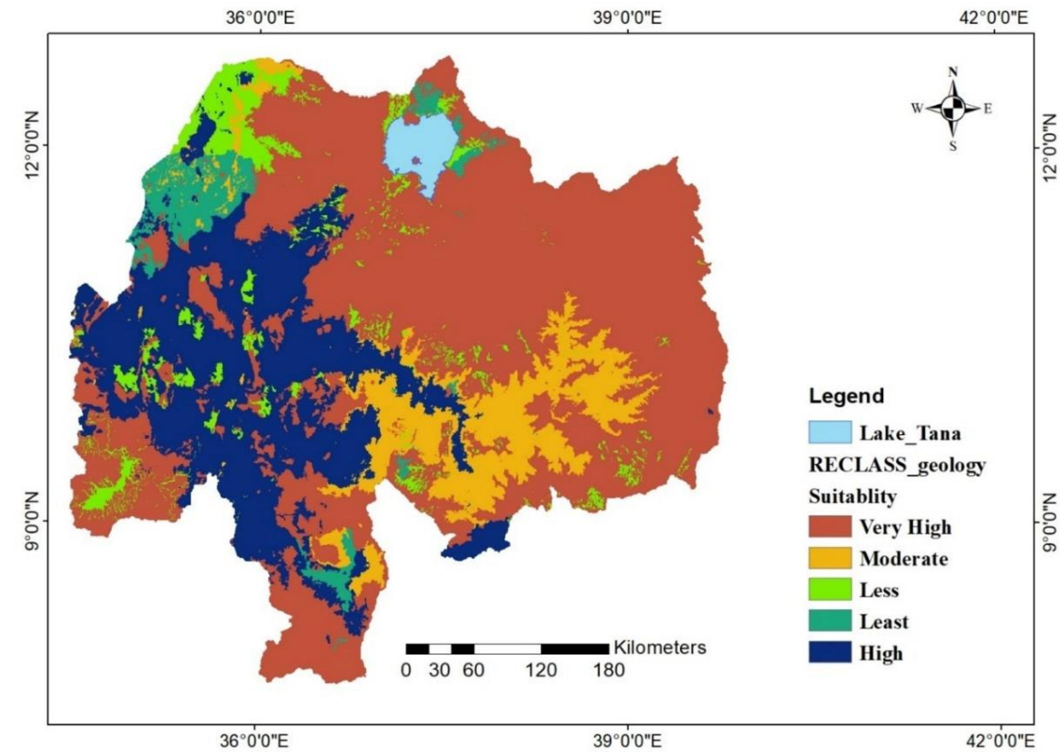


Figure 4-5: Geology suitability map of the study area

Table 4-5: Geology suitability area percent coverage

Suitability class	Area (%)
Very High	56.7
High	23.7
Moderate	10.6
Less	5.3
Least	3.7

As the map indicates Table 4-5,. The profusion of alluvium and basalts in the study area allows for suitable locations for dam construction Amba Aiba Basalts/Termaber Basalts (2)/Ashangi Basalts/Lake/Basalts related to volcanic center (2)/Posttectonic granites/Amba All those are very high suitable class and 56.73%are area covered, Undifferentiated Lower Complex/Tsaliet & Tambien Group clastics/Syntectonic granites/Syntectonic granodiorites & diorites/Alcali are high suitability class and 23.64% of area coverd, Adigrate

Sandstone/Amba Aradam Sandstone (1)/Antalo Sandstone/Ultra- basic rock/Abbai Beds/Laterite on Adigrate Sandston are moderate suitability class and 10.6% of area covered, Alluvium/Lacustrine deposites are less suitability class and covered 5.31%of area and the last class and not suitable or least class of suitability are Marsh soil, colluvium and covered 3.72%of the area.

4.1.6. Land use land cover

Land cover plays several roles in dam site selection. Firstly, land cover greatly modifies the effect of rainfall which gives land cover a place in influencing soil erosion (Adinarayana et al. 1995), and high soil erosion area makes a weak foundation for constructing dam (Baban & Wan-Yusof 2003).

Asper the literature review, it was interpreted as the classified image have acceptable accuracy and the classified image can be used for further analysis. After cross-checking the accuracy of the classification, In this study, land cover is reclassified from *8* classes into *5* classes, according to(Shao, Jahangir, & Yasir, 2020) the preference of constructing dam on. the image was reclassified into five suitable classes (very high, high, moderately, less and least suitable classes).

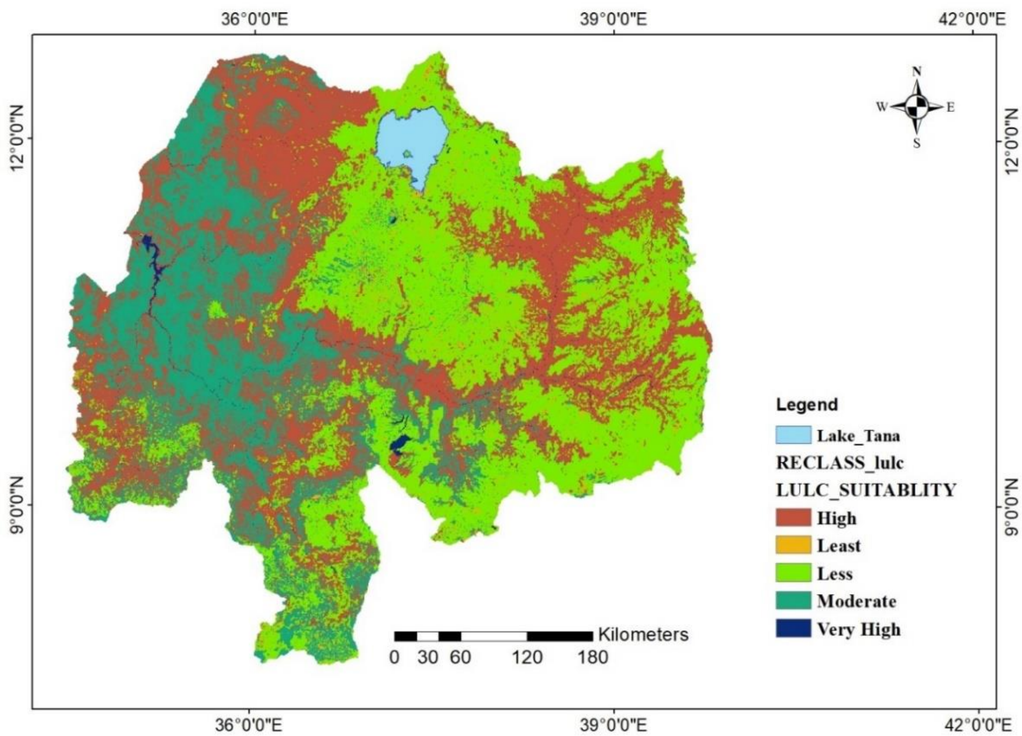


Figure 4-6: LULC suitability map of the study area

Based on the information from land use image classification analysis result Table 4-6 and *Figure 4-6* ,2.08% of the land use in the study area was classified as highly suitable classes. Because, the area was covered with barren land and water body. While, only 3.25% of the area was grouped under not suitable class for dam site, since the land use of the area was covered by built area, cloud and crops where those areas were unsuitable, uneconomical, and restricted to use for dam site (Dai, 2016b).

Table 4-6: LU/LC suitability map and its area coverage in percent.

Suitability class	Area (%)
Very High	2.1
High	40.0
Moderate	23.2
Less	35.5
Least	3.2

4.1.7. SOIL

According to Worqlul et al., (2017), Soil types can be classified according to soil texture, which leads to different rates of soil infiltration and, thus, different effects on the runoff volume. According to these the extracted soil map contains twelve textural class features Figure 3-9 and it was reclassified in to five suitability classes Table 3-8 . Clay/Heavy Clay are very high suitability class, Clay Loam/ Loam are high suitability class, Loam Sand moderate suitability class, Sandy Loam less class and Water least suitability class. These is, therefore, high suitability of 52.92% of the study area was covered with clay loam and loam soil texture, and a minimum and moderate of 0.66% of the area was covered by loam sand soil Figure 4-7.

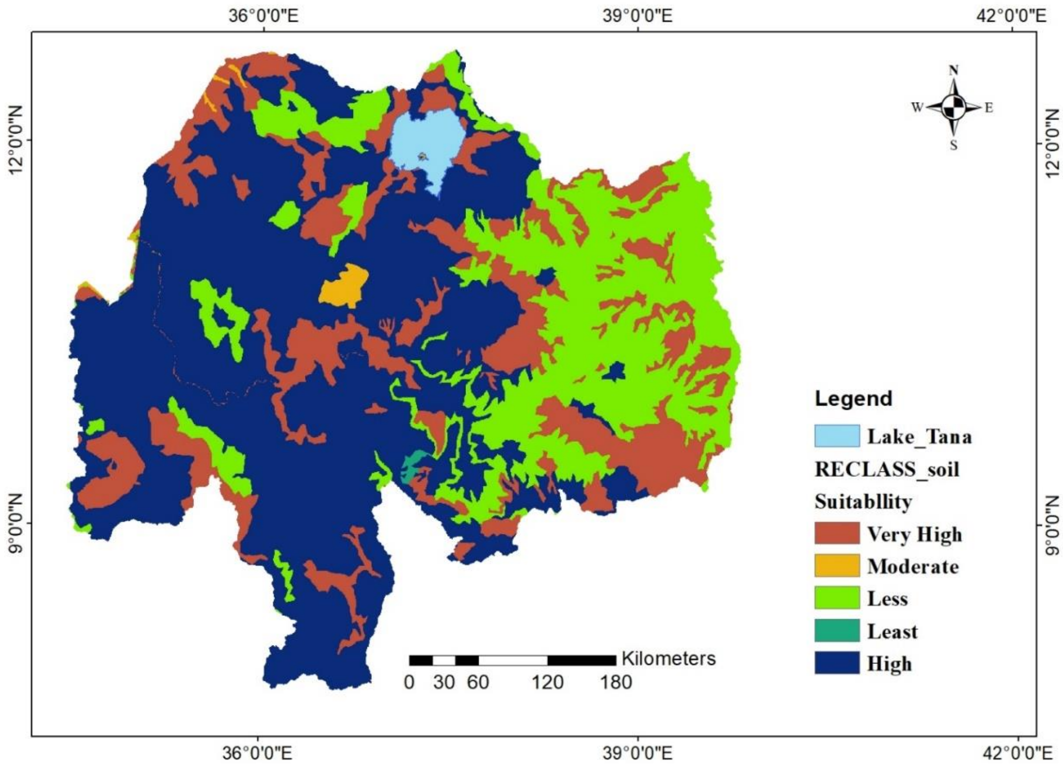


Figure 4-7: Soil suitability map of the study area

Table 4-7: Soil suitability map and its area coverage in percent.

Suitability class	Area (%)
Very High	20.8
High	52.9
Moderate	0.7
Less	23.9
Least	1.7

During the reclassification of the soil map for the suitability of dam site, approximately 23.88% of study is less suitability for dam site. the area was covered by sandy loam and 1.67% of the study area was classified as least suitable for dam site, because, the area was covered by water body. are Those soil type doesn't hold water to the targeted time period and lost water as infiltration. On the other hand, 20.87% of the study area is very highly and 53% are high suitable for dam site.

4.2. Weighting of factors for Suitability Dam Site mapping

4.2.1. Multi-Criteria Decision Analysis to identify Suitable Dam Sites

MCDA is a useful tool for addressing complex decision problems and provides a systematic and transparent way of considering multiple and conflicting criteria. It helps decision-makers to evaluate and rank alternatives based on multiple criteria and to make informed decisions that take into account the trade-offs between different objectives.

The factors used in suitability assessment were tabulated and compared with each other means that column factors with the rows for their significance to Identification Of Suitability Dam Site , the highest value (9) corresponds to absolute importance, and the reciprocal of all scaled ratios were entered in the transpose position (i.e., 1/9 shows an absolute triviality using *Table 4-8*, and then the pair-wise comparison matrices were filled and the weights of the factors were computed by normalizing the eigenvector by the cumulative vector. The eigenvector was calculated as the product of the row matrix. The weights are done for both surface and groundwater sources.

Table 4-8, shows the comparison of each suitability factor and weights of suitability factor from dam identification and the consistency ratio of the pair wise matrix.

Table 4-8: Pairwise comparison preference matrix

Class	RF	DD	TWI	SLOPE	GEOLOGY	LULC	SOIL
RF	1.0	2.0	2.0	3.0	3.0	4.0	5.0
DD	0.5	1.0	2.0	2.0	2.0	4.0	4.0
TWI	0.5	0.5	1.0	2.0	2.0	3.0	4.0
SLOPE	0.3	0.5	0.5	1.0	3.0	2.0	4.0
GEOLOGY	0.3	0.5	0.5	0.3	1.0	2.0	3.0
LULC	0.3	0.3	0.3	0.5	0.5	1.0	2.0
SOIL	0.2	0.3	0.3	0.3	0.3	0.5	1.0
sum	3.12	5	6.58	9.08	11.83	16.5	23

Table 4-9: Normalized matrix.

Class	RF	DD	TWI	SLOPE	GEOLOGY	LULC	SOIL	weight	CR
RF	0.32	0.40	0.30	0.33	0.25	0.24	0.22	0.30	
DD	0.16	0.20	0.30	0.22	0.17	0.24	0.17	0.21	
TWI	0.16	0.10	0.15	0.22	0.17	0.18	0.17	0.17	
SLOPE	0.11	0.10	0.08	0.11	0.25	0.12	0.17	0.13	
GEOLOGY	0.11	0.10	0.08	0.04	0.08	0.12	0.13	0.09	
LULC	0.08	0.05	0.05	0.06	0.04	0.06	0.09	0.06	
SOIL	0.06	0.05	0.04	0.03	0.03	0.03	0.04	0.04	
sum	1	1	1	1	1	1	1	1	0.034

$$CI = \frac{\lambda\text{max} - n}{n-1} = \frac{7.27}{7-1} \;,\; CR = \frac{CI}{RI} \;,\; \frac{0.045}{1.32} = 0.034 < 10\%$$

Based on the results of the factors weight table above, Rain fall was the most influential factor from groundwater sources. Drainage density and Topographic Wetness index was found to be the second and the third influential factors from dam site identification. After all the consistency ratio was calculated using cumulative eigenvector and the weight module to check the consistency of the developed matrix, and the acceptable CR value is up to 0.1 based on (Rodrigues & Liebe, 2013; Saaty, 1977). The consistency of pairwise matrix was checked, CR = 0.034, for dam site identification sources, below the acceptable limit.

4.3.2. Weight overlay

After each suitability parameter was assessed, reclassified and the weight has developed separately the weights were distributed to individual factors of suitability classes based on an equal interval ranging technique, and the factors were combined using weighted overlay to obtain the final suitability map of dam site identification. Weights from *Table 4-8* and Table 4-9 are assigned to “scale value” and “influence% “options in the tool, respectively. All the raster layers with 30 m × 30 m spatial resolution with their calculated weights are input.

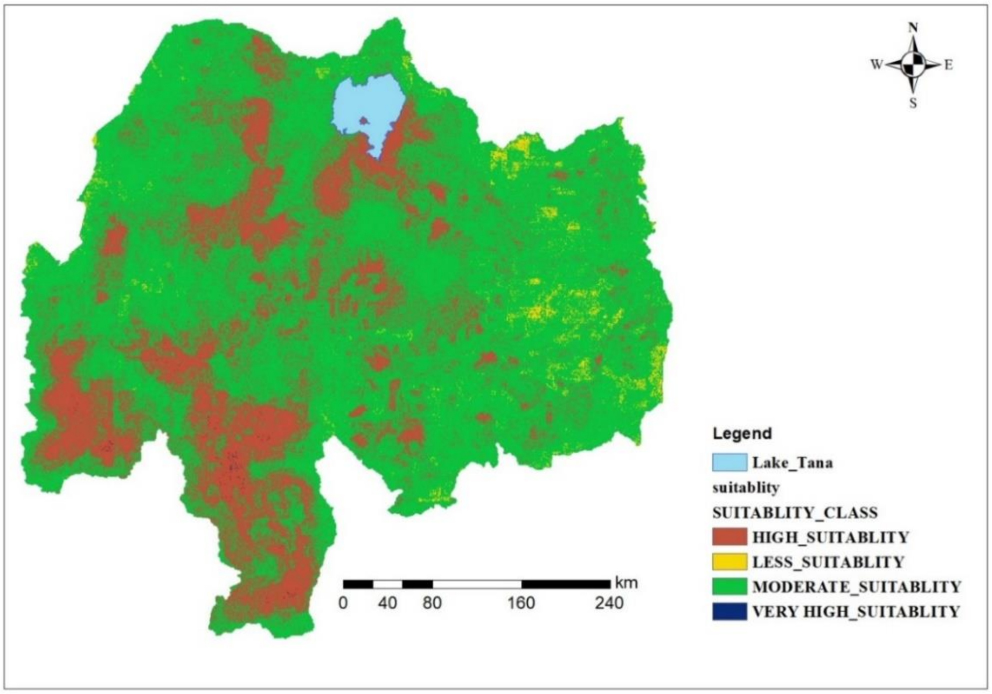


Figure 4-8: Dam Suitability map

Table 4-10: Proposed Dam Suitability

SUITABLITY CLASS	Value	Area (Km^2)	Area (%)
Less	2	3128.3	1.6
Moderate	3	141471.6	72.0
High	4	51785.3	26.3
Very high	5	60.6	0.1

The result from Table 4-9, shows the pairwise comparison matrix to calculate the weights of factors. Based on the total number of criteria the random index (RI) value 1.32 was found in% Table 3-10. To compute the, the consistency vector or Eigenvector (ʎ) value is computed by multiplying the weight of each criterion Table 4-9, by the sum total of the column of the individual factor from the original pairwise comparison matrix Table 4-8.

For example, multiply the weight of the first criterion, rainfall which is 0.3 from Table 4-9 by the total of the first column of the original pairwise comparison matrix (rainfall) which was 3.12 from Table 4-8. Then multiply the weight of the second criterion Drainage density by the total of the second column of the original pairwise comparison matrix Drainage density. Replicate this procedure till the last Finally, the summation of the product gives the consistency vector (ʎ) which was 7.27. The result of the consistency index from equation 4, was found 0.034 and the consistency ratio of this study was about 3% equation3, , which is less than 10%. These is, therefore, the random assignment of the weight for each factor and the comparison between them was acceptable(Dai, 2016b).

After assigning the weight for each criterion, all factors and groups of factors were integrated to produce fsuitability class units based on weighted overly analysis.

The result of many research such as (Al-Ruzouq et al., 2019), (Shao, Jahangir, & Yasir, 2020), (Baban, S. M. J., & Wan-Yusof, 2003), (Dai, 2016b) ,(Rahmati et al., 2019), (Othman et al., 2020)and (Al-shabeeb, 2016) revealed that the maximum weight was assigned to rainfall and Drainage density respectively. For the case of this researchfrom the result of AHP Table 4-9, the maximum weight was assigned to rainfall which is 30%.

This that it has a greater influence on the selection of suitable sites for dam site and the minimum weightwhich is 4% was assigned to soil thematic layer Table 4.6, which infers, it has a lesser influence on the site selection process. This result was in agreement with(Dai, 2016b) and the weight distribution of each criterion was described in *Table 4-8*.

The suitability of the site in the study area was categorized into five suitable class units, such as very highly suitable, highly suitability, moderately suitable, less suitable, and least suitable. Based on the result of suitable Dam site identification and Table 4-10, show the proposed dam site and their area coverage.

According to the area coverage of the final proposed dam suitable site Table 4-10, only 0.03 % of the area is very highly suitable for proposed dam. That means 0.03% of the area has sufficient rainfall potential, relatively flat topography, clay soil texture (having high water holding capacity), and other factors having first-class units. That means, it does not need any physical adjustment and technological advancement for dam site identification intervention. The remaining 26.36% and 72.02% of the study area, were leveled under moderately suitable and high suitable class units. This implies that it is the second and third option to use for irrigation dam suitable site. But it needs physical and technologicaladvancement for the implementation of dam site identification technologies and related activates because some of the criteria were not suitable in terms of Drainage density, TWI, slope, LU/LC type, soil texture, and others. But,most parts of the study area that is 1.59% of the study area was leveled under less suitable class units of Dam site identification. This is most dominantly due to the influence of the priority of criteria in the site selection process.

4.3. Proposed Dam Sites and Evaluation

To evaluate and study the profile of proposed dam sites, seven parameters, volume, elevation of dam base, the elevation of dam surface, dam height, dam width, catchment area, and contour closeness, are used. Contours are generated with a difference of 15 m from the DEM. 3D The analyst tool in ArcGIS is used to find out the cross-section (height and width), which also exemplifies graphical representation. Spatial analysis supplement tool tools are applied for find elevation-area-capacity.

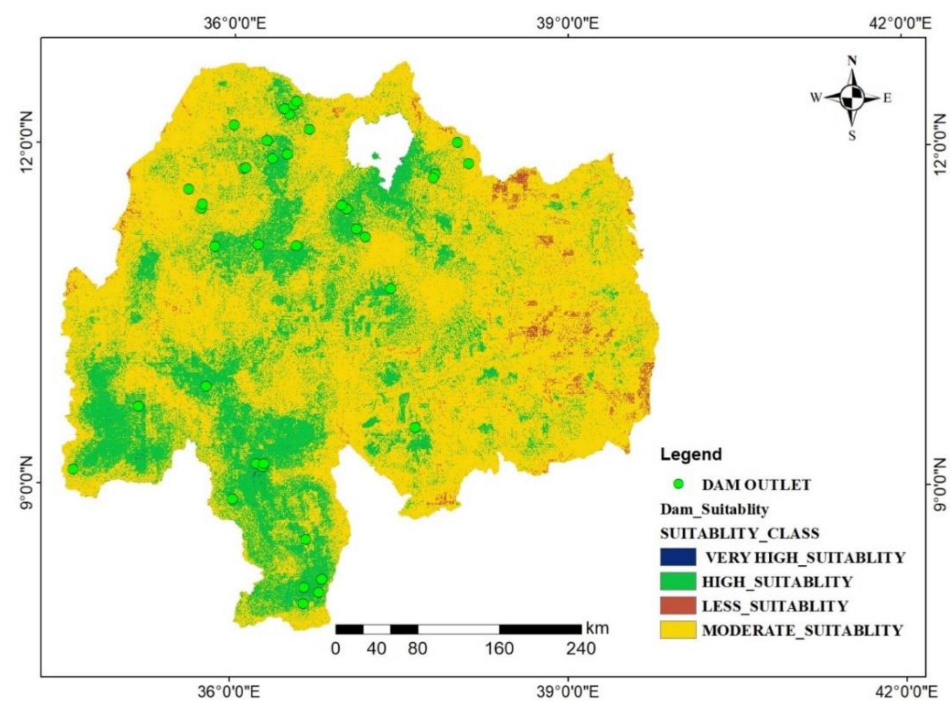


Figure 4-9: Proposed dam site

Table 4-11: Selected dam According to suitability class

Suitability Class	No. Of Suitability Dam	Percent Of Suitability
High	31	81.6
Moderate	7	18.4
Total	39	100

A total of 39 appropriate dams were chosen, and of those, 31 (or 81.6%) are determined to be of high suitability, while 7 (or 18.4%) are found to be of moderate suitability. The location of the chosen suitable dam site was located in with 30.8% of the dams in the Oromia area, 51.3% in the Amhara region, and 17.9% in the Beneshangul gumuz region.

