Evaluation of Vertical Accuracy of Open Source Global DEMs for Hydrological Application: A Case Study of Adama Town, Ethiopia

Tarekegn Bekele

A Thesis Submitted to

The Department of Geomatics Engineering

School of Civil Engineering and Architecture

For Partial Fulfillment of the Requirement for the Degree of Master's of Science in Geo-informatics

Office of Graduate Studies

Adama Science and Technology University

Adama, Ethiopia
July, 2020

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Approval of Board of Examiners

We, the undersigned, members of the Board of Examiners of the final open defense by Tarekegn Bekele have read and evaluated his thesis entitled “Evaluation of Vertical Accuracy of Open Source Global DEMs for hydrological application : a case study of Adama Town, Ethiopia and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Master of Science.

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Advisor's approval sheet

To: Geomatics Engineering department

Subject: Thesis Submission

This is to certify that the thesis entitled "*Evaluation of Vertical Accuracy of Open Source Global DEMs for Hydrological Application: A Case Study of Adama Town, Ethiopia*" submitted in partial fulfillment of the requirements for the degree of Master's in Geoinformatics, the Graduate program of the department of Geomatics Engineering, and has been carried out by Tarekegn Bekele Id. No PGR/18160/11, under my supervision. Therefore, I recommend that the student has fulfilled the requirements and hence hereby he can submit the thesis to the department.

Name of major Advisor Getachew B/Meskel (PhD) Signature ___________ Date

Declaration

I declare that this thesis which I submitted to the School of Civil Engineering and Architecture of Adama Science and Technology University in partial fulfillment of Degree of Masters of Science in Geoinformatics is my own original work. The thesis has not been submitted previously to qualify for any academic award. I was cared for the academic rights of others in the processes of thesis work.

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Signature: -----------------------

This MSc Thesis has been submitted for examination with my approval as thesis advisor

Name: Getachew B/Meskel (PhD)

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Date of submission: July 20,2020

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LIST OF ACRONYMS

ALOS – Advanced Land Observing Satellite

AWSSE- Adama Water and Sanitary Service Enterprise

AW3D30 – ALOS World 3D 30 meter Topographic Data

ASPRS – American Society for Photogrammetry and Remote Sensing

ASTER – Advanced Spaceborne Thermal Emission and Reflection Radiometer

CGIAR-CSI – Consultative Group for International Agricultural Research - Consortium for Spatial Information

DEM – Digital Elevation Model

DSM – Digital Surface Model

DTM – Digital Terrain Model

EGM96 –Earth Geopotential Model of 1996

E.G.I.A – Ethiopian Geospatial Institute Agency

ESRI – Environmental Systems Research Institute

GCP – Ground Control Point

GDEM – Global Digital Elevation Model

GIS – Geographic Information System

GNSS – Global Navigation Satellite System

GPS – Global Positioning System

LiDAR – Light Detection and Ranging

MSL – Mean Sea Level

NMAS − National Map Accuracy Standard

STRM − Shuttle Radar Topography Mission

USGS – United State Geological Survey

ABSTRACT:

Digital Elevation Models (DEMs) provide one of the most useful digital datasets for a wide range of hydrological applications. DEM can be generated from wide range sources including land survey, Photogrammetry and Remote sensing satellites. SRTM 30m DEM by The Shuttle Radar Topography mission (SRTM), the Global Digital Elevation Model by Advanced Spaceborne Thermal Emission and Reflectance Radiometer (ASTER GDEM) and a global surface model called ALOS Worldview 3D 30 meter (AW3D30) by Advanced Land Observing Satellite (ALOS) are satellite based global DEMs open source DEM datasets. The accuracy of these dataset is subject to errors due to various reasons including radar characteristics, type of topography in different regions and physical properties of the surface. This study aims to assess the vertical accuracy of ASTER GDEM2, SRTM 30m and ALOS (AW3D30) global DEMs over Ethiopia in study area-Adama by using DGPS points and available accurate reference DEM data. The method used to evaluate the vertical accuracy of those DEMs range from simple visual comparison to relative and absolute comparisons providing quantitative assessment(Statistical) that used the elevation differences between DEM datasets and reference datasets. The Root-Mean-Square Error (RMSE) of the elevation residuals and other statistics used for evaluating vertical accuracy. The vertical accuracy of DEMs assessed in two stages based on the reference datasets used. The first vertical accuracy test is done by taking the residual from elevation differencing between GPS points and DEM elevation values at the location of every GPS points. The result of this assessment showed better accuracy of SRTM 30m DEM (having RMSE of ± 4.63 m), and closely followed by ALOS (AW3D30) DEM which scored RMSE of ± 5.25 m respectively. ASTER GDEM 2 showed the least accuracy by scoring RMSE of ± 11.18 m in study area. The second accuracy assessment was done by analysis of derived products such as slope and drainage network. This also resulted in better quality of DEM derived products for SRTM than ALOS DEM and ASTER GDEM. This concludes SRTM 30m DEM can be used for slope classification and Drainage network for hydrological application in the Adama Town.

Key Words: Evaluation, Open Source, Global DEMs, RMSE, Vertical accuracy, Hydrological Application

CHAPTER I. INTRODUCTION

1.1. Background of the Study

Digital Elevation Model (DEM) and its derivative attributes (slope, aspect, drainage network …*etc*.) constitute important parameters for an assessment of any process using digital terrain analysis. These morphometric parameters are commonly used in various applications including flood simulation (Honghai *et al*., 2011) ,Flood Inundation Modeling. (Tarekegn and Sayam, 2013) , Soil Erosion Mapping (Nekhay *et al*.,2009) and erosion processes modeling (Kovalchuk *et al*.,2018).Summaries of DEM applications in hydrological, geomorphological, and biological applications can be found in Moore et al., (1991).

DEMs can be generated using different techniques such as air-borne and satellite-borne stereoscopic photogrammetry, RADAR/SAR interferometry , Light Detection and Ranging (LIDAR), and conventional surveying techniques like., GPS, leveling etc. These techniques can be compared considering four aspects (i.e., price, accuracy, sampling density, pre-processing requirements). Each technique has its exclusive advantages but also some disadvantages; for a comprehensive review, see (Hengl and Reuter, 2008). However, four main steps are encountered during the generation process of each DEM, regardless of which technology is used (Li *et al*.,2006): (i) data acquisition (source of elevation data); (ii) resampling to required grid spacing (i.e., regular spaced grid); (iii) interpolation to extract height of required point (i.e., in between two grid cell centers) and (iv) DEM representation, editing and accuracy assessment. All of these steps mentioned above can introduce errors to the final DEM.

DEMs, like other spatial data sets, are subject to errors. Fisher and Tate (2006) have investigated errors on gridded data sets and classified them into three main classes: gross errors or blunders; systematic errors and random errors and remain even after known blunders (Wechsler, 2007). These errors vary geographically depending on terrain conditions (Holmes, 2013).Causes and consequences of error in DEM have been widely explored (Fisher and Tate,2006).A DEM quality depends on several factors including the acquisition system;

methodology and algorithms; complexity of the terrain; grid spacing and data characteristics (Gong *et al.*, 2000 ; Hebeler *et al*., 2009).

DEMs can be derived from a wide variety of sources. Historically, surveying techniques involving basic tools such as leveling and triangulation were used to generate DEMs. This was followed by photogrammetric techniques involving multiple stereo paired aerial photos. Recently with the advancement in spaceborne/airborne sensors, very high resolution DEMs can now be generated from the data obtained through radarmetry, interferometry, and Light Detection and Ranging (LiDAR) techniques. Each method has different spatio-temporal resolutions, formats, projection systems, and accuracies (Balzter *et al*, 2016; Santillan *et al.*, 2016; Mohd *et al.*, 2014 Gamett, 2009) investigated the accuracy of different DEM data sets over various terrain level and environmental settings; and noted that the accuracy of the models depends on multiple factors such as sensor types, methodology involved, terrain type, and grid spacing. And others have shown that the quality of a particular DEM depends on the area for which DEM is acquired (Wessel *et al.*, 2014). The accuracies can be estimated by comparing the DEM data with a set of check points measured by high-precision methods, such as GPS or LiDAR.

A variety of DEMs including Advanced Spaceborne Thermal Emission and Reflection Radiometer-Global Digital Elevation Model (ASTER GDEM), Shuttle Radar Topography Mission(SRTM), and Advancing Land Observation Satellite (ALOS) are freely available for the scientific community worldwide. Scientific user can submit, via USGS home page, a scientific proposal in order to get cost-free DEM extracts. These DEM products may constitute an alternative for researchers in many developing countries with poor geospatial infrastructure (Manfreda *et al.*, 2011) including Ethiopia. However, it is advisable, before attempting to extract different information from these models, to validate their accuracies and to understand the potential and limitations of using these datasets for a specific area . To use these DEMs for the various applications it is important to evaluate their accuracy with the help of higher accuracy standard datasets.

Hydrological variables derived from a DEM are highly sensitive to the accuracy of the DEM. Consequently, high-precision DEMs are required in hydrological modeling to produce unbiased predictions and outcomes (Vaze *et al*., 2010;Xiao *et al*.,2010). Furthermore, accurate elevation information is an important component of hydrological modeling at high spatial resolution. DEM-extracted variables, such as water-flow direction and accumulation, micro-basins, flow paths, drainage points, depression zones and drainage area, need to be derived from highly accurate elevation models (preferably also at high resolution) to ensure good quality outcomes (Erskine *et al*., 2007)

Techniques for DEM validation have been widely investigated. Gonga-Saholiariliva *et al*., 2011 gave an overview and mentioned various papers related to DEM validation. An approach of investigation uses the terms of internal and external validation depending on whether or not independent reference data are included in the assessment procedure (Kasser and Yves. ,2001). Another way, often applied, is to group methods of DEM accuracy assessment into quantitative, based on statistics and accuracy measures, and into qualitative based on visual analysis. Numerous studies were carried out for validation of DEMs using various kinds of reference data and reference DEMs (Athmania *et al*., 2014; Yap *et al*., 2018; Abdi I. (2018) ;Li P *et al*., 2013 and Elkhrachy, 2017). Those studies covered different continental areas, but not the Adama Town of Ethiopia. Therefore, This study was undertaken to assess the vertical accuracy of ASTER GDEM2, SRTM30m and ALOS(AW3D30) by comparing them to Global Navigation Satellite System (GNSS) validation points over Adama Town

1.2. Statement of the Problem

Digital Elevation Models are chief sources of height information which are greatly applied in many disciplines. Many areas where DEMs are applied include: flood hazard evaluation (Gesch *et al*.,2013); hydrological analysis and simulations (Sarmiento *et al*., 2012); Catchment Geomorphology and Hydrology (Hancock *el al*., 2006); and monitoring erosions and sedimentations (Du *et al*., 2015). In another study, the author further categorized the various areas where global or near global DEMs can be applied (Yap *et al*., 2018).

It is true that DEMs have become very useful sources of data for a range of applications in Earth and environmental sciences (Hirt *et al*., 2010) but despite their usefulness, there are many sources of errors inherent in them (Varga and Bašić, 2015). Owing to this fact, and as a result of recent improvement and release of newer versions of the Advanced Land Observing Satellite World 3D Digital Surface Model version 2.1 (ALOS W3D30); the Shuttle Radar Topography Mission Digital Elevation Model version 3.0 (SRTM30) and the Advanced Spaceborne Thermal Emission and Reflection Radiometer Global DEM version 2.0 (ASTER GDEM2), it is very important to assess and compare the quality of these data in order to see how well the DEMs fit the locally available or acquired data. This will help in determining the size of their errors within an area of application.

Several researchers (Table 2.1) from different regions of the world assessed the accuracy or fitness of these DEMs with respect to their locally available or acquired data and reported the most accurate DEM in their region. Table 2.1 presents the results obtained by these authors from different countries of the world. Although SRTM30 is reported as the most accurate DEM in some of the studies, there is need to determine its actual level of accuracy per study area since the studies show varying levels of accuracy. This is because the accuracy of DEMs depends on region of study, nature of environment, methods of algorithm development, input data, data processing and the resolution of the sensor. For example from Table 2.1, the RMSE of SRTM30 in Egypt, Tunisia(Anaguid)andAlgeria,(Tebessa) 7.04 m, 3.6 m and 8.3 m respectively.

Presently, there is no readily available topographic map that can easily provide topographic information for various hydrological modeling applications in Adama Town and it is a well known fact that terrestrial acquisition of geospatial data is more laborious, time-consuming and very expensive than doing same remotely. Although several studies have been carried out on the accuracy assessment of DEMs in different parts of the world, yet there is no comprehensive study on the vertical accuracy of these freely available DEMs over Ethiopia (Adam Town). This is despite the fact that these DEMs are being used as chief sources of topographic information for numerous hydrological applications in earth and environmental sciences. These global DEMs and their derivatives (slope and drainage networks) are used as input data for various hydrological applications in the Adama Town. Care for DEMs vertical accuracy and quality before use for hydrological application is important ; for instance use of inappropriate DEMs may lead to overland flow of drainage water and may direct a major stream line in a wrong direction. For this reason, the present study is interested to evaluating the accuracy of these DEMs over Adama Town by using terrestrially acquired GPS (Global Positioning System) survey data and reference DEM since it provides an independent way of assessing the quality of these three DEMs for hydrological application.

1.3. Objectives

1.3.1. General objective

The objective of the study is to evaluate the vertical accuracy of open source Global DEMs for hydrological application over Adama Town in Ethiopia.

1.3.2. Specific objectives: The Specific objectives of the study are to:

- Compute the vertical accuracy of these DEMs based on elevation differences using statistical measures.
- Evaluate DEM accuracy in terms of their derived terrain derivatives and applications
- Compare their vertical accuracy to select which DEM has better accuracy to represent the study area's topography

1.4. Research Questions

- What is the vertical accuracy of ALOS (AW3D30), ASTER GDEM2 and SRTM30 DEM?
- What are the accuracy differences between three DEMs?
- Which one of the three DEMs has better quality of derivative products and applications?
- Which one of the three global DEMs has accurate for the study area's topography?

1.5. Significance of the Study

The final output of this study will provide information for different stakeholders such as researchers, government Agencies, NGOs and other groups.

It will serve as an input data to those who have interest to pursue in related aspects of the research, modeling and analysis.

It will give detail information about accuracy and quality of open source global DEMs for researchers which use these DEMs as input data.

Adama Town municipality can use output of the study for drainage network analysis downloading from online portal (https://lpdaac.usgs.gov/) freely.

It will help to extracting elevation, slope and drainage network for any hydrological modeling and related applications.

It will help to extract elevation and slope for reservoir site selection and pipeline fair distribution for Adama Water and Sanitary Service Enterprise

It will help for computing slope map, aspect maps for study of flooding, estimation of runoff and erosion.

1.6. Scope of the Study

The positional accuracy of DEMs is measured in terms of horizontal and vertical accuracy. This study focused on the vertical accuracy of three Global DEMs, and do not consider the horizontal accuracy. The vertical accuracy of DEM is the measure of positional accuracy of DEM datasets with respect to a specified vertical datum, at specified confidence level. The vertical datum of global DEM is EGM96 (Earth Gravitational Model 1996) geoid. This datum has difference with local M.S.L (mean sea level) datum. This difference and the limitations of EGM96 geoid model are not considered in thus study.

1.7 Thesis structure

This thesis consists of five chapters and it is summarized as follows: Chapter one presents introduction, problem statement of the study, objectives of the study, research questions of this study, significance of the study and scope this study. Chapter two aims to present literature review which include theory related Digital elevation model, sources of DEM and descriptions of major open source global DEM; vertical datum and height system; EGM96 Geoid model; and concept related to GNSS and vertical accuracy. Chapter three presents the general description of the study area, data acquisition; software's, materials; data preparation &processing and accuracy assessment methods in the study are described in detail. Chapter four presents results and discusses from DEM accuracy analysis by different test datasets. Chapter five aims to present the key research conclusions and recommendation based on the finding of the research.

CHAPTER II. LITERATURE REVIEW

2.1 Introduction

This chapter reviews the concept of DEM, sources of DEM and open source Digital Elevation model to which measured values represented in DEM are referenced; the concepts of GPS measurement system, accuracy assessment method, accuracy standards and previous studies are also discussed.

2.2 Digital Elevation Model

A DEM is defined as "any digital representation of the continuous variation of relief over space,"(Burrrough,1986),where relief refers to the height of earth's surface with respect to the datum considered .It can also be considered as regularly as spaced grids of the elevation information, used for the continuous spatial representation of any terrain. Digital Elevation Model (DEM) is the digital representation of the land surface elevation with respect to any reference datum. DEMs can used to determine terrain attributes such as elevation at any point, slope and aspect. Terrain features like drainage basins and channel networks can also be identified from the DEMs. The Digital Elevation Model (DEM) which represents the 3-D information on the ground is one of essential layers in the field of geographic information systems. Its applications extend over wide ranges in the scientific fields, e.g., hydrology, geomorphology, ecology, etc., as well as in the practical use, e.g., infrastructure design, disaster monitoring, environmental monitoring, natural resources survey….*etc* (Takaku *et. al*, 2016). DEMs are typically used to represent terrain relief and are particularly relevant for many applications such as soil erosion volume calculations, flood estimate, quantification of earth materials to be moved for channels, roads, dams, embankment etc. DEM is a general term that represents a continuous surface representation, mainly referred to a raster. However, in practice, this general term is divided in to two main categories. Digital Terrain Model (DTM): which represents the bare ground surface without any natural or man-made structure on top of it such as trees or buildings; and Digital Surface Model, represents an earth surface that combines the ground surface and the top of all natural and man-made features (Wassim, 2016).

DEM can be represented digitally in many ways, including: a grid model in which elevation is estimated from each cell in regular grid, a triangular irregular network (TIN) which represents a surface of a set of contiguous, non overlapping triangles, and as contour line connecting points of equal terrain height.

2.2.1 Sources of Digital Elevation Model

Elevation information for a DEM may be acquired though field surveys, from topographic contours, aerial photographs or satellite imageries using the photogrammetric techniques. Recently radar interferometric techniques and Laser altimetry have also been used to generate a DEM.

DEMs can be generated by Conventional topographic surveys, Kinematic GPS surveys, Analogue and digital photogrammetric approaches, Radar techniques, Laser surveys, Shipboard echo sounding, Airborne optical sensing, Satellite radar altimetry, Airborne ice-penetrating radar techniques and Digitizing of contours (Igor V. Florinsky, 2012.).For measuring the 3D information on the ground various methods are used depending on target scales or accuracies. (Ketarji ,2016);(Kyaruzi, 2005); (San & Suzen,2005) have discussed different ways of measuring and collecting elevation (height) data, which forms the basic elements of DEM. The first conventional method for collecting topographic information about terrain was through ground topographic surveying.

