ARDHI UNIVERSITY

ASSESSMENT OF AFRICA 3″ × 3″ DTM AND ITS COMPARISON TO MERIT 1″, NASADEM-1″, TANDEM-X-3″ AND ALOS-v3.2″ USING TANZANIA GPS GROUND CONTROL POINTS

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BSc Geomatics

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A Dissertation Submitted to the Department of Geospatial Sciences and Technology in Partially Fulfilment of the Requirements for the Award of Science in Geomatics (BSc. GM) of Ardhi University

CERTIFICATION

The undersigned certify that they have proof read and hereby recommend for acceptance of a dissertation titled "**Assessment of Africa 3″ × 3″ DTM and its comparison to MERIT 1″, NASADEM-1″, TANDEM-X-3″ and ALOS-v3.2″ using Tanzania GPS ground control points**" in partial fulfilment of the requirements for the award of degree of Bachelor of Science in Geomatics at Ardhi University.

………………………………

Ms. REGINA V. PETER

(Main Supervisor)

Date…………………...

DECLARATION AND COPYRIGHT

I MARIJANI, KELVIN hereby declare that the contents of this dissertation are my own original work and that to the best of my knowledge, has not been presented to any other University for a similar or any other degree award except where due acknowledgements have been made in the text.

…………………………………..

MARIJANI, KELVIN

(**22798/T.2019)**

(Candidate)

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DEDICATION

To my parents and my sisters, Happiness and Rehema Marijani together with my niece Glory Richard for their fulltime support through their constant prayers, love, support and encouragement throughout my academic journey which have led me this far.

ABSTRACT

Accurate digital elevation models (DEMs) are essential for a wide range of applications, including terrain analysis, hazard mitigation, sea level rise assessments, and engineering projects. The aim of this research was to assess the accuracy of AFRICA 3" × 3" DTM and its comparison with MERIT 1″, NASADEM-1″, TANDEM-X-3″ and ALOS-v3.2″. The accuracy assessment is conducted using Tanzania Ground GPS Control Points (TGGCPs) to evaluate the suitability of these DEMs for various applications. To assess the accuracy of a particular GDEM, statistical analysis of Mean and Root Mean Square are employed to determine the superiority of one over another. In this case, a smaller value indicates higher data accuracy.

The vertical accuracy assessment of these GDEMs involved the use of 593 TGGCPs distributed across Tanzania and representing twelve different land covers. To ensure uniformity, the TGGCPs' ellipsoidal heights were converted to orthometric heights using the EGM 96 geoid model, employing the GNSS leveling equation.

The statistical results at 95% confidence level based on the least values of mean, SD and RMS respectively were as follows, for vertical assessment of GDEMs using TGGCPs the results showed that ALOS-v3.2″ appeared to be closer to the control points than other GDEMs. General comparison of the GDEMs with Africa 3" × 3" DTM show that the pair of MERIT 3″ and Africa 3" × 3" DTM show higher agreement at the common grid intersection while pair of Africa 3" × 3" DTM and ALOS-v3.2″ show higher agreement in most land covers with least values of mean, SD and RMS. Generally, performance of Africa 3″×3″ DTM in Tanzania is inferior compared to ALOS-v3.2″ and NASADEM 3″ which has mean 2.594, SD 1.889 as well as RMS of 3.506.

Keywords: GDEMs, TGGCPs, landcover, Assessment of vertical accuracy and Comparison.

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ACRONYMS AND ABBREVIATION

ALOS	Advanced Land Observation Satellite
ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer
DEM	Digital Elevation Model
DSM	Digital Surface Model
DTM	Digital Terrain Model
EGM	Earth Gravitational Model
GDEMs	Global Digital Elevation Models
GeoTIFF	Geographic Tagged Image File Format
GPS	Global Positioning System
InSAR	Interferometric Synthetic Aperture Radar
JAXA	Japan Aerospace Exploration Agency
NASA	National Aeronautics and Space Administrations
RSM	Root Mean Square
SD	Standard Deviation
SRTM	Shuttle Radar Topographic Mission
TGGCPS	Tanzania GPS Ground Control Points

CHAPTER ONE

INTRODUCTION

1.1 Background

Digital elevation model is a digital representation of the Earth's surface, primarily focused on capturing elevation or height information. Vegetations, buildings and other cultural features are removed digitally leaving just underlying terrain. Nowadays there are new technologies of radar interferometry and airborne laser scanning that are used to generate high quality of DEMs useful in a wide range of civil urban planning and military uses. Also, DEMs can be used for route planning in construction of highway and railways. DEMs are important factor in assessing any process using digital topography analysis including slope, curvature, roughness and local relief that are its derivative attributes. DEMs can be generated by various field, remote and laboratory techniques; conventional topographic surveys, kinematic GPS surveys, analogue, radar techniques, laser surveys and digitizing of contours. Each cell in DEMs represent the elevation of a feature at its location (X and Y). DEMs can be used to create topographic maps of overland terrain as well as bathymetric maps which serve to illustrate underwater terrain (Kramer, 2021).

DEMs are categorized into two types; DTM where the terrain refers to the ground or bare-earth surface and DSM which refers the top-most surface of a given area considering features like buildings and vegetations. These models are provided for free applications, on which due to the advancement of technology, different DEMs with different resolutions covering a large portion are being generated. DEMs are widely used in numerous activities in the world including; hazard monitoring, natural resources exploration, agricultural management, ground water modelling and flood prone area mapping (Takaku, et al. 2020).

Recently public Global DEMs have many useful applications in many areas. Many developing countries including Tanzania are not in position to determine their own reliable GDEMs. Often a resort is to search for the public GDEMs that suits its purpose better. The study for a suitable DEM in Tanzania has been conducted over a long time and a method used is the statistical assessment of the height's differences between the GDEM and GPS controls (Kramer, 2021).

Some researches of validating different GDEMs by using GPS ground control points have been conducted in Tanzania so as to determine their vertical accuracy in different land covers in Tanzania. Such researches include the following;

a) In 2017 the validation was done between ALOS-1″ -v2 and SRTM1″ – v3 GDEM over Tanzania using GPS Ground Controls (Marwa, 2017). The performance of SRTM- 1″-v3 was slightly better over ALOS-1″-v2 in terms of RMS, but in terms of standard deviation, ALOS-1″-v2 perform slightly better than SRTM-1″-v3. Therefore, the accuracies of SRTM-1″-v3 and ALOS-1″-v2 in Tanzania are almost the same as assessed from GPS ground controls.

b) In 2018, assessment of vertical performance of MERIT-3″ GDEM in Tanzania using Ground Control points and its comparison with SRTM-3″ CGIAR-CSI v4.1 and ALOS-1″-v2 was carried out by (Mng'ong'o, 2018). The results show that, the fitting of SRTM-3″ CGIAR-CSI v4.1 to MERIT-3″ GDEM is inferior compared to the fitting of ALOS-1″-v2 to MERIT-3″ GDEM countrywide. The performance of MERIT-3″ was better in flat and bare terrain but worse in mountainous and highland terrain.