4.3.1. Choosing possible inundation area of reservoir area

According to the description in section 3.4 to select the inundation area the procedure followed are illustrated in Figure 4-10 and appendix-1:Figure 8-1.

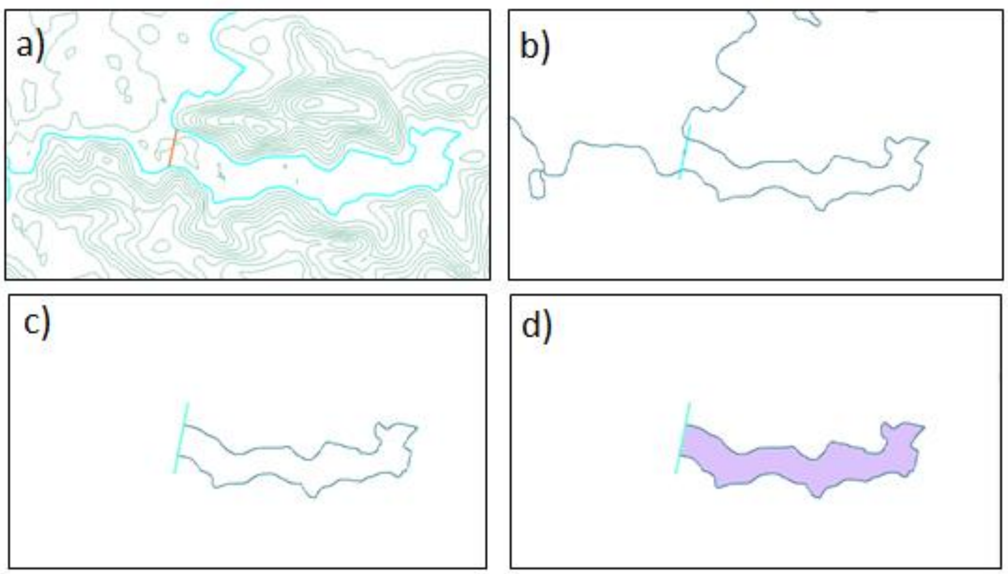


Figure 4-10: a) Abay basin contour b) Extract selected contour c) Dam site d) polygon dam site for dam D1905

4.3.2. Determination of reservoir catchment area

Based on the procedure outlined in section 3.4.1 the catchment areas of all the 39 dams were generated and their areas determined. Accordingly, the average catchment area of 39 dams was 1960.6 km^2 ranging from the minimum 53.6 km^2 to the maximum 27812.2 km^2. The reservoir inundation area as part of the catchment area contribution is calculated and about 46.2%,35.9 %, 7.7 %, and 10.3% of reservoirs have less than 1 % ,1-2%, 2-3% and >3 % reservoir area to catchment area ratio respectively. More than 56 % of the reservoirs have more than the average ratio. More details are shown in Figure 4-11and Figure 4-12 and appendix -7:

Figure 8-6.

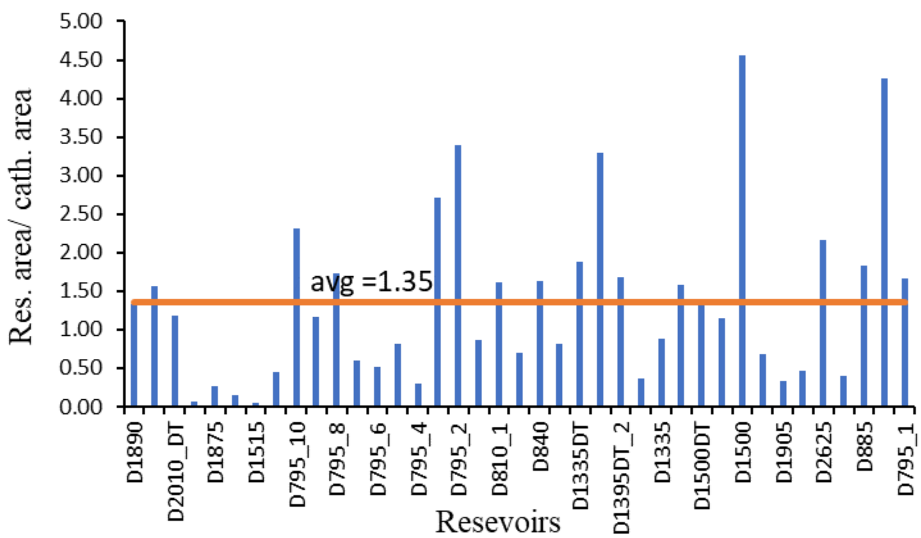


Figure 4-11: Reservoir area (mm^2) ratio with Catchment area(km^2)

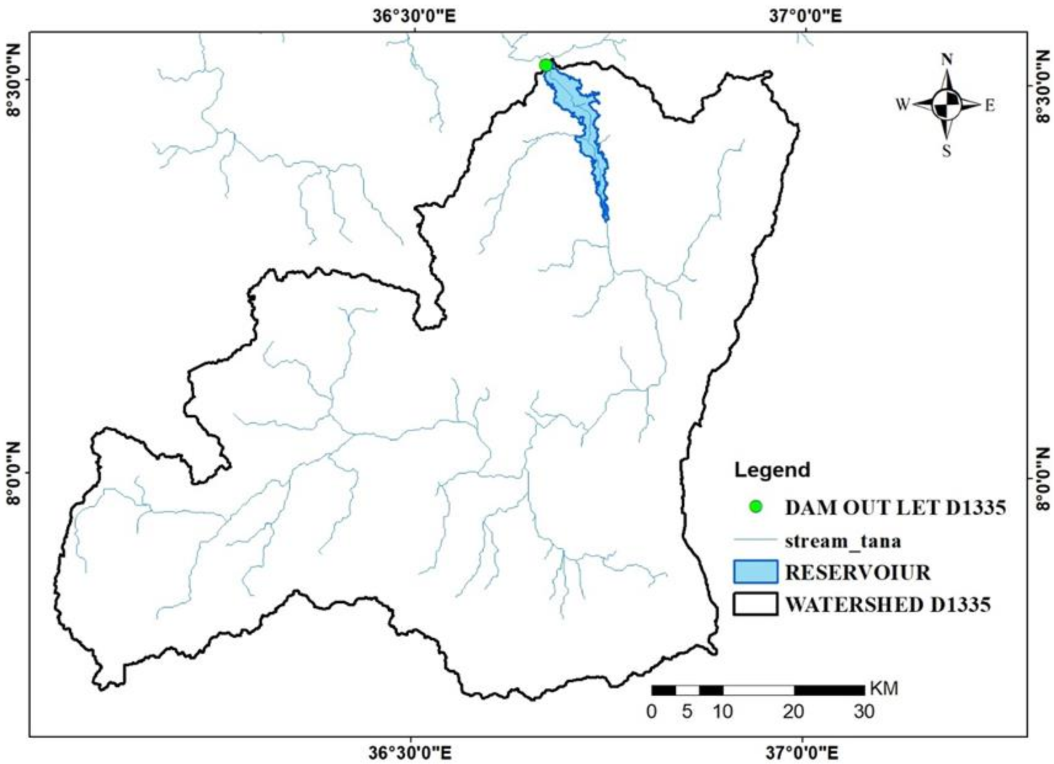


Figure 4-12: Watershed dam site and reservoir area

4.4. Validation of the dam site suitability map

The validation was done by comparing the result of suitable dam from existing proposed and constructed dam in the basin. The result of suitable dam from that the area of suitable dam but the data or the area selected for validation is the result was extracted by existing dam area coverage. As a result, in this dam site suitability study, the outcomes of the modeling employed are contrasted with those from the location of an existing dam and reservoir was utilized are contrasted with those from the location of an already-built dam and reservoir that was carefully selected and constructed. the very high, high, and moderately acceptable dam site locations from the model's generated output were used to build an existing dam in the basin.

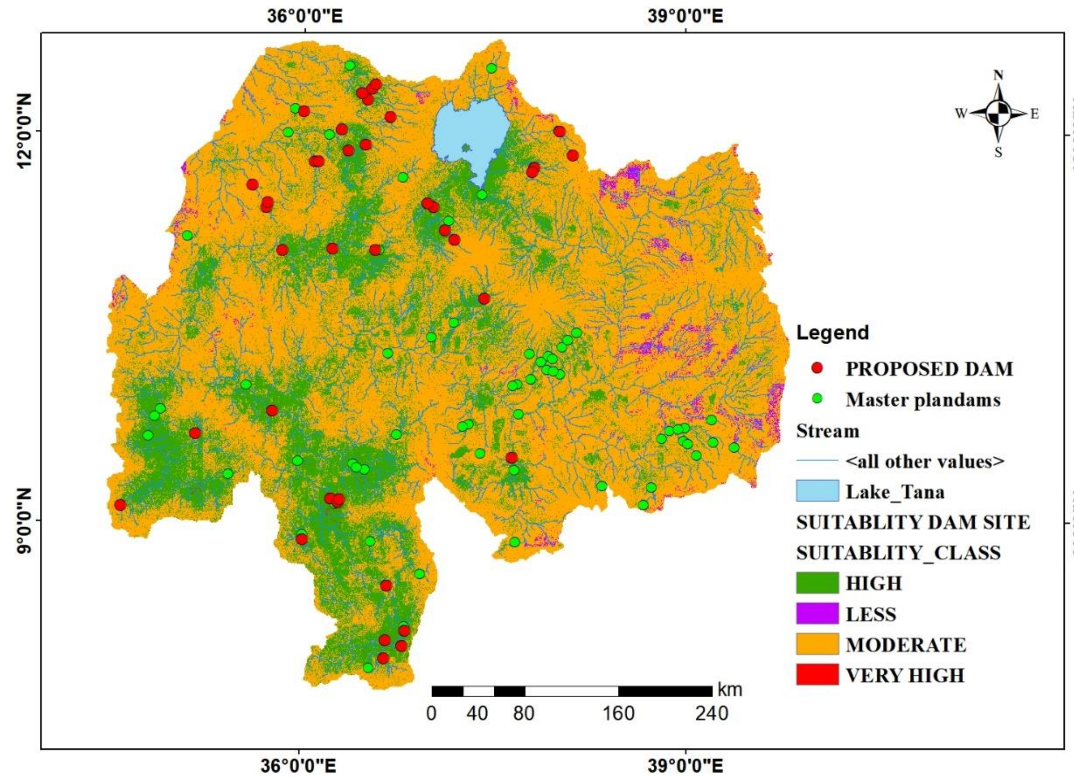


Figure 4-13: Validation of Proposed Dam and Dams in the Blue Nile Master Plan in the suitability area

Table 4-12: Comparation of Dams in the Blue Nile Master Plan and Proposed Dams Suitability Class for Validation

Class	Prop Suitable Dams	% Suitability	Master Plan Dams	% Master Plan Suitability
High	31	81.6	27	59.70
Moderate	7	18.4	40	40.30
Total	39	100	67	100

Based on the findings of the validated *Table 4-12: Comparation of Dams in the Blue Nile Master Plan and Proposed Dams Suitability Class for Validation*, above, high and moderate class were discovered in the planned dam and existing dam. These studies were conducted in order to confirm the accuracy of the current data and to support it.

4.5. Reservoir Elevation-Area-Capacity Curve and Profile of Proposed Dams

4.5.1. Reservoir elevation-area-capacity curve

Based on Rodrigues & Liebe,(2013) area-capacity curves are of the most important physical characteristics of dams'/reservoirs. These curves are used for reservoir flood routing, dam operation, determination of water surface area and capacity corresponding to each elevation, reservoir classification and prediction of sediment distribution in reservoirs. Therefore, obtaining the area-capacity relationships has great significance from a practical aspect (Haghiabi et al., 2013). The cross-section of dams, the elv- area-capacity of all the 39 dams were developed as shown in Figure 4-14, Figure 4-15 and elevation -area equations as in Table4-13 and appendix-2: Figure 8-2.

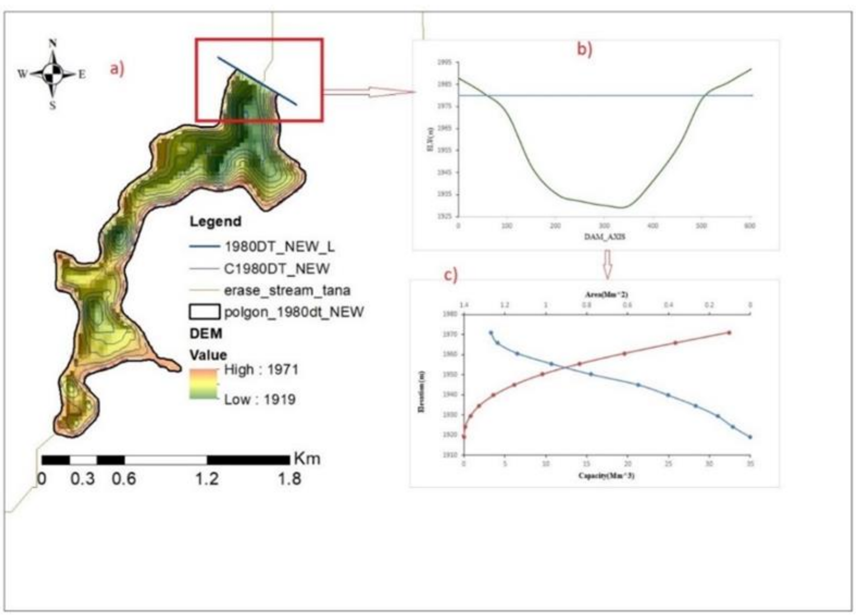


Figure 4-14: a) Dam site b) Dam x-section c) Elevation-Area-Volume for D1980dt_n

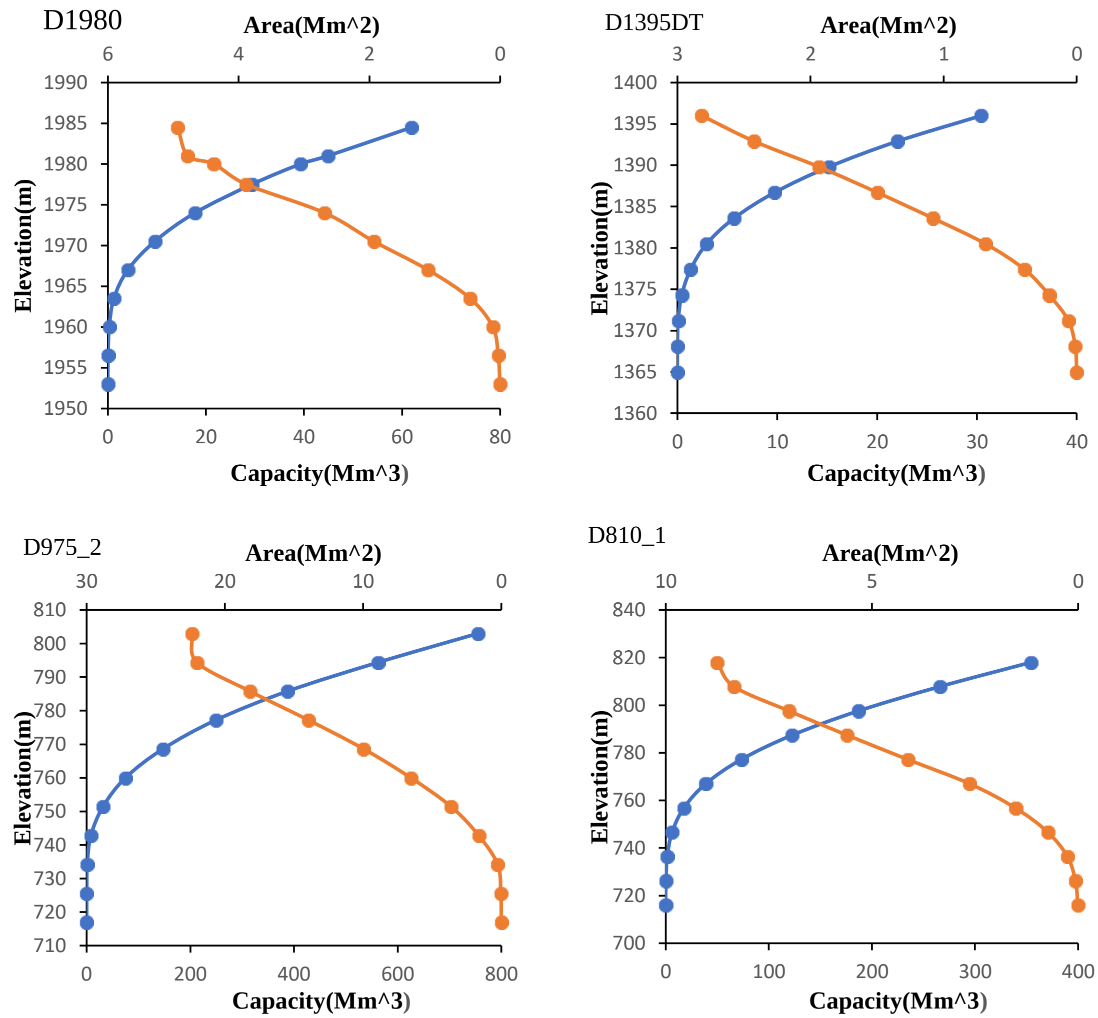


Figure 4-15: Elevation-Area-Capacity curve

Table4-13: Elevation- Area equation

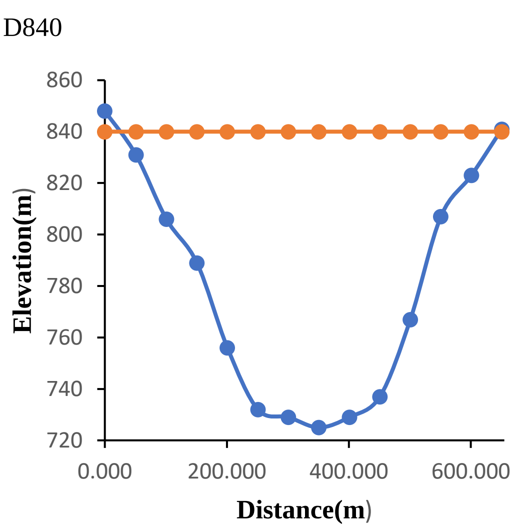
SN.	DAM	Area-Elevation equation	R2
1	D1890	$y = 0.2112x^3 - 3.7567x^2 + 20.492x + 1852.4$	0.81
2	D2115	$y = 0.4788x^5 - 4.2942x^4 + 14.848x^3 - 27.356x^2 + 38.012x + 2071.7$	1.00
3	D2010_DT	$y = 0.2616x^5 - 3.7375x^4 + 19.224x^3 - 43.068x^2 + 42.812x + 1985.3$	0.98
4	D1845	$y = 345.96x^5 - 1395.3x^4 + 2083.2x^3 - 1400.6x^2 + 424.3x + 1779.8$	0.99
5	D1875	$y = 27.124x^5 - 141.66x^4 + 264.43x^3 - 217.03x^2 + 87.507x + 1849.1$	0.99
6	D960	$y = 0.0121x^5 - 0.4029x^4 + 4.8596x^3 - 25.932x^2 + 61.168x + 887.29$	0.96

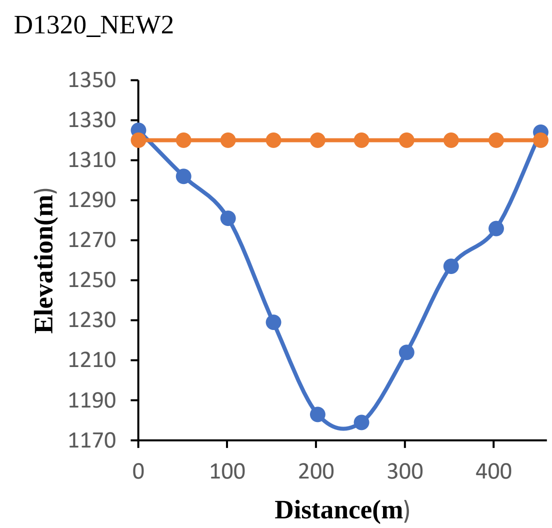
7	D1515	$y = 151195x^5 - 110922x^4 + 30607x^3 - 3818.3x^2 + 264.95x + 1490.1$	1.00
8	D810_2	$y = 3E\text{-}07x^5 - 8E\text{-}05x^4 + 0.0091x^3 - 0.4316x^2 + 9.3269x + 630.57$	0.97
9	D795_10	$y = -0.0655x^4 + 1.4968x^3 - 11.201x^2 + 32.23x + 757.54$	0.92
10	D795_9	$y = 44.656x^5 - 235.24x^4 + 453.71x^3 - 388.26x^2 + 147.25x + 767.44$	0.98
11	D795_8	$y = 0.0036x^5 - 0.135x^4 + 1.8143x^3 - 10.703x^2 + 30.516x + 721.03$	0.99
12	D795_7	$y = 570.99x^5 - 1748.5x^4 + 1967.6x^3 - 1000.1x^2 + 252.87x + 749.27$	0.98
13	D795_6	$y = 0.0214x^5 - 0.5379x^4 + 4.9155x^3 - 20.082x^2 + 39.363x + 747.15$	0.98
14	D795_5	$y = -0.0165x^6 + 0.4313x^5 - 4.2964x^4 + 20.516x^3 - 48.508x^2 + 56.911x + 747.84$	0.98
15	D795_4	$y = 0.8141x^5 - 9.5018x^4 + 41.046x^3 - 80.079x^2 + 76.705x + 738.7$	1.00
16	D795_3	$y = 67.108x^5 - 281.56x^4 + 440.44x^3 - 325.12x^2 + 135.76x + 750.04$	1.00
17	D795_2	$y = 0.0003x^5 - 0.0166x^4 + 0.3496x^3 - 3.3161x^2 + 16.3x + 723.68$	0.99
18	D1320_3	$y = 8.1043x^3 - 41.438x^2 + 103.72x + 1191.6$	1.00
19	D810_1	$y = 0.0341x^5 - 0.7881x^4 + 6.7372x^3 - 26.091x^2 + 51.914x + 720.75$	1.00
20	D690	$y = 0.0477x^5 - 0.943x^4 + 6.8954x^3 - 22.784x^2 + 35.269x + 658.02$	0.99
21	D840	$y = 1E\text{-}07x^5 - 4E\text{-}05x^4 + 0.0057x^3 - 0.3307x^2 + 8.7774x + 703.34$	0.96
22	D1530	$y = 0.2703x^5 - 3.9104x^4 + 20.403x^3 - 46.461x^2 + 48.797x + 1491.8$	0.98
23	D1335DT	$y = 0.5182x^5 - 4.8167x^4 + 16.581x^3 - 25.995x^2 + 21.475x + 1318.1$	0.99
24	D1395DT_1	$y = 2.3157x^5 - 18.093x^4 + 52.262x^3 - 68.842x^2 + 48.195x + 1366.8$	0.99
25	D1395DT_2	$y = 180.3x^5 - 698.93x^4 + 990.4x^3 - 623.21x^2 + 178.34x + 1364.9$	0.98
26	D1320_NEW	$y = 0.0412x^5 - 0.9406x^4 + 7.8561x^3 - 29.742x^2 + 58.177x + 1235$	0.99
27	D1335	$y = -0.0002x^4 + 0.0235x^3 - 0.9801x^2 + 13.828x + 1276.7$	0.92
28	D1395	$y = 0.0011x^3 - 0.1099x^2 + 3.6119x + 1348.4$	0.92
29	D1500DT	$y = 599.79x^5 - 1206.4x^4 + 842.43x^3 - 267.83x^2 + 83.306x + 1468.8$	1.00
30	D1440	$y = 82.48x^3 - 94.289x^2 + 54.601x + 1421.1$	1.00
31	D1500	$y = -5E\text{-}06x^6 + 0.0006x^5 - 0.0271x^4 + 0.5694x^3 - 5.8012x^2 + 26.786x + 1412.3$	0.99
32	D1320_NEW2	$y = 5E\text{-}05x^5 - 0.007x^4 + 0.3122x^3 - 5.7967x^2 + 44.38x + 1141.3$	0.97
33	D1905	$y = 91.44x^5 - 343.03x^4 + 479.41x^3 - 310.91x^2 + 113.66x + 657.65$	0.99
34	D1980DT	$y = 68.675x^5 - 178.49x^4 + 183.23x^3 - 116.26x^2 + 79.573x + 1918.7$	1.00
35	D2625	$y = 22.161x^5 - 138.3x^4 + 319.64x^3 - 343.51x^2 + 199.64x + 2536.5$	1.00
36	D1890DT	$y = 3.4852x^5 - 29.809x^4 + 93.474x^3 - 130.76x^2 + 85.167x + 1854$	0.99
37	D885	$y = 5.76x^5 - 38.664x^4 + 94.589x^3 - 103.16x^2 + 54.039x + 864.73$	0.99

38	D1410	y = 0.3104x^5 - 3.9162x^4 + 18.147x^3 - 37.404x^2 + 34.635x + 1389.8	0.98
39	D795_1	y = 0.0068x^5 - 0.237x^4 + 2.8781x^3 - 14.536x^2 + 31.655x + 736.46	0.99

4.5.3. Profile of proposed dams

According to the generated dam profile the width and the height of dams are calculated for all the selected 39 reservoirs. Hence, the average width of the reservoirs is 531.8 m with the average depth of 50.3 m. The width of the dams varies from 165.4-1025 m. The depth also varies from 12-174 m. The generated profiles of some of the reservoirs are shown in Figure 4-16 and appendix-3: Figure 8-3.