Topographic surveying is the science of measuring distances and angles on the terrain and above features, relative to a reference point and height (Wassim, 2016). Topographic surveying is also the process of determining the positions, on the earth's surface, of the natural and artificial features of a given locality, and of determining the configuration of the terrain. The surveyor collects several points in the study area using special instrument like total station starting from certain well defined points such as national geodetic network, and recomputed their xyz values accordingly. The main output from this method is a set of XYZ points that needs to be interpolated in order to generate continuous surface of the terrain or DEM using various methods of interpolation techniques. Although this method can provide height accuracy result (Leica Geosystem, 2015), it consume more time and depends on the presence of the surveyor in the field along with the equipment. For this reason, it is suitable only for relatively small and accessible areas. Instead, satellite GPS surveying and 3D laser scanning are taking over conventional ground surveying (Haddad, 2011)

Photogrammetry is the art and science of extracting meaningful information about objects and phenomenon from imagery, either in analog or digital form, and other spatial measurement systems like laser and radar data. Photogrammetry is also the science and technology of obtaining spatial measurements and other geometrically reliable derived products from photographs. Photogrammetric analysis procedures can range from obtaining approximate distances, areas, and elevations using hardcopy photographic products, unsophisticated equipment, and simple geometric concepts to generating precise digital elevation models (DEMs), orthophotos, thematic GIS data, and other derived products through the use of digital raster images and relatively sophisticated analytical techniques (Thomas, Ralph and Jonathan, 2004). Historically, the most common use of Photogrammetry has been to produce hardcopy topographic maps. Today, photogrammetric procedures are used extensively to produce a range of GIS data products such as precise raster image backdrops for vector data and digital elevation models. Thematic data (in three dimensions) can also be extracted directly from photographs for inclusion in a GIS.

Topographic maps have been produced from hardcopy stereo pairs in a device called a stereo plotter. With this type of instrument, the photographs are mounted in special projectors that can be mutually oriented to precisely correspond to the angular tilts present when the photographs were taken. Once oriented properly, the projectors recreate an accurate model of the terrain that, when viewed stereoscopically, can be used to plot a planimetric map having no relief distortions. In addition, topographic contours can be plotted on the map and the height of vertical features appearing in the model can be determined (Abdi, 2018)

Stereoscopic Photogrammetry is based on the concept of stereoscopic-viewing mentioned above. The advancement of computer technology enabled us to measure 3D features directly from digital images by the means of visualizing stereoscopic- images via specialized computer transmitters and glasses and using ground control points (Linder 2009). Stereoscopic Photogrammetry provides the means to generate DEM by collecting a set of mass points in the form of XYZ. These mass points will be interpolated later on to generate the continuous surface. In addition to stereoscopic aerial photos, there exist several satellite sensors that provide stereoscopic satellite images. The study in (Krishnan, Sajikumar and Sumam 2016) showed a method of high quality DEM generation from Cartosat-I stereo data.

Results from the study shows that the DEM generated from Cartosat-I stereo data using Leica Photogrammetry Suite (LPS) is more accurate than the publically available Carto DEMs.

Remote sensing is the science (and to some extent, art) of acquiring information about the Earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information. Remote sensors collect data by detecting the energy that is reflected from Earth. These sensors can be on satellites or mounted on aircraft. Todays, various applications frequently use remote sensing data rather than direct survey data to generate elevation data. The importance of aerospace observation is evident: satellites carrying a variety of sensors and looking toward the earth can collect data, at relatively low costs, broadly consistent with the required spatial, spectral and temporal resolutions to interpolate new DEMs (Kobrick ,2006) .

Satellite sensors that provide stereoscopic satellite images include: Advanced spaceborne Thermal Emission and Reflectance Radiometer (ASTER) Global Digital Elevation Model (GDEM) and Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) an optical sensor onboard the Advanced Land Observing Satellite (ALOS).

The global elevation data derived from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER/GDEM) derived from the optical stereo sensors was released in 2009 first. It has the height accuracy of 13 m in 1 arcsec (30 m) pixel spacing (Tachikawa et al., 2011). Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) was an optical sensor onboard the Advanced Land Observing Satellite (ALOS) operated from 2006 to 2011, and was designed to generate worldwide elevation data. The sensor consists of three independent panchromatic radiometers for viewing forward, nadir, and backward producing in-track triplet stereoscopic images in 2.5 m ground resolution (Tadono *et al*. 2009).

In recent years global DEM datasets derived from spaceborne remote-sensing techniques are being widely used with its wide coverage and homogeneous data quality. Radargrametry is the concept of collecting data through an active sensor that works on the basics of echo, where the sensor periodically transmits a high powered and short-period signal toward the target surface. The system records the backscattered signal and deducts from it the distance based on the time taken for the signal to hit the target and back (Gomarasca, 2009).The Shuttle Radar Topography Mission (SRTM) was the first global datasets made by space borne radar instruments and was released in 2003 first. The data has 3 arcsec (90 m) pixel spacing at the first release in which the absolute and relative height accuracies are ~9 m and ~10 m respectively (90 % errors) (Rodriguez *et al*., 2006).

Another advance in Radargrametry is the Airborne Interferometric SAR (InSAR) that provides an intermediate level of detail between the Airborne LiDAR and the space borne SAR sensors. The study in (Byran, 2008) showed that such technology provides either DTM or DSM with 5 meter spatial resolution. On the other hand Light Detection and Ranging (LiDAR) is one of the best and latest technologies that measure distance by transmitting a laser beam on the target feature and analyzing the reflection. LiDAR sensors can be mounted on airplane, called Airborne LiDAR, or on cars called Terrestrial LiDAR and can reach vertical accuracy higher than 5 centimeters (LiDAR, 2013).

2.2.2 Source of Errors in Digital Elevation Model

DEM errors occur in vertical directions. Errors propagate from the input data used in creating a DEM right through to calculating surface derivatives and using DEMs in complex applications (Hutchinson and Gallant, 2000; Fisher and Tate, 2006). Whatever their source, DEMs can appear to provide a definitive and plausible representation of topography which can often lull the user into a false sense of security regarding their accuracy, with many users unaware of DEM errors or how to treat them (Wechsler, 2003&2007). Whilst accuracy statistics such as RMSE provide an indication of DEM accuracy, they assume error to a spatial (Hunter and Goodchild, 1997; Carlisle, 2005; Fisher and Tate, 2006; Wechsler,2007). Holmes *et a*l., (2000) observe that “although global (average) error is small, local error values can be large, and also spatially correlated.” The spatial variation of DEM error is most frequently estimated by calculating accuracy statistics of areas disaggregated by slope and/or land cover class, and more rarely spatial structure of error.

Wise (2000) categorized DEM errors as systematic, blunders or random. These types of errors derive from: (a) deficient spatial sampling and/or age of data; (b) processing errors such as interpolation or numerical errors; (c) measurement errors from poor positional inaccuracy, faulty equipment or observer bias (Wechsler, 2007). Systematic errors occur in the DEM creation procedure by processing techniques that can cause bias or artifacts. Blunders arise from human error (Wise, 2000) or equipment failure (Fisher and Tate, 2006). Random errors occur in any system of measurement due to the wealth of measurement and operational tasks performed to create a DEM (Wise, 2000; Fisher and Tate, 2006), and remain even after known blunders and systematic errors are removed (Wechsler, 2007).An example of random error is speckle noise (multiplicative noise in a granular pattern) (Rodriguez *et al*., 2006; Farr et al.,2007). Sources of systematic errors and blunders relevant to flood modeling derive from interpolation techniques (Wise, 2007; Guo *et al*., 2010), erroneous sink filling (Burrough and McDonnell, 1998), hydrological correction (Woodrow *et al*., (2016), slope and aspect (foreslope vs backslope) (Szabó *et al*., 2015), striping caused by instrument setup (Walker et al., 2007; Tarakegn and Sayama, 2013) .The errors propagate into errors in surface derivatives including, but not limited to, slope (Holmes *et al.*,2000), aspect (Januchowski *et al*., 2010),drainage basin delineation (Oksanen and Sarjakoski, 2005) and upslope contributing area (Wu *et al*., 2008). As many models rely on these surface derivatives (e.g., change in slope is the dominant control on flow in flood models), error propagation from DEMs can substantially affect results of models that use these surface derivatives. DEM errors have been related to production methods and terrain complexity; increased errors have been correlated with terrain complexity.

2.2.3 Effect of Digital Elevation Model Accuracy on Hydrological Applications.

Topography is an importance role in hydrological modeling which is for water management and flood protecting. It can be derived from Digital Elevation Model (DEM) which is one of the most commonly used and widely available basic spatial information. Several studies have been undertaken on the effects of relative elevation accuracy in published DEMs on hydrologic modeling or geomorphic parameters used in hydrology. Application of inappropriate DEMs in hydrological and environmental modeling has a significant effect on the modeling results. This was evident in Datta and Schack-Kirchner (2010) where it was noted that the choice of a DEM for soil erosion modeling has a significant effect on the relevant topographic parameters (elevation, slope, aspect, and LS factor) and consequently on the modeling results. (Lane et al., 1994) hydrology, like deriving drainage network and overland flow areas that contribute to (suspended) sediment loads and Rojas et al (2008) expressed results when they studied the effects of DEM accuracy on result of modeling upland erosion and sediment yield from natural watersheds and found that using not accurate DEMs significantly reduces land surface slopes and channel network topology, resulting in varied upland erosion estimates. Care for the consequence before using the DEMs in modeling hydrological and environmental problems without knowing which of them is best suited for their particular applications. The neglect vertical accuracy may have led to poor modeling results which have an attendant consequence on the environmental problems being modeled. For instance, in modeling areas that are prone to flooding, the use of inappropriate DEM may result to wrongly assigning land use land cover types such as buildings, farmland to flood prone areas and may direct a major stream line in a wrong direction. One wonders the attendant implication-socio economic loss, trauma or even death this may cause to the victims of this wrong modeling result. The DEM's accuracy, quality and fits the earth's surface are the main target for most application and analysis. Users of global elevation dataset are still confused on the choice of global dataset to use for a particular application and for a particular region.

Many applications use ALOS, SRTM and ASTER products around the world, there is limited scientific literature on their quality and application fitness. It is apparently not clear as to which DEMs are most suitable for a particular environmental modeling, types, study area or climate zone. For instance, Ejikeme, *et al*.,(2017)the vertical accuracy of these global DEM varies depending on the terrain characteristics , and may affect the quality of products such as slope, aspect and stream channels derived from these data needed for topographic and hydrologic modeling.

It is quite evident that users of freely available global DEMs in Ethiopia especially in Adama Town are recklessly using these DEMs in modeling various environmental problems without knowing which of them is best suited for their particular applications. The neglect may have led to poor modeling results which have an attendant consequence on the environmental problems being modeled. For instance, in modeling areas that are prone to flooding, the use of inappropriate DEM may result to wrongly assigning land use land cover types such as buildings, farmland to flood prone areas. One wonders the attendant implication-socio economic loss, trauma or even death this may cause to the victims of this wrong modeling result. the freely available medium (90 m) and high resolution (30 m) near-global DEMs have opened up many possibilities for hydrological analyses, especially at national and regional scales (De Clercq et al., 2013; Wang et al., 2011; Weepener et al., 2012; Sharma and Tiwari, 2014). Researchers frequently use these DEMs for hydrological studies, mainly because they are freely available (De Clercq et al., 2013; Gichamo et al., 2012; Wang et al., 2011; Weepener et al., 2012). However, little attention has been paid to the quality of the products that are derived from these DEMs. Given their popularity, it is important to assess the accuracy of the derived hydrological parameters (drainage networks) so that uncertainties can be considered in the interpretation of hydrological analysis results

2.3 Global Digital Elevation Models

Satellite are the only viable technologies to acquire large-area DEMs over large areas. This section describes some of popular freely available wide-area global DEMs

2.3.1 Shuttle Radar Topography Mission (SRTM)

Shuttle Radar Topography Mission) acquired DEMs in February 2000 by single-pass SAR interferometry in the C- and X-bands (Farr et al., 2007). There are several versions, with or without holes; patched with data from other sources, etc. the SRTM DEM version discussed here is The SRTM-30m ("SRTM V3.0, 1 arcsec"). The SRTM-30m is a an enhancement to the low resolution SRTM topographic data having 90-m (3arcseconds, which is 1/1200th of a degree of latitude and longitude) resolution covering regions outside the United States (US) which was released publicly in 2003. The new data, released in September 2014, increase the detail to 30-m (or 1 arc-second), revealing the full resolution of the world's landforms as originally released by SRTM in the year 2000 (NASA JPL, 2014). Before this release, the best available 90-m SRTM DEMs for regions outside the US were: (i.) SRTM Version3 (also called "SRTM Plus") released by the National Aeronautics Space Administration (NASA) in November 2013 (NASA LP DAAC, 2013); and (ii.) CGIARCSI SRTM Version 4.1 released by the Consultative Group for International Agricultural Research - Consortium for Spatial Information (CGIAR-CSI) in 2008 (Jarvis et al., 2008). According to its mission objectives, SRTM DEMs are expected to have linear vertical absolute height error of less than16m, linear vertical relative height error of less than 10 m, circular absolute geo-location error of less than 20 m, and circular relative geo-location error of less than 15 m (Farr et al., 2007). SRTM-30m accuracy assessments conducted by NIMA, the USGS, and the SRTM project team have shown the absolute vertical error to be much smaller, with the most reliable estimates being approximately 5 m (Kellndorfer et al., 2004).

2.3.2 Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER GDEM2)

Advanced Space borne Thermal Emission and Reflection Radiometer) GDEM was created from data acquired between 1999 and 2009 with stereo matching of image data in the visible and near-infrared range. It covers the landmasses between 83°N and 83°S at ~30 m grid spacing, with some small holes. The accuracy (95% confidence) is 20 m. Empirical valuations have shown that ASTER has somewhat inhomogeneous quality (Schindler, et al.2011). The ASTER GDEM Version 2 was considered to be the highest resolution DEM among the free accessible global DEMs during its release in 2011 (Arefi and Reinartz, 2011).

The ASTER GDEM v2 contains significant improvements of Version 1 (released in 2009) in terms of spatial coverage, refined horizontal resolution, increased horizontal and vertical accuracy, water masking, and inclusion of new ASTER data to supplement the voids and artifacts (NASA JPL, 2011). In Japan, the ASTER GDEM2 was reported by the ASTER GDEM Validation Team to have an RMSE of 6.1 m in flat and open areas, and 15.1 m in mountainous area largely covered by forest (Tachikawa et al., 2011). In the conterminous US, the RMSE computed for GDEM2 was 8.68m based on the comparison with more than18, 000 independent reference ground control points (Gesch et al., 2012).. An external validation conducted by Athmania and Achour (2014) shows the GDEM2 to have RMSE of 5.3 and 9.8 m in test sites located in southern Tunisia and in northeastern Algeria, respectively. In Banten province, Indonesia, RMSE values ranging from4.543 to 7.759 m was computed by Suwandana et al (2014). According to ASTER GDEM Validation Team expected vertical absolute height error of less than17m. The results of these example studies show that the accuracy of ASTER GDEM2 varies from one location to another. Hence, localized or site-specific accuracy assessment of the ASTER GDEM2 is very important

2.3.3 Advanced Land Observation Satellite (AW3D30)

The ALOS (AW3D30) was released in 2015 by the Japan Aerospace Exploration Agency (JAXA). The AW3D-30 is actually a resampling of the 5-meter mesh version of the World 3D Topographic Data, which is considered to be the most precise global-scale elevation data at this time (JAXA, 2015). AW3D30 was generated using the traditional optical stereo matching technique as applied to images acquired by the Panchromatic Remote sensing

Instrument for Stereo Mapping (PRISM) sensor onboard the Advanced Land Observing Satellite (ALOS) (Takaku *et al*., 2014). Details on how the DEM was generated are discussed in the papers of Tadono *et al*., (2014) and Takaku et al (2014). Tadono *et al*., (2014) found the AW3D-5m to have height accuracies better than 5m in four test sites with varying terrain features while Takaku et al. (2014) found the same DEM version to have a Root Mean Square Error (RMSE) of almost 4 m based on comparisons with various datasets including airborne LiDAR Digital Surface Model (DSM) and ground control points (GCPs). Recent assessment conducted by Tadono et al (2015) confirmed an RMSE of 4.10 m.

2.4 Vertical Datum and Height Systems

Vertical datum provides a base values from which elevations or height are determined. On the earth a vertical datum expresses a surface of zero elevation. The term in which a height system is defined is dependent on the way that the Earth's gravity field is observed or modeled. There are three types of heights: orthometric ,geoid and ellipsoidal

2.4.1 Ellipsoidal Height

Ellipsoid defines mathematical surface approximating the physical reality while simplifying the geometry. Ellipsoid is a good approximation to the shape of the earth but not an exact representation. It is the only regular surface among the three geodetic surfaces; hence it has a regular shape which made it possible to be represented mathematically, and therefore enables computation to be carried on it (Moka and Agajelu,2006; Vanicek, P.,2015).Ellipsoidal height is fast, easy and convenient to obtain from GPS and is equally useful. To make full use of the three-dimensional potentials of GPS, one needs to determine the separation between the ellipsoid and the geoid. This separation is known as geoidal undulation (N). The ellipsoid is also a geometric surface which approximates the geoid in a least squares sense. For geodetic purposes, the ellipsoid of revolution is produced when an ellipse is rotated about its semi minor axis, provides a well-defined mathematical surface whose shape and size are defined by two parameters viz., Size of a reference ellipsoid can be described by semi-minor axis, b or semi-major axis, a; Shape of a reference ellipsoid can be described by its flattening, f or its eccentricity, e. The ellipsoid height is the distance along the normal to the ellipsoid to the Earth's surface. Unlike the above definitions, it is independent of gravity and therefore does not correctly determine the flow of fluids. In some cases the gradient of ellipsoid heights can be in the opposite direction to orthometric heights. (Soler, 2015) The ellipsoid, h above the surface of ellipsoid is shown in Figure 2.1

2.4.2 Orthometric Height

The orthometric height is defined as the distance along the curved plumb line between a surface point and the ellipsoid (Torge, 2001). This definition corresponds to the common understanding of height above sea level. However, because of the curved nature of the plumb line and unknown variations in gravity down the plumb line, it is not possible to physically observe or compute a true orthometic height (Bernhard Hofmann-Wellenhof, 2005). The use of gravity field models does enable its relative determination.