c) In 2019, assessment based on comparison and vertical performance of SRTM-1″-v3, ALOS-1″-v2, MERIT- 3″ and TANDEM-X-3″ public GDEMs in Tanzania using GPS Ground Controls (Mapunda, 2019) was done. The results showed that, the general performance of TANDEM-X-3″ is superior to SRTM-1″-v3, ALOS-1″-v2 and MERIT-3″ GDEMs based on the smallest value of RMS which is 2.67m, followed by MERIT-3″, SRTM-1″-v3 and ALOS -1″-v2 with RMS of 3.23m, 4.20m and 5.26m respectively. However, TNDEM-X-3″ showed better performance in every place to place such as in flat terrain and forested terrain.

d) In 2022 the validation was done on GLL_DTM_v1, CoastalDEM-v2.1, TanDEM-X-3″, ALOS-1″-v3.2 and NASADEM-1″ along coastal areas in Tanzania using GGCPs (Manoni, 2022). The results showed that, GLL_DTM_v1 outperformed all other GDEMs. The overall fit (RMS) of GLL_DTM_v1 to GGCPs in the AOI was 1.724m followed by CoastalDEM-2.1, TanDEM-X-3″, NASADEM-1″ and ALOS-v3.2″ with 2.596m, 2.638m, 3.088m and 6.042m, respectively.

From the above researches in Tanzania, ALOS-v-3.2″ and NASADEM proved to be better in different terrain.

Apart from GDEMs, there are other initiatives that have been going on regionally. For instance, Africa have computed a DTM of $3'' \times 3''$ which was created on September, 2017 for the purpose of developing a detailed digital terrain model (DTM) for Africa to be used within the remove-restore technique for the geoid determination in Africa. The available DTMs for Africa suffer from their accuracy deficiency especially on land, therefore it is needed to develop a more precise DTM for Africa to be used in the geoid determination for Africa, among other geodetic purposes and applications (Abd-Elmotaal, et al. 2017). However, since public African 3" × 3" DTM have not yet being validated in Tanzania, hence this research will assess it and compare with previous GDEMs so as to determine which will do better in a specified area of interest in Tanzania.

1.2 Statement of The Problem

In Tanzania, the use of public Global Digital Elevation Models (GDEMs) is dominant in numerous applications, including hazard monitoring, natural resources exploration, agricultural management, groundwater modeling, and flood-prone area mapping. Nevertheless, different GDEMs shows disparities in performance across terrains and land covers, mostly due to differences in their reference datums. Thus, there is a need to identify DTM with superior performance for these applications, ensuring accurate and reliable elevation data.

This study aims to assess the accuracy of the Africa 3″×3″ DTM in comparison to other widely used GDEMs, namely MERIT 1″, NASADEM-1″, TANDEM-X-3″, and ALOS-v3.2″, using GPS ground control points. By conducting a comprehensive evaluation, including suitable statistical analyses and comparison metrics.

1.3 Objectives

1.3.1 Main Objective

The main objective of this research is to assess Africa 3" × 3" DTM using Ground control points, also, include general comparison to other GDEMs which are MERIT 1″, NASADEM-1″, TANDEM-X-3″ and ALOS-v3.2″.

1.3.2 Specific Objectives

i. To convert of all GDEMs vertical datum to Orthometric height using EGM96 to have common reference datum.

ii. Comparison of Africa 3" × 3" DTM with other public Global Digital Elevation Models.

1.4 Significance of the Research

After Africa 3" × 3" DTM being assessed, it will be used in many applications such as terrain analysis, hazard mitigation, sea level rises and various engineering projects.

1.5 Beneficiaries

The following are the beneficiaries of this research

i. Construction Engineers
ii. Physical geodesists
iii. Planners
iv. Society in Geo-hazards mitigation like flood risk
v. Military
vi. Civil engineers in designing the route using topographic maps that are obtained by using DEMs.

1.6 Scope and Limitation of the Study

The Africa $3'' \times 3''$ DTM was assessed in Tanzania mainland covers latitudes -1° to -12° and longitudes 29° to 40° east of Greenwich meridian.

1.7 Research Question

How accurate is the Africa $3'' \times 3''$ DTM in Tanzania mainland compared to other public GDEMs.?

1.8 Structure of Dissertation

This dissertation consist of five chapters as follows;

a) Chapter one

This chapter comprised of background of the study, statement of the problem, main objective, scope of the research, study area, significance and beneficiaries of the research.

b) Chapter two

This chapter is all about literature review which describes about recently released GDEMs, method of analysis of the results and the method selected to be used in this research.

c) Chapter three

This chapter explains about the methods used, data acquisition, data description, data preparations, mathematical models used in computations and softwares used.

d) Chapter four

This chapter presents the results obtained after data processing and discussion of the results.

e) Chapter five

This chapter describes briefly the achievements of this research and recommendations for the future related researches.

CHAPTER TWO

LITERATURE REVIEW

Digital elevation models (DEMs) are quantities measurements of Earth's elevation with respect to any reference datum. Assessment on Digital Elevation Models (DEMs) can be done through vertical accuracy assessment on which vertical accuracy is the height difference between the modelled height and the actual height on the land but it is also defined as a description of errors in elevation data. Absolute vertical accuracy accounts for all the effects of systematic and random errors, and relates the modelled elevation with respect to an established vertical datum. Relative accuracy is a measure of the point-to-point vertical accuracy within a specific dataset (Agustino, 2020). DEMs provide a three-dimensional view of the Earth's topography and can be used to derive additional attributes such as slope, aspect and curvature which is used for various applications (Athmania & Achour, 2014). DEM can be created by using various methods which some of them includes; stereoscopic Photogrammetry of Air-Borne or Satellite-Borne, RADAR or SAR interferometry, Light Detection and Ranging (LIDAR) and conventional surveying (GPS or GNSS). Each method has a limitation depends on price, accuracy, sampling density and pre-processing requirements. Each DEM is normally made by using four steps which includes data acquisition, resampling to grid spacing, interpolating a height of point and DEM representation, repeating and DEM accuracy assessment (Athmania & Achour, 2014).

2.1 Description of DEMs used in this Research

In this study, the DEMs used were Africa 3" × 3" DTM, NASADEM-1″**,** ALOS-v3.2″**,** TANDEM-X-3″ and MERIT 1″**.** This research focuses on assessing Africa 3" × 3" DTM since it has not been validated in our country.

2.1.1 Africa 3" × 3" DTM

It was created on September, 2017 for the purpose of developing a detailed digital terrain model (DTM) for Africa to be used within the remove-restore technique for the geoid determination in Africa. The available DTMs for Africa suffer from their accuracy deficiency especially on land, therefore it is needed to develop a more precise DTM for Africa to be used in the geoid determination for Africa, among other geodetic purposes and applications. (Abd-Elmotaal, et al. 2017).