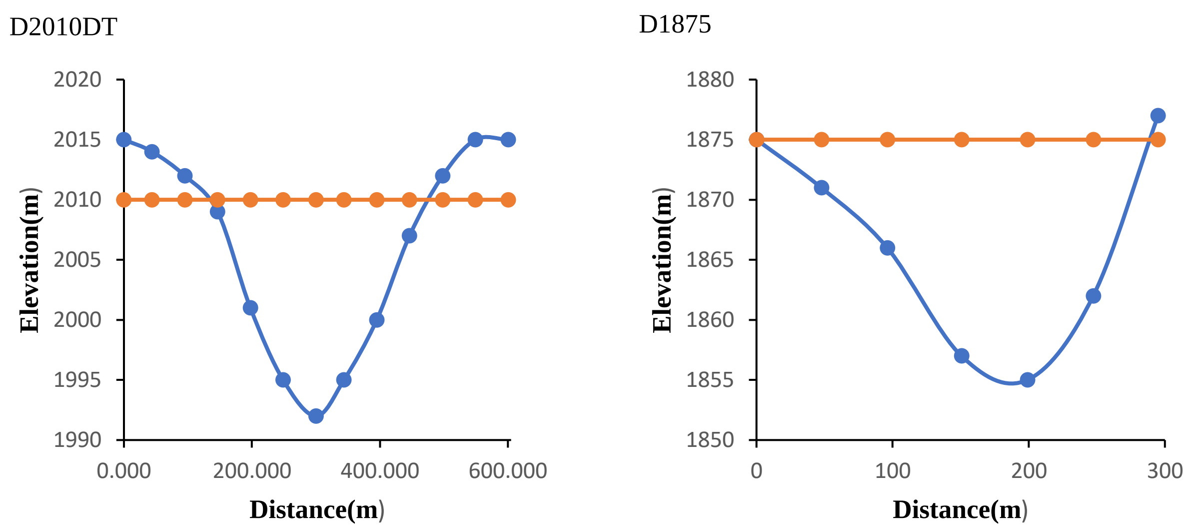


Figure 4-16:Dam axis profile

4.5. **Classification of selected Dams**

Ren et al., (2017) classifies the size of dams into three categories based on their height and reservoir capacity. In light of this, 17 of the 39 proposed dams are large, while 9 are classified as intermediate. The remaining dams did not meet the height and capacity standards. But according to the height classification, 3 are in the small class, 15 are in the intermediate, and 21 are in the large class.

4.6. Characteristics of Proposed Dams site

The maximum height at the cross section of the 39 proposed dams ranged from a minimum of 12 m to a maximum of 174 m, and their widths ranged from a minimum of 165.4 m to a maximum of 1025 m. These dams have on average 531.8 meters wide and a height of 50.3 meters. These reservoirs ranged in area from 0.24 million square meters to 148.49 million square meters, and their storage capacities ranged from 3.2 million cubic meters to 8532.44 million cubic meters.

Table 4-14: Characteristics of dam profile

S.	NAME	X	Y	Elev.	HT	Width	Cap. (Mm^3)	A (Mm^2)	Ht/w
1	D1890	327160	1187840	1890	46	745.64	72.75	9.60	0.06
2	D2115	301814	1238570	2115	42	672.20	55.88	3.45	0.06
3	D2010_DT	293515	1246430	2010	18	336.10	31.77	4.89	0.05
4	D1845	283659	1266190	1845	29	388.42	21.59	1.31	0.07
5	D1875	278882	1269270	1875	20	311.84	15.19	1.89	0.06
6	D960	197563	1231100	960	94	388.74	1893.54	6.82	0.24
7	D1515	234383	1229780	1515	12	165.43	3.17	0.24	0.07
8	D810_2	146213	1092500	810	174	721.44	8532.45	124.38	0.24
9	D795_10	141182	1266380	795	21	917.80	79.13	9.29	0.02
10	D795_9	142314	1270780	795	15	211.06	10.83	1.66	0.07
11	D795_8	182523	1305450	795	78	1025.00	377.64	14.34	0.08
12	D795_7	185387	1305800	795	48	365.80	14.52	0.98	0.13
13	D795_6	211234	1315060	795	54	851.36	110.57	8.78	0.06
14	D795_5	205606	1332860	795	35	712.87	89.49	6.26	0.05
15	D795_4	227729	1358440	795	47	394.83	80.76	3.90	0.12
16	D795_3	222742	1363630	795	46	544.52	22.44	1.45	0.08
17	D795_2	231796	1367460	795	78	855.40	571.60	21.44	0.09
18	D1320_3	247101	1343550	1320	118	596.63	130.49	2.52	0.20
19	D810_1	173373	1348230	810	77	663.64	280.44	8.23	0.12
20	D690	128967	1285670	690	30	652.50	59.66	6.73	0.05
21	D840	154906	1229550	840	115	626.70	5085.46	148.49	0.18
22	D1530	80028.8	1073170	1530	16	220.47	68.23	4.94	0.07
23	D1335DT	195693	1017390	1335	12	381.32	25.46	3.39	0.03
24	D1395DT_1	201730	1014290	1395	25	478.36	26.77	2.53	0.05
25	D1395DT_2	202818	1016840	1395	23	484.63	11.38	1.25	0.05
26	D1320_NEW	171681	982379	1320	82	663.66	215.32	8.13	0.12
27	D1335	243340	942879	1335	35	468.98	556.06	47.89	0.07
28	D1395	259233	903970	1395	26	601.25	757.73	60.62	0.04
29	D1500DT	256574	891237	1500	26	517.73	10.37	0.79	0.05

30	D1440	241907	895912	1440	12	371.50	5.51	0.64	0.03
31	D1500	241197	880406	1500	91	518.08	1027.96	32.66	0.18
32	D1320_NEW2	350643	1052310	1320	141	421.30	1720.76	47.80	0.33
33	D1905	370255	1300190	1905	15	430.00	9.24	1.25	0.03
34	D1980DT	368155	1297570	1980	50	349.00	40.29	1.12	0.14
35	D2625	402984	1310480	2625	92	516.74	62.91	2.19	0.18
36	D1890DT	391744	1330910	1890	29	467.81	34.56	2.86	0.06
37	D885	225983	1319520	885	22	724.50	15.83	2.33	0.03
38	D1410	16059.8	1011400	1410	14	436.36	31.31	4.52	0.03
39	D795_1	234740	1371360	795	55	542.23	297.04	13.35	0.10

4.7. Relationship of Depth with Area and Volume

According to reservoir depth-area-volume relationship is important information for water resource planning and managing hydrology and modeling, it is laborious, time consuming and costly to obtain them. Therefore, the Depth Area equation developed in Figure 4-17 shows that if an engineer is studying in the Blue Nile on dams and identify a site at a specific place, he can insert the expected depth of the dam in the depth Area equation and can find the size of the inundation area easily with this exponential equation with a 50% accuracy. In the other hand, in Figure 4-18 and appendix7 -4: *Table 8-1*. the Depth Volume will tell us the amount of water we can accumulate in the reservoir with that depth with 80% accuracy. Therefore, site selection will be easier with these equations in the upper Blue Nile.

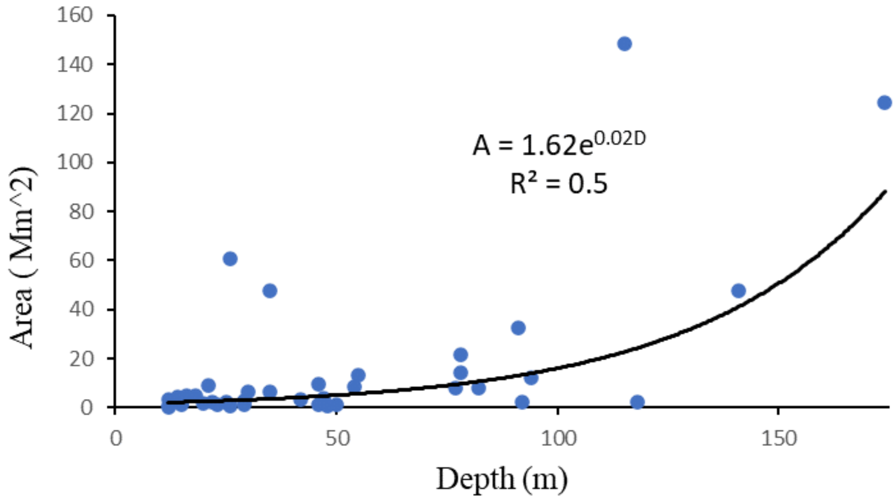


Figure 4-17: Depth vs Area

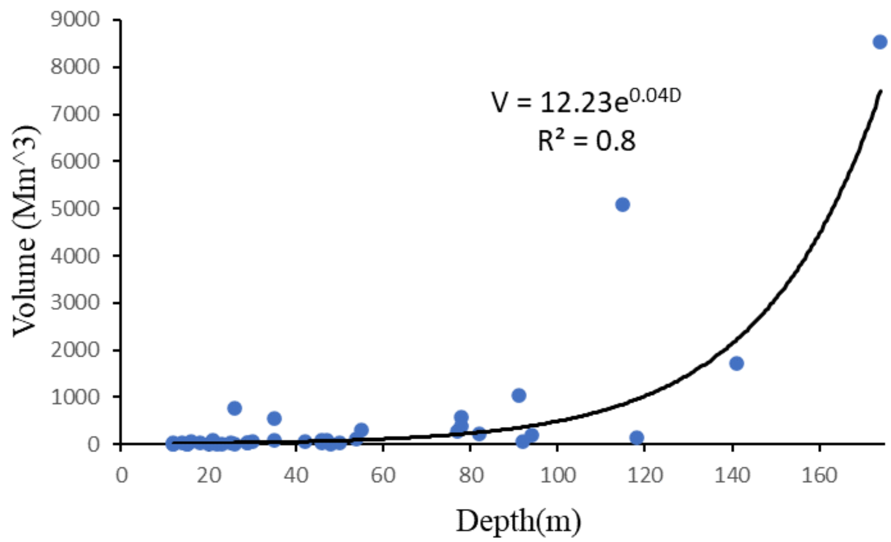


Figure 4-18: Volume vs depth

4.8. Administrative Location of selected dams

Dams were selected based on the criteria set for selection and using overlaying the final suitability map with the 15m contour generated from the DEM. The selection was mainly based on the availability of a suitable constricted abutment for the dam axis. Based on these 39 dams were selected all over the Upper Blue Nile. However, these dams are administratively situated in the three regions of Ethiopia. These dams are found in Awi, North Gonder, South Gonder and West Gojam in Amhara Region, Kemashi and Metekel in Beneshangul Gumuz and East Wellega, Illubabor, Jimma, Kelem Wellega, West Shewa and West Wellega in Oromia Regions. Details are shown in Table 4-15 and appendix-8: *Table 8-2*.

Table 4-15: Number of selected dams in the Administrative Region

REGION	DAMS	PERCENT
Oromia	12	30.8
Amhara	20	51.3
Beneshangul Gumu	7	17.9
	38	

4.9. Hydrological Data Analysis

4.9.1. Computing Dependable Catchment Yield from Rainfall

The 80% dependable rainfall had been calculated as stated in section 3.11.1 for all reservoirs as shown in Figure 4-19. According to the calculation done for all the reservoirs the range of dependable rainfall is in 935.9-1732.4 mm with an average value of 1270.1 mm and standard deviation of 245.5 mm as shown in Figure 4-20.

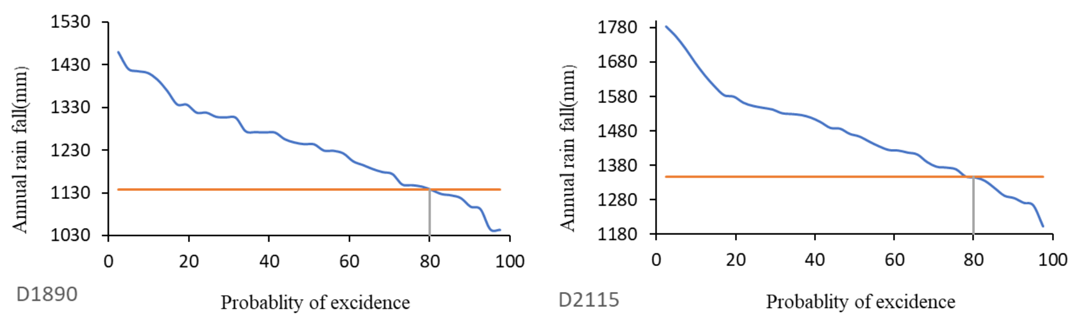


Figure 4-19: 80% dependable Rainfall for the reservoir D1890 and D2115

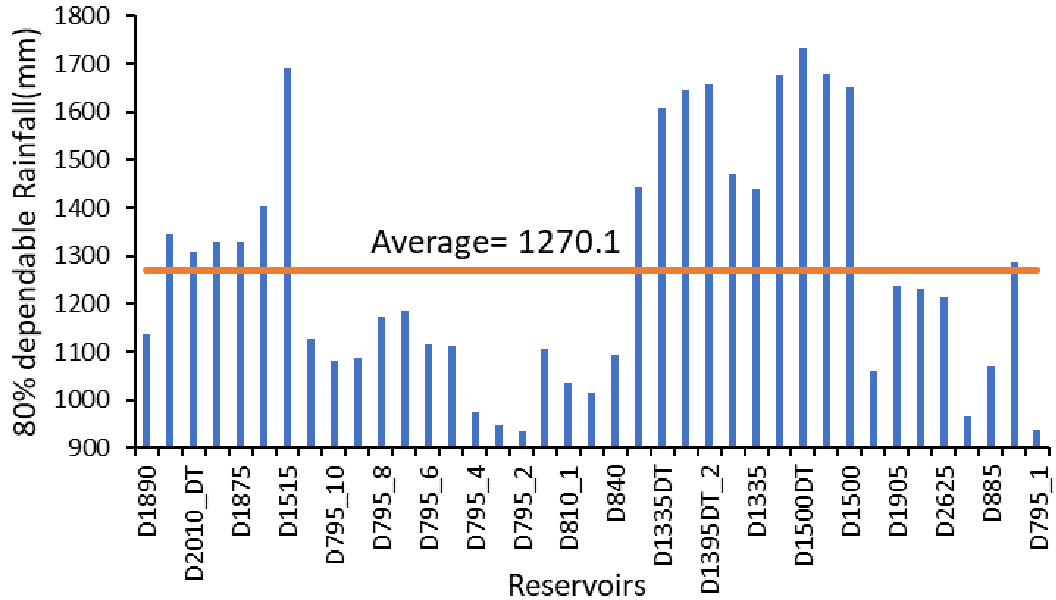


Figure 4-20: Variability of 80% dependable rainfall for all reservoir

4.9.2. Trap efficiency calculation

4.9.2.1. Capacity-Inflow Method (Brune's Curve):

Brune's method of evaluating trap efficacy is used to estimate the volume of sediments held in a reservoir using reservoir capacity and inflow. Based on equations in section 3.11.2.1 using equations10-12, the trap efficiencies of all dams were calculated as shown in Figure 4-21 and appendix-9: Table 8-3. However, we used the Midian curve (orange colour) that's developed by equation 11.

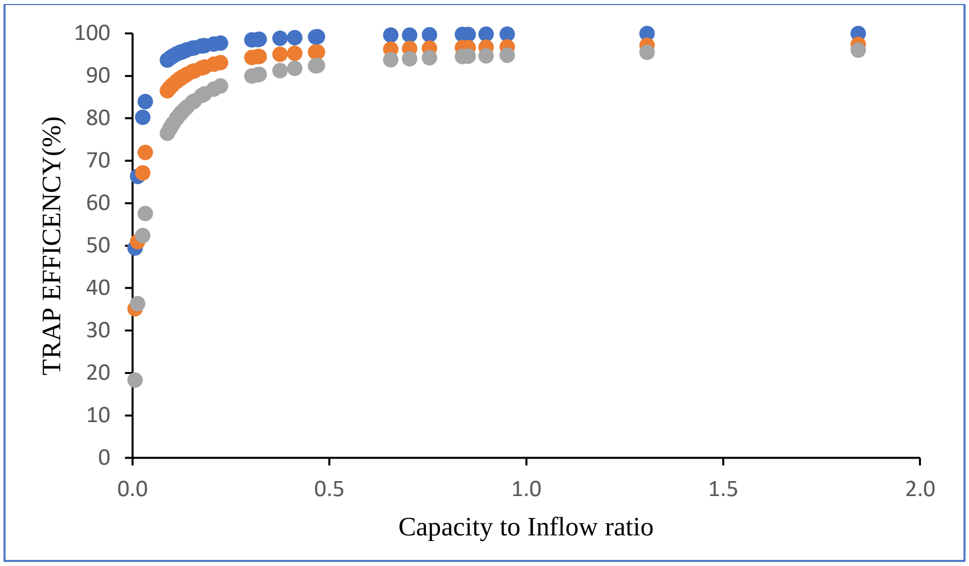


Figure 4-21: Sediment Trapping Efficiency From equation 10 ,11and 12 Primarily Highly Flocculated and Coarse-Grained Sediment, Median Curve (for medium sediments) and *Primarily* Colloidal and Dispersed Fine-grained Sediments

4.9.3. Volume of Sediment trapped in the Reservoirs

Utilizing the inflow, the average suspended sediment concentration, and the trap efficiency, the annual accumulation of sediment for all the dams is calculated. Given the capacity of the reservoir in the upper Blue Nile basin, the plot of capacity vs yearly sediment accumulation shows an interesting relationship that can be helpful to calculate the annual sediment accumulation for a dam under consideration. The exponential equation given in the figure below can therefore be used to estimate the annual accumulation of sediment with an accuracy of about 90%. According to this research the total volume of sediment trapped by all the 39 reservoirs is 353.7 M.tons/year.