Orthometric heights (H) are more desirable, because they better relate to mean sea level in the geophysical sense. Orthometric height refers to a vertical datum that is usually taken to be a best fit to mean sea level, either in a global sense or simply adopted from a local tide gage. Such a surface of equal potential of gravity (geopotential) best serves for describing height changes, because water will flow and self-level to the lowest geopotential surface (Roman *et al*., 2010). Theoretically, both ellipsoidal height and orthometric heights are measured along the normal to the ellipsoid and along the direction of the plumb line (vertical), respectively. The actual gravity plumb line (over exaggerated in drawing) along which H is reckoned is a curved distance due to effects of direction of gravity, known as deflection of the vertical. For engineering purposes, the error produced by this approximation can normally be ignored. Figure 2.1 provides the relationship between geoid, ellipsoid and orthometric heights. Oluyori, P. D.*et al* (2018) Orthometric height is required for survey, mapping, engineering/environmental applications as well as geo-scientific studies. These heights are referred to the geoid surface which is a surface that is at all places on the surface at right angles to the gravity vector direction. The orthometric heights are referenced to Mean Sea Level (MSL) approximation of the geoid surface (Eteje, 2018 and (Sun et al.,2003).

2.4.3 Mean Sea Level

The reference datum for orthometric heights, ellipsoid and the geoid, is approximated by Means Sea Level (MSL). The EGM96 surface is very close approximation of MSL (Sun et al.,2003), the height. Because of the assumption that MSL and the geoid coincide in the open oceans, it is possible to relate MSL to the geoid using tide gauge measurements and therefore define a vertical datum. In order to accurately define MSL, it is necessary to take regular measurements of MSL over a period sufficient to cancel out the effects of features such as long term tidal cycles and sea surface topography variations. A continuous record of at least 19 years is recommended for this purpose (Bernhard Hofmann-Wellenhof, 2005).

2.4.4 Geoid Height

To understand what geoid heights mean, it is imperative to know what does geoid entails. The geoid is an equipotential surface of the earth's gravity field which, a least square sense coincides with mean sea surface in the open ocean. It is a best fit mean sea level surface. The geoid serves as a reference surface for height systems such as orthometric heights. It is a physical surface which represents the size and shape of the earth, by describing origin surfaces for point heights, determining mean earth ellipsoid, determining the horizontal and vertical datum of reference systems, examining changes in the earth and sea surfaces (Yilmaz and Karaali, 2010).

Geoid heights from the Global Geopotential Models (EGM96 and EGM08) are given as a set of spherical harmonic coefficients (Pavlis et al, 2008). Different datasets are often used to determine these coefficients ranging from satellite observations, which give the so called satellite-only solutions, to data which incorporate satellite altimetry and surface gravity data (Rapp, 1996). A geoid is of importance to engineering and geosciences as a physically defined surface for determining orthometirc heights (Torge, 2001). Therefore it is orthometric heights which are of greatest concern (Torge, 2001). The geoid undulation ranges from – 107m to 85m worldwide relative to the World Geodetic System1984 (Okiwelu, 2011). Geoid height (undulation) is applied to the study of regional and global problems, for example, dynamic structure of the Earth’s interior. The anomalous results obtained from surface gravity measurement may be due to earth’s density variation or topography features (Cazenave, 1995)

2.5 Geoid Models

A geoid model is a three-dimensional (3D) geospatial model defines the relationship between the ellipsoid and the geoid surfaces at a specific area. In a sense, geoid models have been one of the main activities of the geodetic community a long time ago. However, a geoid model became an essential task since the spread of Global Navigation Satellite Systems (GNSS) utilizations in 1980s. Since GNSS-based heights are referred to the surface of an ellipsoid, a geoid model converts them to the MSL-based orthometric elevations used in civil engineering applications. On a global basis, the separations between the geoid and ellipsoid surfaces are in the range of ± 100 meters (Essam M. Al-Krargy, 2017). A geoid model is a model of the separation values between an ellipsoid and the geoid for a given area, be it global, regional or local. It is used to convert ellipsoid heights to an orthometirc height, such as mean sea level. A geoid model enables the transformation of the GPS measured heights into the MSL orthometric heights needed for geomatics applications(Khalid A. Al-Ghamdi, 2013). The relationship between the different height systems is described by the following equation (Elkhrachy, 2017):

H = h – N-- (2.1)

Where:

H = Orthometric height

h = Height above Ellipsoid

N = Geoid -Ellipsoid separation value

The N is termed geoid undulation that is the difference between ellipsoid and geoid surface used for the conversion of ellipsoidal height to orthometric height. The geoid height calculator is an online tool that calculates the geoid undulation correction at a specified location on Earth using EGM96 gravity models. The error for EGM96 geoidal undulation is in the range ±0.5 to ±1.0m (Lemoine et al. 1998). With the geoid undulation of each point, the following relationship (1) was used to transform elevation from ellipsoidal height to orthometric height (Bomford 1980): The N is given by Heiskanen and Moritz (1967) and Eteje et al (2018) as:

N = h-H -- (2.2)

Therefore the orthometric height (H) can be determined by subtracting the geoid - ellipsoid separation value from the ellipsoid height. Note that if the geoid is above the ellipsoid, the N value is positive, if it is below the ellipsoid, the N value is negative. This relationship is shown in figure 2.1 below.

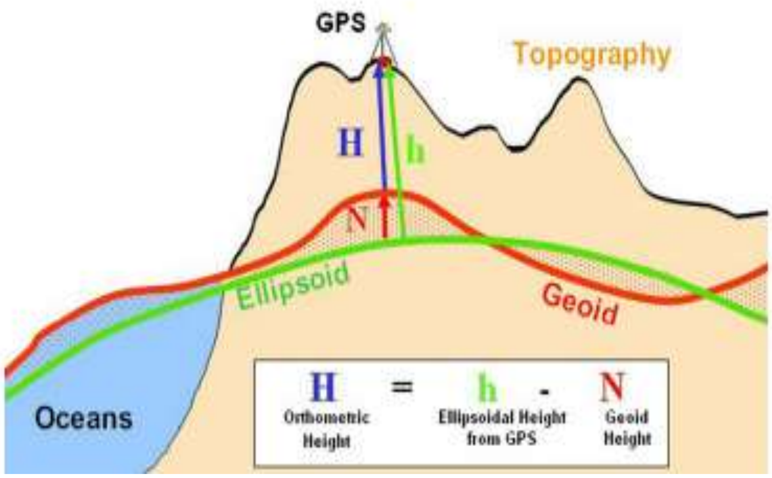

Figure 2-1 Relation between of Orthometric, ellipsoidal and geoid, height

2.5.1 Earth Gravitational Model 1996 (EGM96)

The Earth Gravitational Model 1996 (EGM96) is one global geoid models that can be used to calculate the orthometric elevation when the values of ellipsoid heights are given by GPS positioning instruments. It is expressed by a spherical harmonic expansion of the gravitational potential and complete through degree and order 360 with an error range of 0.5 to 1.0m worldwide (Xiong and Hans-Jurgen, 2001). The EGM96 is the most recent and precise spherical harmonic model representing the potential field of the earth. New terrestrial gravity and satellite altimeric data have been used in the development of EGM96 and lead to significant improvement in the precision of geoid determining using this model. This model is the result of collaboration between the National Imagery and Mapping Agency (NIMA), the NASA Goddard Space Flight Center, and the Ohio State University. The joint project took advantage of new surface gravity data from many different regions of the globe, including Africa, Canada, parts of South America, Greenland and parts of the Arctic and the Antarctic, Southeast Asia, Eastern Europe, and the former Soviet Union. In addition, there have been major efforts to improve NIMA's existing 30' mean anomaly database through contributions over various countries in Asia EGM96 model is used to compute geoid undulations accurate to better than one meter (with the exception of areas void of dense and accurate surface gravity data) with reference to WGS84 ellipsoid(Kumar and Chauhan 2006).

2.6 Global Positioning System

The United States Department of Defense (DoD) has developed the Navstar GPS, which is an all-weather, space based navigation system to meet the needs of the USA military forces and accurately determine their position, velocity, and time in a common reference system, anywhere on or near the Earth on a continuous basis. GPS satellite constellation buildup started with a series of 11 satellites known as Block I satellites. The first satellite in this series (and in the GPS system) was launched on February 22, 1978; the last was launched on October 9, 1985. Block I satellites were built mainly for experimental purposes. The inclination angle of the orbital planes of these satellites, with respect to the equator, was 63°, which was modified in the following satellite generations. Although the design lifetime of Block I satellite was 4.5 years, some remained in service for more than10 years. The last Block I satellite was taken out of service on November 18, 1995(Ahmed 2002).

The launch of the second generation of GPS satellites, called Block II, began in February 1989. In addition to radiation-hardened electronics, these operational satellites had full SA/AS capability and carried a navigation data message that was valid for 14 days. Additional modifications resulted in the satellite called Block IIA. These satellites can provide about 6 weeks of positioning service without contact from the control segment. Twenty-eight Block II/IIA satellites were launched between 1989 and 1997 into six planes, 55∘inclined. The first third-generation GPS satellite, called Block IIR (R for replenishment), was successfully launched in 1997. These satellites have the capability to determine their orbits autonomously through UHF cross-link ranging and to generate their own navigation message by onboard processing. They are able to measure ranges between themselves and transmit observations to other satellites as well as to ground control. In recent years, GPS has undergone a major modernization. Most importantly, the GPS satellites are transmitting more signals that allow a better delineation of military and civilian uses, and thus increase the performance of GPS even more (Alfred, Lev and Tatarnikov, 2015).

If the distances from a point on the Earth (a GPS receiver) to three GPS satellites are known along with the satellite locations, then the location of the point (or receiver) can be determined by simply applying the well-known concept of resection. Each GPS satellite continuously transmits a microwave radio signal composed of two carriers, two codes, and a navigation message. When a GPS receiver is switched on, it will pick up the GPS signal through the receiver antenna. Once the receiver acquires the GPS signal, it will process it using its built-in software. The partial outcome of the signal processing consists of the distances to the GPS satellites through the digital codes (known as the pseudoranges) and the satellite coordinates through the navigation Message(James Bao ,2005).As mentioned before, theoretically, only three distances to three simultaneously tracked satellites are needed. In this case, the receiver would be located at the intersection of three spheres; each has a radius of one receiver-satellite distance and is centered on that particular satellite. From the practical point of view, however, a fourth satellite is needed to account for the receiver clock offset.

The accuracy obtained with the method described earlier was until recently limited to 100m for the horizontal component, 156m for the vertical component, and 340 ns for the time component, all at the 95% probability level. This low accuracy level was due to the effect of the so-called selective availability; technique used to intentionally degrade the autonomous real-time positioning accuracy to unauthorized users (Hoffmann-Wellenhof, 1994). GPS positioning accuracy can be improved by the so-called differential method, which employs two receivers simultaneously tracking the same GPS satellites. In this case, positioning accuracy level of the order of a sub-centimeter to a few meters can be obtained.

Each GPS satellite broadcasts radio signals containing synchronized orbital information and timing signals at two frequencies, designated by L1and L2 (Hofmann-Wellenhof & Moritz, 2006). L1 is the principal GPS carrier signals, at a frequency of 1575.42 MHz, equivalent to a wavelength of about 19 cm. The GPS L2 signal, transmitted by the satellite at 1227.60 MHz (~ 24 cm wavelength), was established to provide GPS user receivers with a second frequency for ionospheric delay corrections. The combination of L1 and L2 frequencies provides a real time technique for determining the ionospheric delay effects on the GPS signal paths caused by the free electron content in the ionosphere (Gao & Liu, 2002; Liao, 2000).

2.7 Accuracy Assessment

Accuracy refers to the bias of an estimator; it measures how close an estimated or calculated value is to its true value. In positional accuracy assessment, it is interested in characterizing the accuracy of a geospatial data set. It takes samples to determine if a bias (systematic inaccuracy) exists in the data set, and estimate the magnitude and precision of the bias. The Glossary of the Mapping Sciences (ASPRS and ASCE, 1994) defines positional accuracy as "the degree of compliance with which the coordinates of points determined from a map agree with the coordinates determined by survey or other independent means accepted as accurate." positional accuracy has been assessed by comparing the coordinates of sample points on a map against the coordinates of the same points derived from a ground survey or some other independent source deemed to be more accurate than the map. Positional accuracy can refer to either horizontal (planimetric) or vertical (elevation) accuracy. Since the aim of this study is to assess the accuracy of open source Digital Elevation Models this section will focus on the vertical (height) aspect of positional accuracy assessment.

According to the United States National Map Accuracy Standards (NMAS) published by U.S. Bureau of the Budget (U.S. Bureau of the Budget, 1947) Vertical accuracy defined as: Vertical accuracy, as applied to contour maps on all publication scales, shall be such that not more than 10% of the elevations tested shall be in error by more than one-half the contour interval. In checking elevations taken from the map, the apparent vertical error may be decreased by assuming a horizontal displacement within the permissible horizontal error for a map of that scale. The accuracy of any map may be tested by comparing the positions of points whose locations or elevations are shown upon it with corresponding positions as determined by surveys of a higher accuracy. Tests shall be made by the producing agency, which shall also determine which of its maps are to be tested, and the extent of such testing. American Society for Photogrammetry and Remote Sensing (ASPRS) (ASPRS, 2014) also stated that "vertical accuracy is the measure of the positional accuracy of a data set with respect to a specified vertical datum, at a specified confidence level or percentile."

2.7.1 Accuracy assessment methods

Estimating positional error parameters requires the comparison of coordinates and/or elevations of identical sample locations from (FGDC, 1998):

- The spatial dataset to be assessed (map or imagery) and
- The reference data, which must be an "independent source of higher accuracy"

Accuracy assessment can be qualitative or quantitative. The goal of quantitative accuracy assessment is the identification and measurement of DEM errors. This quantitative assessment is done through sampling, because measuring every point in the geospatial data set being assessed would be prohibitively expensive, and sampling can provide highly reliable estimates of the error population's parameters (Congalton & Green, 2008). NSSDA (FGDC, 1998) outlines several requirements fort sampling design and collection which includes:

- The reference data may be independent from the data being tested.
- For statistical rigor, more than 20 sample locations should be chosen.
- The sample points must also be well distributed across the project area, and represent the full variety of topography.

Using metric units, ASPRS recommends 100 static vertical checkpoints for the first 2,500 square kilometer area within the project, which provides a statistically defensible number of samples on which to base a valid vertical accuracy assessment. Checkpoints should be distributed generally proportionally among the various vegetated land cover types in the project (ASPRS, 2014).

To assess the vertical accuracy of a DEM, there exist three main techniques that rely on statistics*:* Root Mean Square Error (RMSE), variance, and 95th percentile. The NSSDA uses root-mean-square error (RMSE) to estimate positional accuracy. RMSE is the square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points (FGDC, 1998).

RMSE is given as

$$\text{RMSE} = \sqrt{\frac{\sum(\boldsymbol{Zt}-\boldsymbol{Zi})^2}{\boldsymbol{n}}}$$

Where Zi is the interpolated DEM elevation of a test point, Zt is the true elevation of a test point and n is the number of test points.

When using RMSE it is assumed that systematic errors have been eliminated as best as possible and if vertical error is normally distributed, the factor 1.9600 is applied to compute linear error at the 95% confidence level (Greenwalt and Schultz, 1968). Therefore, vertical accuracy, Accuracy reported according to the NSSDA shall be computed by the following formula:

Vertical Accuracy = 1.9600 *RMSE.

The problems with this as a measure of DEM quality are that normally it is based on a very small sample of check points and perhaps more importantly it does not assist in identifying the source of the error - it is not possible to determine whether the level of error found is due to random errors, systematic errors or blunders (wise, 2000). Despite this, it has been used as a means of comparing the quality of DEMs produced by different methods (Gorokhovich *et al.,* 2006; Chaieb *et al.,* 2016 and Abdi, 2018).DEM accuracy assessment can be done through comparison of DEM derivatives like slope, aspect and drainage extracted from DEM in question and reference DEM. quality assessment can also be carried out visually by preparing shaded relief map and profile studies (Indian space research Organization, 2014).

Slope identifies the steepest downhill slope for a location on a surface. Slope is calculated for each triangle in TINs and for each cell in raster's. For a triangulated irregular network (TIN), this is the maximum rate of change in elevation across each triangle. For raster, it is the maximum rate of change in elevation over each cell and its neighbors. Aspect identifies the downslope direction of the maximum rate of change in value from each cell to its neighbors. It can be thought of as the slope direction. The area upon which waterfalls and the network through which it travels to an outlet are referred to as a drainage system (ESRI, 2016). Reddy, G.P.O., et al(2017) studied automatic extraction of stream network based on digital elevation models from ASTER GDEM and Cartosat-1 of 30 m resolution and compared the result. In this study they found that threshold of 0.05 km^2 is optimum to obtain the finer drainage networks particularly from Cartosat-1 DEM, when compare to the ASTER GDEM of same resolution.

2.7.2. Accuracy Standards

There exist several national and international standards that define the norms and accuracy limits of DEM products and link it to its usability. One of the national standards that have international impact is the National Geospatial Program Standards and Specifications, which was developed by the United States Geological Survey (U.S. Geological Survey, 2015). As previously defined, the accuracy of a DEM is defined by its RMSE, which must be calculated using a minimum of 28 control points, 20 interiors and 8 on the edges. The standard divides DEM products into three levels and sets a specific standard for each:

- Level 1: Includes standard 7.5-minute DEM product in the US, which have a spatial resolution on 1 arc-second or approximately 30 meters or any equivalent DEM from stereo profiling or image correlation. An RMSE less than or equal to 7 meters is desired, with a maximum of 15 meters allowed
- Level 2: Includes DEMs that were generated from hypsographic and hydrographic data collected using Photogrammetry or existing maps. An RMSE of one-half contour interval is the maximum allowed, with no errors greater than one contour interval.
- Level 3: Similar to Level 2, but includes additional data to represent the terrain more accurately, such as ridge lines and transportation features. An RMSE of one-third contour interval is the maximum allowed, with no errors greater than two thirds contour interval.