2.1.2 NASADEM-1 ″

NASADEM is the abbreviation of National Aeronautics and Space Administration Digital Elevation Model in which the data products where derived from original telemetry data from the Shuttle Radar Topographic Mission (SRTM). It was a collaboration between NASA and the National Geospatial-Intelligence (NGA), as well as participation from German and Italian space agencies. It is a global DEM with a spatial resolution of 1 arc second (30m) and the vertical datum is EGM96 with the horizontal datum of WGS84. NASADEM output products are flat binary files in big endian bytes order with 3601 rows and 3601 columns. These data are distributed in 1° by 1° tiles and consist of all land between 60°N and 56°S latitude. This accounts for about 80% of Earth's total landmass. NASADEM data are in form of HGT data layers include DEM, number of scenes (NUM) and an updated SRTM waterbody dataset (water mask). The NUM layer indicates the number of scenes that were processed for each pixel and the source of the data. A low-resolution browse image showing elevation is also available for each NASADEM_HGT granule (Uuemaa, et al. 2020).

2.1.3 MERIT 1 ″

It is Multi-Error-Removal Terrain which was created by removing multiple error components (absolute bias, speckle noise and tree height bias) from the existing space borne DEMs which are SRTMv2 and ALOS-30m v1. This DEM represents the Terrain elevation at 3arc second and cover land between 90°N-60°S referenced to EGM96 geoid. Absolute bias, stripe noise and tree height bias are separated using multiple satellites dataset and filtering techniques over an area of no data or low quality from 60°N-60°S was filled in version 1.1 released in March 2017 and 2.1 released in April 2018. Version 2.2 released in April 2019 is an improved version of the northern region over 60°N. Also updating of coastline was also performed (Uuemaa, et al. 2020).

2.1.4 TANDEM-X-3″

It is the abbreviation TerraSAR-X add-on for Digital Elevation Measurement which provides a homogenous elevation model that is used in variety of commercial and scientific applications. The development of the global terrain model from both satellites acquired data set was done in September 2016, with 19,000 tiles available and a grid size of 30m (Kramer, 2021). On 24th January 2006, the Japan Aerospace Exploration Agency (JAXA) launched ALOS-1″-v3.2 into a sun-synchronous orbit from the Tanegashima space centre. However, due to power generation issue, it was forced to switch to low load mode on April 22, 2011. Version of ALOS include version 1.0, which was released in May 2015, version 1.1 issued in March 2017, version 2.1, which was issued in April 2018, version 2.2, which was released in April 2019 and version 3.1, which was released in April 2020. Version 3.1 was made by reconsidering the format, supplementary data and processing mechanism in the high latitude area (Takaku, et al. 2020).

2.1.5 ALOS-v3.2″

It is the abbreviation Advanced Land Observation Satellite. It is a global dataset generated from images collected using the Panchromatic Remote Sensing Instrument for Stereo Mapping (PRISM). This DEM was based on satellite imagery launched by JAXA (Japan Aerospace Exploratory Agency); it become operational in 2006 and terminated in 2011 due to power generation anomaly. The DEM compiled with images acquired by Land Observing Satellite produced by JAXA. In 2015 ALOS world (AW3D) was generated to be used free of charge and became the world first and 3D precise map covering all the globe. The vertical datum is Orthometric EGM96 and the horizontal datum is WGS84, it is an improved version created by reconsidering the format in the high latitude area, auxiliary data and processing method (Nikolakopoulos, 2020).

2.2 Methods of DTMs Assessment

The assessment of DTM consists of its ability to fulfil user requirements based on adapted quality criteria, for each criteria a quality assessment procedure can be implemented to decide whether a DTM is acceptable for a given use. The determination of the DTM with best accuracy of public DTM datasets available, each with many versions, the needed DTM is the most accurate of the bunch. Different approaches for DTM evaluation are used all around the globe to determine the DTM with the highest precision. The following are the methods of assessing the vertical accuracy of the DTMs.

2.2.1 Assessment of vertical accuracy using Ground Control Points

It involves assessment of DTMs elevation using the ground GPS control points (GGCPs) elevations. The process involves several procedures on which before the assessment is undertaken, the vertical datum of the DTMs must be identified and that of the reference data. The procedures involved are; identification of the vertical datum of the DTMs and GGCPs and uniform vertical datum so that conversion processes can take place such as geometric heights of the TGGCPs being converted to Orthometric height by subtracting the geoid height of the TGGCPs points (Agustino, 2020), hence, vertical accuracies of DTM are assessed by comparing the difference between the TGGCP elevation and the corresponding DTM value.

Since the TGGCPs are not directly in accord with a DTM point location, for every control point location, the corresponding DTM elevation is extracted through the bilinear interpolation. Positive differences mean the interpolated DTM elevation is below the TGGCP elevation. Negative differences represent the locations where the DTM elevation is above TGGCP elevation. Three-dimension spatial analysis tools available at the commercial softwares like ArcGIS and Golden surfer can be applied to calculate the slope and slope aspect of DEM at the location of each TGGCP. The statistical maximum and minimum, mean, standard deviation and root mean square are computed after the error estimation to depict the DEMs correctness in relation to the TGGCPs. Because ground control points are permanent, this approach is preferred because their precision is greater, increasing the spatial accuracy of the data. Because TGGCPs are not available is densely forested regions or locations with rough/mountainous terrain due to the difficulty of obtaining them, the approach is not recommended in these areas (Ulotu, 2017).

2.2.2 Vertical accuracy assessment of DTM using another DEMs

The reference DTM also used to assess accuracy of DTMs in terms of surface derivatives such as Slope, drainage extraction and another DTM uses. The accuracy assessment process is performed by subtracting pixels of DTM to be assessed from the reference DTM pixels and hence DTM differences are obtained and perform statistical analysis of the resulting Difference. Accordingly, the maximum, minimum and mean errors are calculated and finally the standard deviation and RMSE can be calculated to give the accuracy of the required DTMs (Ibrahim, 2018). This statistical technique is then used to analyze the results by comparing the ones with the smallest RMS and standard deviation and positive differences represents locations where the reference DTM elevation was higher than the corresponding DTM elevation and negative differences occur at locations where the reference DEM elevation is lower than the corresponding DTM (Nikolakopoulos, 2020).

2.2.3 Vertical accuracy assessment using topographic maps

Topographic maps are maps used to show the relief on land surface of the Earth and provides spot heights as well as contour lines which are used as a secondary data for evaluating the vertical accuracy of DEMs (Mapunda, 2019). Through this method, digitization of contours and height points, all analysis, calculations, and DEM visualizations are performed in the ArcGIS environment. Additionally, visual evaluation of the Topographic maps is made using ArcGIS. Following the cartographical rules, that one should always compile a map from source materials of the same or larger map scales. In the digital environment one has to create a raster map from data at the same or higher spatial resolution than the ground resolution, hence, the values of DEMs will depend on the scale of the map (Szypuła, 2019). The spot elevation values are subtracted from the elevation values in the topographic DEMs to create residual surfaces.