Table 4-16: Volume of sediment trapped in all reservoirs M.ton/year

Dams	Capacity (Mm^3)	inflow (Mm^3)	catchment(ha)	equ11	Sediment (Mton)
D1890	72.75	478.87	72258.84	98.04	3.05
D2115	55.88	184.65	22000.05	98.03	1.22
D2010_DT	31.77	334.97	41509.62	98.04	2.05
D1845	21.59	1697.80	205600.2	98.04	6.05
D1875	15.19	594.55	72028.08	98.04	2.79
D960	1893.54	4077.65	459510	98.04	27.29
D1515	3.17	482.40	42648.03	98.04	1.19
D810_2	8532.45	18165.50	2781278	98.04	121.62
D795_10	79.13	245.96	40094.19	98.03	1.63
D795_9	10.83	88.58	14266.44	98.03	0.55
D795_8	377.64	575.79	83270.25	98.04	3.88
D795_7	14.52	114.70	16327.98	98.03	0.72
D795_6	110.57	1099.53	170952.8	98.04	6.76
D795_5	89.49	489.86	76430.88	98.04	3.16
D795_4	80.76	675.40	128788	98.04	4.22
D795_3	22.44	26.79	5359.77	98.00	0.18
D795_2	571.60	310.07	63185.67	98.04	2.11
D1320_3	130.49	185.36	29191	98.03	1.25
D810_1	280.44	294.66	51167.34	98.04	2.00
D690	59.66	533.23	95742.9	98.04	3.31
D840	5085.46	5661.59	906655.2	98.04	38.35
D1530	68.23	555.22	60244.11	98.04	3.48
D1335DT	25.46	191.72	18063.81	98.03	1.21
D1395DT_1	26.77	83.95	7672.32	98.03	0.56
D1395DT_2	11.38	82.49	7467.12	98.03	0.52
D1320_NEW	215.32	2088.61	221173.9	98.04	12.87
D1335	556.06	4956.09	538567.3	98.04	30.78
D1395	757.73	4317.53	385586.8	98.04	27.77
D1500DT	10.37	66.37	5684.13	98.02	0.42
D1440	5.51	62.53	5578.2	98.02	0.38
D1500	1027.96	786.57	71545.14	98.04	5.35
D1320_NEW 2	1720.76	4181.00	699900.7	98.04	27.90
D1905	9.24	284.96	38188.26	98.04	1.44
D1980DT	40.29	180.55	24371.19	98.03	1.18
D2625	62.91	73.80	10173.96	98.02	0.50
D1890DT	34.56	363.94	70584.75	98.04	2.22

D885	15.83	76.83	12693.24	98.02	0.50
D1410	31.31	83.55	10594.71	98.03	0.56
D795_1	297.04	393.78	80059.41	98.04	2.66
Total					353.66

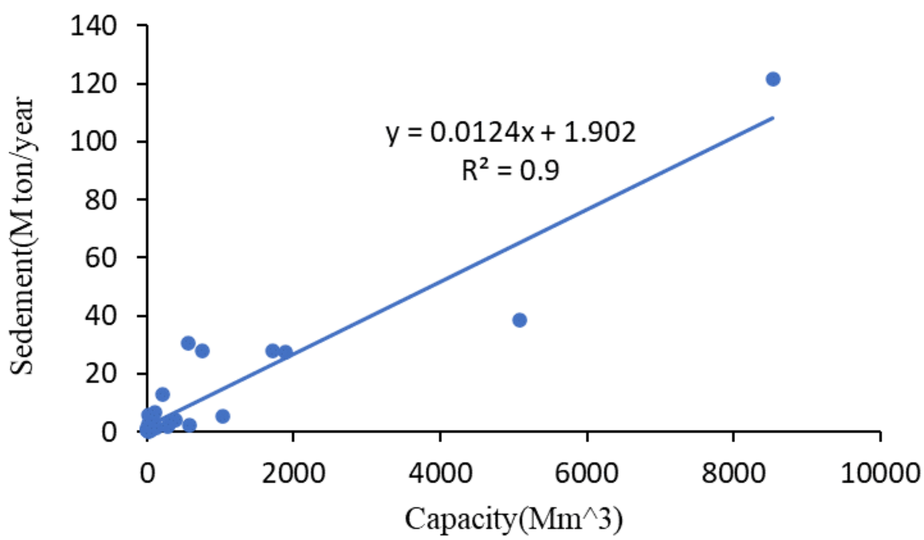


Figure 4-22: Sediment trapped in reservoirs vs Capacity

5. CONCLUSION

Some senior researchers in the Blue Nile like Whittington believe that it is economical , if dams are built upstream rather than downstream, more water will be available for downstream users to use, reducing evaporation and seepage losses(Whittington et al., 2004).

In this study, a suitability map for selecting several proposed dam sites with profile were generated for Abay Basin. Due to the complexity of dam site selection depending on a number of factors, a Multi-Criteria Decision Analysis (MCDA) method and Analytic Hierarchy Process (AHP) were used in this study. As a powerful and flexible tool, AHP provides an integrated measurement on tangible factors with different priority by pairwise comparison.

Raster layers of all criteria were integrated by a weighted summation using the weights generated by pairwise comparison to generate a suitability map showing different levels of suitability for dam construction. The suitability map is useful for decision makers and whoever interested in this topic to have a quick idea on suitable areas distribution and determine the potential area for dam sites.

In general, from the analysis southern, south west, and central part of Abay basin was found to be the densest area with high suitability for constructing dam while north east and eastern parts were found as low or extremely low suitable area for constructing dam. Accordingly, *26.36%* of the Abay basin is in the highly suitable and very high suitability in which only *0.03%* was very highly suitable; *72.01%* of the Abay basin area was found in the moderate suitability; *1.59%* on low or extremely low suitability

Based on the suitability map, *39* possible dam sites were proposed. Along with the location of proposed dam sites, a profile of each dam was generated including a cross section of the dam site, dam heights, dam widths, elevation-area-capacity of the reservoirs were determined.

Reservoirs were classified based on their height and reservoir capacity. According to this, 17 of the 39 proposed dams are large, while 9 are classified as intermediate. The remaining dams did not meet the height and capacity standards. But according to only height classification, 3 are in the small class, 15 are in the intermediate, and 21 are in the large class. The height of dams varied from *12 m* to 174 *m*, the width of these dams also varied from 165 to 1025 m. The storage capacities of these varied from $3.16Mm^3$ to $8532.4Mm^3$; the surface area of reservoir varied from $0.24\ Mm^2$ to $148.49\ Mm^2$.

The depth-area-volume or elev-area-capacity relationship for reservoirs is crucial knowledge for hydrology, modeling, and planning water resources. Therefore, the Elevation(depth)-Area-Capacity curve of the 39 reservoirs are developed. To support future design and development endeavors different equations were developed from the data generated from these 39 dams. Accordingly, the equation developed between depth and areas of 39 dams will support during studies if one knows the depth of the selected dam to find the inundation area of the reservoir easily with this equation with a 50% accuracy. In the other hand, the Depth Volume will tell us the amount of water we can accumulate in the reservoir with that depth with 80% accuracy.

Another interesting relationship that can be helpful to calculate the annual sediment trapped for a reservoir under consideration when its capacity is known in the upper Blue Nile basin, the equation estimates the annual accumulation of sediment with an accuracy of about 92%.

These reservoirs contribute to improving the livelihoods of those living in the basin and reduce their exposure to drought. The reservoirs have a large impact on downstream flows as well because they can act as a flood buffer by postponing and reducing flash floods by temporarily storing the extra water. Additionally, they contribute to groundwater aquifer recharge, which raises base flow in the catchment area's downstream region. These planned reservoirs apart from their use for irrigation, they can trap a lot of sediment (353.7 M.tons/year) that could have been deposited in GERD which reduces the life time of our great dam that will benefit our children and grandchildren economically. These dams help not only on trapping sediment but also harness the flood that inundates Sudan in the high rainy season.

6. RECOMMENDATIONS

The application of integrated methods of AHP, GIS, and Multi-Criteria Decision Analysis for dam site selection have been proved to provide a good result. Therefore, similar studies incorporating more reservoirs should be conducted in the region to develop best planning tools like the once developed in this research.

For future works researchers can estimate the sediment accumulation using the sediment generated in the nearby constructed dams.

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8. APPENDICES

APPENDICE1: Dam site selection

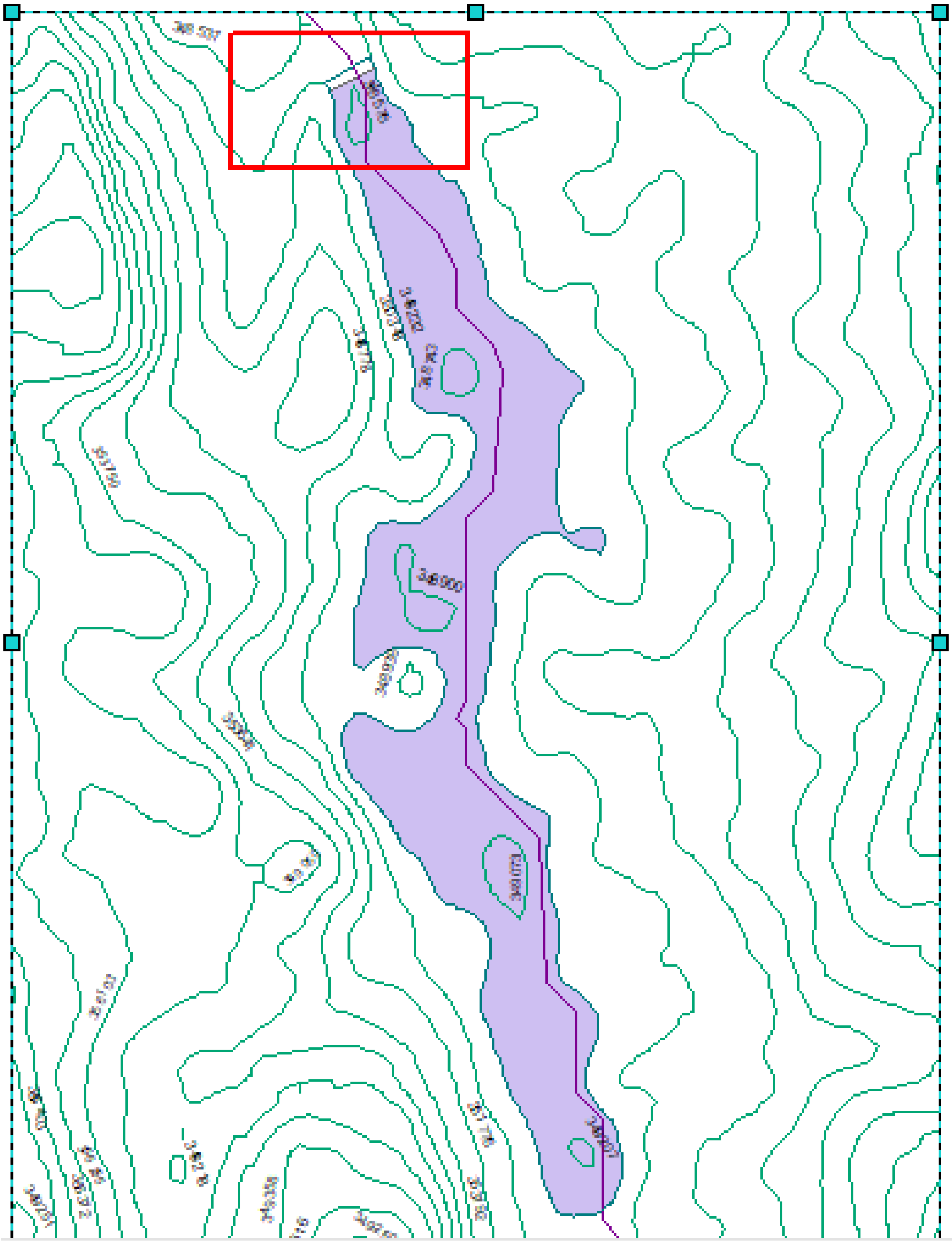
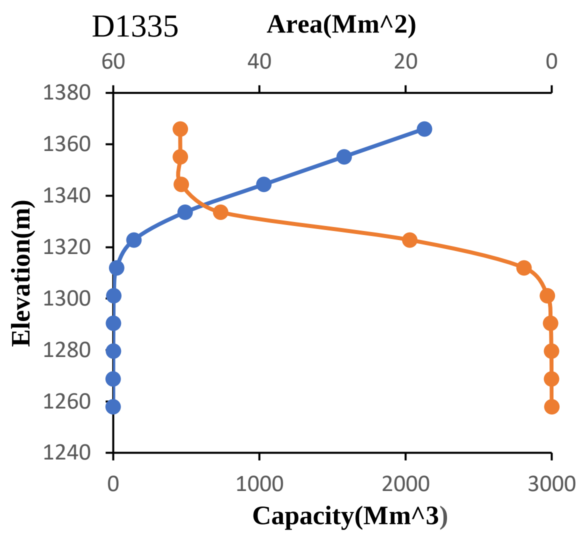
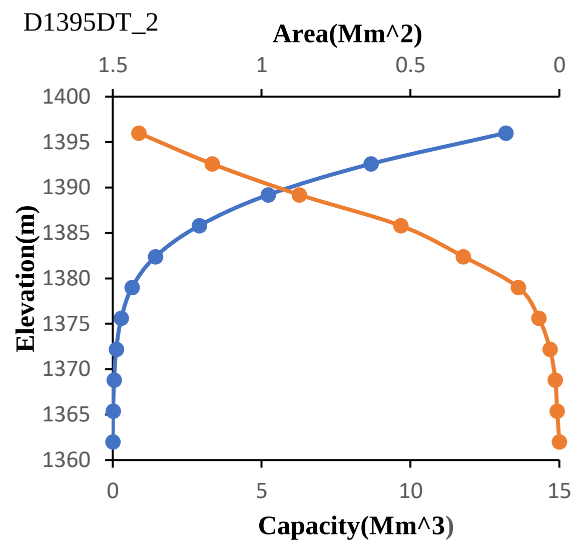
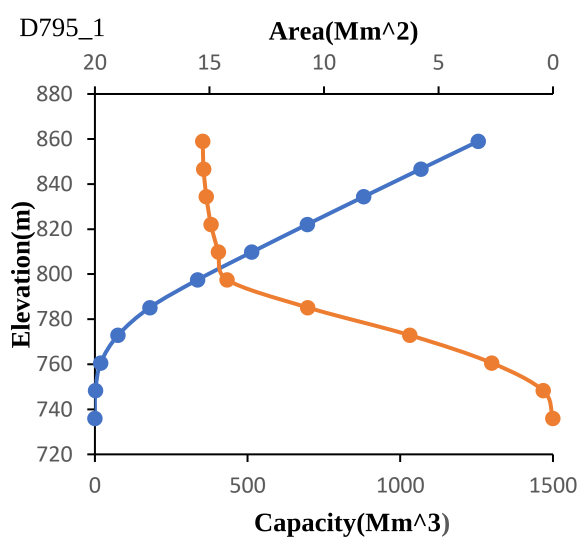


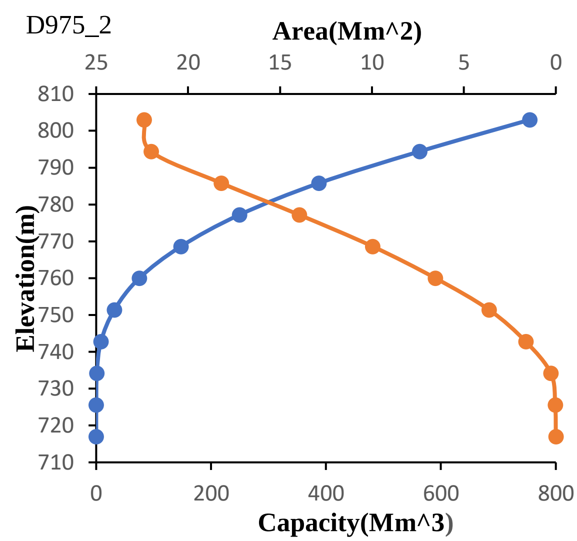
Figure 8-1:Dam site selection with contour

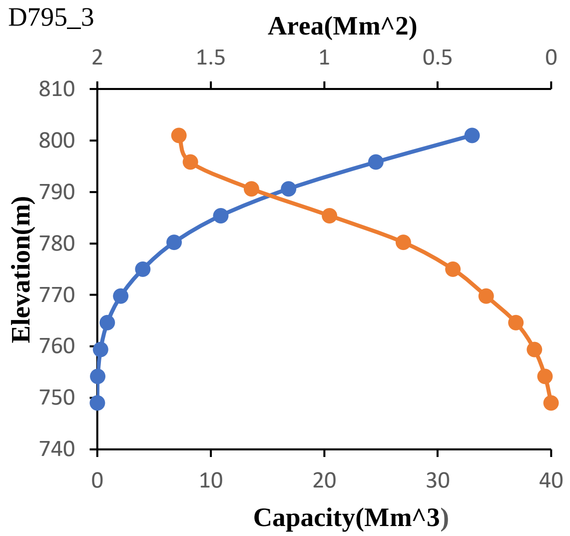
APPENDIX 2: Elevation-Area-Capacity curve

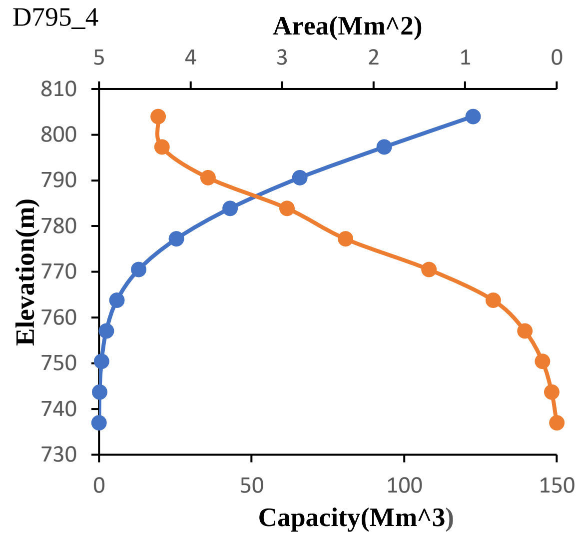


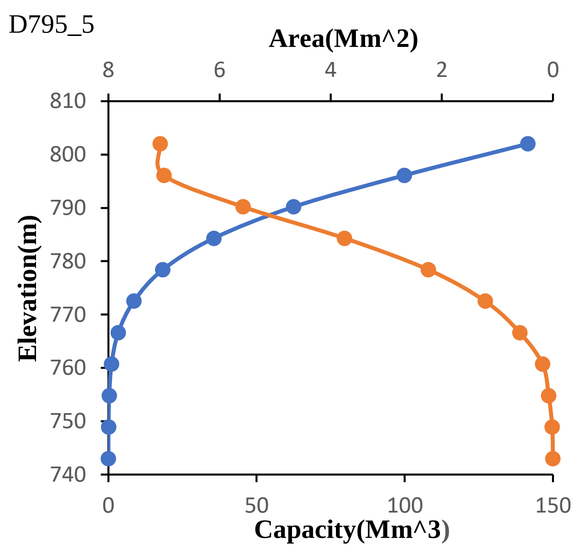


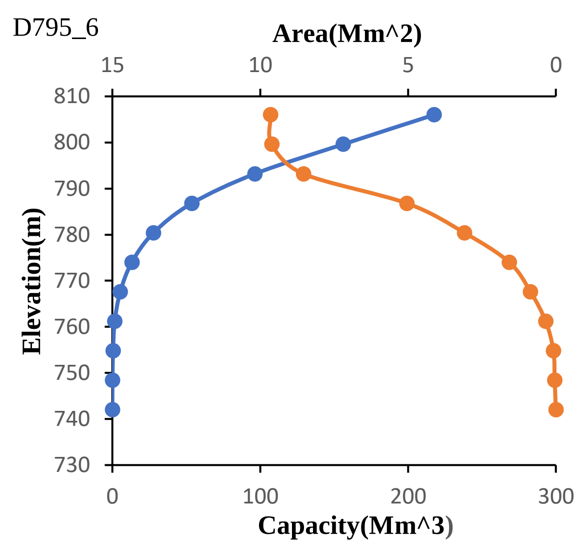




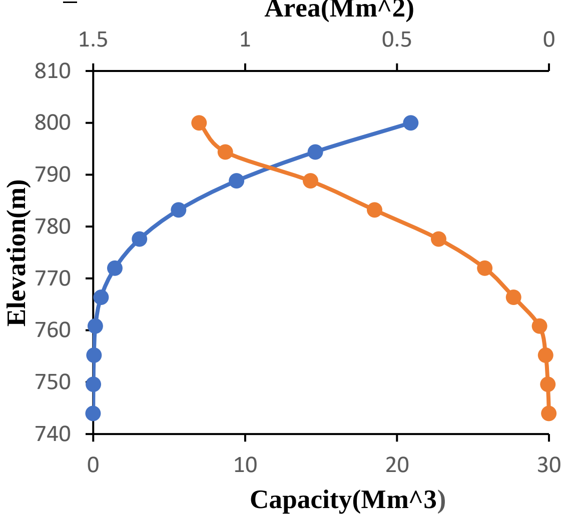

D795_3
Area(Mm^2)
2
1.5
1
0.5
0
810
800
790
780
770
760
750
740
Elevation(m)
0
10
20
30
40
Capacity(Mm^3)


D795_4
Area(Mm^2)
5
4
3
2
1
0
810
800
790
780
770
760
750
740
730
Elevation(m)
0
50
100
150
Capacity(Mm^3)

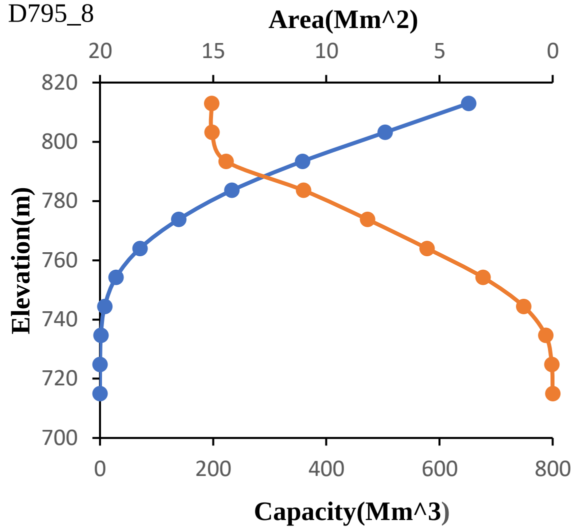

D795_5
Area(Mm^2)
8
6
4
2
0
810
800
790
780
770
760
750
740
Elevation(m)
0
50
100
150
Capacity(Mm^3)


D795_6
Area(Mm^2)
15
10
5
0
810
800
790
780
770
760
750
740
730
Elevation(m)
0
100
200
300
Capacity(Mm^3)