Another standard is the European Commission' Infrastructure for Spatial Information in the European Community (INSPIRE), Data Specifications on Elevation (INSPIRE Thematic Working Group Elevation, 2013). This standard is spread among all the European countries that are part of the European Union. The specification document divides the elevation value depending on the geometry of the data:

- Vector or TIN: The maximum allowed vertical RMSE is equal to the contour line interval divided by six. In low reliability areas such as dense forests, the maximum RMSE can be increased by 50%.
- Raster: The maximum allowed vertical RMSE is equal to the spatial resolution (referred to as Ground Sample Distance in the documentation) of the raster divided by three

2.7.3 Vertical Accuracy of Open Source Global DEMs for Hydrological Application

For the elevation accuracy assessment, this study used widely applied error metrics such as mean absolute error (MAE) and root mean square error (RMSE) (Eckert et al. 2005). Additionally, and to make this study comparable to other research and to freely available DEM accuracy reports, we also calculated metrics such as vertical accuracy at 95% confidence level(NDEP 2004). To accurately calculate absolute vertical accuracy, each sample plot was analyzed individually. For this, at the location of each ground-truth GPS point, the corresponding elevation provided by the ALOS, ASTER and SRTM DEM was extracted. For the vertical accuracy assessment, the GPS points were compared directly to the open source global DEM data. Study used this approach rather than a GPS-DEM versus global DEM comparison to avoid errors introduced by interpolation algorithms. It well known that distributed hydrological models make use of gridded DEMs to extract topographic variables in order to simulate several hydrological phenomena in a watershed. Those variables are used to simulate and predict hydrological processes such as surface runoff, or they are used as input datasets for further analyses, for example, in modeling sediment/nutrient/pollutant transportation, in erosion and natural hazard modeling, or assessing biological diversity (Mooreet al. 1991).Hydrological variables derived from a DEM are highly sensitive to the accuracy of the DEM. Consequently, high-precision DEMs are required in hydrological modeling to produce unbiased predictions and outcomes (Vaze et al. 2010, Xiao et al.2010). Furthermore, accurate elevation information is an important component of hydrological modeling at high spatial resolution. DEM-extracted variables, such as water-flow direction and accumulation, micro-basins, flow paths, drainage points, depression zones and drainage area, need to be derived from highly accurate elevation models (preferably also at high resolution) to ensure good quality outcomes(Erskine et al. 2007).

2.8 Previous Studies

Table 2-1 Previous Studies Summary

No	Authors	Region/Country	Assessed DEMs	Reference dataset	Vertical accuracy RMSE	Results
1	Apeh *et al*.(2019)	Nigeria	ALOS W3D30, ASTER GDEM2 SRTM30	65 GPS points	5.40 m 7.47 m 20.03 m	ALOS W3D30 proved to be the most accurate DEM that best represents the topography and used for environmental applications
2	Santillan *et al*.(2016)	Philippines	ALOS W3D30, ASTER GDEM2 SRTM30	GPS (274 GCPs)	5.68 m 11.98 m 8.28 m	AW3D30 is more accurate than SRTM-30m and ASTER GDEM2,
3	Kovalchuk *et al*.(2018)	Shumsky district of Ternopil region, Western Ukraine,	ALOS W3D30, ASTER GDEM2 SRTM30 SRTM90	topographical map 1:50000	7.02m, 8.71 m 7.12 m, 7.60m	ALOS DEM is the most accurate in reflecting the absolute altitudes of the Earth's surface and ASTER GDEM is the least acceptable for studying
4	Yap *et al*. (2018)	Cameron	ALOS W3D30, ASTER GDEM2 SRTM30	555 GPS/Leveling Ground Control Points.	13.06 m 18.87 m 13.25 m	SRTM30 is better accuracy relative to others
5	Adrián Pedrozo-Acuña, Laurent Courty(2017)	Coahuila and Reynosa in the state of Tamaulipas , Mexico	ALOS W3D30, ASTER GDEM2 SRTM30	LiDAR (reference DEM)	5.38 m 14.65 m 9.87 m	The result show that AW3D30 DEM performs better than the SRTM DEM for flood modelling purposes
6	Florinsky *et al*. (2018)	Russia	ALOS W3D30, ASTER GDEM2 SRTM30	69 GPS Ground Control Points	7.87 m 9.1 m 17.91 m	ALOS W3D30, is the has accurate for study area topography
7	Dawod *et al*.	Egypt	ALOS W3D30,	416 Ground	2.4 m	The results show

	(2017)		ASTER GDEM2 SRTM30	Control Points	5.7 m 2.6 m	that ALOS W3D30, is the most accurate
8	Ejikeme and Igbokwe (2017)	Onitsha, South East Nigeria	ASTER ver1 ASTER ver2 SRTM	1:50000 topographic map GCPs	13.987m 12.558m 14.125m	ASTER ver2 is good and acceptable than SRTM, ASTER ver1, for hydrological modeling
9	Abdi (2018)	Addis Ababa and Dire Dawa,Ethiopia	ALOS W3D30, ASTER GDEM2 SRTM30	635 and295 GPS control points and reference DEM	5.28m& 5.13m 13.66m & 11.70m 5.13m& 5.80m	SRTM 30m DEM has better accuracy in the two study area and ALOS DEM has better quality of derivative surface for classification of slope for land use Planning agricultural land use planning and similar applications.
10	Hanafy *et al*.(2017)	Egypt	ASTER GDEM2 SRTM30	389 GPS ground control points (GCP) and Topographic Maps scale 1:50,000	12.658 m 7.040 m	SRTM DEM is perform with high accuracy better than ASTER GDEM2 over Egypt topography for the Geomatics applications
11	Chaieb *et al*. (2016)	Kasserine area, central west Tunisia	ASTER GDEM2 SRTM30	23 GPS ground control points	10.13m 8.88m	SRTM DTM precision is better and more reliable than that of ASTER DTM for Kasserine region terrain feature Geomatics modeling.
12	Mukherjee *et al*. 2013	Dehradun, India.	ASTER GDEM2 SRTM30	GCPs, Reference	12 m 17 m	ASTER GDEM2 high accurate and

				DEM, Topo sheet		reliable DEM
13	Elkhrachy (2017)	Najran city, Saudi Arabia	ASTER GDEM2 SRTM30	50 GPS points Topographic maps scale of 1:10,000	7.45 m 7.92 m	The accuracy of ASTER is better than SRTM. The reasons for that may be the accuracy of both ASTER and SRTM DEM depends on the region that you are interested and its terrain type
14	Shaopeng Luana Xiyong Houa Yetang Wan(2015)	Shandong province, Eastern China	ASTER GDEM1 ASTER GDEM2 SRTM90m	Ground control points from 1:50000 digital line graphs	24.11 m 12.12 m 13.74 m	ASTER GDEM2 shows better performance than ASTER GDEM1 and SRTM DEM
15	Mohamed *et al*.(2016)	northern Morocco, Morocco	ASTER, SRTM, and GTOPO30	Terrain morphology And survey points	Correlation 0.997 for ASTER and 0.993 SRTM	ASTER surface provides a better accuracy compared to SRTM.
16	Ouerghi *et al*. (2015)	SW Grombalia in North East of Tunisia	ASTER and SRTM	Reference DEM (contour generated from topographic maps)	10.53m *7.62m*	SRTM is comparatively more accurate than ASTER-GDEM.
17	Athmania and Achour(2014)	Tunisia, Anaguid and Algeria, Tebessa	ASTER GDEM2 GMTED2010 and SRTM30	and 60 GPS (Ground Control Points)	5.3m,4.5 m and *3.6m* 9.8m,9.6 m and *8.3m*	The results indicate that the vertical accuracy of SRTM 30 model is much higher accurate than ASTER GDEM2 and GMTED2010 for both sites.

CHAPTER III. MATERIALS AND METHODS

3.1 Description of the Study Area

Adama Town is situated in Rift valley within Awash River Watershed in Oromia Regional State of Ethiopia. The geographic location is between 8°25’00”N to 8° 37’00”N latitude and 39°12’00”E to 39°22’00” E longitude. It is located about 100km southeast of Addis Ababa. Its elevation lies within 1444m to 2032m above mean sea level (Dejene Tesema *et al*., 12015) .The boundary of the study area was delineated according to the current administrative boundary of Adama Town administration which has the total area of 313.0422 km². Adama is selected based on topographic characteristics and on the availability of control data sets for the vertical accuracy assessment. Figure 3.1 shows location of study area

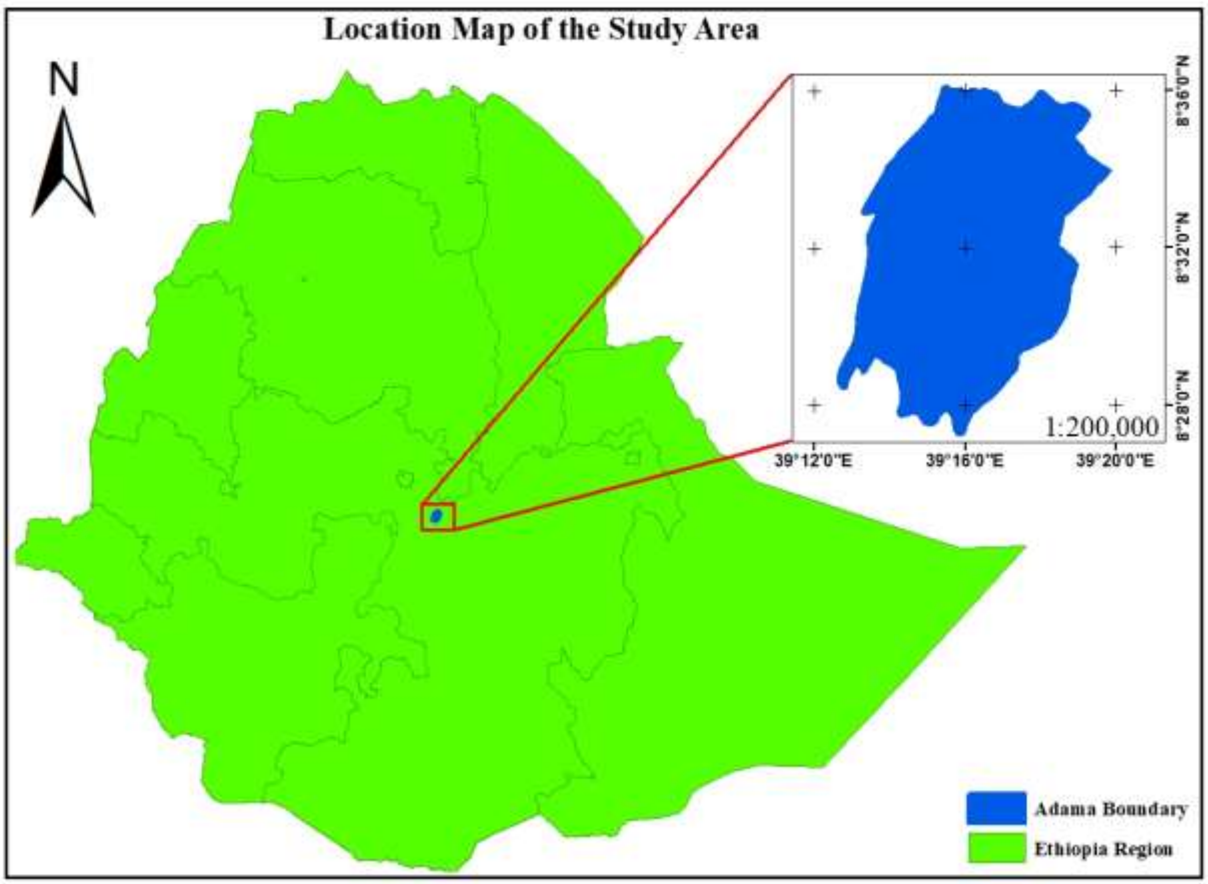

Figure 3-1 Location map of the study area

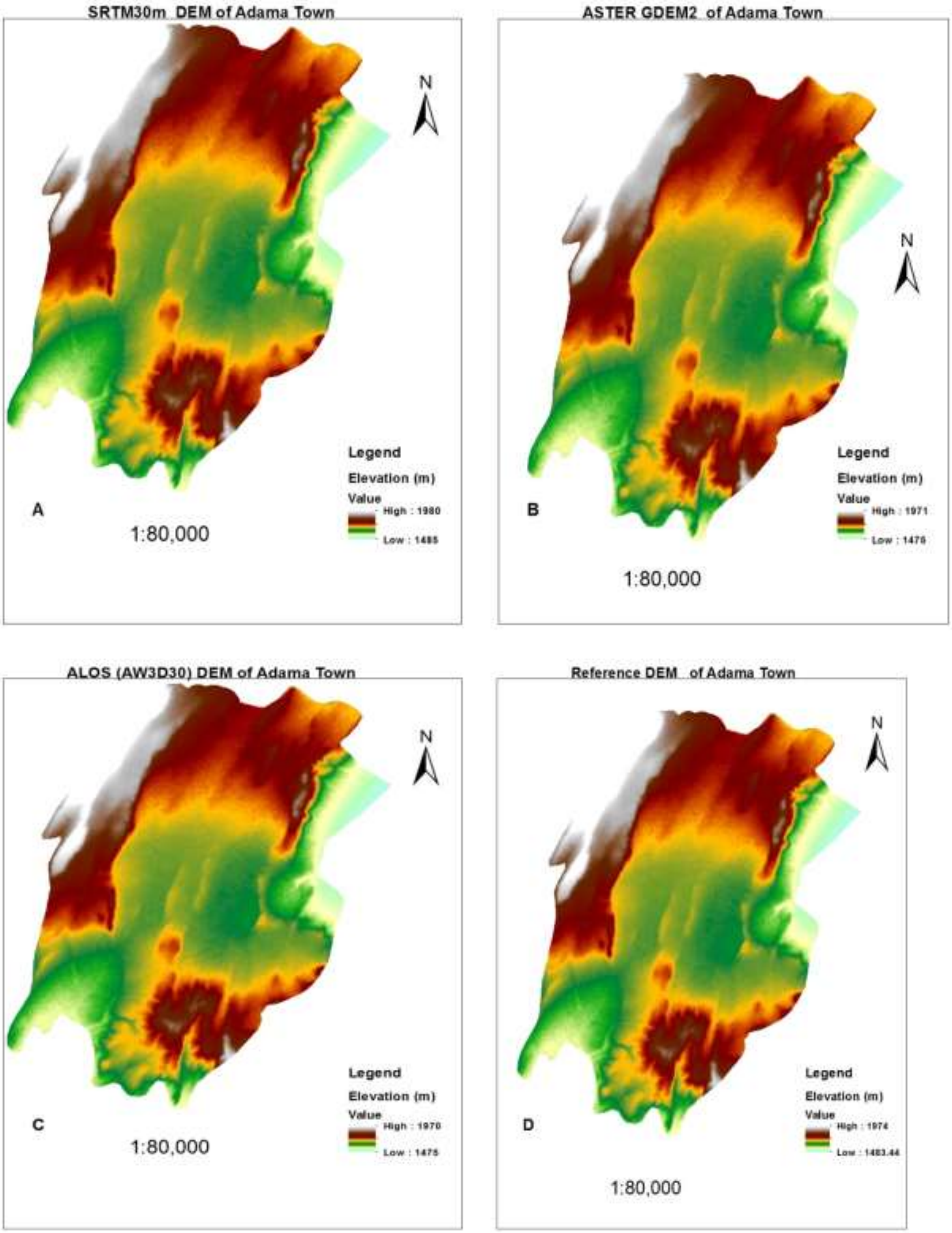

Figure 3-2 Digital elevation model (DEM) datasets used in the study :(A)SRTM;(B)ASTER GDEM;(C) ALOS (AW3D30); (D)Reference DEM

3.2 Data source

The three Open source global DEMs and reference dataset used for this study are clearly discussed as follows.

3.2.1 SRTM-30m

The SRTM-30m ("SRTM V3.0, 1 arcsec") is a an enhancement to the low resolution SRTM topographic data having 90-m (3arcseconds, which is 1/1200th of a degree of latitude and longitude) resolution covering regions outside the United States (US) which was released publicly in 2003. The new data, released in September 2014, increase the detail to 30-m (or 1 arc-second), revealing the full resolution of the world's landforms as originally released by SRTM in the year 2000 (NASA JPL, 2014). SRTM 30m DEM Data was downloaded from USGS official website. Detail about this DEM dataset are given in table 3.1

3.2.2 ALOS World 3D - 30m (AW3D30)

The AW3D30 was released in 2017 by the Japan Aerospace Exploration Agency (JAXA),and can be downloaded free of charge from http://www.eorc.jaxa.jp/ALOS/en/aw3d30/. The AW3D-30 is actually a resampling of the 5-meter mesh version of the World 3D Topographic Data, which is considered to be the most precise global-scale elevation data at this time (JAXA, 2015). The data is Digital Surface Model (DSM) processed in unprecedented 5 m grid spacing utilizing the original triplet stereo images in 2.5 m resolution. The target accuracy of the product was set to 5 m (RMSE) in vertical accuracy. The DSM datasets are generated on 1°x1° tiles of geographic latitude/longitude grids as the final products. Total number of output tiles to be processed is approx. Twenty-three thousand for global land areas (Takaku *et al.* ,2016). Table 3.1 gives details of this dataset.

3.2.3 ASTER GDEM2

The ASTER GDEM Version 2 was considered to be the highest resolution DEM among the free accessible global DEMs during its release in 2011 (Arefi and Reinartz, 2011). The ASTER GDEM v2 contains significant improvements of Version 1 (released in 2009) in terms of spatial coverage, refined horizontal resolution, increased horizontal and vertical accuracy, water masking, and inclusion of new ASTER data to supplement the voids and artifacts (NASA JPL, 2011). In Japan, the ASTER GDEM2 was reported by the ASTER GDEM Validation Team to have an RMSE of 6.1 m in flat and open areas, and 15.1 m in mountainous area largely covered by forest (Tachikawa *et al*., 2011). The data was downloaded from USGS official website. Table 3.1 gives details of DEM datasets..

3.2.4 Reference datasets

GPS data was collected by Ethiopian Geospatial Institute Agency (E.G.I.A) or former (EMA) during the establishment of Ground Control Points (GCP) for cadastral mapping purpose in Adama. There were no much documentation about this data, but the discussion made with employee of the Agency shows that this data was collected with dual frequency Leica GNSS receivers with long observation. The vertical accuracy of Leica GNSS receivers is 5mm+0.5ppm (RMSE) (Leica Geosystems, 2012). According to (Maune, D.F., Ed.; 2007), the accuracy of the checkpoints should be at least three times more accurate than the DEM elevations. The accuracy assessment of the DEMs requires a number of checkpoints with high accuracy to obtain reliable measures. According to ASPRS recommendation 100 vertical checkpoints for the first 2,500 square kilometer area within the project, which provides a statistically defensible number of samples on which to base a valid vertical accuracy assessment. One hounded fifty eight DGPS ground control points were used for 313.0422 square kilometer area to evaluate the accuracy of these global DEMs (ALOS (AW3D30), SRTM 30 and ASTER) in the study area. Data from DGPS survey (GCPs) were used as ground truth data and considered as high accuracy with RMSE 5mm vertical accuracy as mentioned above.