2.2.4 Vertical accuracy assessment of DEMs derived from remote sensing data

This method involves the following procedures;

i. Define the level and method of inspection according to the characteristics and objectives of DEM to be calculated.
ii. Identification of uncertainties associated with terrain.
iii. Access source with greater accuracy.
iv. Select type of sampling.
v. Determine the sample size.
vi. Implement the probabilistic sample design that allows the main objectives of the quality assessment to be achieved and the additionally responds to the practical limitations related, for example, the cost and availability of reference data.
vii. Implement a response protocol based on partially and temporally representative sources of reference data to validate each sampling unit (the values of control points are considered to be true values which means that they are measured without error, with respect to the values of the DEM to be evaluated) and
viii. Implement the coherent analysis with sampling plan and response design protocols (Szypuła, 2019).

2.3 Method for Results Analysis

2.3.1 Statistical analysis

The mathematical relations that have been widely used in explaining research outputs in statistical measurements are based on standard deviations (SD), Root Mean Square (RMS) and mean. Standard deviation is a measure of the amount of variation or dispersion of a set of values where low standard deviation indicates that the values tend to be close to the mean of the set while high standard deviation indicates that the values are spread out over a wider range. RMS is a measure of the difference between data that are known and the data that have been interpolated or digitized. RMS is derived by squaring the differences between known and unknown points, adding those together, dividing that by the number of test points and then taking the square root of the results (Dettlaff, 2006). RMS have the ability to encompass all the random error and systematic errors. They also measure surface quality and provide insight into the distribution of deviation on either side of the mean value. Most researchers have been conducted by comparing the RMS and SD where by the one with small value is considered to be superior (Ulotu, 2017).

2.3.2 Visual comparison

DEMs represents the topography of the bare Earth and above the ground features, visualizing DEMs in their raster format, one may not fully understand the terrain. Elevation profiles describing the terrain or various features on the area are generated for an easy visual description. Profiles show the change in elevation surface along a line, they are helpful in assessing difficulty in trail or feasibility of placing a trail along a given route (Szypuła, 2019).

2.4 Method used for this Research

The method selected for validating Africa $3'' \times 3''$ DTM is by using Ground GPS Control Points where by both DTM and TGGCP elevation points were converted to EGM96 so as to have the same height format. The height difference between the DTMs and TGGCP points were calculated and hence the results were used in computation of statistical analysis using RMS, Standard Deviation and Mean. This method is selected because TGGCPs have high accuracy compared to the method used to obtain the elevations of DTMs.

CHAPTER THREE

METHODOLOGY

Since this research is based on the assessment of vertical accuracy of Africa $3'' \times 3''$ DTM using Tanzania GPS ground control points (TGGCPs) in the selected land covers, therefore, this chapter focuses on the methods, procedures, data collection and softwares used in data processing.

3.1 Vertical Accuracy Assessment of Africa $3'' \times 3''$ DTM Using Ground GPS Controls

The four steps were required to attain the objective of this research as follows; unification of datums, calculation of difference in elevations for DEMs and TGGCPs, comparison between GDEMs and statistical assessment of difference in elevation.

3.1.1 Unification of resolution

It involves adjusting the spatial resolution of the datasets to a common value where it was performed to MERIT 1″, NASADEM-1″ and ALOS-v3.2″ since they are in 1 arcsecond, they had to be adjusted to 3 arcsecond in order to have a uniform resolution with that of Africa $3'' \times 3''$ DTM. Unification of resolution is necessary when having datasets of different resolutions when assessing them in common grid intersection.

3.2.1 Datum unification

Before continuing any further in fulfilling the objectives of this research, the unification of datum for all data sets to be used had to be performed in order to have the common reference system where by all DEMs based on EGM08 were converted into EGM96 also together with the conversion of all the elevations to orthometric height using EGM96. Due to this, the following conversions had to be performed.

a) Conversion of Tanzania GPS Ground Control Points to EGM96 Orthometric height

This process involves the conversion of Tanzania GPS Ground Control Points from ellipsoidal height to EGM96 Orthometric height by using GNSS levelling equation so as to have the same format as the heights of GDEMs. This was done through the following equations;

$$\mathrm{H}_{\mathrm{EGM96}}^{\mathrm{TGGCP}} = \mathrm{h}^{\mathrm{TGGCP}} - \mathrm{N}^{\mathrm{EGM96}} \quad \ldots\ldots (3.1)$$

Where;

$\mathrm{H}_{\mathrm{EGM96}}^{\mathrm{TGGCP}}$ is the orthometric height of TGGCP based on EGM96

$\mathrm{h}^{\mathrm{TGGCP}}$ is Ellipsoidal height of TGGCP

N^{EGM96} is Geoidal height of EGM96

b) Conversion of DEMs Orthometric Height to EGM96 Orthometric Height

The DEMs NASADEM-1 ", ALOS-v3.2 ", Africa 3" × 3" DTM and MERIT 1" elevations are Orthometric heights referenced to WGS84 as horizontal datum and EGM96 as vertical datum except for TANDEM-X-3 " which is based on EGM08 therefore, to have the same format as the heights of TGGCPs, TANDEM-X-3 " orthometric height must be converted to EGM96 orthometric height. This was done by using the following equations;

$$H_{DEM}^{EGM96} = h^{DEM} - N^{EGM96} \quad \text{..... (3.2)}$$

Where;

h^{DEM} is the ellipsoidal height of DEM

H_{DEM}^{EGM96} is the orthometric height of DEM based on EGM96

N^{EGM96} is the geoidal height of EGM96

c) Assessment of Africa 3" × 3" DTM using TGGCPs over the area of interest

This involves the DTM and TGGCPs where by relative height differences between the points were computed. To assess the difference between DTM and TGGCPs elevations, the dataset must be obtained and the evaluated on the orthometric height system made so as to compare with TGGCPs. This is done through the following equation.

$$\Delta H_{DTM}^{TGGCP} = H^{TGGCP} - H^{DTM} \quad \text{..... (3.3)}$$

Whereby;

ΔH_{DTM}^{TGGCP} is the height difference between TGCCPs and DTMs.

H^{TGGCP} is orthometric height of TGGCPs

H^{DTM} is orthometric height DTMs.

d) General comparison of the DEMs and the DTM over the AOI

This is done by assessing the differences in elevation between the public DEMs all over the area of interest to check how they relate between Africa 3" × 3" DTM and each DEM. This is done by using the following equation.

$H^{GD1,GD2} = H^{GD1} - H^{GD2}$ ………………………………………………………… (3.4)

Whereby;

H^{GD1} and H^{GD2} are Orthometric heights of DEMs.