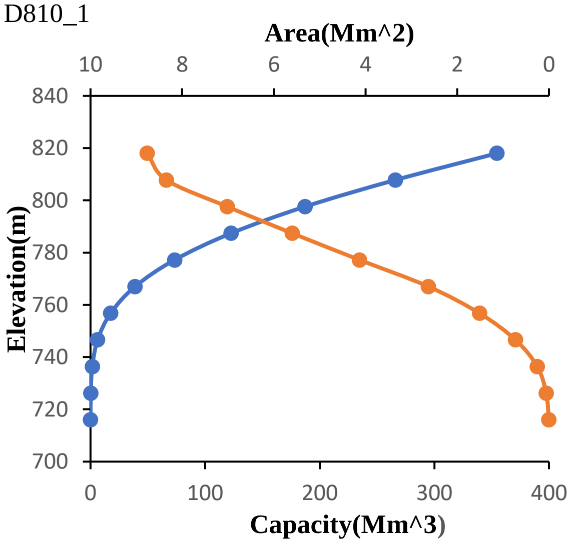
D795_7



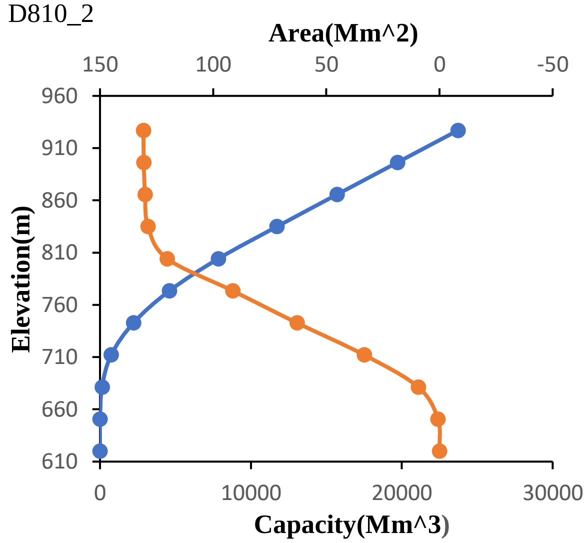
D795_8

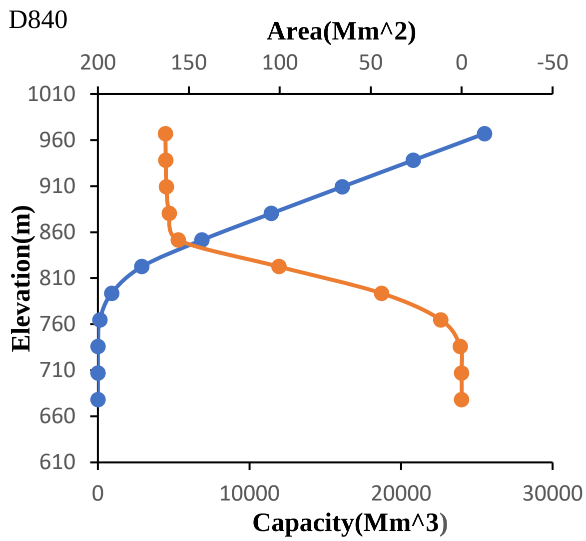


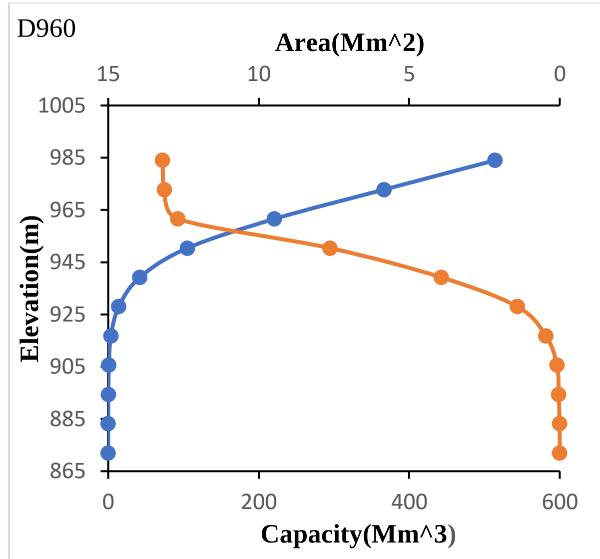
D810_1

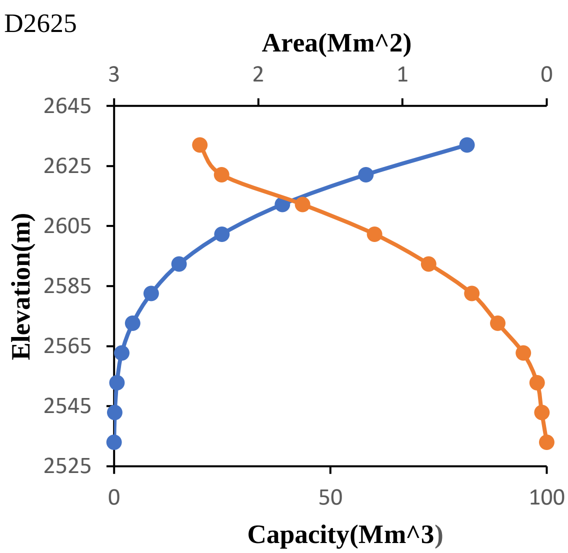


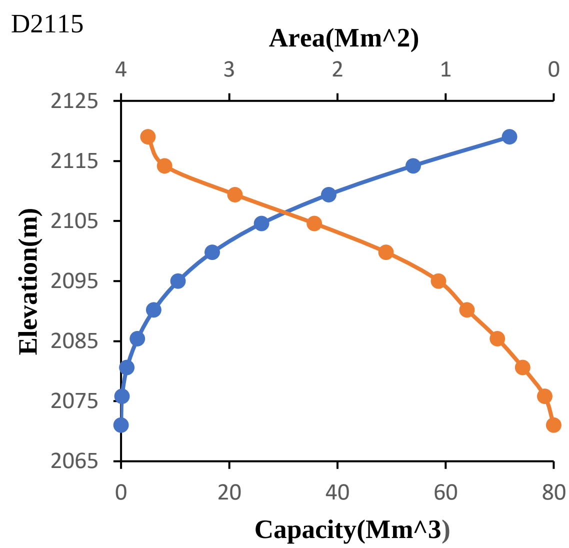
D810_2

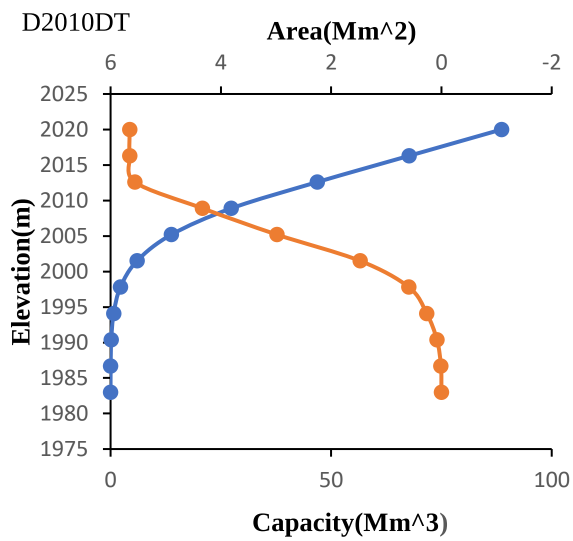


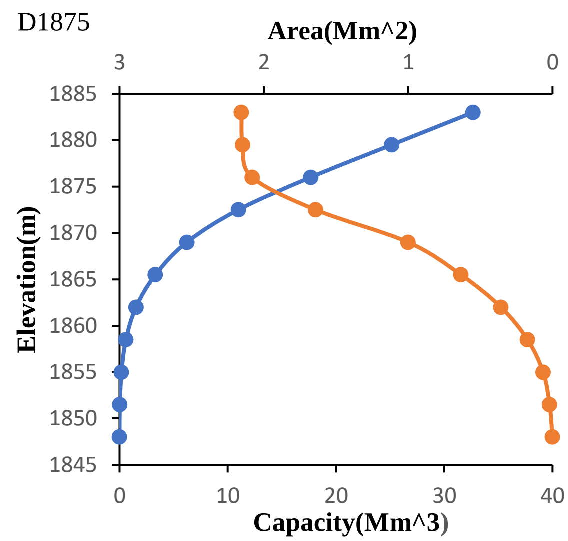

D840
Area(Mm^2)
200
150
100
50
0
-50
1010
960
910
860
810
760
710
660
610
Elevation(m)
0
10000
20000
30000
Capacity(Mm^3)

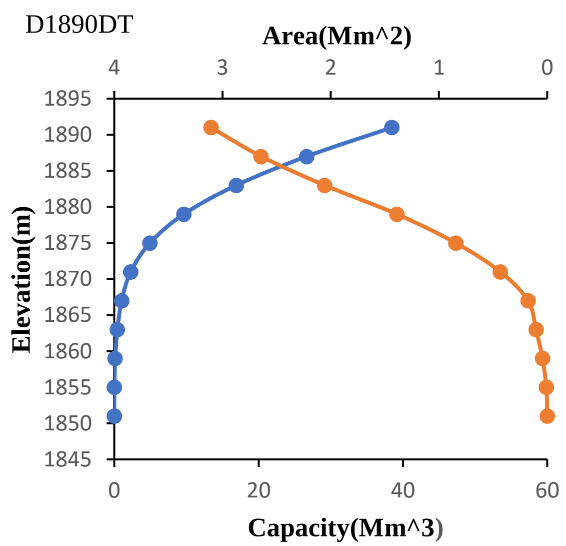

D960
Area(Mm^2)
15
10
5
0
1005
985
965
945
925
905
885
865
Elevation(m)
0
200
400
600
Capacity(Mm^3)

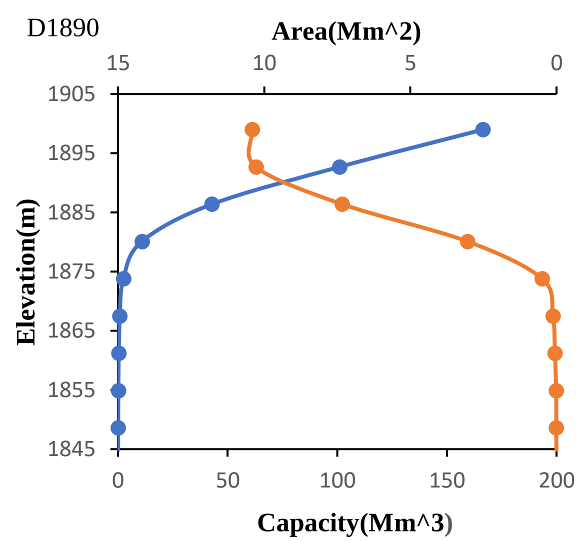

D2625
Area(Mm^2)
3
2
1
0
2645
2625
2605
2585
2565
2545
2525
Elevation(m)
0
50
100
Capacity(Mm^3)

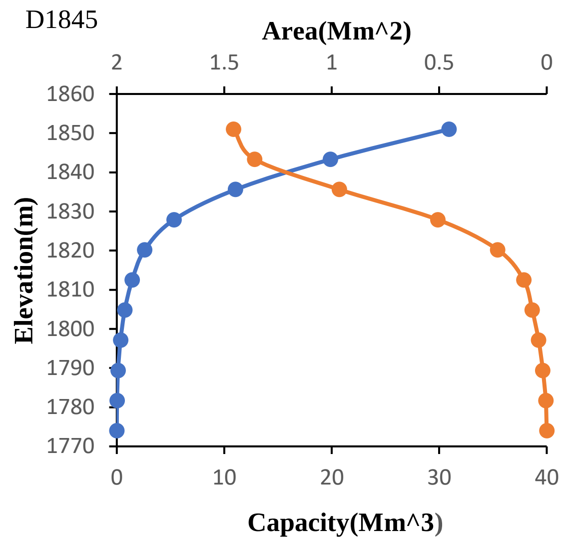

D2115
Area(Mm^2)
4
3
2
1
0
2125
2115
2105
2095
2085
2075
2065
Elevation(m)
0
20
40
60
80
Capacity(Mm^3)

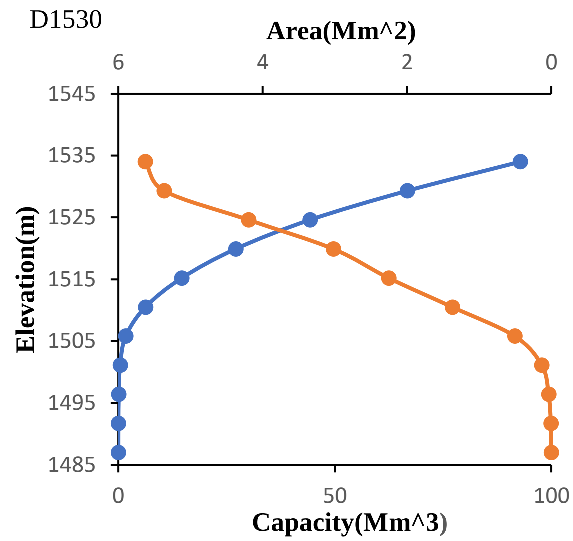

D2010DT
Area(Mm^2)
6
4
2
0
-2
2025
2020
2015
2010
2005
2000
1995
1990
1985
1980
1975
Elevation(m)
0
50
100
Capacity(Mm^3)

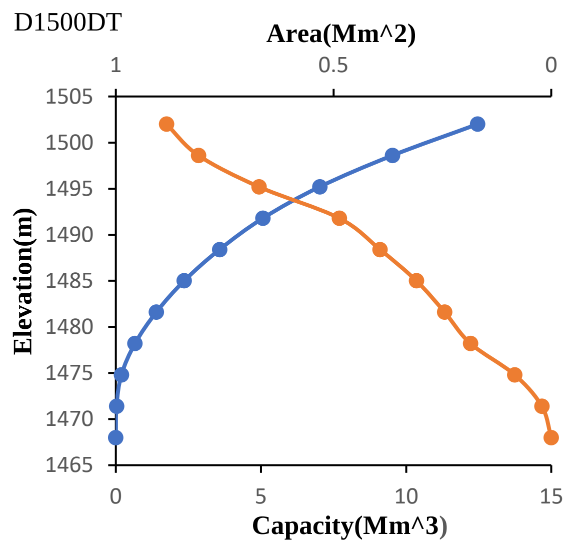

D1875
Area(Mm^2)
3
2
1
0
1885
1880
1875
1870
1865
1860
1855
1850
1845
Elevation(m)
0
10
20
30
40
Capacity(Mm^3)

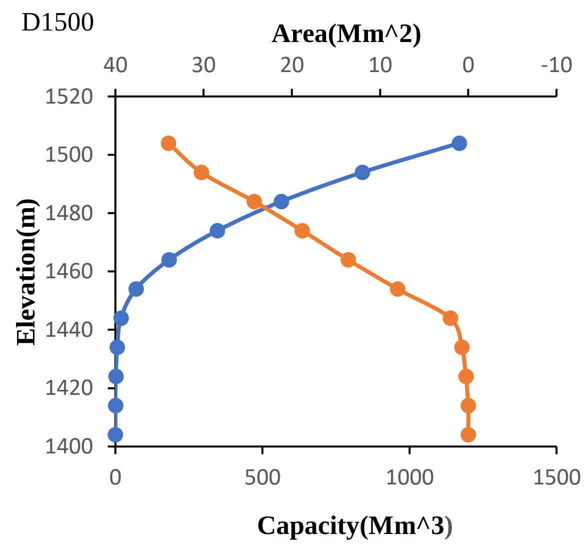

D1890DT
Area(Mm^2)
4
3
2
1
0
1895
1890
1885
1880
1875
1870
1865
1860
1855
1850
1845
Elevation(m)
0
20
40
60
Capacity(Mm^3)

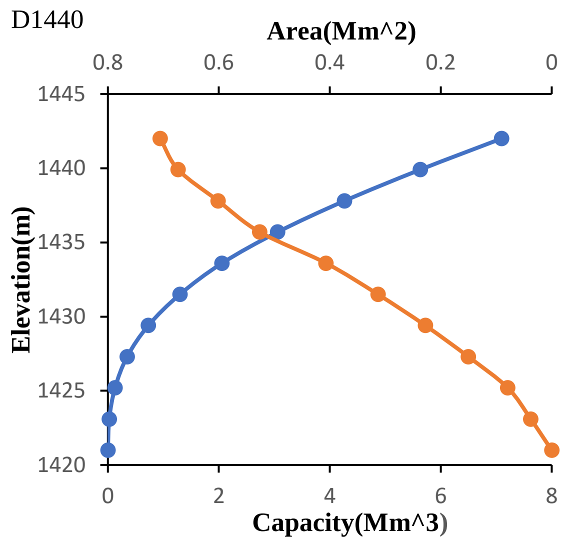

D1890
Area(Mm^2)
15
10
5
0
1905
1895
1885
1875
1865
1855
1845
Elevation(m)
0
50
100
150
200
Capacity(Mm^3)

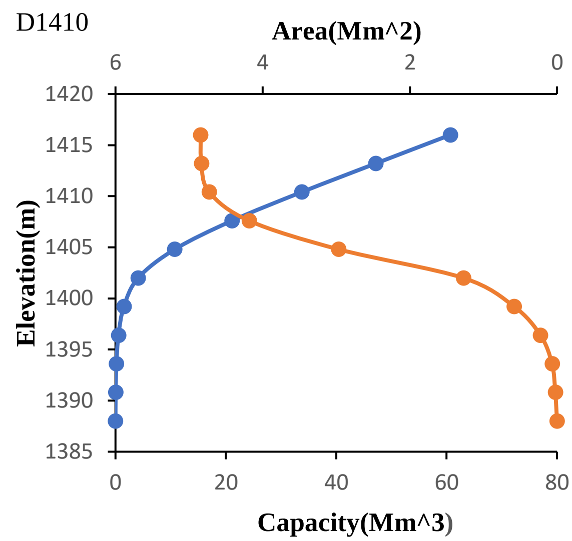

D1845
Area(Mm^2)
2
1.5
1
0.5
0
1860
1850
1840
1830
1820
1810
1800
1790
1780
1770
Elevation(m)
0
10
20
30
40
Capacity(Mm^3)

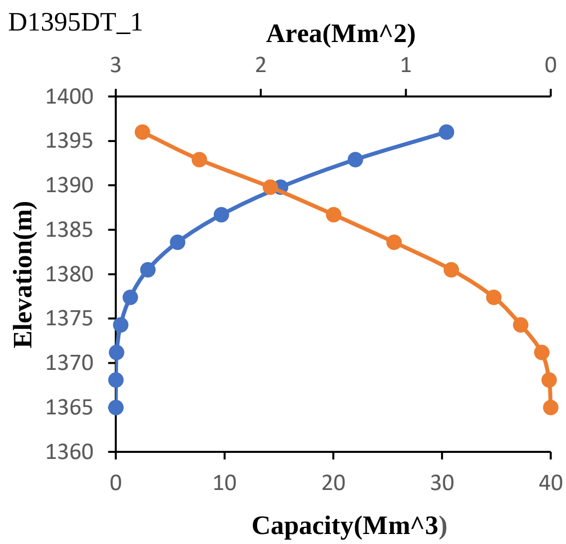

D1530
Area(Mm^2)
6
4
2
0
1545
1535
1525
1515
1505
1495
1485
Elevation(m)
0
50
100
Capacity(Mm^3)

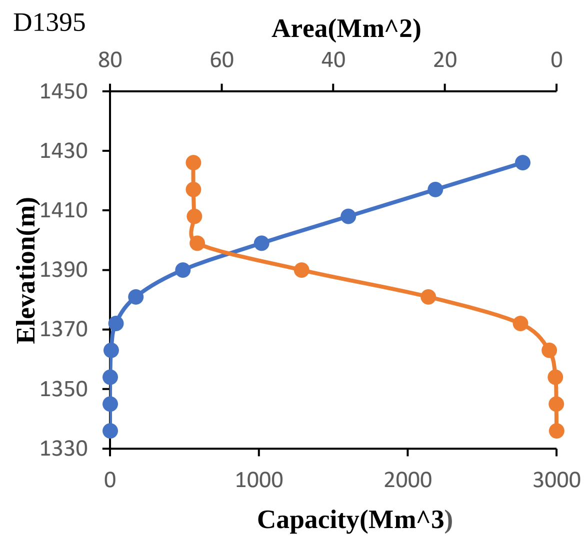

D1500DT
Area(Mm^2)
1
0.5
0
1505
1500
1495
1490
1485
1480
1475
1470
1465
Elevation(m)
0
5
10
15
Capacity(Mm^3)

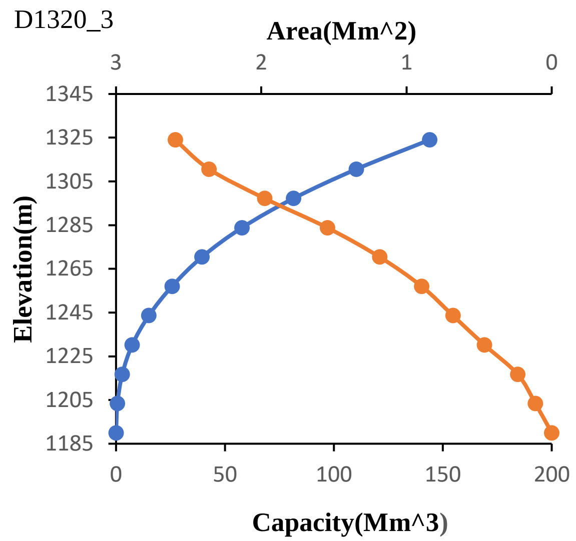

D1500
Area(Mm^2)
40
30
20
10
0
-10
1520
1500
1480
1460
1440
1420
1400
Elevation(m)
0
500
1000
1500
Capacity(Mm^3)

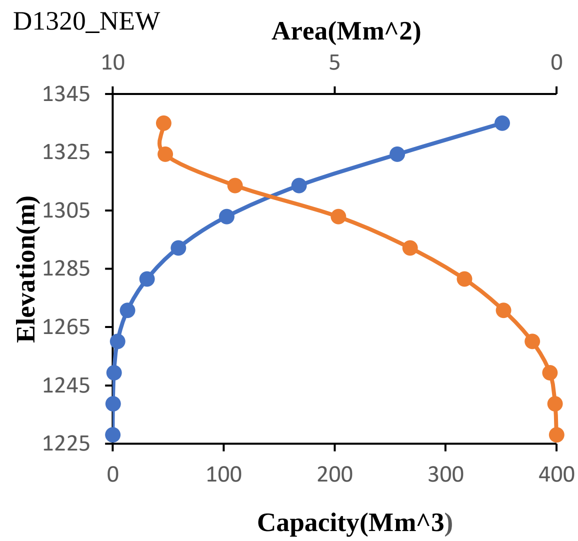

D1440
Area(Mm^2)
0.8
0.6
0.4
0.2
0
1445
1440
1435
1430
1425
1420
Elevation(m)
0
2
4
6
8
Capacity(Mm^3)

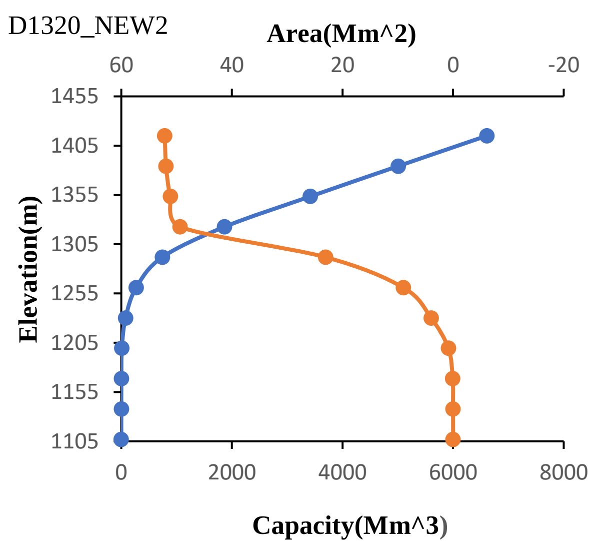

D1410
Area(Mm^2)
6
4
2
0
1420
1415
1410
1405
1400
1395
1390
1385
Elevation(m)
0
20
40
60
80
Capacity(Mm^3)