The reference DEM used to evaluate the vertical accuracy of ALOS, SRTM and ASTER DEMs in terms of surface derivatives such as Slope, drainage extraction and other DEM applications. This DEM data was created from digital contour data of 2 meter contour interval in Arc GIS 10.4 software environment for Adama. The contour data was produced by E.G.I.A from 10 centimeter resolution aerial photograph of the study area in 2013 for Adama photogrammetrically. Table 3.1 shows Test datasets used in this study. The reference DEM chosen for this study was 30m resolution cell size and 1.2m vertical accuracy.

Table 3-1Data Source and their characteristics details

MODEL	ALOS(AW3D30)	ASTER GDEM2	SRTM30m
Data source	ALOS	ASTER	Space shuttle radar
Organization/	Japan Aerospace Exploration Agency (JAXA)	U.S.National Aeronautics and Space Administration (NASA) and Japan's Ministry of Economy, Trade,andIndustry(METI)	U.S. National Aeronautics and Space Administration (NASA)
DEM Coverage	82˚N-82˚S,180˚E-180˚W	83˚N-83˚S,180˚E-180˚ W	60˚ N-56˚ S, 180˚ E-180˚ W
Acquisition technique	Optical	Satellite stereo Images	SAR Interferometry (InSAR)
Format	GeoTIFF	GeoTIFF	GeoTIFF
Projection system	Geographic	Geographic	Geographic
Horizontal datum	WGS84	WGS84	WGS84
Vertical datum	EGM96/Orthometric	EGM96/ Orthometric	EGM96/ Orthometric
Vertical units	Meter	Meter	Meter
Resolution	1''(≈30 m)	1''(≈30 m)	1''(≈30 m)
Product specification vertical accuracy(RMSE)	±5m	±17m	±16m
Website	*http://www.eorc.jaxa.jp/ALOS/en/aw3d30/*	*https://lpdaac.usgs.gov/*	*https://lpdaac.usgs.gov/*
Reference Datasets			
Data	Source	Number of GCP	Datum Hor/ver.
Adama GCP	E.G.I.A	158	UTM Adindan 37N/ m. s.l
Digital contour	E.G.I.A	2 meter contour interval	UTM Adindan 37N/ m.s.l

Software			
No	Name	Version	Purpose
1	ArcGIS software	10.4	For mosaicking tiles, clip the relevant portion ,and extracting elevation values of points. To create reference DEM
2	Global Mapper software	2019	For coordinate transformation
3	Microsoft excel	2013	For the statistical analysis

3.3 Data Processing and Analysis Method

3.3.1 Data Preparation and processing

Open source global DEMs (ALOS, ASTER GDEM2, and SRTM) DEMs are open access and downloaded from their respective online portals. After downloading mosaic independently all the tiles of the ASTER GDEM2, SRTM and AW3D30, DEMs and overlay the study area shape file on mosaicked DEM, then clip the relevant portion. As mentioned in data source Table 3.1, the three DEMs are given in terms of orthometric heights with respect to the geoid model computed from the Earth Geopotential Model 1996 (EGM96). In order to assess accuracy of these global DEMs for application based analysis they have to be projected to local projected coordinate system which is Adindan UTM Zone 37 North. The transformation parameters between these two datum are given in Table 3.2 below. When accuracy is assessed by GPS points (test data), global DEM datum transformation is not needed because GPS data is the measured GPS data is given in WGS84 and E.G.I.A GCP data is projected to geographic coordinates and WGS 84 datum.GPS data (GCPs) obtained from E.G.I.A were processed and adjusted by using EGM96 geoid model calculator. The coordinate system of this data is Adindan datum, UTM Zone 37 North and Ellipsoidal height converted to Orthometric height (msl) by EGM96 geoid model. The GPS used Word Geodetic System 1984 (WGS84) as default vertical datum to compute the relative heights (Kaya and Saritas,2005). The datum conversion operations are an important step to get the two data sets are coincides in the same datum and same coordinate system with the three DEM's .The transformation of all the data sets into a common system using ArcGIS 10.4 and Global mapper ver.19 software. To transform the measured WGS84 coordinate system to the local projection system. Table 3.2 shows the transformation parameters, as published by the E.G.I.A , used for the conversion

The first three are the translation parameters between the two systems, the following Rx, Ry and Rz are the rotation parameters of the X, Y and Z axes from the reference WGS84 to the local system, and the scale factor is expressed in parts per million. The transformation parameters referenced to the WGS84 system are described in Table 3.2

Table 3-2Transformation parameters from WGS84 to local system, Adindan UTM.

Parameters :WGS84 to Adindan UTM_37N	
Dx	-162
Dy	-12
Dz	206
Rx	0
Ry	0
Rz	0
Scale (ppm)	0

Source: Ethiopia Geospatial Institute Agency

After all datasets are prepared extracting the DEM height requires overlaying the Ground control points (GCPs) on them, and then the height value from the two data at their position of coincidence gives the DEMs orthometric height for computing the accuracy statistic. The extract values to points tool in ArcGIS is used to extract the elevation value from the DEM at each control point location. Then the elevation between GPS (Ground Control Points) and given DEM is compared in tabular form by converting in Excel sheet.

3.3.2 Reference DEM Preparation

The reference DEM used for this study is produced from digital contour line data using 'ArcGIS 10.4's Topo to raster tool'. Topo to raster tool is an interpolation method specifically designed for creation of hydrologically correct DEMs(Hutchinson *et al*., 2011). This tool uses drainage (stream) data to enforce conditions which, increases the accuracy of DEMs in terms of drainage properties and surface shape. There are many interpolation methods used to generate a DEM from contour data (Hengl and Evans, 2009). Comparison of these techniques has been extensively carried out by many researchers (Wise, 2000). Li et al. (2005) points out that there is no universal interpolation technique that is clearly superior, and appropriate for all sampling techniques and DEM applications. The Topo to raster interpolation method has been designed to take the advantage of the type of input data commonly available and the known characteristics of elevation surface. This method uses an iterative finite difference interpolation technique. It is optimized to have the computational efficiency of local interpolation method such as Inverse Distance Weighted (IDW) without losing the surface continuity of global interpolation method such as kriging and spline(ESRI 2016). Srajis Saleke et al. (2018) compared three interpolation method and found that topo to raster produced a more realistic and consistent DEM, relative to IDW and Natural Neighborhood Interpolation method. This process was be done in ArcGIS 10.4 software.

The accuracy of Reference DEM was validated by using 100 ground control points collected DGPS for cadastral mapping purpose of cross Adama Town. According to validation result of reference DEM has accuracy of 1.2 meter. The closer the value of the RMSE to zero, the dataset is more accurate (Apeh et al., 2019). This DEM is assumed to be accurate and covering about 313 sq. km in total area of study area.

3.3.3 Comparison of DEMs

Two methods were used to compare and validate the vertical accuracy of open -access DEMs (ALOS, SRTM and ASTER). The first method is statistical analysis using GPS elevation values. One hundred fifty eight GCPs were used as ground truth in the study area. To evaluate DEM vertical accuracy assessment the elevation values extracted from DEM are subtracted from the measured GPS elevation values. ArcGIS's "extract values to point" tool is used to extract values from each DEM for GPS point locations. For each point, an elevation difference was computed as the difference between explored and reference data (Equation (3.1)):

Elevation difference ($Z_{diff.}$)= $Z_{GPS} – Z_{DEM}$---(3.1)

In Equation (1), Z_{diff} is the elevation difference, Z_{DEM} is the elevation of the explored DEM, and Z_{GPS} is the elevation of the GPS points. Positive differences mean the interpolated DEM elevation was below the GCP elevation (underestimation) and negative errors represent the locations where the DEM elevation was above GCP elevation (overestimation)

3.3.3.1 Statistical Analysis of Elevation Differences

The variation of errors in these global DEMs is compare through statistical analysis of the tabular data with the help of RMSE (Root Mean Square Error), mean error, standard deviation of errors, maximum error, minimum error, Skewness and Kurtosis. The main statistical parameter is RMSE which provide the understanding of differences between GPS elevation value and DEM elevation value. RMSE is considered as a standard and specification way of assessing the accuracy of DEM (Federal Geographic Data Committee, 1998 and ASPRS, 2015). RMSE for DEM vertical accuracy is defined by the USGS as:

$$\text{RMSE}= \sqrt{\frac{\sum(\text{Z}GPS - \text{Z}DEM)^2}{n}} \text{--- (3.2)}$$

Where Z*DEM* is the interpolated DEM elevation of a test point**,** Z*GPS* is the true elevation of a test point and *n* is the number of test points. The RMSE is meant to represent the average vertical difference in elevation modeled in the DEM. Smaller RMSEz values indicate a closer fit between the control and the tested DEM data. The standard deviation shows how much variation or dispersion exists from the average (mean), or expected value

- Minimum Error = min (|Z*GPS* – Z*DEM* |)---(3.3)
- Maximum Error = max (|Z*GPS* – Z*DEM* |)---(3.4)
- Mean Error(ME) = $\frac{(|\text{Z}GPS - \text{Z}DEM|)}{n}$--(3.5)
- SD= standard deviation = $\sqrt{\frac{\sum(Zdiff - \text{ME})^2}{n-1}}$ --(3.6)

Standard deviation is a measure of the dispersion of an error from its mean. If the data points are further from the mean error, there is higher deviation within the data set. Mean is simply the average of the errors that indicate the “central" value of a set of errors (Howell, 2007).

When using RMSE it is assumed that systematic errors have been eliminated as best as possible and if vertical error is normally distributed, the factor 1.9600 is applied to compute linear error at the 95% confidence level (Greenwalt and Schultz, 1968). Therefore, vertical accuracy, Accuracy reported according to the NSSDA shall be computed by the following formula:

Vertical Accuracy at 95% Confidence Level = 1.9600 *RMSE.

Maune et al., 2001 accuracy is the closeness of observation to a true value . The value of the RMSE closer to zero, means the heights obtained from DEMs are more accurate while the value of the RMSE far from zero , the heights obtained from DEMs are less accurate (Apeh et al., 2019) and Chirico et al., 2012).

The level of agreement between ASTER GDEM2, SRTM and ALOS(AW3D30) derived elevation values and GPS data is also evaluated in terms of linear regression and correlation.

3.3.3.2 Visual analysis

Visual analysis is another accuracy evaluation method based on comparison of DEM derived surface that are generated from DEM and different application that uses DEM with same products generated from higher standard DEM. This method as stated in Wassim, (2016);Abdi (2018) and mile (2013) is a relative accuracy evaluation method that shows how accurate the derived surface and application are presented. To perform DEM accuracy test in this method.

- ✓ Shade relief map in both reference and open access DEMs were compared.
- ✓ The slope derived from SRTM, ALOS and ASTER DEMs and Reference DEMs and compared though visual inspection. Accuracy of these DEMs with reference to terrain slope was analyzed
- ✓ Drainage network extracted from SRTM , ALOS and ASTER DEMs were compared with same product of Reference DEM for same

As specified in (S.Wise, (2000); (National Remote sensing Center Indian Space Research organization Dept. of Space, Govt. of India 2014); Abdi (2018) and (Gorokhovich and Voustianiouk 2006) DEM accuracy can be assessed by comparison of derived DEM products namely drainage network with same products derived from Reference DEM prepared for the purpose. Drainage network can give some information about DEMs quality such as whether these DEMs could capture the general topographic features of the study areas (Sertel 2010). All derivative analysis carried out by ArcGis 10.4 software analysis toolset.

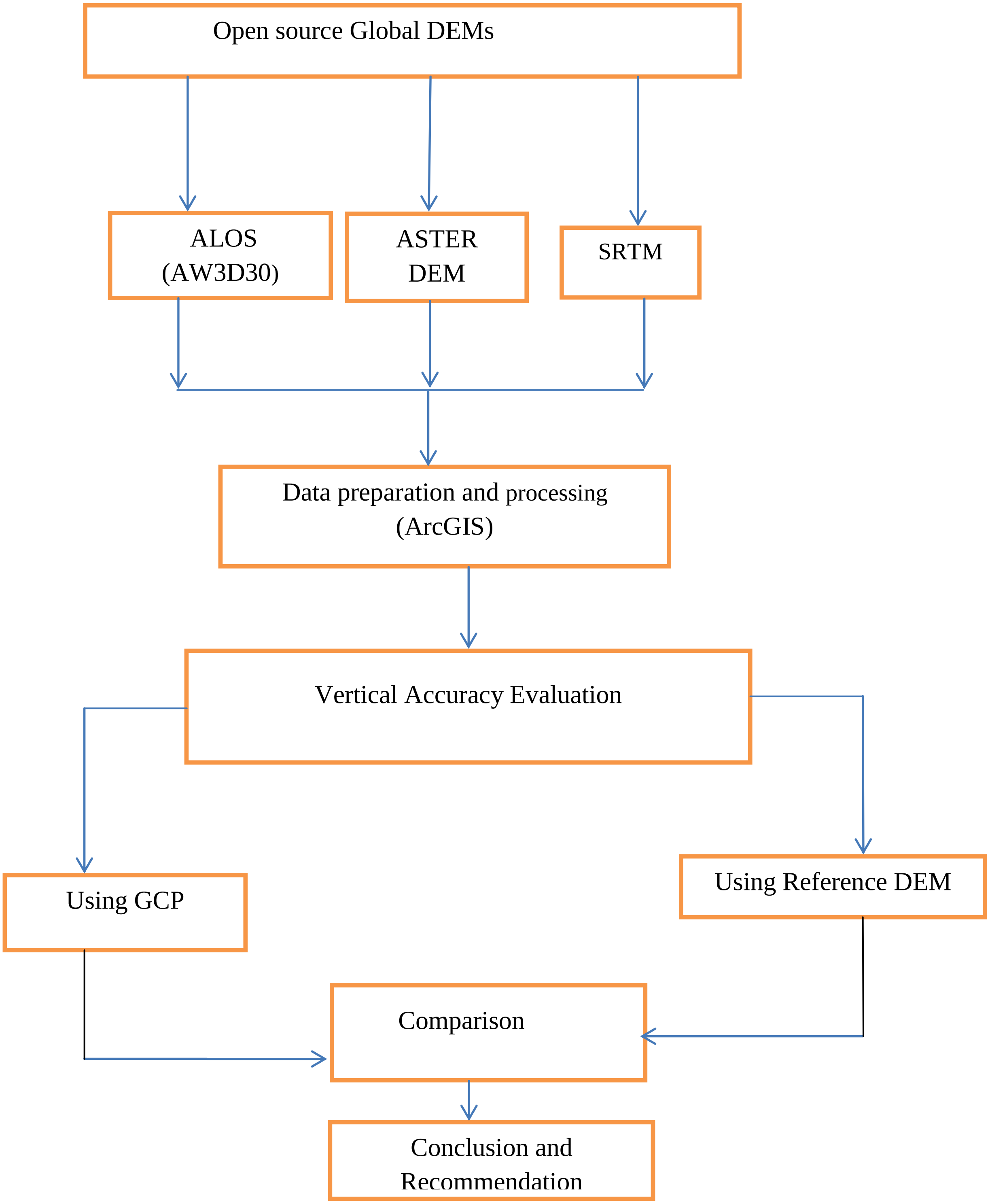

Figure 3-3 Technological Scheme of Study

CHAPTER IV. RESULTS AND DISCUSSION

4.1. Results

4.1.1 Accuracy Assessment of DEMs Using DGPS Ground Control Points

To determine accuracy of the ALOS, SRTM and ASTER DEMs ground control points surveyed by GNSS instrument used as reference data with a high accuracy .One hounded fifty eight(158) Differential Ground surveyed control points are available being well distributed in study area .Elevation values (Z)of ASTER, SRTM and ALOS (here after called Z-ASTER, Z-SRTM and Z-ALOS) are extracted from corresponding DEM pixel for each point using Spatial Analyst Tools of Arc GIS software (i.e. Extract Value to point). The elevation values of DEMs (i.e. Z-ASTER, Z-SRTM and Z-ALOS) were subtracted from the corresponding GPS surveyed point's elevation values (ZGPS) to calculate the error (using equation 3.1 through 3.6). Statistical parameters are minimum error, maximum error, mean error and standard deviation of the elevation difference between GPS elevation points and DEMs were calculated. Finally DEM accuracy is assessed through calculating vertical RMSE. The RMSE statistics are essentially a standard deviation and are thus based on the assumption that errors in the DEM are random and normally distributed. For Adama the RMSE values are 11.18m, 4.63m and 5.25m for ASTER, SRTM and ALOS DEMs respectively.

Table 4-1Statistics analysis of elevation difference between GCP points and ASTER, SRTM and ALOS DEM

Statistical parameters	Statistics analysis of DEMs		
	SRTM 30	ASTER GDEM2	ALOS
Count	158	158	158
Minimum(m)	-20.78	-17.78	-3.77
Maximum(m)	16.65	38.79	14.62
Mean error(m)	-1.9	8.16	4.09
Standard Deviation(m)	4.23	7.67	3.30
Kurtosis	5.2	3.09	0.24
Skew	-0.2	1.25	0.22
RMSE(m)	±4.63	±11.18	±5.25
Accuracy (95%)	9.1m	21.91m	10.29m

As Table 4.1 show that RMSE value for ASTER is 11.18 m , for SRTM 4.63 m and for ALOS 5.25 m . The SRTM model has a better accuracy (RMSE = 4.63 m) than ALOS (RMSE = 5.25 m) and ASTER (RMSE = 11.18 m). SRTM models present a mean error near to zero and an RMSE approximately equal to the standard deviation, indicating that the estimator for these datasets is unbiased. The vertical accuracy evaluation of the three DEMs reveals that the SRTM data has smaller RMSE was obtained for SRTM than AW3D30, ASTER GDEM2. So, SRTM is a better vertical accuracy than both ASTER GDEM2 and ALOS for study area. The vertical accuracy of ASTER GDEM2 is less accuracy than the accuracy of ALOS and SRTM, as it achieved a much higher RMSE compared to ALOS and SRTM. The better accuracy of SRTM over ASTER has been noted in previous studies(Chaieb *et al.*,2016 ; Abdi (2018) ;Hanafy *et al*., 2017 and Yap *et al*.,2018).

Elevation difference histograms were drawn for investigating the error distribution behavior of these three DEMs. The relative frequency distribution of the height differences between reference (GPS) data and examined DEMs is provided in figure below.

However, the histograms of elevation differences shows positive or negative skew for these DEMs which indicate that the examined DEMs are underestimates or overestimate the terrain elevation of study area.