$H^{GD1,GD2}$ is the difference in Orthometric heights between two DEMs.

e) Statistical analysis of the height differences between the DTM and TGGCPs

After obtaining the Orthometric height differences between DEMs, they were used to assess the vertical performance of the DTM in different terrains. This was also done by using Mean, Standard deviation and the Root mean square.

i. Mean of height differences

Mean of height differences between DTMs and TGGCPs on both general and in the selected terrains were computed using the following formula.

$$\Delta H_{mean}^{TGGCP,DTM} = \frac{1}{N}\sum_{i=1}^{n} \Delta H_i^{TGGCP,DTM} \quad (3.6)$$

$\Delta H_{mean}^{TGGCP,DTM}$ is mean height difference between TGGCPs and DTMs.

ii. Standard Deviation (SD)

$$SD = \pm\sqrt{\sum_{i=1}^{N} \frac{(\Delta H_i^{TGGCP,DTM} - \Delta H_{mean})^2}{N-1}} \quad (3.7)$$

Whereby;

$\Delta H_{mean}^{TGGCP,DTM}$ is mean height difference between TGGCPs and DTMs.

iii. Root Mean Square of height differences

RMS is a measure of the magnitude of a set of numbers on which it was computed by taking the height differences between DTMs and TGGCPs by considering the following formula.

$$RMS = \sqrt{\sum_{i=1}^{n} \frac{(\Delta H_i^{TGGCP,DTM})^2}{n}} \quad (3.8)$$

Whereby;

$\Delta H_i^{TGGCP,GDEM}$ is the difference in Orthometric heights between TGGCPs and DTMs.

3.3 Data Requirements, Description and Preparation

This involves data collection, organizing and processing for the purpose of analysis, on which the dataset required in this study were; Africa 3" × 3" DTM, NASADEM-1″**,** ALOS-v3.2″**,** TANDEM-X-3″, MERIT 1″ and Tanzania GPS Ground Control Points.

3.3.1 African 3" × 3" DTM

It is a digital terrain model for Africa and the surrounding region covering the window 42°S ≤ φ ≤ 44°N, 22°W ≤ λ ≤ 62°E. Abd-Elmotaal has developed a set of digital height models for Africa by merging the bathymetric model and the GTOPO30 model. The SRTM30+ DTM model, after being interpolated to the 3" × 3" resolution, has been used to fill-in the sea regions only of the ASTER-GDEM model. The Kriging interpolation technique with zero error variance has been used to grid the 30" × 30" SRTM30+ DTM on a 3" × 3" grid covering the African window 42°S ≤ φ ≤ 44°N, 22°W ≤ λ ≤ 62°E. In the sea region, there is only bathometric depths at the 30" × 30" grids of the SRTM30+ DTM. Accordingly, the Kriging interpolation technique with zero error variance was used because it is well-known that Kriging interpolation reproduces the data at the data points if their precision is set to zero (Abd-Elmotaal, et al. 2017). The data where provided via personal contact with Prof. Hussein Abd-Elmotaal who provided the data covering the window 12°S ≤ φ ≤ 1°S, 29°W ≤ λ ≤ 40°E in a resolution of 3 arcsecond.

3.3.2 ALOS-v3.2″

ALOS Global Digital Surface Model is a global digital surface model (DSM) at 1 arc-second (approximately 30 m) resolution that was released by the Japan Aerospace Exploration Agency (JAXA). This model has been compiled with images acquired by the advanced land observing satellite (ALOS). The elevation data are published based on the DSM data set (5-m mesh version) of the 'World 3D Topographic Data. A huge number of stereo-pairs images derived from satellite mission in the years 2006–2011 were source data. Next, they were processed semi-automatically to provide a digital surface model (DSM). The horizontal resolution of the dataset is 5×5 m and the height accuracy is approximately <5 m from the evaluation with ground control points (GCPs) or reference DSMs derived from LiDAR in WGS-84 coordinate system. It can be downloaded free of charge from http://www.eorc.jaxa.jp/ALOS/en/aw3d30/.

3.3.2.1 Procedures used to download ALOS-v3.2″ Dataset

i. Fill in the links with the use of search engine such google.com
ii. Create account in Open topography.

iii. Choose the region you want to download then move the cursor to the area of interest and highlight it with a rectangle block.
iv. Once you have submitted your project, they will provide you information through email that allows you to start downloading the data.

3.3.3 NASADEM-1″ dataset

The NASADEM-1″ data products were publicly released by LP DAAC in February 2020. Interferometric SAR data from SRTM were reprocessed with an optimized hybrid processing technique in producing the data products. The data rely on multiple radar images to create interferograms with 2-dimensional phase arrays that result in greater elevation accuracy. Because of inherent characteristics of interferometric data, it needs to be wrapped and unwrapped so the data are quantifiable. NASADEM-1″ relied on the latest unwrapping techniques and auxiliary data that were not available during the original processing of SRTM data. Vertical and tilt adjustments were applied based on ground control points and laser profiles from the Ice, Cloud and Land Elevation Satellite (ICESat) mission. This application improved the vertical accuracy, swath consistency, and uniformity within the swath mosaic.

3.3.3.1 Procedures used to download NASADEM-1″ dataset

i. Fill in the links with the use of search engine such google.com
ii. Create account in Open topography.
iii. Choose the region you want to download then move the cursor to the area of interest and highlight it with a rectangle block.
iv. Once you have submitted your project, they will provide you information through email that allows you to start downloading the data.

3.3.4 TANDEM-X-3″ dataset

The TanDEM-X-3″ DEM was developed based on interferometric synthetic aperture radar (InSAR) images acquired by X-band radar and full polarimetric synthetic aperture radar sensors on two satellites (TerraSAR-X and TanDEM-X). The sensors imaged the Earth’s surface at least twice between 2010 and 2015, and additional images were acquired for areas with complex topography, such as mountain regions. The TanDEM-X-3″ DEM product with a spatial resolution of 12 m that was released in September 2016 is reported to have a horizontal and vertical absolute accuracy of < 10 m, and a relative vertical accuracy of 2 m for slopes $\leq 11°$ and 4 m for slopes $> 11°$. SAR acquisitions over complex terrain are often affected by geometric distortions including foreshortening, layover, and shadow (Uuemaa, et al. 2020). The dataset can be obtained via website;https://download.geoservice.dlr.de/TDM90#download

3.3.5 MERIT 1" DEM dataset

The MERIT 1" DEM was created to provide an error-reduced DEM product. The DEM was developed by combining data acquired from SRTM with data from the ALOS World 3D data with 30 m resolution (AW3D-30m v1), and used error-removal techniques that reduced the bias and other sources of noise. The reported accuracy is ±12 m (90th percentile of the error range). Studies suggested that the reduced-error DEM performed well, but that artifacts remain in the DEM product.

3.3.5.1 Procedures used to download MERIT 1" dataset

i. Fill in the links with the use of search engine such google.com
ii. Create account in Open topography.
iii. Choose the region you want to download then move the cursor to the area of interest and highlight it with a rectangle block.
iv. Once you have submitted your project, they will provide you information through email that allows you to start downloading the data.

3.3.6 TGGCPs dataset

The GPS control points were obtained from Ministry of Lands Housing and Human Settlement Development (MLHHSD) through surveying and mapping division (SMD). There are about 594 control points including those used in previous researches by (Mapunda, 2019), (Agustino, 2020), (Mavunde, 2021) and (Mbura, 2022). These control points cover most parts of Tanzania and were used in this research to assess the DTM. The data provided are in form of longitude, latitude and elevation.