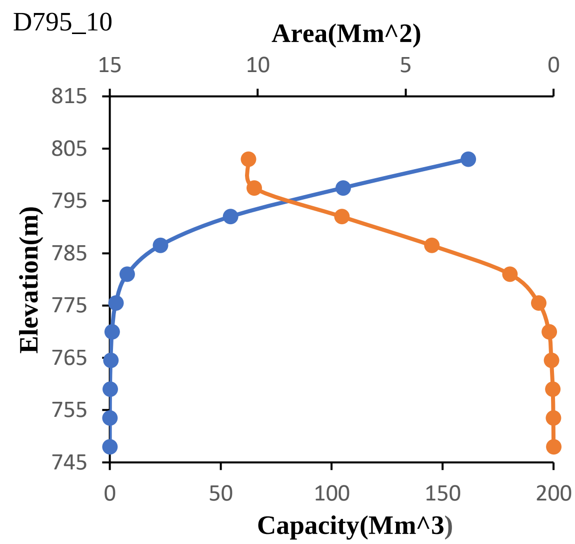

D1395DT_1
Area(Mm^2)
3
2
1
0
1400
1395
1390
1385
1380
1375
1370
1365
1360
Elevation(m)
0
10
20
30
40
Capacity(Mm^3)

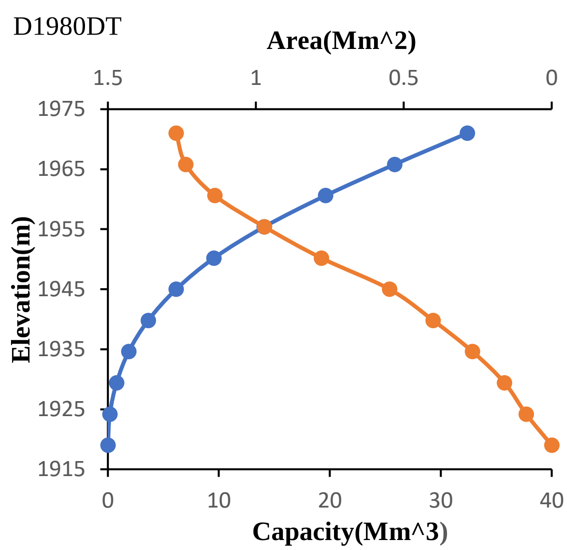

D1395
Area(Mm^2)
80
60
40
20
0
1450
1430
1410
1390
1370
1350
1330
Elevation(m)
0
1000
2000
3000
Capacity(Mm^3)

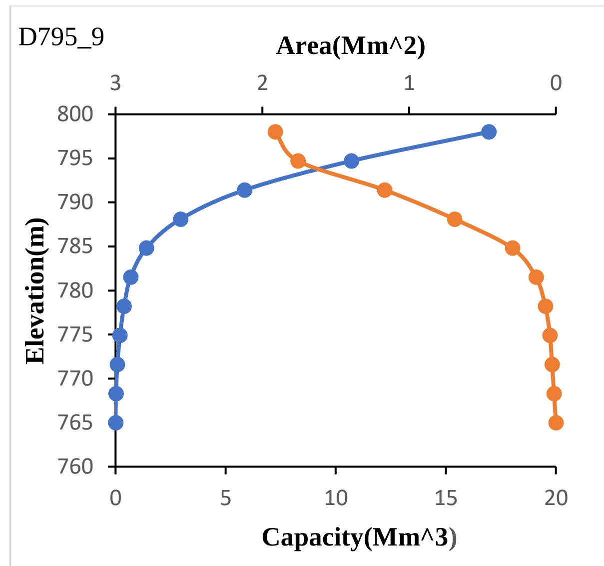

D1320_3
Area(Mm^2)
3
2
1
0
1345
1325
1305
1285
1265
1245
1225
1205
1185
Elevation(m)
0
50
100
150
200
Capacity(Mm^3)

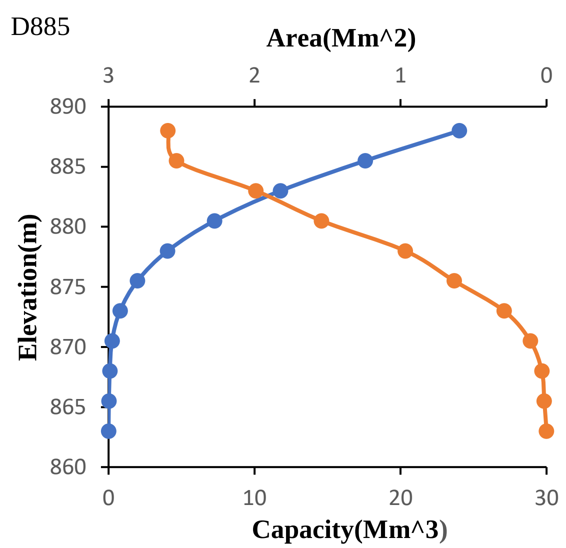

D1320_NEW
Area(Mm^2)
10
5
0
1345
1325
1305
1285
1265
1245
1225
Elevation(m)
0
100
200
300
400
Capacity(Mm^3)

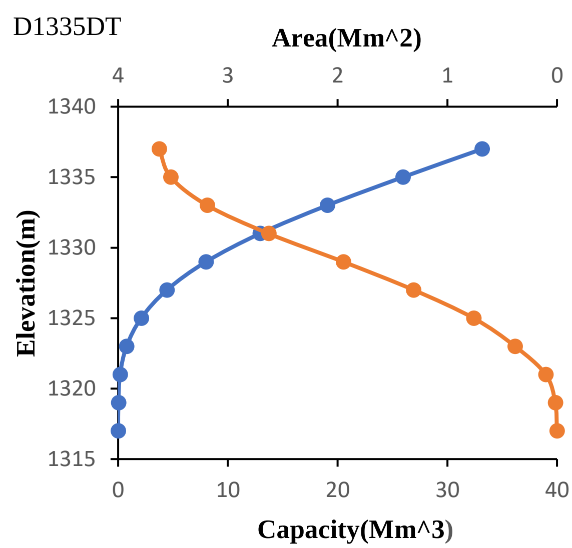

D1320_NEW2
Area(Mm^2)
60
40
20
0
-20
1455
1405
1355
1305
1255
1205
1155
1105
Elevation(m)
0
2000
4000
6000
8000
Capacity(Mm^3)


D795_10
Area(Mm^2)
15
10
5
0
815
805
795
785
775
765
755
745
Elevation(m)
0
50
100
150
200
Capacity(Mm^3)


D1980DT
Area(Mm^2)
1.5
1
0.5
0
Elevation(m)
1975
1965
1955
1945
1935
1925
1915
0
10
20
30
40
Capacity(Mm^3)


D795_9
Area(Mm^2)
3
2
1
0
Elevation(m)
800
795
790
785
780
775
770
765
760
0
5
10
15
20
Capacity(Mm^3)


D885
Area(Mm^2)
3
2
1
0
Elevation(m)
890
885
880
875
870
865
860
0
10
20
30
Capacity(Mm^3)


D1335DT
Area(Mm^2)
4
3
2
1
0
Elevation(m)
1340
1335
1330
1325
1320
1315
0
10
20
30
40
Capacity(Mm^3)

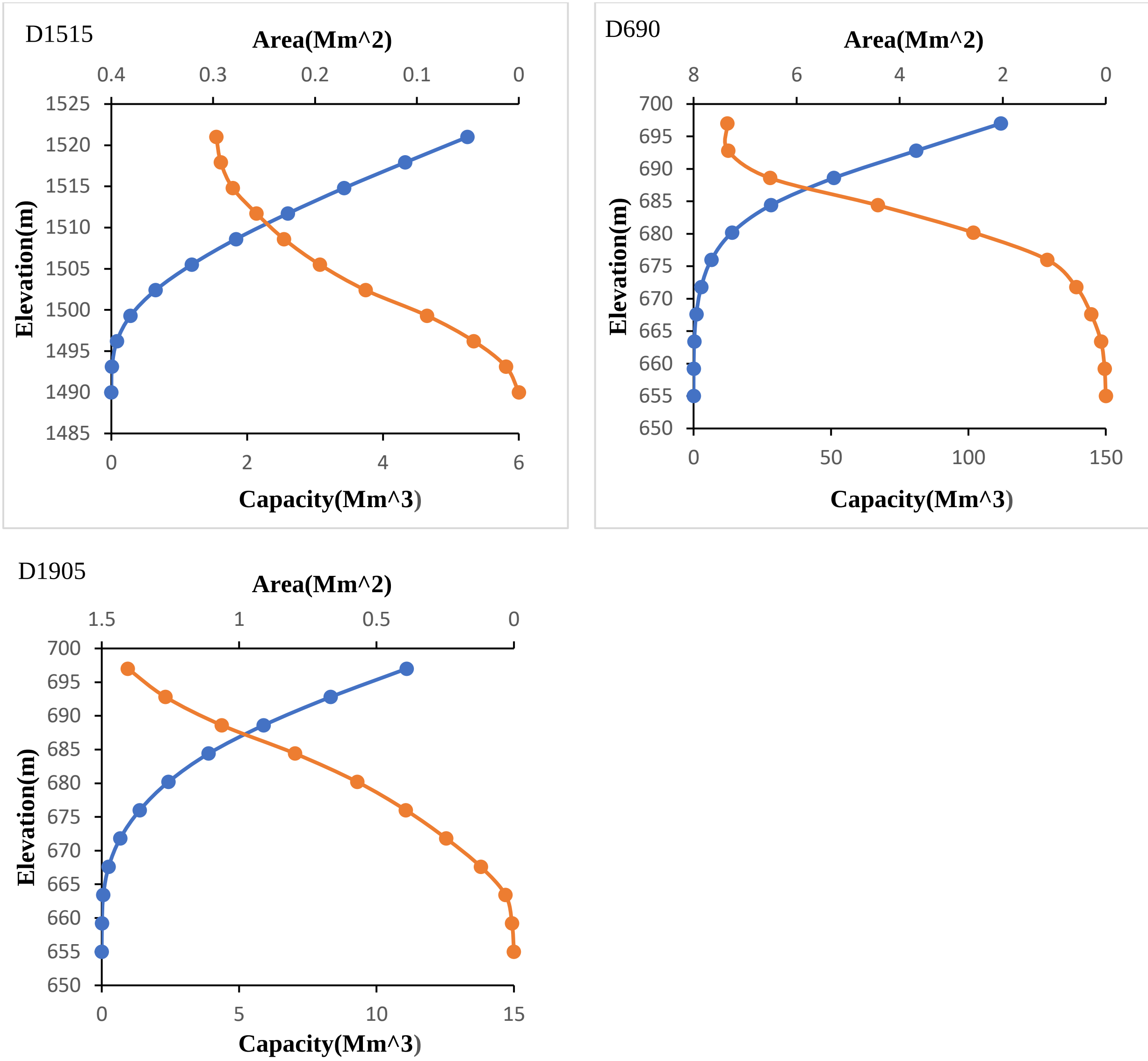
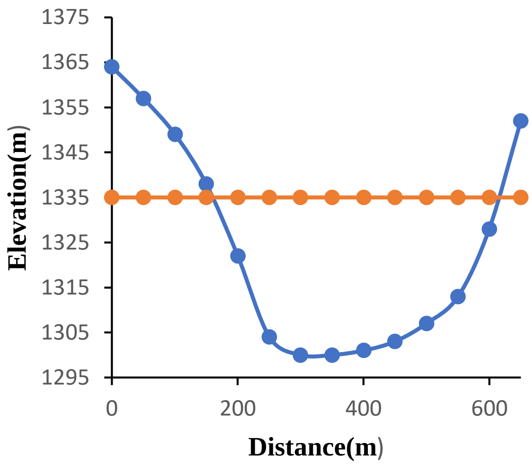


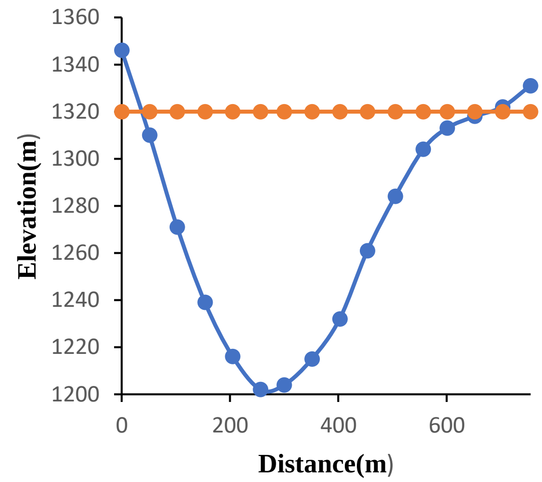
Figure 8-2: Elevation-Area-Capacity Curve

APPENDIX 3: Proposed Dam profiles

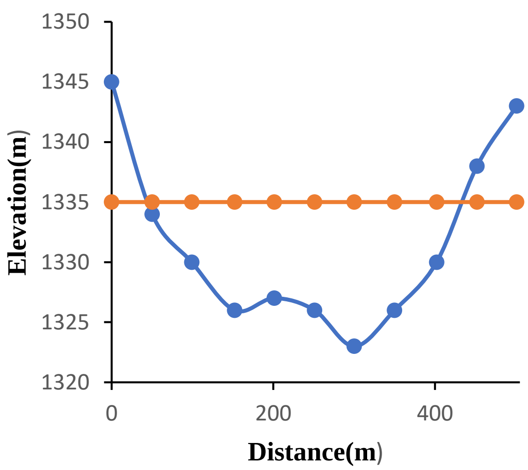
D1335



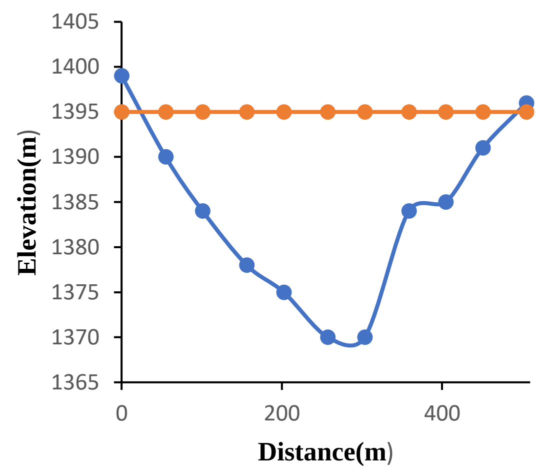
D1320_3

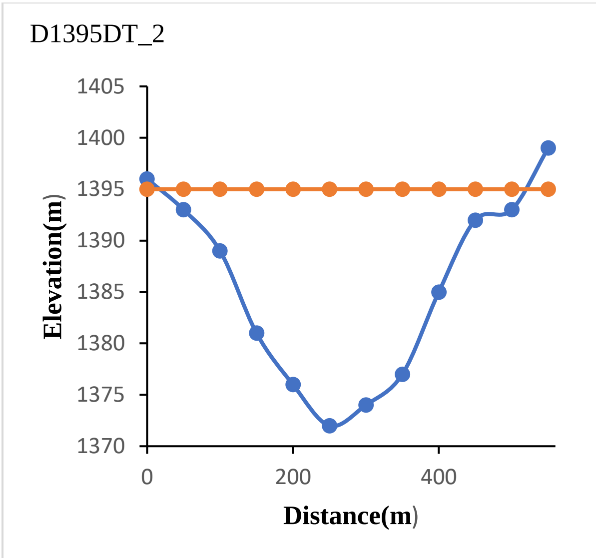


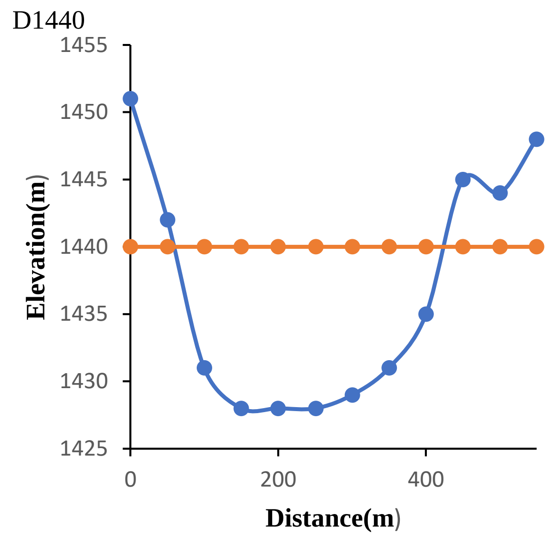
D1335DT

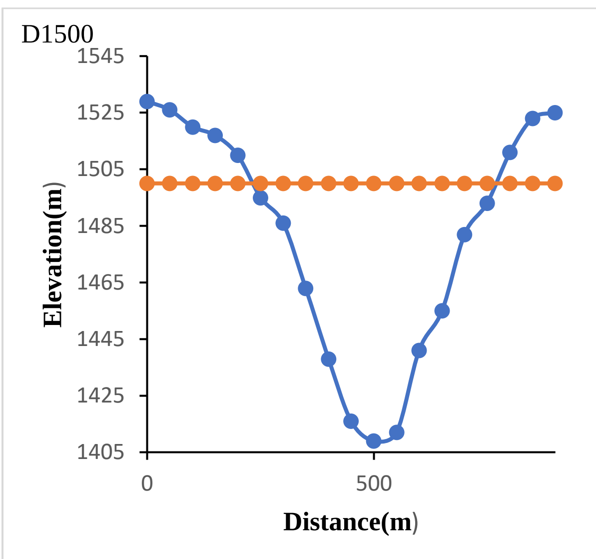


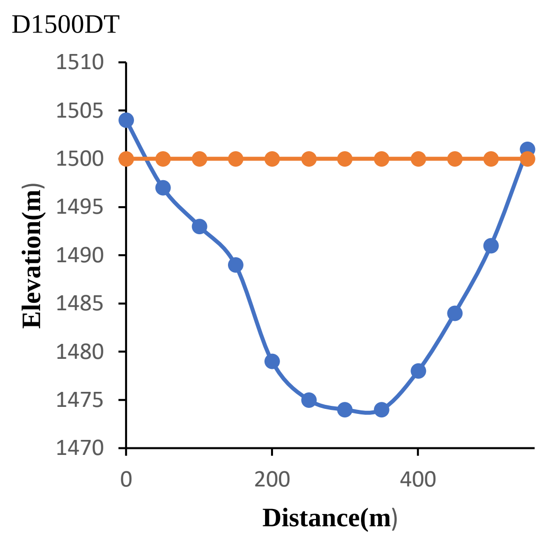
D1395DT_1

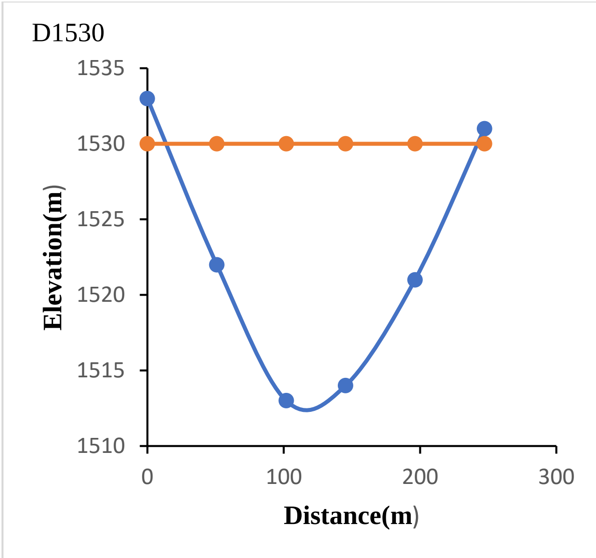


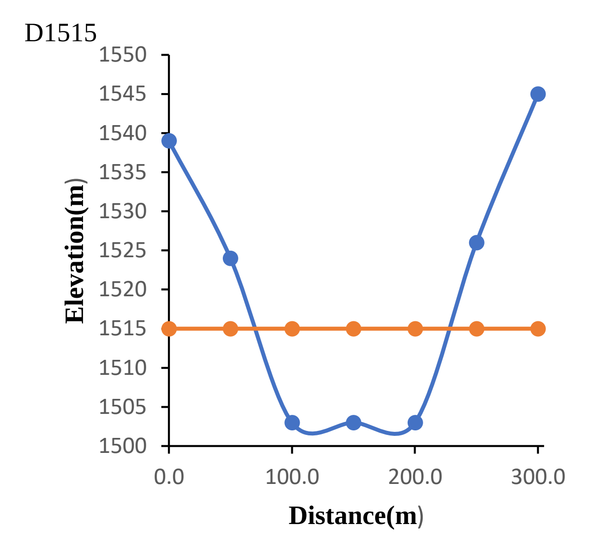

D1395DT_2
1405
1400
1395
1390
1385
1380
1375
1370
Elevation(m)
0
200
400
Distance(m)

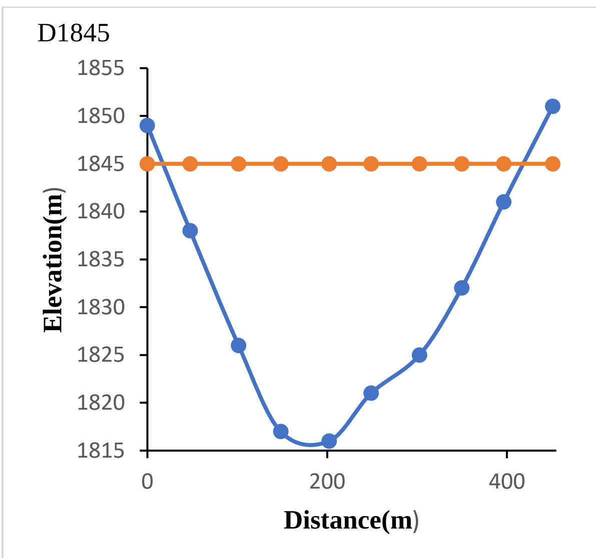

D1440
1455
1450
1445
1440
1435
1430
1425
Elevation(m)
0
200
400
Distance(m)

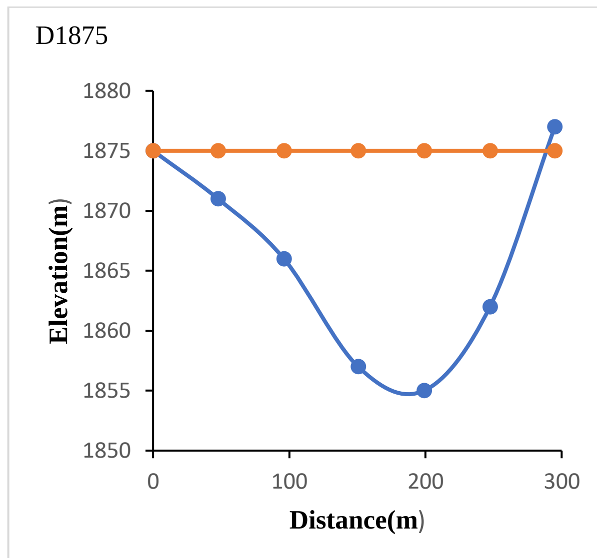

D1500
1545
1525
1505
1485
1465
1445
1425
1405
Elevation(m)
0
500
Distance(m)