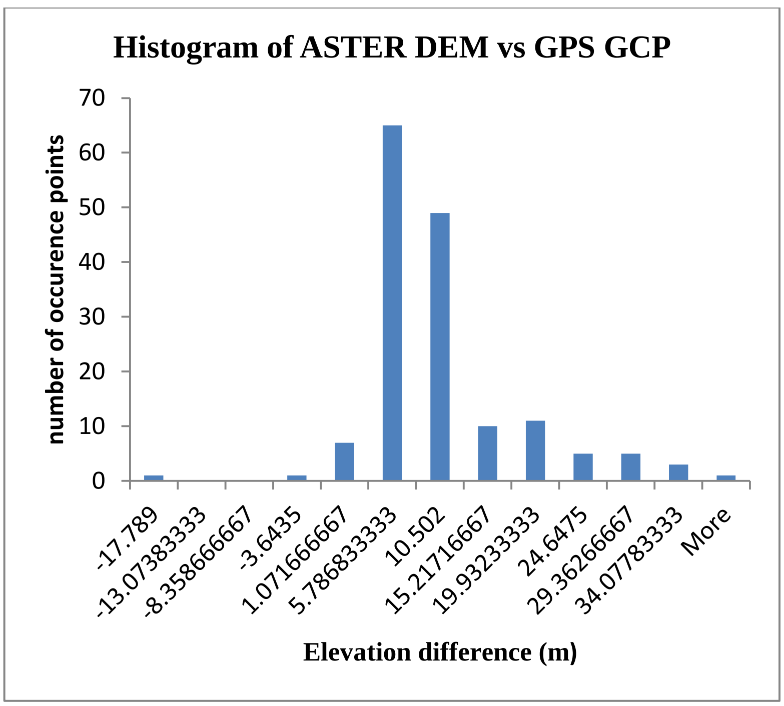

Figure 4-1 Histogram of ASTER and GCP elevation differences

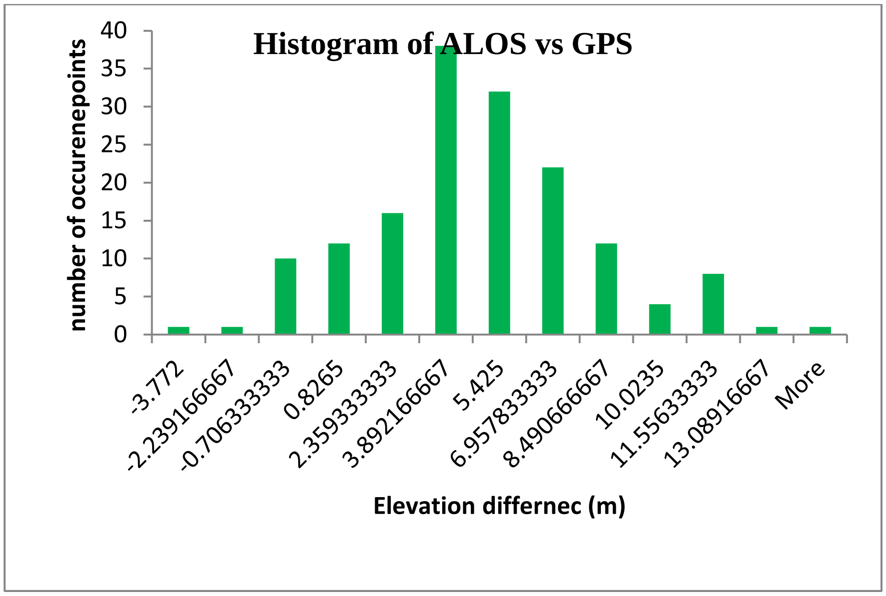

Figure 4-2 Histogram of ALOS and GPS GCP elevation differences

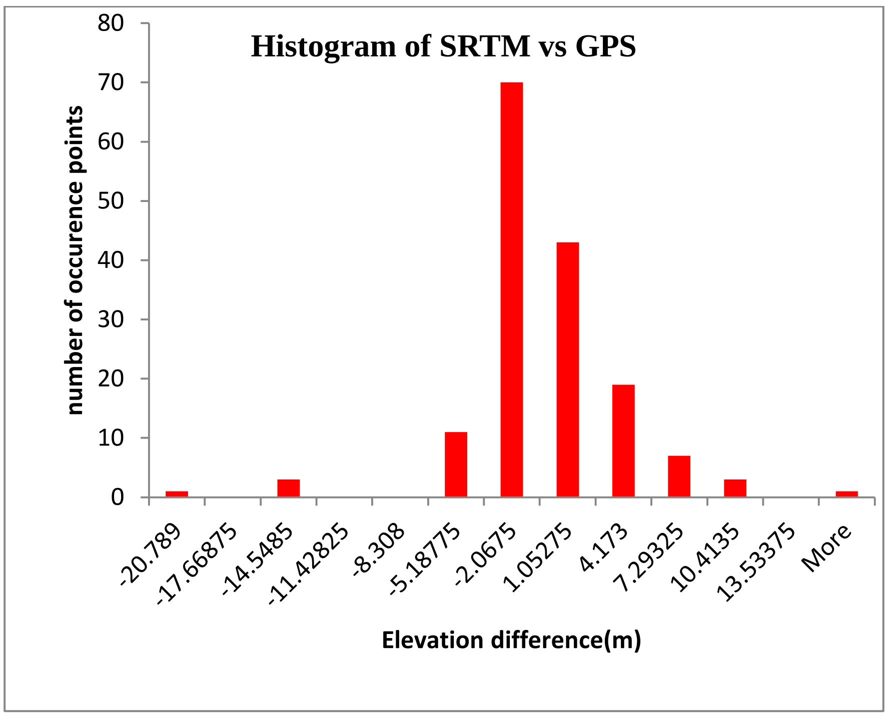

Figure 4-3 Histogram SRTM and GPS GCP of elevation differences

The histogram of elevation difference figure (4.3) present a negative, indicating that the SRTM model overestimates the spatial distribution of terrain elevation. The histogram Figures (4.1) present frequencies of positive errors greater than those of the negative errors. A large positive bias is clearly observed in figure (4.1) indicating that the ASTER underestimated the terrain elevation.

In the graphs ASTER elevation differences with GPS elevations have mainly positive values. This shows ASTER GDEM has under estimated the topography of the area which means that ASTER GDEM elevation values are below to GCPs elevation values. SRTM and ALOS elevation differences with GPS elevation are mainly negative. These shows SRTM and ALOS DEMs have moderate overestimation of the study area topography (i.e SRTM and ALOS elevation values are above to GCPs elevation values).

4.1.1.2 Correlation and Regression Analysis of variation in elevation

Whereas R^2determines the percentage of variation in the values of errors in this study. $R^2$is known as coefficient of determination and Its value varies from 0 to 1. It is the measure of how well the regression line. If the regression line passes through every point in scatter plot it would be able to define all variation and as much regression line is away from the points, explanation would be poor (Howell, 2007).

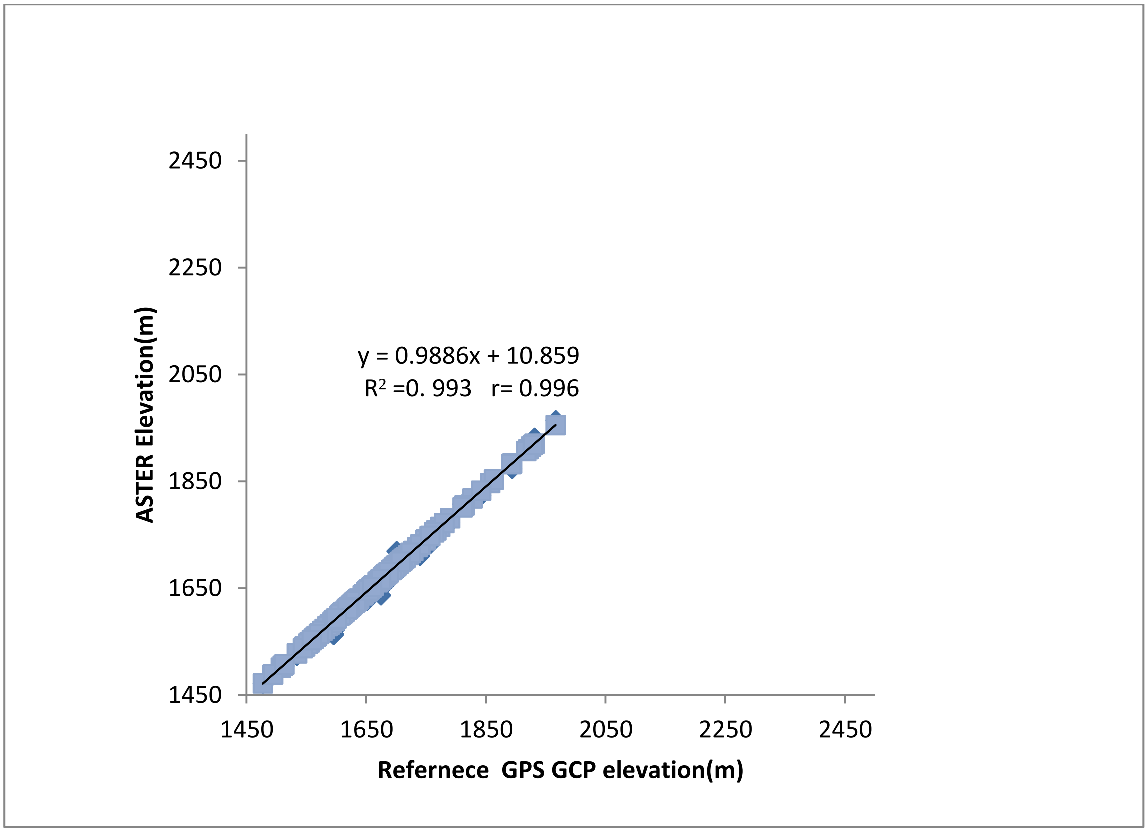

Figure 4-4 Correlation between Aster Elevation (m) and GPS Elevation (m)

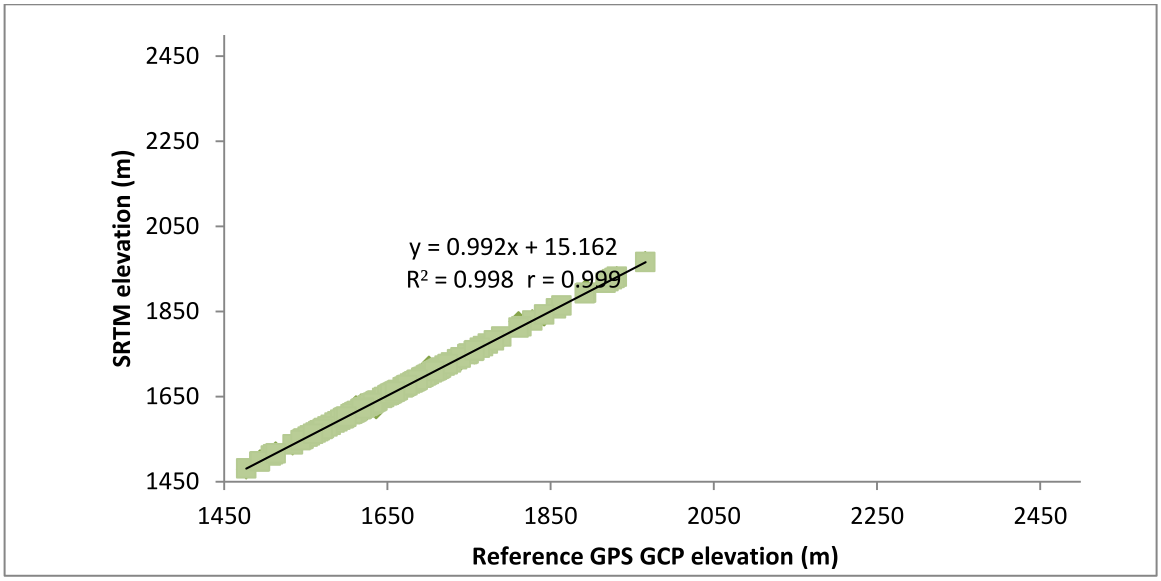

Figure 4-5 Correlation between SRTM Elevation (m) and GPS Elevation (m)

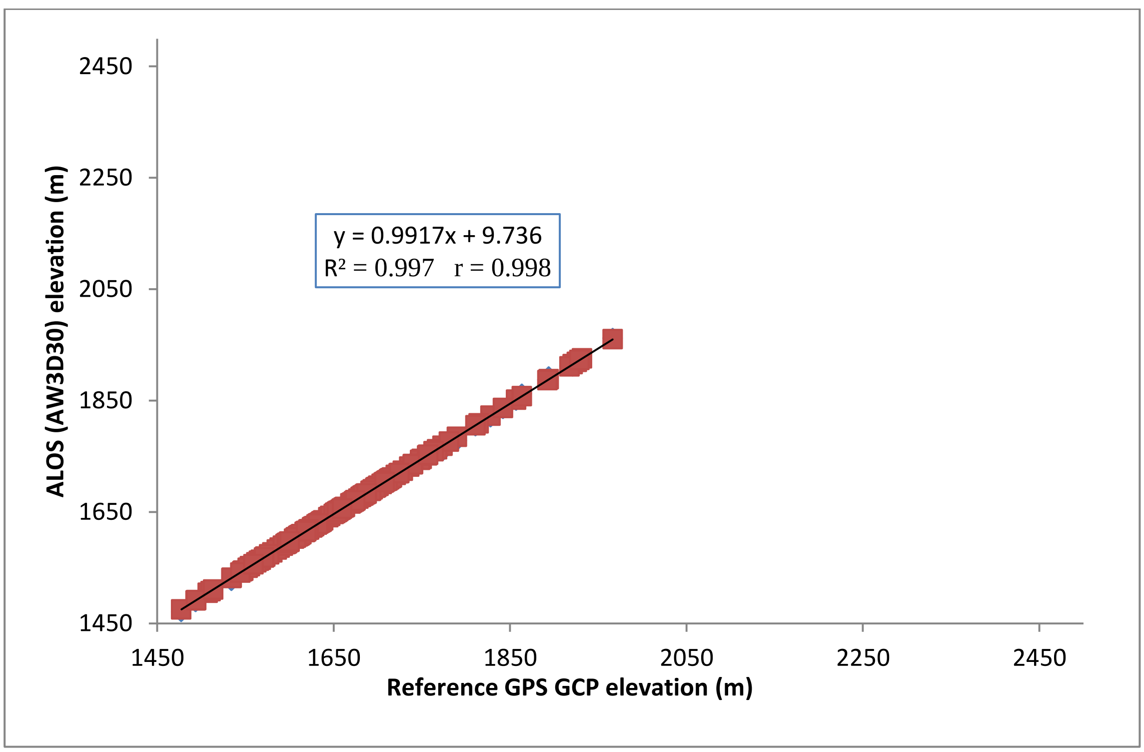

Figure 4-6 Correlation between ALOS (AW3D30) Elevation (m) and GPS Elevation (m)

The deterministic model (R^2) and the correlation coefficients (r) between the variables were calculated and the results are shown in Table 4.2 below respectively.

Table 4-2 R^2 and r Statistic computed values

Scatter plots	R^2	r
Aster Elevation (m) against GPS Elevation (m)	0.993	0.996
SRTM Elevation (m) against GPS Elevation (m	0.998	0.999
ALOS Elevation (m) against GPS Elevation (m	0.997	0.998

The values of R^2 (Table 4.2) help to interpret the relationships exiting between the variables (DEMs and GPS elevation) in terms of variations. These R^2 values indicate that 99.8%, 99.3% and 99.7% of the changes in SRTM, ASTER and ALOS elevation are explained by the change of GPS elevation. The closer R^2 is to 1, then there is an indication that the data points lie close to the least square line. This can be seen in Figures above. With reference to Table 4.2, it can be seen that the R^2 value for SRTM is relatively closer to 1. This means that the linear regression analysis performed to estimate the R^2, comparatively, describe the variation in the data with reliable accuracy for Adama. The coefficient of correlation (r) further corroborated this high strength of linear dependence between the variables. In this study, the correlation coefficient (r) was used as a criterion to determine the strength and nature of the linear relationship between the three DEMs (ASTER, ALOS and SRTM) and the referenced GPS elevation.

In analysis the value of R^2 is highest in SRTM DEM among three open source global DEMs. SRTM has maximum value which indicates the best correlation of elevation of GPS GCP from among all three DEMs. SRTM has better values of R^2 than ALOS and ASTER .

4.1.2 Accuracy Assessment using DEM Derivative Analysis

DEM accuracy has been evaluated by comparison of derived DEM products namely- slope and drainage network, as specified in(Wise, (2000); Abdi, (2018) ; (National Remote sensing Center Indian SpaceResearch orginazation Dept. of Space, Govt. of India 2014) and (Gorokhovich and Voustianiouk (2006), with same products derived from Reference DEM prepared for the purpose of this present study. Visual interpretation of derived surface like shaded relief map can give some information about DEMs quality DEM such as whether these DEMs could capture the general topographic features of the study area (Sertel, 2010). Comparing the produced shaded relief map with that of reference DEM clearly shows the problem of investigated DEMs particularly in peak and high elevation area. All derivative analysis carried out by ArcGIS10.4 software 3D analysis toolset.