3.4 Relief Areas Selected

There were twelve selected terrains and land covers included in this research. The selection is referred to previous studies on validation of DEMs in Tanzania by (Agustino, 2020), (Mavunde, 2021) and (Mbura, 2022). These reliefs are;

a) Highlands and forested terrain

It is located at Mbeya region, bounded between latitudes 7.59°S to 9.02°S and longitude 33.27°E to 35.08°E.

b) Forested and slightly flat terrain

This part is located in Tanga region which lies within latitude 4.16°S to 5.48°S and longitudes 37.72°E to 39.30°E.

c) Flat and slightly bare terrain

This relief is located in Dodoma which lies between latitudes 5.3°S to 6.92°S and longitudes 35.6°E to 37.4°E.

d) Flat and forested coastal terrain

This area is located in Lindi region lies between latitudes 8°S to 11°S and longitudes 37°E to 40°E.

e) Flat and slightly plain terrain

This area is located in Tabora region lies between latitude 4°S to 7°S and longitudes 31°E to 34°E

f) Barely flat and forested coastal terrain

This selected area is located in Mtwara which ranges between latitudes 10°S to 12°S and longitudes 38°E to 41°E.

g) Mountainous and forested terrain

This relief is located in Kilimanjaro region on which the selected part ranges between latitudes 2.36°S to 4.4°S and longitudes 36.3°E to 38.42°E.

h) Lake zone areas

This part is found between latitudes 1°S to 2°S and longitudes 31°E to 33°E.

i) National parks

This area is found in western part of Arusha (Ngorongoro crater) located at latitudes 1°S to 3°S and longitudes 35°E to 37°E.

j) Slightly mountainous and forested terrain

This relief is located in Morogoro and the selected part is bounded between latitudes 5.967°S to 9.98°S and longitudes 35.42°E to 37.11°E.

k) Eastern branch of Great Rift Valley

This area is found along Dodoma Region to lake Natron which is between latitudes 4.43°S to 8.854°S and longitudes 29.62°E to 30.15°E.

l) Western branch of Great Rift Valley

This area is found along Lake Tanganyika to Uganda in east Africa which is between latitudes 1.98°S to 3.29°S and longitudes 35.57°E to 36.44°E.

3.5 Software Package

Softwares used for data processing and analysis are;

a) Golden Surfer

It was used to convert DTM to list grid format, and calculating difference between grid intersection of both DTM and TGGCPs as well as statistical analysis of the dataset used.

b) Microsoft office

It was used in report writing and performing some statistical analysis of which Microsoft word was used in report writing and Microsoft excel was used in statistical analysis such as obtaining maximum and minimum values.

c) Global mapper

It was used to convert the GDEMs from GeoTIFF format to XYZ format so as they can be transferred to golden surfer for further processing.

CHAPTER FOUR

RESULT, ANALYSIS AND DISCUSSION

4.1 Results

The main objective of this study was to assess Africa 3" × 3" DTM using ground control points as well as general comparison with other DEMs which are MERIT 1″, NASADEM-1″, TANDEM-X-3″ and ALOS-v3.2″, thus, the output was a validated Africa 3" × 3" DTM based on mean, SD and RMS. The assessment was done by statistics of height differences between Africa 3" × 3" DTM and TGGCPs as well as Africa 3" × 3" DTM with other DEMs including; MERIT 1″, NASADEM-1″, TANDEM-X-3″ and ALOS-v3.2″.

discussion of the output was done using RMS, SD and mean as measures of accuracy. Lower RMS and Mean were considered as higher vertical accuracy. SD is a statistical measurement of the amount of number varies from the average number in series, a low SD means that the data is very close to the average, thus very reliable.

4.1.1 Validation results

The land covers assessed were assigned with letters A1-A12 for simplification of tabular presentation of the results as shown in the Table 4.1 below.

Table 4.1: Letters representing twelve selected land covers

Letter	Land cover	Region
A1	Flat and slightly bare terrain	Dodoma
A2	Mountainous and forested terrain	Kilimanjaro and Arusha
A3	Flat and slightly plain terrain	Tabora
A4	Slightly flat and forested coastal terrain	Mtwara
A5	Slightly mountainous and forested terrain	Morogoro
A6	Forested and slightly flat terrain	Tanga
A7	Highlands and forested terrain	Mbeya
A8	Flat and forested coastal terrain	Lindi
A9	Western branch of great lift valley	Natron
A10	Eastern branch of great lift valley	Tanganyika

A11	Lake zone areas (Victoria)	Mwanza, Kagera and Mara
A12	National parks (Ngorongoro)	Arusha

4.1.2 Statistics of comparison between TGGCPs and DTM countrywide and in selected land covers

Statistics obtained from height differences between TGGCPs and DEMs countrywide are shown in the Table below.

Table 4.2: Statistics of height differences between TGGCPs and DEMs countrywide

HEIGHT DIFFERENCE	NO	SUM (m)	MIN (m)	MAX (m)	MEAN (m)	SD (m)	RMS (m)
H (TGGCP- Africa 3″ × 3″ DTM)	573	-264.444	-9.903	7.388	-0.899	4.605	4.692
H (TGGCP-MERIT-3″)	574	-171.856	-10.240	6.976	-0.456	3.589	3.618
H (TGGCP-NASADEM-3″)	574	544.704	0.002	7.105	2.594	1.889	3.506
H (TGGCP-TANDEM-X-3″)	575	1176.192	-5.183	21.588	2.673	5.529	6.141
H (TGGCP-ALOS-v3.2 ″)	572	192.246	0.021	4.480	1.814	1.367	2.271

Table 4.3: Statistics of height difference between TGGCPs and Africa 3″ × 3″ DTM in the representative land covers in Tanzania

REGION	NO	SUM (m)	MIN (m)	MAX (m)	MEAN (m)	SD (m)	RMS (m)
A1	11	19.136	-8.847	7.388	1.740	5.966	6.215
A2	9	114.678	9.880	16.183	1.742	2.497	3.045
A3	17	-55.222	-4.975	-1.561	-3.248	1.068	3.419

A4	13	154.633	-21.693	59.885	1.895	5.795	6.063
A5	17	159.405	2.000	13.937	9.377	3.163	9.896
A6	7	111.748	11.066	22.449	1.964	4.35	4.773
A7	8	-32.381	-8.669	-2.277	-4.048	1.986	4.902
A8	36	-161.36	-22.543	13.655	-4.482	9.801	10.777
A9	6	30.592	-6.701	20.482	5.099	8.914	10.269
A10	4	-18.726	-8.095	-0.063	-4.681	3.756	6.002
A11	21	116.451	0.310	10.766	5.545	3.468	6.54
A12	5	24.325	0.714	8.669	1.865	3.561	4.019

Table 4.4: Statistics of height difference between TGGCPs and MERIT-3″ in the representative land covers in Tanzania