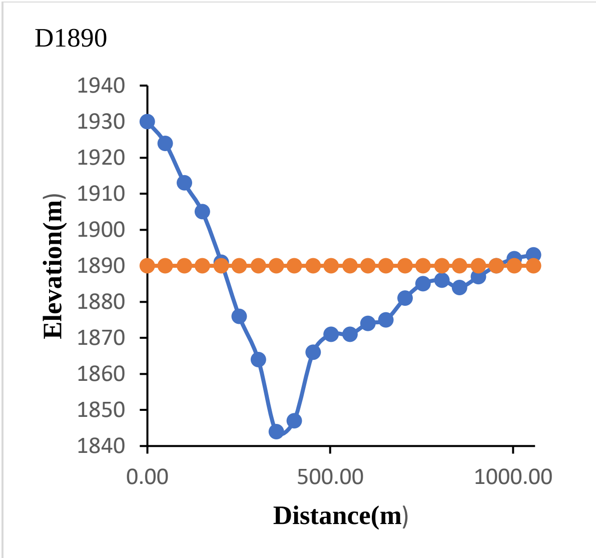

D1500DT
1510
1505
1500
1495
1490
1485
1480
1475
1470
Elevation(m)
0
200
400
Distance(m)

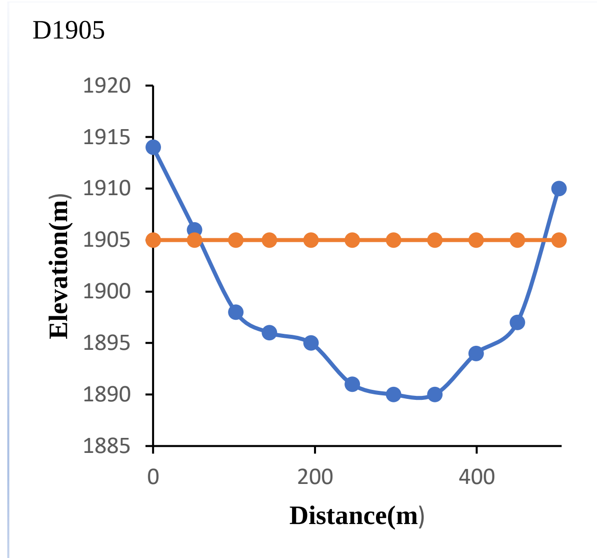

D1530
Elevation(m)
Distance(m)
1535
1530
1525
1520
1515
1510
0
100
200
300

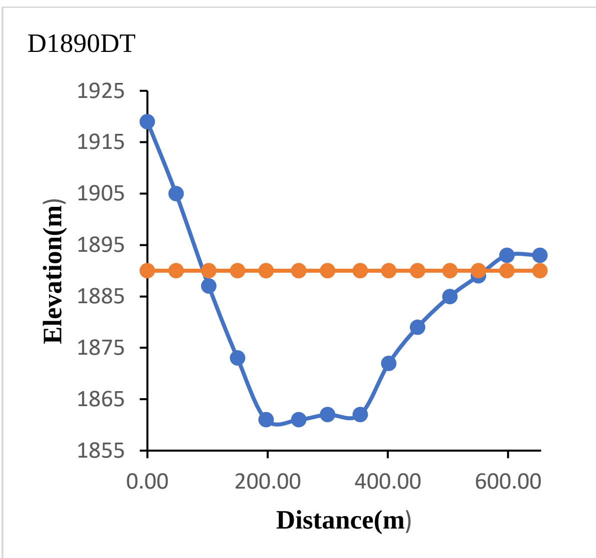

D1515
Elevation(m)
Distance(m)
1550
1545
1540
1535
1530
1525
1520
1515
1510
1505
1500
0.0
100.0
200.0
300.0

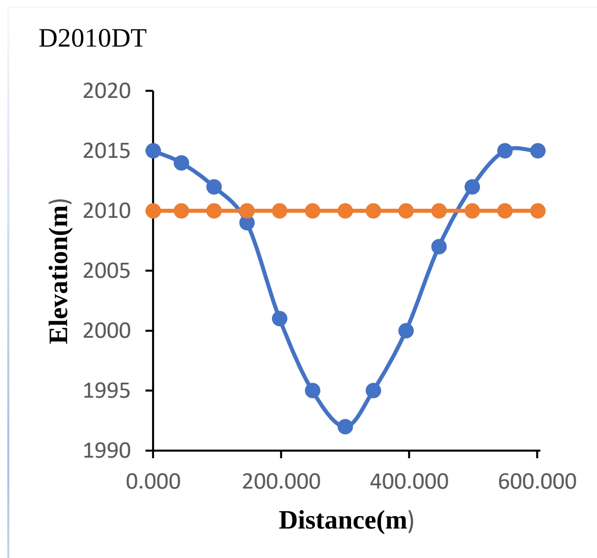

D1845
Elevation(m)
Distance(m)
1855
1850
1845
1840
1835
1830
1825
1820
1815
0
200
400

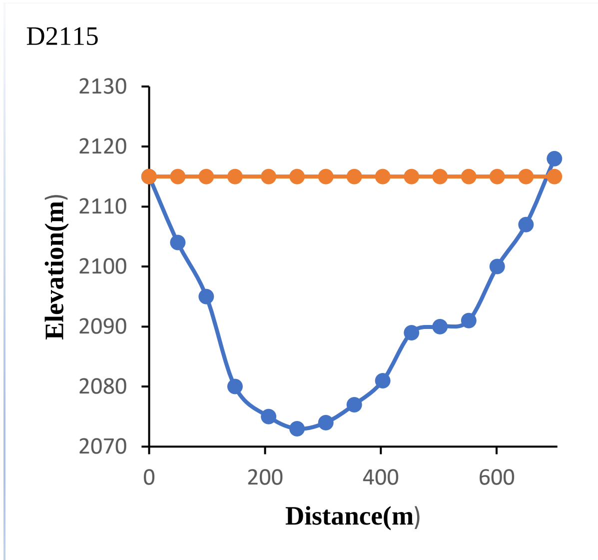

D1875
Elevation(m)
Distance(m)
1880
1875
1870
1865
1860
1855
1850
0
100
200
300

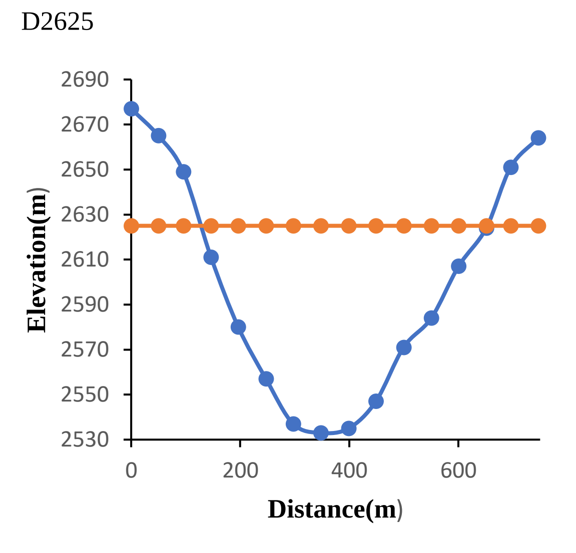

D1890
1940
1930
1920
1910
1900
1890
1880
1870
1860
1850
1840
Elevation(m)
0.00
500.00
1000.00
Distance(m)

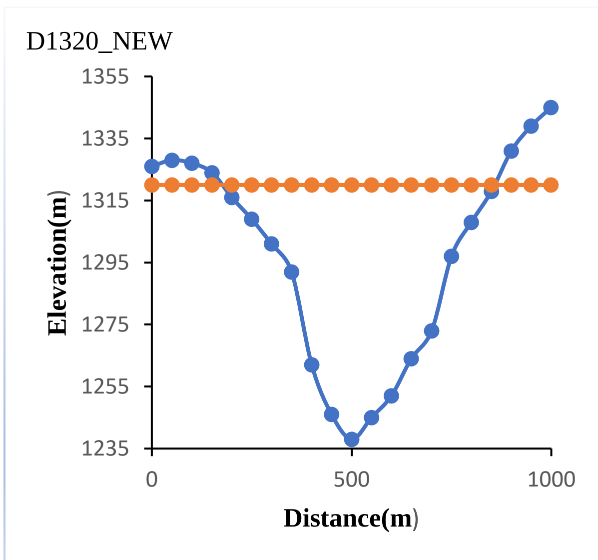

D1905
1920
1915
1910
1905
1900
1895
1890
1885
Elevation(m)
0
200
400
Distance(m)

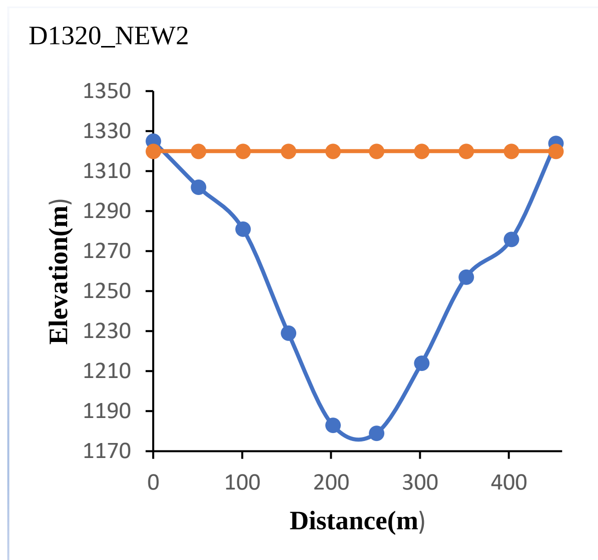

D1890DT
1925
1915
1905
1895
1885
1875
1865
1855
Elevation(m)
0.00
200.00
400.00
600.00
Distance(m)

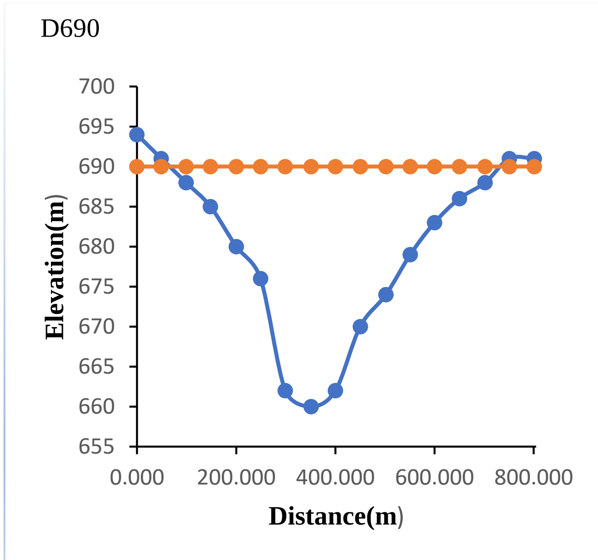

D2010DT
2020
2015
2010
2005
2000
1995
1990
Elevation(m)
0.000
200.000
400.000
600.000
Distance(m)

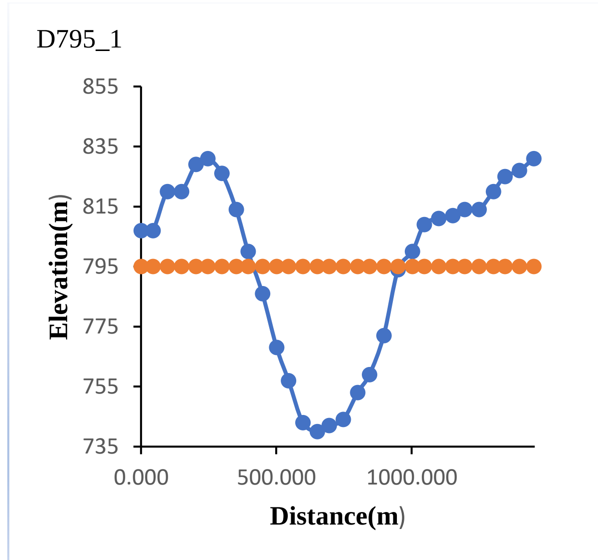

D2115
2130
2120
2110
2100
2090
2080
2070
0
200
400
600
Elevation(m)
Distance(m)

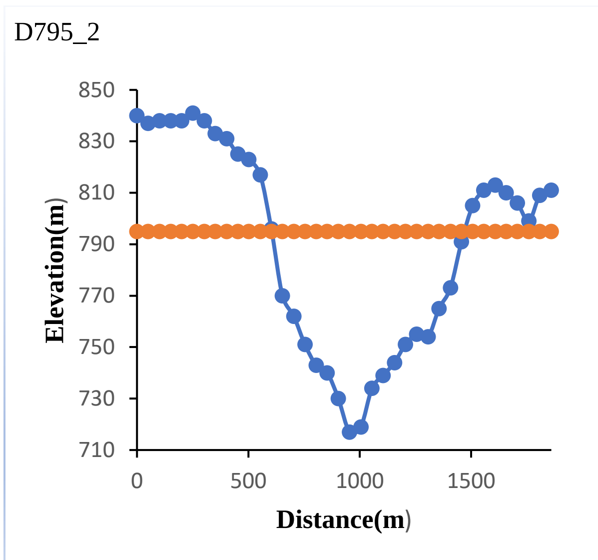

D2625
2690
2670
2650
2630
2610
2590
2570
2550
2530
0
200
400
600
Elevation(m)
Distance(m)

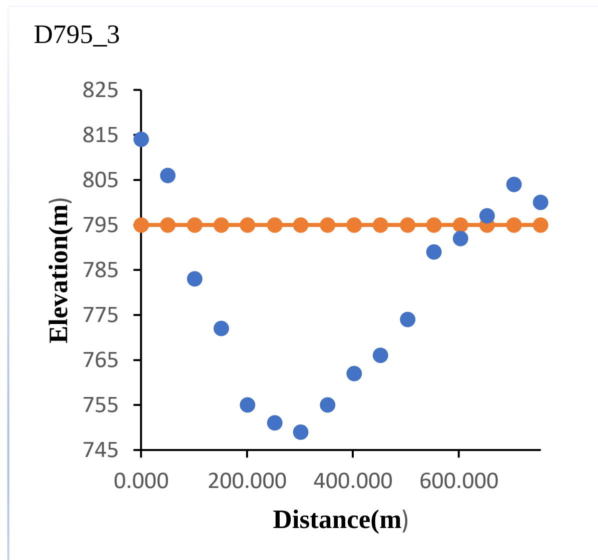

D1320_NEW
1355
1335
1315
1295
1275
1255
1235
0
500
1000
Elevation(m)
Distance(m)

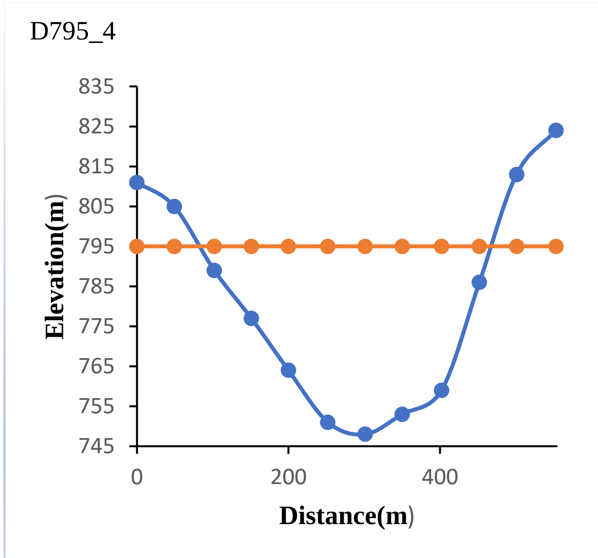

D1320_NEW2
1350
1330
1310
1290
1270
1250
1230
1210
1190
1170
0
100
200
300
400
Elevation(m)
Distance(m)

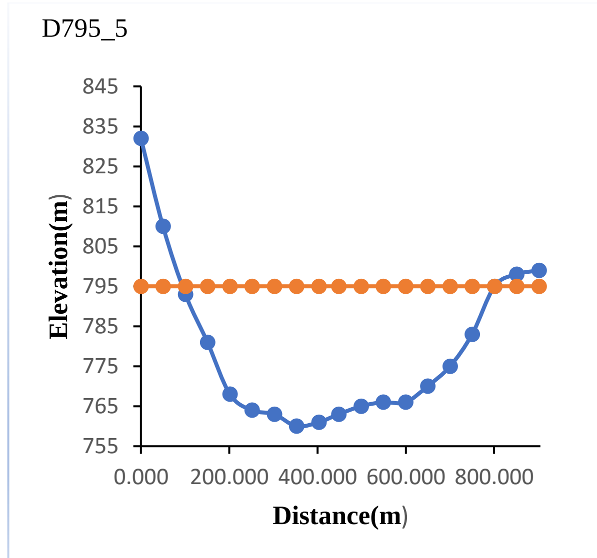

D690
700
695
690
685
680
675
670
665
660
655
Elevation(m)
0.000
200.000
400.000
600.000
800.000
Distance(m)

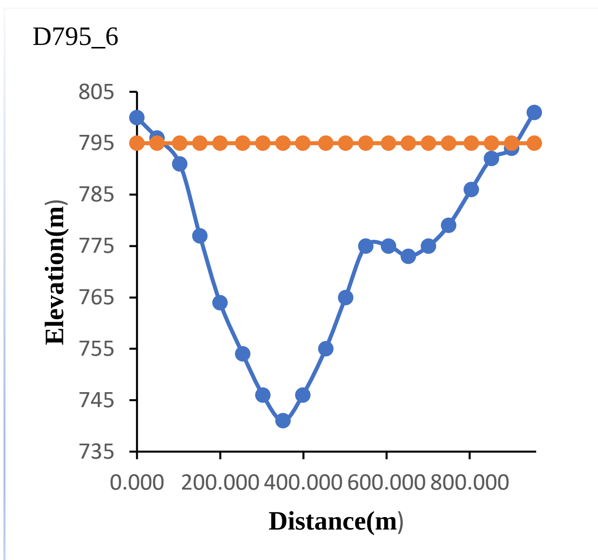

D795_1
855
835
815
795
775
755
735
Elevation(m)
0.000
500.000
1000.000
Distance(m)

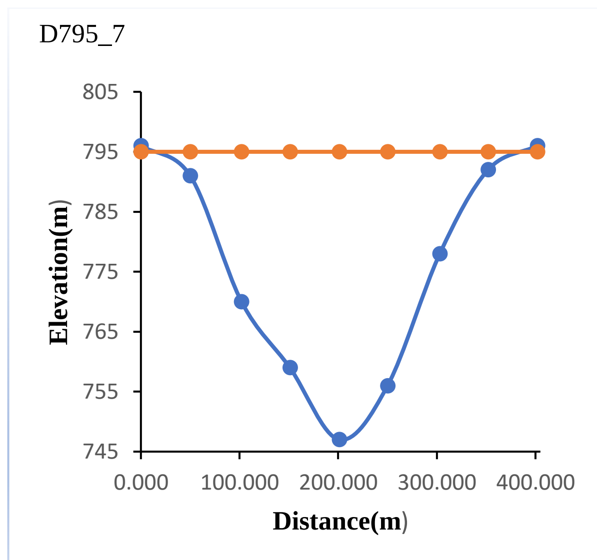

D795_2
850
830
810
790
770
750
730
710
Elevation(m)
0
500
1000
1500
Distance(m)


D795_3
825
815
805
795
785
775
765
755
745
Elevation(m)
0.000
200.000
400.000
600.000
Distance(m)

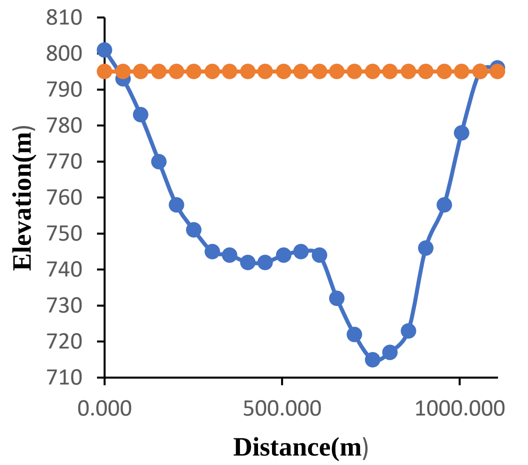

D795_4
Elevation(m)
Distance(m)
835
825
815
805
795
785
775
765
755
745
0
200
400


D795_5
Elevation(m)
Distance(m)
845
835
825
815
805
795
785
775
765
755
0.000
200.000
400.000
600.000
800.000

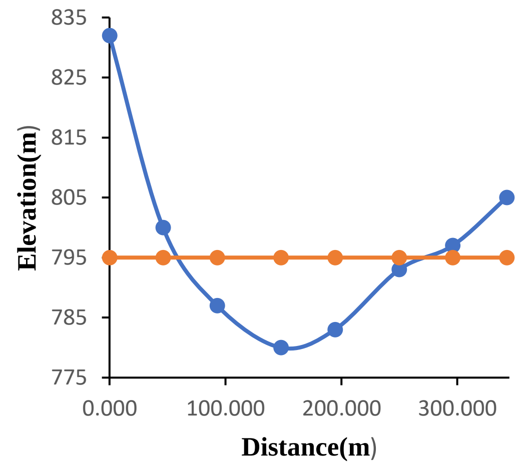

D795_6
Elevation(m)
Distance(m)
805
795
785
775
765
755
745
735
0.000
200.000
400.000
600.000
800.000


D795_7
Elevation(m)
Distance(m)
805
795
785
775
765
755
745
0.000
100.000
200.000
300.000
400.000