Figure below shows that SRTM DEM has good appearance as compared to the ASTER and ALOS with respect to reference DEM. ASTER GDEM 30m is poorly represented the topography of the area. The area in the peak shows that ASTER DEM would affect the extraction of drainage network from this data. Shaded relief map for this study area reveals that SRTM DEM has good representation of the topography of the study area

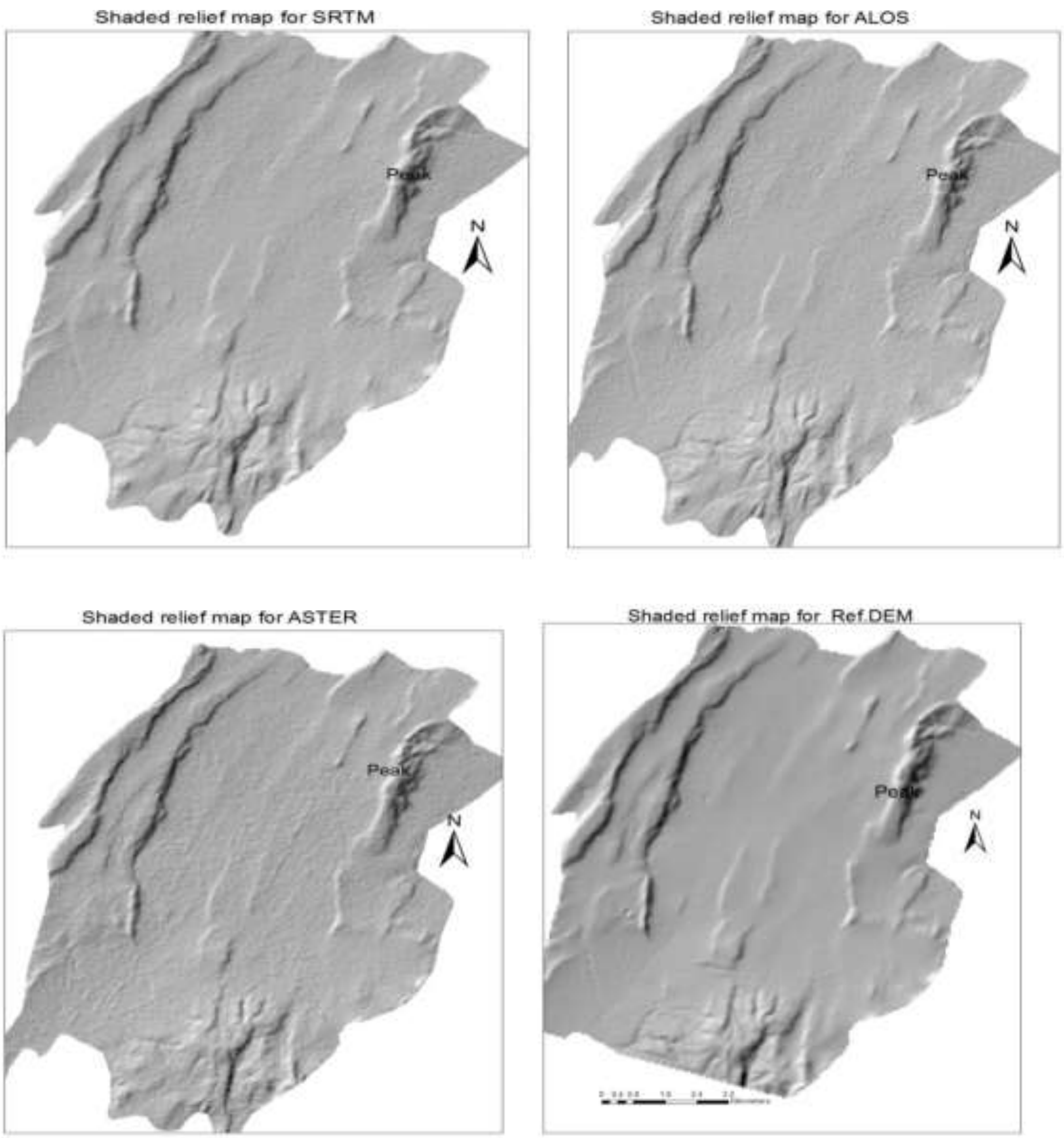

Figure 4-7Shaded relief maps for: SRTM, ALOS, Ref.DEM and ASTER DEMs of Adama study area

4.1.2.1 Slope and DEM Accuracy

Slope of terrain topography is major influencing factors for vertical accuracy of DEM (Imrani, et al., 2016 and Abdi, 2018). Slope identifies the steepest downhill slope for a location on a surface. Mathematically, slope of a line in a two-dimensional Euclidean system describes the steepness of this line. For rasters, it is the maximum rate of change in elevation over each cell and its eight neighbors (ESRI, 2016). As terrain slope affects the accuracy of DEMs, its quality also affected by the quality of its source, one of which is DEMs. In this study slope analysis was used to assessing the quality of DEMs by visual inspection of slope derived from DEMs. To do all DEMs are classified into nine (9) slope surface was derived from each DEM. All these process was performed in ArcGIS software environment using 3D and spatial analyst toolsets. As Figure 4-8 shows slope derived from SRTM DEM is better than those derived from ALOS and ASTER DEMs as compared to reference DEM for this study area. Slope extracted from ASTER DEM reveals the rough accuracy of the dataset. As the figure below shows the red color that represents rugged slope is distributed over the low land areas in slope map extracted from ASTER DEM. On the other hands SRTM slope map is more similar to that of Reference DEM. The average slopes of the Town could be taken as 4 %.The major proportion, more than 75 % of the City, can be represented between 1 to 10% slopes. The visual analysis of the investigated DEMs indicates that the SRTM 30(Figure below) is the most similar to the reference DEM.

In general visual analysis of slope maps shows that SRTM DEM has better representation of the topography of this study area.

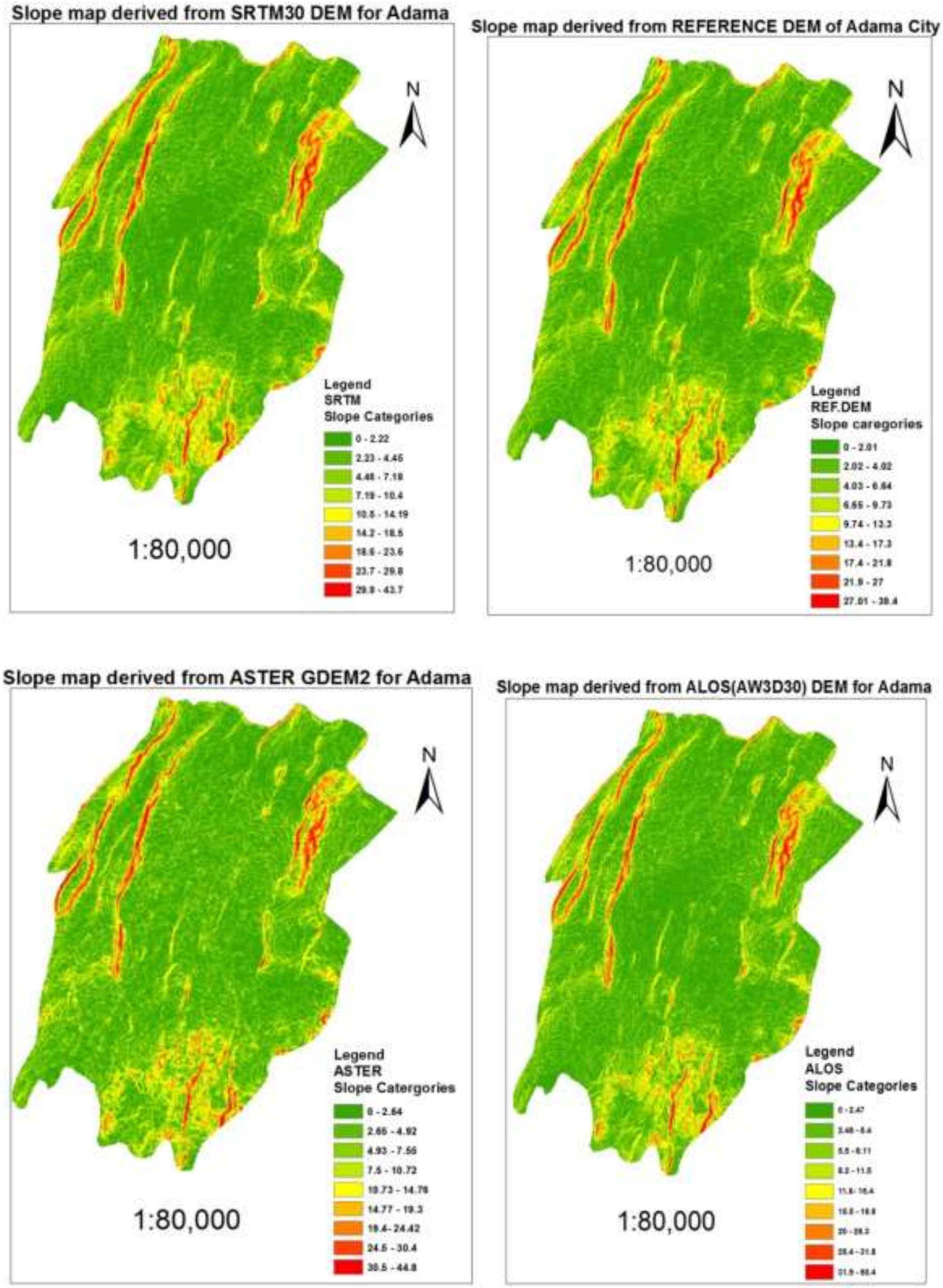

Figure 4-8 Slope maps derived from,Upper left- SRTM DEM ,Upper right- Ref. DEM, lower left-ASTER DEM and lower right- ALOS of Adama

4.1.2.2 Accuracy Assessment by Comparison of Derived Drainage Network

DEM as a source of topographic based application is one of widely used Spatial data source for drainage network extraction in hydrological modeling application. Comparative assessment of the accuracy of DEMs through comparison of drainage (stream) network derived different DEM dataset could assist others in determining whether or not a specific DEM dataset is appropriate for hydrological application at a particular accuracy level(Abdi ,2018). Drainage network is a network of water passes through which water travels to the outlet. It is one hydrologic unit. According to the Federal Standard for Delineation of Hydrologic Unit Boundaries.(United States Geological Survey, 2004): “A hydrologic unit is a drainage area delineated to nest in a multilevel, hierarchical drainage system. Its boundaries are defined by hydrographic and topographic criteria that delineate an area of land upstream from a specific point on a river, stream or similar surface waters. A hydrologic unit can accept surface water directly from upstream drainage areas, and indirectly from associated surface areas such as remnant, noncontributing, and diversions to form a drainage area with single or multiple outlet points.”

Hydrologic units are only synonymous with classic watersheds when their boundaries include all the source area contributing surface water to a single defined outlet point." In this study stream networks are derived from all DEMs under investigation and compared with stream (drainage) network derived from Reference DEM in study area. Multiple tools are available which are specialized for derivation of watersheds and drainages networks, including Arc hydro and Arc SWAT (ESRI, 2016). These tools use DEM as input and can perform watershed and drainage network extraction in an automated manner for hydrological modeling.

However, in this study drainage network extraction was performed through the hydrologic modeling tools in the ArcGIS Spatial Analyst extension toolbox. The ArcGIS hydrologic tools allow us to identify sinks, determine flow direction, calculate flow accumulation, delineate watersheds, and create stream networks (ESRI, 2016). To automate the process and integrate with other ArcGIS tools such as Raster Calculator, a model tool was created in Arc Map’s Model Builder window, which helped to simplify workflows by string together sequences of tools, feeding the output of one tool into another tool as input

The model tool used here takes DEM as input and performs the following processes (ESRI, 2016):

i. Using Flow Direction tool the direction in which water would flow out of each DEM cell is determined.
ii. Any sinks in the original DEM are identified using Sink Tool. A sink is usually an incorrect value lower than the values of its surroundings. Sink tool uses the output from flow direction.
iii. To ensure proper drainage mapping, sinks must be filled using the Fill tool. The output raster from sink helps to identify sink location and their depth which helps to determine the Z-limit for Fill tool.
iv. Ones Sinks are filled using proper Z-limit, Flow Direction is calculated and used in the subsequent processes.
v. In order to create stream network the output from ***step iv*** is used to calculate Flow Accumulation. The Flow accumulation tool used to calculate the number of upslope cells flowing to a location.
vi. Using Raster calculator tool of spatial analyst toolbox on the output from ***step v*** (Flow accumulation raster) stream networks is defined by selecting cells (from Flow accumulation raster) where cells value exceeds specified threshold. Since there is no standard procedure to select this threshold value it was selected though trial-and-error method, the syntax: "flow accumulation" >= 70 applied as stream network selector.
vii. To represent the order of each of the segments in a network, the Stream Order tool was applied to the output in *step vi*. The steam ordering method used was the Strahler method recommended by ESRI.
viii. Finally the Arc toolbox's stream to feature to was used to convert the stream network from raster to vector polyline feature class data.

Drainage extraction in ArcGIS model tool that was used to assess the relative accuracy of the three DEMs. The stream network from the three DEMs, namely ASTER, SRTM and ALOS(AW3D30) was first visually compared (as in figure below) with stream network derived from reference DEM for study area. Then, stream length and numbers (count) at 5 different stream orders was compared with that of reference stream network data in study area

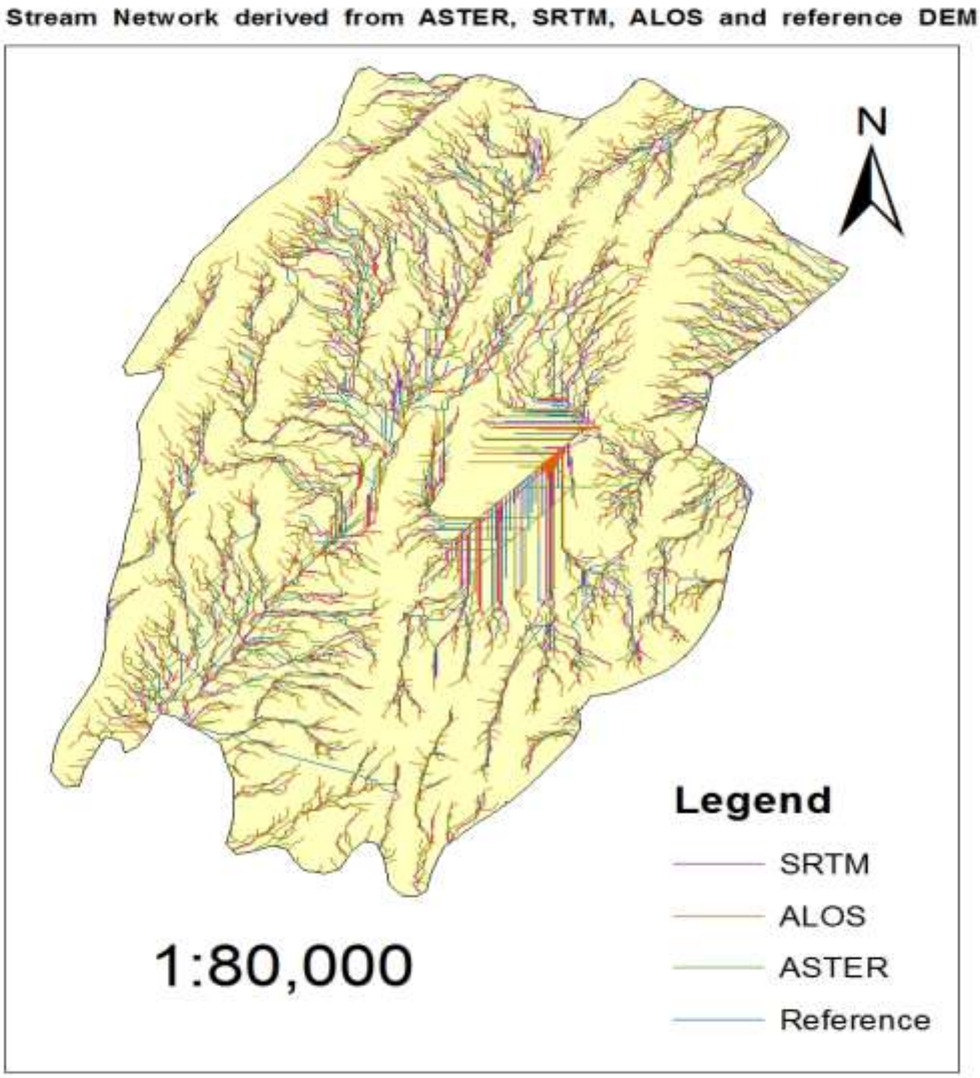

Figure 4-9 Stream Network derived from ASTER, SRTM, ALOS and reference DEM for Adama

The visual inspection of the derived stream network shows that ASTER DEM (green color in the above figure) has the most deviation from the reference stream network and SRTM has the least deviation. SRTM and ALOS stream line features (pink color and brown) are more similar and close to the Ref.DEM derived stream line features in study area.

SRTM stream network is more accurately produced than ASTER and ALOS DEMs when compared with respect to Ref. DEM derived stream networks. When compared by stream length and order (Table 4-3), SRTM derived stream network the highest first order stream but the lowest higher order stream lines. The total length of first order stream lines is 233.4 km for

SRTM, 225.5km for ALOS, 223.05 km for ASTER and 241.83km for Ref. DEM respectively in Adama.

Table 4-3 Stream length differences (km) for 5 stream orders derived from SRTM ALOS ASTER and Reference DEM Adama

Stream order	Reference DEM		SRTM			ALOS			ASTER		
	Count	Length	Count	Length	Diff.	Count	Length	Diff	Count	Length	Diff.
1	6678	241.83	6446	233.43	**8.4**	6226	225.46	**16.3**	6192	223.05	**18.8**
2	3215	111.23	3167	109.57	**1.7**	3145	107.8	**3.4**	3167	110.9	**0.33**
3	1564	54.08	1575	54.46	**-0.38**	1678	58.02	**-3.9**	1577	55.2	**-1.1**
4	346	12.62	380	13.86	**-1.24**	432	15.75	**-2.7**	449	15.3	**-2.3**
5	283	10.04	276	9.8	**0.24**	297	10.54	**-0.5**	287	10.4	**-0.36**
Total	12036	430.16	11844	421.12	**8.72**	12278	417.57	**12.6**	11672	414.9	**15.4**

As table 4-3 shows stream network derived from SRTM DEM is better than the reference Stream networks. ASTER has the highest difference (15.4km) in total.

4.2 Discussion

This section discusses the result found by this particular study for the study area. The study investigated accuracy of three global and open source DEMs: ASTER GDEM2, ALOS (AW3D30) and SRTM 30m DEMs by using DGPS and supplementary topographic data as a reference DEM data.

For present study, GPS points were used to evaluate the accuracy of three DEMs (ASTER, SRTM and ALOS). The elevation difference values of these DEMs were extracted for the location of GPS points and subtracted from these GPS points' elevation values.

Table 4.1 shows the summary statistics for elevation errors of ASTER-GDEM ver.2, SRTM 30, and ALOS elevation errors over the study area. The RMSE for SRTM is 4.63m and that of ALOS is 5.25m, ASTER is 11.18 m and thus, their vertical accuracy (RMSE* 1.96) are 9.1 m 10.29 m and 21.9 m respectively. Study by (Santillan and Makinano-Santillan , 2016) shows that ALOS(AW3D30) DEM has RMSE 5.68m and SRTM-30m has RMSE of 8.28 and that of ASTER GDEM2 11.98 over Philippines, which are comparable to the RMSE values obtained in this study. The evaluation of vertical accuracy of three global DEMs explains that the SRTM data displays a better vertical accuracy than the two DEM. The accuracy of SRTM is better than ALSO and ASTER, which has been marked in previous studies. SRTM gives better accuracy and those results were concluded (Table 2.1) that were mentioned by (Chaieb *et al*., 2016 and Abdi, 2018). On the other hand, the large variations in global height precision are found in the examined DEMs literature. It shows that the DEMs on vertical precision depend on location, errors of reference point, terrain characteristics, and surface properties. Hence, this recommendation performs to an investigation about those factors. In addition, Table 4.1 explains that the RMSE value of 11. 18m for ASTER GDEM2 are very similar to those described by Chaieb et al.2016. The SRTM 30m presents the RMSE value about 4.63 m to close with Athmania and Achour (2014) and Abdi (2018). According to the open source global DEMs evaluation, this study reports that the ASTER GDEM2 is lower accuracy to compare with SRTM 30m and ALOS (AW3D30) for a the same resolution . In general, Accuracy of SRTM is better than that concluded in literature review which has been marked in previous studies (Yap *et al*., 2018; Ouerghi *et al*., 2015) and officially stated vertical accuracy of ±16 m at 95% confidence in the SRTM data mission specification.