REGION	NO	SUM (m)	MIN (m)	MAX (m)	MEAN (m)	SD (m)	RMS (m)
A1	9	76.059	6.067	11.112	0.451	1.793	1.849
A2	9	7.390	-0.788	4.538	0.821	1.578	1.779
A3	23	20.662	-0.201	3.127	0.898	0.961	1.315
A4	12	108.107	-14.002	53.770	9.009	19.166	21.178
A5	21	49.673	-1.471	9.330	2.365	2.990	3.812
A6	10	85.741	2.383	16.838	1.574	5.582	5.800
A7	6	-12.446	-4.871	0	-2.074	2.070	2.930
A8	39	-8.719	-16.987	17.806	-0.224	7.600	7.603
A9	6	25.430	-5.521	18.647	4.238	9.793	10.671
A10	6	-2.177	-2.388	1.480	-0.363	1.542	1.584
A11	23	96.805	0.183	11.057	1.809	3.391	3.843
A12	6	5.841	-3.474	5.624	0.973	3.338	3.477

Table 4.5: Statistics of height difference between TGGCPs and NASADEM-3″ in the representative land covers in Tanzania

REGION	NO	SUM (m)	MIN (m)	MAX (m)	MEAN (m)	SD (m)	RMS (m)
A1	15	23.956	-3.134	5.355	1.597	2.835	3.254
A2	9	25.363	0.872	5.576	2.818	1.580	3.231
A3	26	17.548	-0.441	2.910	0.675	0.912	1.135
A4	12	107.066	-18.785	54.504	1.922	4.296	4.706
A5	22	93.056	-0.651	10.407	1.203	3.099	3.324
A6	7	52.748	3.370	14.269	1.535	3.545	3.863
A7	8	-8.240	-2.904	1.134	-1.030	1.501	1.820
A8	39	-19.004	-22.104	18.255	-0.487	7.716	7.731
A9	6	24.258	-6.579	19.254	4.043	9.282	10.124
A10	6	-0.257	-4.256	2.130	-0.043	2.600	2.600
A11	25	120.664	1.002	11.515	1.827	3.323	3.792
A12	6	3.194	-2.707	4.315	0.532	2.529	2.584

Table 4.6: Statistics of height difference between TGGCPs and TANDEM-X-3″ in the representative land covers in Tanzania

REGION	NO	SUM (m)	MIN (m)	MAX (m)	MEAN (m)	SD (m)	RMS (m)
A1	15	6.174	-3.109	4.657	0.412	2.221	2.259
A2	8	20.079	0.142	5.889	0.510	2.025	2.088
A3	24	9.857	-0.823	1.831	0.411	0.781	0.883
A4	7	148.874	2.642	54.481	1.268	8.798	8.889
A5	23	41.223	-2.121	6.833	1.792	2.479	3.059
A6	7	48.024	2.761	12.815	0.861	3.655	3.755
A7	4	-4.733	-1.912	-0.117	-1.183	0.865	1.466

A8	37	13.105	-10.316	17.817	0.354	6.309	6.319
A9	6	16.492	-5.678	16.218	2.749	8.047	8.504
A10	8	-5.886	-4.259	3.209	-0.736	2.521	2.626
A11	25	90.239	0.754	9.695	1.609	2.705	3.147
A12	7	12.646	-1.420	8.346	1.807	3.572	4.003

Table 4.7: Statistics of height difference between TGGCPs and ALOS-v3.2 " in the representative land covers in Tanzania

REGION	NO	SUM (m)	MIN (m)	MAX (m)	MEAN (m)	SD (m)	RMS (m)
A1	14	-0.544	-3.234	2.244	-0.039	1.925	1.925
A2	10	10.846	-0.813	4.373	1.085	1.903	2.191
A3	24	-44.006	-2.780	-0.659	-1.834	0.680	1.956
A4	11	86.832	-11.738	48.556	1.894	8.291	8.505
A5	24	14.155	-3.234	5.719	0.590	2.878	2.938
A6	9	49.082	1.158	10.353	0.454	3.417	3.447
A7	7	-15.274	-3.928	-0.737	-2.182	1.339	2.560
A8	38	-183.285	-23.264	12.649	-4.823	7.002	8.502
A9	6	-0699	-6.874	13.226	-0.116	6.958	6.959
A10	6	-13.576	-6.290	1.469	-2.263	2.803	3.602
A11	28	69.051	-0.499	7.556	2.466	2.767	3.706
A12	8	23.877	-1.903	8.786	2.985	3.673	4.733

4.1.2 Statistics of comparison between Africa 3" × 3" DTM and other DEMs countrywide and in selected land covers.

The statistics were obtained using mathematical relations presented in chapter 3 which involves equation (3.6) -(3.8). The results are presented in the following Table

Table 4.8: Statistics of height difference between GDEMs countrywide.

HEIGHT DIFFERENCES	NO	SUM (m)	MIN (m)	MAX (m)	MEAN (m)	SD (m)	RMS (m)
H (ALOS-v3.2 " - Africa 3" × 3" DTM)	160132978	-502779126	-344	310	-3.140	20.585	20.823
H (MERIT 3″ - African 3" × 3" DTM)	167120564	-1994669	-35	35	-0.012	9.194	9.194
H (NASADEM-3″ - Africa 3" × 3" DTM)	143121018	-243981286	-360	326	-1.705	21.597	21.664
TANDEM-X-3″ Africa 3" × 3" DTM	139964619	2356675726	-95	126	16.838	11.237	20.243

Table 4.9 statistical height difference between Africa 3″×3″ DTM and ALOS-v3.2 " in the selected land covers in Tanzania.

REGION	NO	Sum (m)	Min(m)	Max(m)	Mean(m)	SD(m)	RMS(m)
A1	2407	-33374365	-41	24.75	-8.25	-3.49	5.24
A2	3601	-46934739	-97.75	84.5	-7.54	-2.17	4.834
A3	2198	30108587	-10.25	15	2.363	3.132	2.394
A4	2547	1180690.25	-33	33.5	0.238	1.6	6.312
A5	2410	-56453964	-49.4	37.15	-5.95	-4.7	6.43
A6	2476	-16979946	-26.5	17	-6.58	-1.51	3.497
A7	2321	8010812.5	-27.75	32.25	2.201	2.8	5.581

A8	3610	-28463474	-96.75	37.25	-2.39	-1.03	5.076
A9	2321	-11660221	-39.2	32.03	-3.56	-5.96	10.33
A10	2397	-7030369.3	-42.25	33.5	-4.4	1.289	3.91
A11	2325	43551301.8	-39.75	68.75	1.22	8.28	8.9
A12	2377	-39193598	-36.75	23	-0.02	-1.96	3.334

Table 4.10: Statistical height difference between Africa 3″×3″ DTM and MERIT 3″ in the selected land covers in Tanzania.