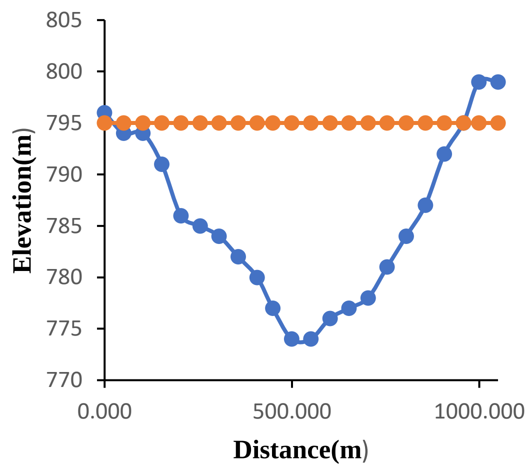
D795_8



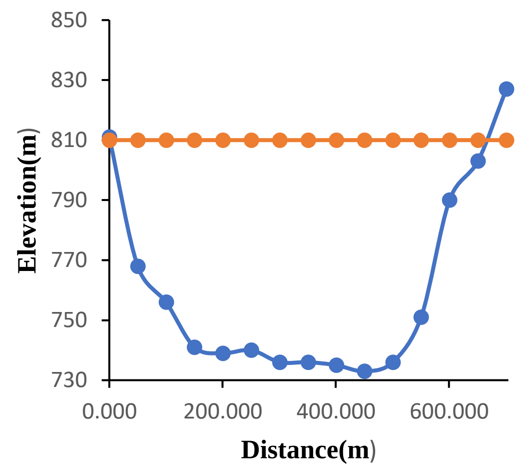
D795_9

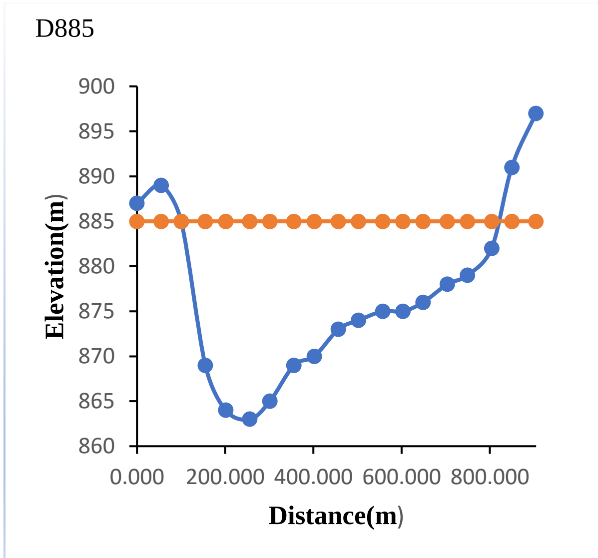


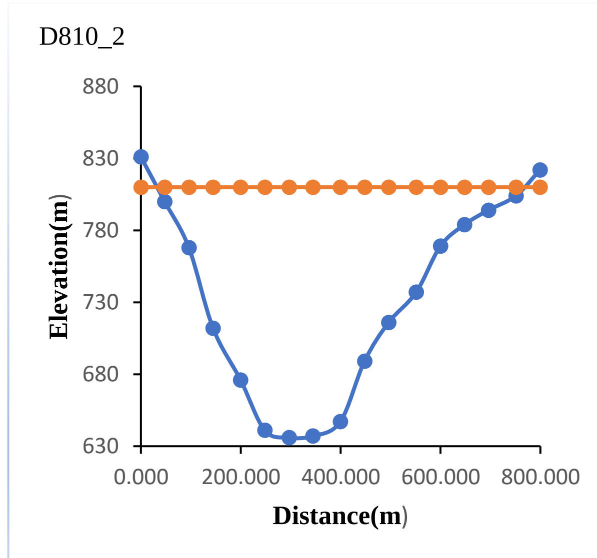
D795_10

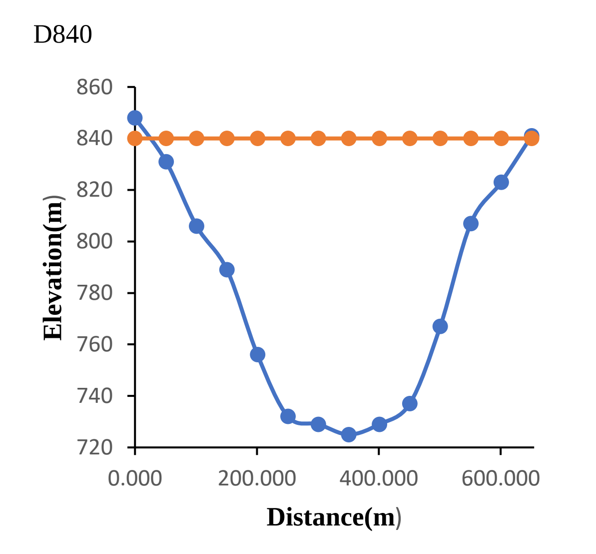


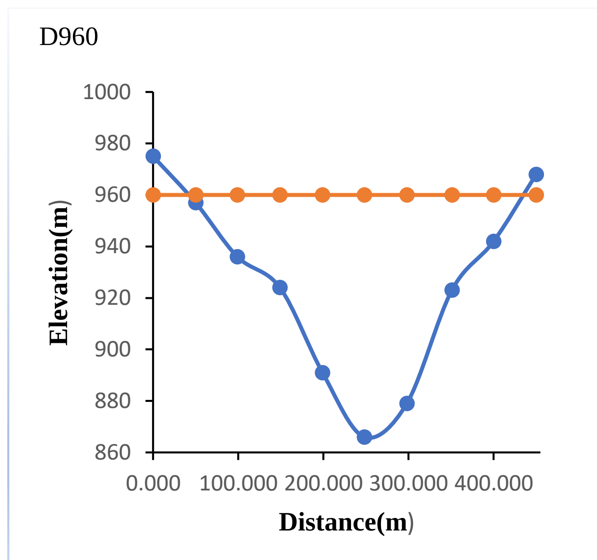
D810_1




D885
900
895
890
885
880
875
870
865
860
Elevation(m)
0.000
200.000
400.000
600.000
800.000
Distance(m)


D810_2
880
830
780
730
680
630
Elevation(m)
0.000
200.000
400.000
600.000
800.000
Distance(m)


D840
860
840
820
800
780
760
740
720
Elevation(m)
0.000
200.000
400.000
600.000
Distance(m)


D960
1000
980
960
940
920
900
880
860
Elevation(m)
0.000
100.000
200.000
300.000
400.000
Distance(m)

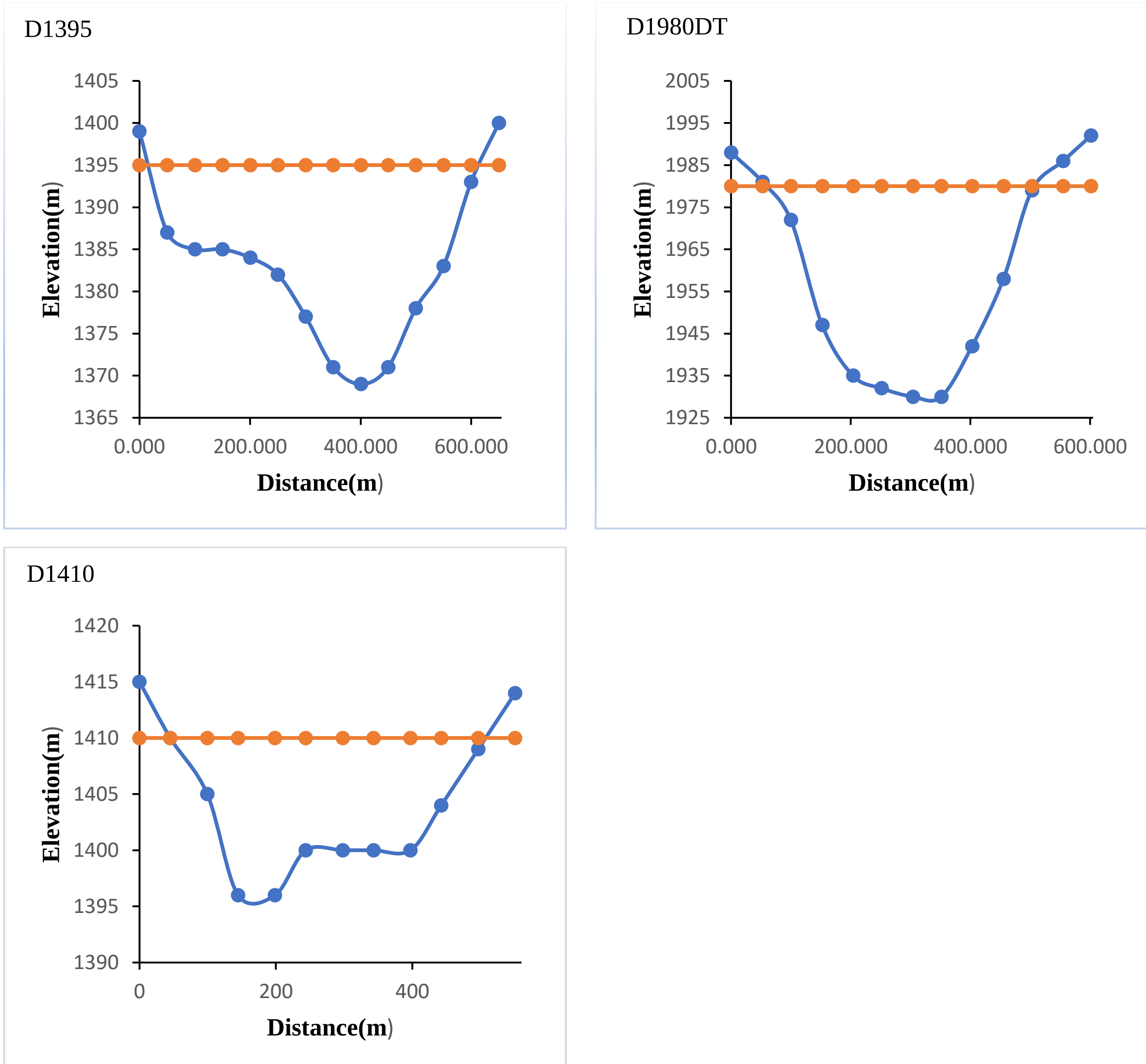


Figure 8-3: Proposed Dam Profiles

APPENDIX 4: Relationship of Depth with Area and Volume

Table 8-1: Relationship of Depth with Area and Volume

DAMS	DAM HIGHT	DAM WIDTH	Volume (Mm^3)	Area (Mm^2)
D1890	46	745.64	72.75	9.60
D2115	42	672.20	55.88	3.45
D2010_DT	18	336.10	31.77	4.89
D1845	29	388.42	21.59	1.31
D1875	20	311.84	15.19	1.89
D960	94	388.74	199.30	12.00
D1515	12	165.43	3.17	0.24
D810_2	174	721.44	8532.45	124.38
D795_10	21	917.80	79.13	9.29
D795_9	15	211.06	10.83	1.66
D795_8	78	1025.00	377.64	14.34
D795_7	48	365.80	14.52	0.98
D795_6	54	851.36	110.57	8.78
D795_5	35	712.87	89.49	6.26
D795_4	47	394.83	80.76	3.90
D795_3	46	544.52	22.44	1.45
D795_2	78	855.40	571.60	21.44
D1320_3	118	596.63	130.49	2.52
D810_1	77	663.64	280.44	8.23
D690	30	652.50	59.66	6.73
D840	115	626.70	5085.46	148.49
D1530	16	220.47	68.23	4.94
D1335DT	12	381.32	25.46	3.39
D1395DT_1	25	478.36	26.77	2.53
D1395DT_2	23	484.63	11.38	1.25
D1320_NEW	82	663.66	215.32	8.13
D1335	35	468.98	556.06	47.89
D1395	26	601.25	757.73	60.62

D1500DT	26	517.73	10.37	0.79
D1440	12	371.50	5.51	0.64
D1500	91	518.08	1027.96	32.66
D1320_NEW2	141	421.30	1720.76	47.80
D1905	15	430.00	9.24	1.25
D1980DT	50	349.00	40.29	1.12
D2625	92	516.74	62.91	2.19
D1890DT	29	467.81	34.56	2.86
D885	22	724.50	15.83	2.33
D1410	14	436.36	31.31	4.52
D795_1	55	542.23	297.04	13.35

APPENDIX 5: TWI CREATION

$$TWI = ln\frac{\alpha}{tan\beta}$$

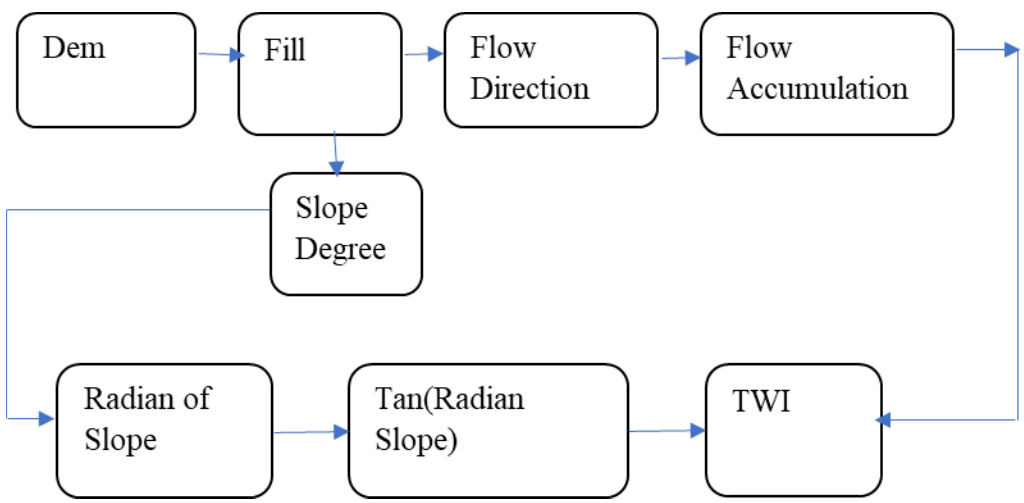


Figure 8-4: Flowchart TWI creation

APPENDIX 6: Capacity-Inflow Method (Brune's Curve

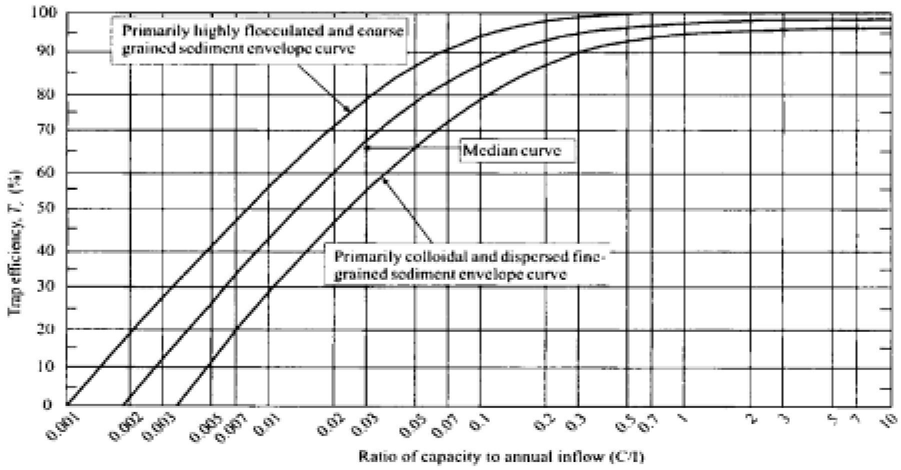


Figure 8-5: Sediment trapping efficiency as per (Dendy, 1974)

APPENDIX 7: Watershed with reservoir inundation for selected dams' area

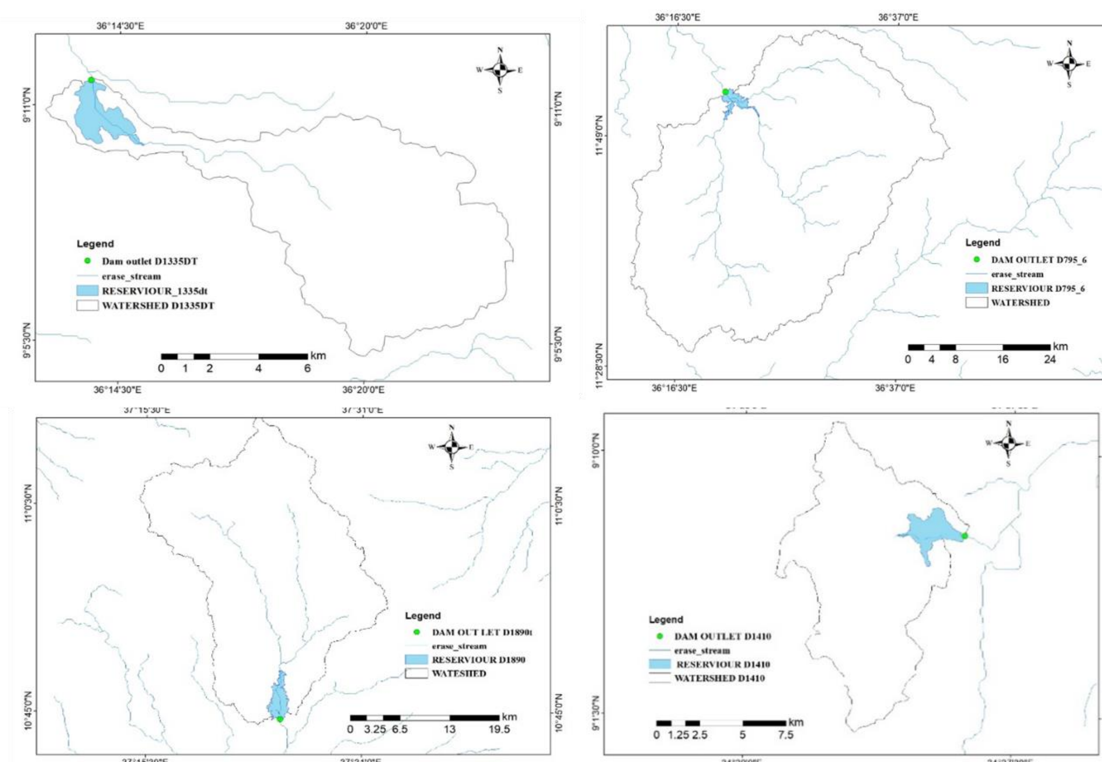


Figure 8-6: Catchments of reservoir

APPENDIX 8: Administrative location

Table 8-2: Location of selected dam site

SN.	X	Y	DAM_NAME	REGIONNAME	ZONENAME	WOREDANAME
0	241197	880406	D1500	Oromia	Jimma	Goma
1	256574	891237	D1500DT	Oromia	Jimma	Limu Kosa
2	241907	895912	D1440	Oromia	Ilubabor	Dedesa
3	259233	903970	D1395	Oromia	Jimma	Limu Seka
4	243340	942879	D1335	Oromia	East Wellega	Nunu Kumba
5	171681	982379	D1320_NEW	Oromia	Ilubabor	Chwaka
6	16059.8	1011400	D1410	Oromia	Kelem Wellega	Gidami
7	201730	1014290	D1395DT_1	Oromia	East Wellega	Sasiga
8	202818	1016840	D1395DT_2	Oromia	East Wellega	Diga
9	195693	1017390	D1335DT	Oromia	East Wellega	Diga
10	350643	1052310	D1320_NEW2	Oromia	West Shewa	Ginde Beret
11	80028.8	1073170	D1530	Oromia	West Wellega	Kiltu Kara
12	146213	1092500	D810_2	Beneshangul	Kemashi	Yaso
13	327160	1187840	D1890	Amhara	West Gojam	Jabi Tehnan
14	154906	1229550	D840	Beneshangul	Metekel	Dangura
15	234383	1229780	D1515	Amhara	Awi/Agew	Jawi
16	197563	1231100	D960	Beneshangul	Metekel	Dangura
17	301814	1238570	D2115	Amhara	West Gojam	Mecha
18	293515	1246430	D2010_DT	Amhara	West Gojam	Mecha
19	283659	1266190	D1845	Amhara	West Gojam	Mecha
20	141182	1266380	D795_10	Beneshangul	Metekel	Dangura
21	278882	1269270	D1875	Amhara	West Gojam	Debub Achefer
22	142314	1270780	D795_9	Beneshangul	Metekel	Dangura
23	128967	1285670	D690	Beneshangul	Metekel	Guba
24	368020	1296440	D1980DT_NEW	Amhara	South Gonder	Fogera
25	370255	1300190	D1905	Amhara	South Gonder	Fogera
26	182523	1305450	D795_8	Beneshangul	Metekel	Guba
27	185387	1305800	D795_7	Amhara	Awi/Agew	Jawi
28	402984	1310480	D2625	Amhara	South Gonder	Farta
29	211234	1315060	D795_6	Amhara	Awi/Agew	Jawi

30	225983	1319520	D885	Amhara	Awi/Agew	Jawi
31	391744	1330910	D1890DT	Amhara	South Gonder	Ebenat
32	205606	1332860	D795_5	Amhara	North Gonder	Quara
33	247101	1343550	D1320_3	Amhara	North Gonder	Takusa
34	173373	1348230	D810_1	Amhara	North Gonder	Quara
35	227729	1358440	D795_4	Amhara	North Gonder	Takusa
36	222742	1363630	D795_3	Amhara	North Gonder	Metema
37	231796	1367460	D795_2	Amhara	North Gonder	Takusa
38	234740	1371360	D795_1	Amhara	North Gonder	Metema

APPENDIX 9: Trap efficiency calculation

Table 8-3: Trap efficiency calculation with different equation

Dams	Cat. Area(km^2)	80% Dep.	C/I	TRp.eq(9)	eq (10)	eq (11)
D1890	722.59	1138.25	0.15	96.50	90.99	83.79
D2115	220.00	1345.99	0.30	98.47	94.37	89.95
D2010_DT	415.10	1307.97	0.09	94.21	87.22	77.57
D1845	2056.00	1330.09	0.01	66.29	50.92	36.35
D1875	720.28	1329.70	0.03	80.27	67.12	52.40
D960	4595.10	1402.58	0.46	99.18	95.62	92.39
D1515	426.48	1689.32	0.01	49.43	35.12	18.31
D810_2	27812.78	1126.98	0.47	99.19	95.64	92.44
D795_10	400.94	1080.29	0.32	98.59	94.58	90.36
D795_9	142.66	1089.08	0.12	95.56	89.43	81.13
D795_8	832.70	1172.08	0.66	99.57	96.31	93.79
D795_7	163.28	1185.02	0.13	95.73	89.70	81.58
D795_6	1709.53	1115.27	0.10	94.55	87.77	78.44
D795_5	764.31	1112.61	0.18	97.16	92.11	85.75
D795_4	1287.88	975.56	0.12	95.46	89.26	80.84
D795_3	53.60	946.60	0.84	99.78	96.68	94.55
D795_2	631.86	935.91	1.84	100.00	97.42	96.09
D1320_3	291.91	1105.65	0.70	99.64	96.43	94.03

D810_1	511.67	1036.09	0.95	99.87	96.84	94.88
D690	957.43	1013.81	0.11	95.13	88.71	79.95
D840	9066.55	1093.23	0.90	99.83	96.77	94.74
D1530	602.44	1442.85	0.12	95.59	89.47	81.20
D1335DT	180.64	1607.20	0.13	95.94	90.06	82.19
D1395DT_1	76.72	1645.94	0.32	98.57	94.55	90.30
D1395DT_2	74.67	1658.22	0.14	96.11	90.34	82.66
D1320_NEW	2211.74	1469.57	0.10	94.69	88.00	78.80
D1335	5385.67	1441.22	0.11	95.14	88.73	79.99
D1395	3855.87	1675.92	0.18	97.02	91.88	85.35
D1500DT	56.84	1732.37	0.16	96.61	91.18	84.10
D1440	55.78	1677.34	0.09	93.76	86.50	76.45
D1500	715.45	1652.01	1.31	100.00	97.16	95.55
D1320_NEW2	6999.01	1061.38	0.41	99.01	95.31	91.79
D1905	381.88	1236.46	0.03	83.91	71.94	57.56
D1980DT	243.71	1230.15	0.22	97.75	93.13	87.61
D2625	101.74	1211.97	0.85	99.79	96.70	94.60
D1890DT	705.85	965.18	0.09	94.22	87.23	77.59
D885	126.93	1070.71	0.21	97.53	92.74	86.90
D1410	105.95	1286.36	0.37	98.86	95.05	91.28
D795_1	800.59	937.24	0.75	99.70	96.53	94.25