The histograms of the differences between DEMs and the reference DEM data (Figure4.1- 4.3) are closely follow a normal distribution. However, for the SRTM difference histogram present a negative error of -2.06 which is illustrated in the histograms (Figure (4.3)) with negative error observed, indicating that the SRTM Elevation Modem of negative errors greater than those of the positive errors (overestimated the terrain elevation). A general overestimation of terrain elevation of SRTM observations were further confirmed in many previous studies (Suwandana *et al*., 2012 ; Mukherjee *et al*., 2013). The histograms of elevation differences (Figure 4.1) present a slightly positive errors, indicating a clear positive bias for ASTER with respect to reference elevation data, where the ASTER model underestimates the spatial distribution of terrain elevation, this underestimation of ASTER was noted in previous studies(Hirt *et al*., 2010 ; Li *et al*., 2013).

The second accuracy assessment test was carried out by using local DEM as reference Datasets. The DEM used in this study area as reference DEM has accuracy of 1.2 m (at 95% confidence interval). Shaded relief maps produced from ASTER, SRTM and ALOS DEMs show that SRTM is better in representing the relief of the study area. The slope maps derived from these DEM shows that slope calculated from SRTM DEM is more close to that of reference DEM. The visual analysis of the investigated DEMs indicates that the SRTM 30(Fig. 4.8) is the most similar to the reference DEM . Drainage network extracted from these three

DEM were compare with drainage network derived from reference DEM. The result show that SRTM derived stream networks are more similar and good agreement with reference DEM stream networks. On the other hands ASTER GDEM produced stream networks that have the highest deviation from the reference stream networks. SRTM gives better quality and those results were concluded that were mentioned by (Elisabete, 2015 and Abdi, 2018). In general SRTM 30 DEM has shown better quality in derivatives surface quality than the other two DEM and closely followed by ALOS (AW3D30) DEM dataset and ASTER has the least accuracy of the three DEMs evaluated in this research for this study area. Current research is the first study to investigate the accuracy of freely available DEMs ALOS, ASTER and SRTM for Adama Town, Ethiopia. As confirmed by studies Athmania and Achour (2014) and Abdi (2018) SRTM30 DEM is better in accuracy than the other two DEMs evaluated in Adama Town. This means that SRTM30 DEM best represents the topography of the earth's surface.

From the above discussions SRTM 30m has better representative of the topography of Adama Town area. ALOS (W3D30m) DEM can also be considered as best second option, for hydrological modeling applications.

CHAPTER V. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

This study focused on the assessment vertical accuracy of global open source DEMs (ASTER GDEM2, SRTM-30m and ALOS-AW3D30) of Adama Town in Ethiopia by using GCP points measured by DGPS and Reference DEM as reference data. The research used statistical analysis method to calculate RMSE of elevation differences between these DEMs and GCPs elevation datasets. The DEM qualities which are considered appropriate for hydrological application were compared in study area. Their vertical accuracy in comparison with differential GPS ground control points for Adama Town is ±4.63 m for SRTM, ±11.18 m for ASTER and ±5.25 m for ALOS (AW3D30) in terms of their RMSE respectively. The obtained RMSE value for SRTM is smaller than AW3D30 and ASTER GDEM. The vertical accuracy of SRTM30m is more accurate than ALOS and ASTER in the Adama Town, because it contains the smallest root mean square error. Based on the values of the obtained vertical, these DEM can be used for hydrological modeling applications in the study area depending on the accuracy demanded. The vertical accuracy assessment of these three DEMs showed that the RMSE of ASTER GDEM2 is almost twice higher than the RMSE of SRTM-30m and ALOS (AW3D30) in study area. Accuracy of ASTER GDEM2 is less than SRTM and ASTER.

The investigation of vertical accuracy of these DEMs by terrain derivatives (slope and drainage networks) has confirmed the underrepresentation of ASTER DEM for the topography of the study area, which can be seen cleanly from the histogram of elevation difference for these DEMs. It was also confirmed that SRTM and ALOS has overestimation of this area topography. The assessed result indicated that SRTM30m has better quality to extract slope and drainage network (stream network). The visual study for the three DEM's concluded that the SRTM has better quality than ALOS and ASTER GDEM2, because SRTM is more similar to reference DEM.

SRTM30m proved to be the most accurate DEM that best represents the topography of the earth's surface and could be used for hydrological modeling applications in Adama Town.

5.2 Recommendations

Based on the analysis of the research findings, this study gives the following recommendations

- ❖ SRTM 30m DEM has showed better vertical accuracy over Adama Town. Therefore this DEM can be used keeping in mind that this DEM can overestimation terrain topography by 5 meters.
- ❖ SRTM 30m DEM has also showed better quality of derived slope and drainage networks. Particularly the slope and stream networks derive from this DEM is almost similar to that of reference DEM dataset. Therefore this DEM can be used for classification of slope and drainage networks for hydrological modeling and similar applications.
- ❖ SRTM should be used where higher accurate elevation data are not readily available since they can be obtained freely online
- ❖ ALOS DEM can be the best alternative source of DEM for hydrological applications
- ❖ ASTER GDEM has showed higher underestimation of height of this study area on average by up to 19 meters. Therefore users should be aware of this lower vertical quality of ASTER when using for applications that relatively require higher elevation precisions.

- The following recommendations are set for further investigation.

- ❖ DEM accuracy varies from region to region, accuracy assessment over different regions are required.
- ❖ Terrain morphology is one of the factors that influence the accuracy of DEM thus accuracy shall be assessed for difference in terrain morphologies
- ❖ The accuracy of DEM varies for different land use and land cover areas and to assess accuracy of DEM over differing land cover type reliable land use data is required
- ❖ Further studies should be also carried out on the evaluation of these global elevation datasets as new version of them are released for public use

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Appendices

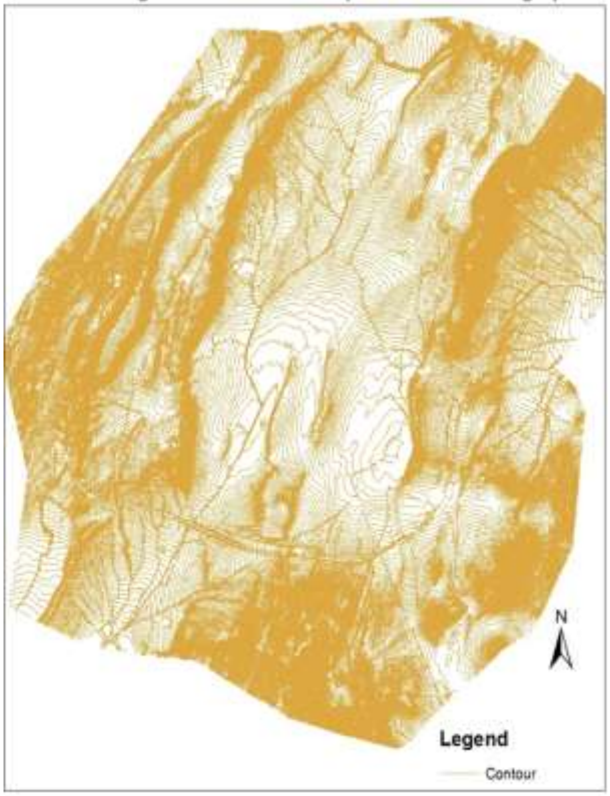
Appendix A. Sample Ground Control Points and DEM elevations.

Name	Coordinates based DGPS (GCPs)			Elevations based DEM		
	Easting	Northing	Elevation	SRTM 30m	ALOS	ASTER
A001	529988.113	951086.665	1773.622	1772	1759	1756
A002	528224.374	950875.748	1921.328	1923	1911	1907
A003	527988.259	950053.99	1931.636	1932	1924	1931
A004	528614.985	950132.092	1893.965	1902	1893	1873
A005	529802.074	950187.56	1767.415	1771	1765	1761
A006	531132.436	949999.451	1713.051	1711	1702	1695
A007	532265.764	949862.459	1701.211	1722	1696	1719
A008	532757.95	949852.507	1710.501	1711	1703	1698
A009	534073.021	949839.662	1652.129	1652	1654	1646
A010	534965.72	950201.534	1654.203	1656	1646	1647
A011	534992.941	948833.745	1685.461	1685	1685	1675
A012	534099.213	949086.831	1680.86	1685	1681	1675
A013	532781.227	948643.001	1694.499	1698	1690	1689
A014	531842.969	949065.183	1723.959	1723	1713	1718
A015	531015.217	949091.507	1698.572	1701	1692	1694
A016	530090.638	948880.918	1709.633	1713	1703	1703
A017	529078.535	949014.629	1790.08	1784	1768	1772
A018	527680.761	949016.845	1925.766	1923	1919	1914
A019	526999.814	949006.656	1917.648	1918	1912	1913
A020	526640.995	948262.389	1966.516	1968	1962	1964
A021	528136.731	947625.197	1750.108	1751	1752	1736
A022	529057.405	947887.455	1711.291	1712	1703	1705
A023	530112.571	947944.912	1691.835	1698	1689	1688
A024	530934.841	947914.524	1686.774	1688	1683	1682
A025	532036.926	948067.827	1713.042	1715	1707	1707
A026	533255.319	947870.16	1706.96	1712	1704	1700
A027	533980.705	948070.546	1735.897	1732	1729	1728
A028	534640.264	947757.905	1625.673	1618	1615	1618
A029	526174.988	946896.693	1928.745	1924	1918	1920
A030	526979.704	946950.432	1827.886	1831	1820	1820
A031	528109.546	947129.073	1700.877	1700	1694	1691
A032	528991.189	946998.637	1684.052	1688	1678	1679
A033	530142.281	947044.304	1669.237	1669	1662	1664
A034	530997.033	946976.003	1678.088	1679	1669	1669
A035	531979.044	947084.867	1720.593	1722	1716	1711
A036	533098.091	946936.298	1715.248	1719	1711	1710
A037	534239.881	947156.986	1589.165	1593	1584	1580
A038	535189.299	947169.448	1534.603	1538	1527	1525
A039	536129.161	946865.765	1493.697	1498	1488	1486
A040	535951.284	945973.713	1477.407	1479	1470	1471
A041	535051.013	946059.816	1507.515	1514	1505	1497
A042	533998.883	945922.063	1555.394	1559	1553	1550

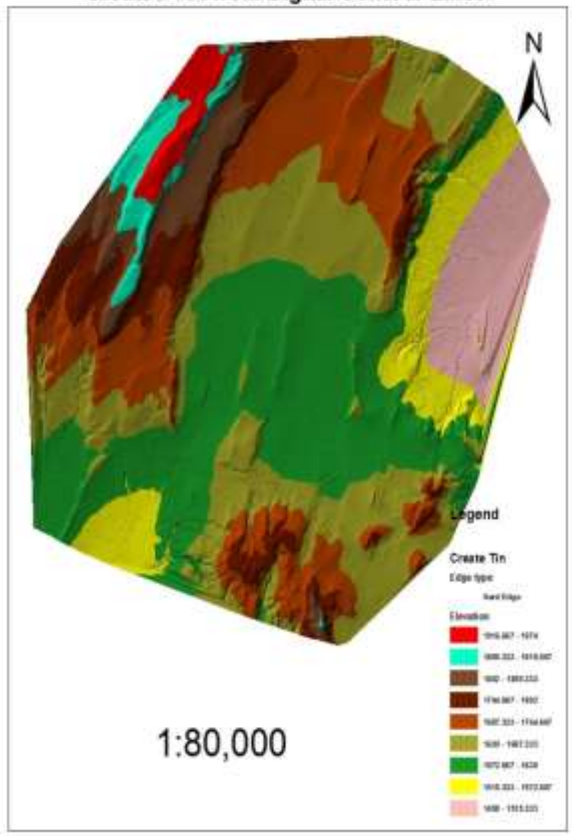
A043	532905.441	945988.294	1704.84	1713	1702	1712
A044	531907.311	945641.809	1655.759	1653	1649	1650
A045	531119.564	945967.332	1653.86	1656	1651	1649
A046	530315.635	946277.747	1661.601	1663	1657	1654
A049	526796.898	946108.695	1814.504	1817	1808	1806
A050	525947.373	945995.659	1892.438	1894	1887	1876
A051	525105.021	945921.044	1856.834	1860	1850	1851
A052	524734.205	945195.783	1810.986	1816	1804	1807
A053	525785.412	945153.817	1863.67	1861	1862	1848
A054	526874.274	944945.071	1780.881	1783	1772	1776
A055	527747.44	945373.526	1651.745	1655	1645	1646
A056	528877.061	944884.998	1622.448	1629	1620	1621
A057	530034.376	945300.045	1631.071	1637	1627	1631
A058	530996.824	945048.94	1636.9	1641	1633	1634
A059	532274.229	944948.428	1638.397	1643	1633	1631
A060	532805.816	944957.09	1674.793	1674	1675	1676
A061	534431.108	944814.183	1510.57	1514	1507	1504
A062	535009.136	945081.924	1494.36	1501	1490	1490
A063	533807.23	943833.099	1546.61	1546	1548	1546
A064	532968.878	944166.574	1635.716	1635	1632	1630
A065	533919.475	942388.875	1534.208	1535	1526	1523
A066	533021.651	941998.448	1580.763	1585	1576	1578
A067	532066.12	941912.971	1617.782	1619	1615	1604
A068	529970.64	942333.067	1610.433	1613	1607	1607
A069	530809.353	942227.792	1595.678	1600	1593	1592
A070	528602.278	941967.076	1631.148	1630	1628	1623
A071	528052.493	942045.138	1611.168	1612	1608	1613
A072	527046.238	942038.786	1630.844	1635	1633	1625
A073	526142.774	941745.524	1681.651	1681	1679	1680
A074	524483.184	941871.046	1704.734	1705	1703	1700
A075	524883.312	941851.332	1682.954	1688	1678	1677
A076	525913.623	941027.252	1626.681	1630	1622	1617
A077	527005.486	940890.487	1607.567	1610	1604	1605
A078	528042.249	940601.805	1632.479	1633	1631	1630
A079	528848.185	940890.966	1669.437	1673	1668	1667
A080	529952.866	940904.337	1607.192	1612	1602	1608
A081	531098.715	940958.836	1596.211	1601	1593	1594
A082	531971.245	941084.619	1611.331	1615	1605	1605
A083	533024.352	941033.145	1612.03	1618	1608	1610
A084	533969.966	940937.465	1617.444	1622	1611	1612
A085	531814.779	943974.552	1605.444	1608	1604	1601
A086	530840.811	944080.594	1610.071	1613	1608	1606
A087	530275.246	944145.91	1621.665	1624	1619	1618
A088	528949.931	943814.931	1636.654	1620	1623	1614
A089	528135.427	944064.572	1618.869	1621	1615	1616

Appendix B.Reference DEM data

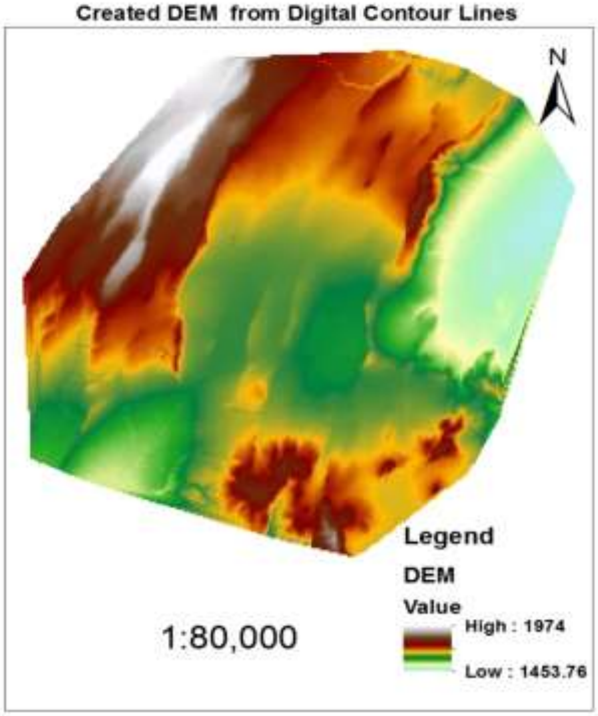
Extracted Digital Contour Lines Map from Aerial Photograph



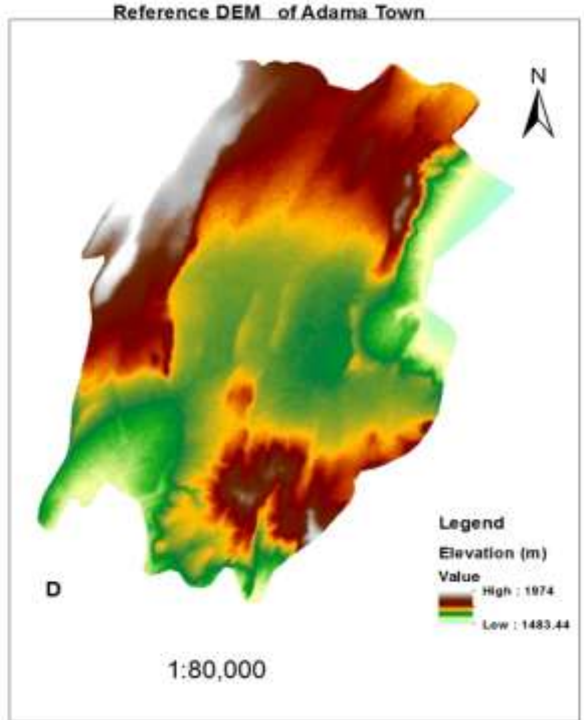
Created TIN from Digital Contour Lines



Created DEM from Digital Contour Lines



Reference DEM of Adama Town



Appendix C. Statistical analysis Result of reference DEM

Statistics of height difference (GCP Minus DEM)	
Accuracy Measure	Reference DEM
Max	1.87
Min	0.03
Mean	0.36
Standard dev.	0.53
RMSE	0.62
Accuracy (95%)	1.2