REGION	NO	SUM(m)	MIN(m)	MAX(m)	MEAN(m)	SD(m)	RMS(m)
A1	4130473	-30067637	-24.42	10.1	-1.28	5.742	5.883
A2	6224502	-46728718	-98.47	85.2	-0.51	8.207	8.223
A3	12836946	59959504	-6.024	15.5	4.67	3.994	6.146
A4	5624154	21849034	-21.26	29.9	1.89	8.176	9.101
A5	1832288	-4523799	-29.67	24.5	-2.63	8.904	9.285
A6	15816660	-8113695	-31.07	21.4	-1.13	9.057	9.127
A7	17162266	40727915	-17.85	22.2	2.37	7.277	7.654
A8	11415326	32368937	-28.5	35.4	2.84	9.275	9.699
A9	1629387	-7503209	-27.15	18	-0.61	8.336	8.358
A10	3365160	-10474315	-25.18	19	-0.11	7.784	7.785
A11	2868897	44453144	-34.79	66.5	1.5	8.944	9.068
A12	1751671	-12665117	-29.01	14.6	-0.36	7.868	7.876

Table 4.11 Statistical height difference between Africa 3″×3″ DTM and NASADEM-3″ in the selected land covers in Tanzania.

REGION	NO	Sum (m)	Min(m)	Max(m)	Mean(m)	SD(m)	RMS(m)
A1	2161	-2781403.7	-24	10.5	-0.751	5.65	5.700
A2	2545	-4003580.5	-101.5	90.5	-6.431	8.03	10.288
A3	3610	48625478	-6.5	14.25	0.793	3.834	3.915
A4	3601	12309967	-27.5	32.25	2.336	8.733	9.040
A5	2860	-2943800.42	-28.617	22.387	-1.06	8.152	8.221
A6	1897	-20902752.5	-205.25	172	-1.254	7.400	7.505
A7	1753	9491746.5	-17.25	22	2.587	7.069	7.528
A8	1690	1529818.75	-77	154	1.275	12.26	12.326
A9	2477	-502021.774	-23.056	16.614	-0.211	7.253	7.256
A10	1573	-6585614.75	-24.5	16.25	-1.048	7.374	7.448
A11	2408	50374457.5	-34.75	70.5	1.560	9.770	9.894
A12	2401	-32324851.5	-24.25	12.75	-0.686	6.72	6.755

Table 4.12 Statistical height difference between Africa 3″×3″ DTM and TANDEM-X-3″ in the selected land covers in Tanzania.

REGION	NO	SUM(m)	MIN(m)	MAX(m)	MEAN (m)	SD(m)	RMS (m)
A1	3596	-26921343.9	-36.5	21.5	-8.25	5.344	9.83
A2	4480	-4507840.29	-97.25	85.25	-7.54	7.49	10.628
A3	1350	30687963.53	-1.25	7.75	2.363	4.219	4.836
A4	3664	9062662.083	-28.5	32	0.238	3.997	4.004
A5	3674	-4469045.59	-43.789	33.994	-5.95	5.78	8.295

A6	5860	-1913849.17	-193.5	163.5	-6.58	9.29	11.384
A7	2842	795874.336	-8.25	12.75	2.201	4.557	5.061
A8	7840	-173996862	-79	28.25	-2.39	8.73	9.051
A9	2579	-3425538.69	-63.5	53.5	-3.56	5.58	6.619
A10	4984	310521267.2	-57.75	46.5	-4.4	8.24	9.341
A11	2200	1913134.519	-35.25	26.25	1.22	4.864	5.015
A12	2579	-3425138.69	-63.5	53.5	-0.02	6.928	6.928

4.2 Analysis of Results

The discussion of results is based on the values of mean, SD and RMS statistics. The DTM with the least value of the mean, SD and RMS is the one which is termed as the best DTM. In addition to that, the assessment of DTMs using TGGCPs and statistics which shows the level of the performances between DTMs in all twelve representative land covers are presented.

4.2.1 Validation of the DTMs using TGGCPs countrywide and in the selected land covers.

Performance of the DTMs countrywide using TGGCPs at 95% confidence level is shown in the Figure 4.1 below;

In Figure 4.1 ALOS-v3.2 " shows to be closer to the control points than other GDEMs. It was followed by NASADEM-3″, MERIT 3″, Africa 3″×3″ DTM and TANDEM-X-3″

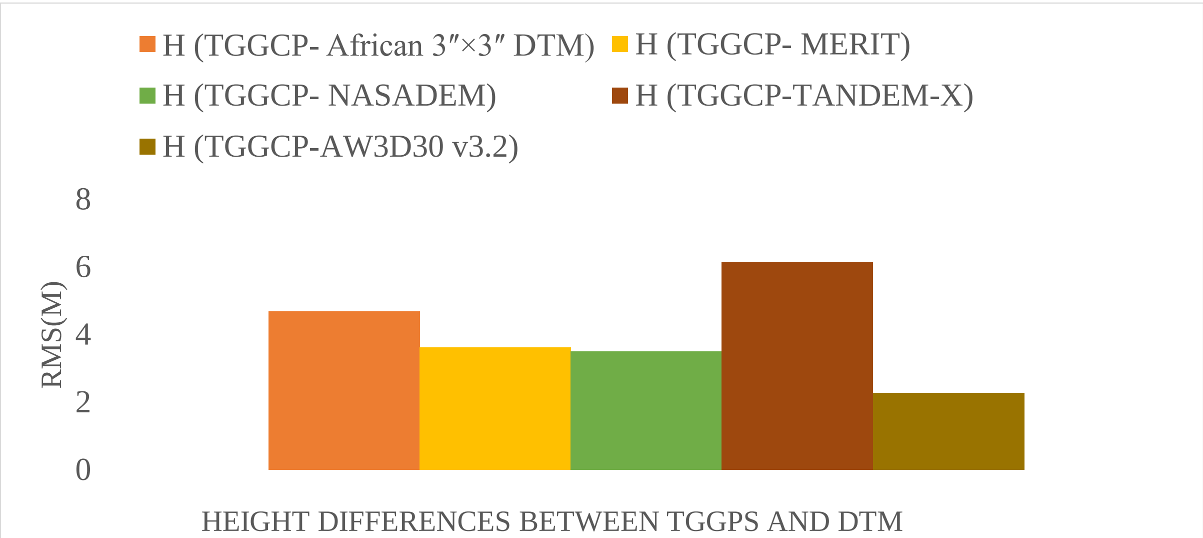

Figure 4.1: Statistical height difference of TGGCPs and DTMs

From the above figure, Africa 3″×3″ DTM comes after ALOS-v3.2 ", NASADEM-3″ and MERIT 3″

4.2.2 General performance of DTMs countrywide and in selected land covers.

The analysis of the comparison of DTMs countrywide was done using the values of mean, SD and RMS as presented in Figure 4.2 below. The height difference between DTMs with value 1 indicates best performance, 2-good performance, 3-5 normal performance, 6-poor performance and 7- worst performance.

Figure 4.2 shows general statistics of fitting between the DTMs countrywide in which the difference between MERIT 3″ and Africa 3″×3″ DTM performed better followed by TANDEM-X-3″ and Africa 3″×3″ DTM while NASADEM-3″ and Africa 3″×3″ DTM showed disagreement at their common grid intersection.

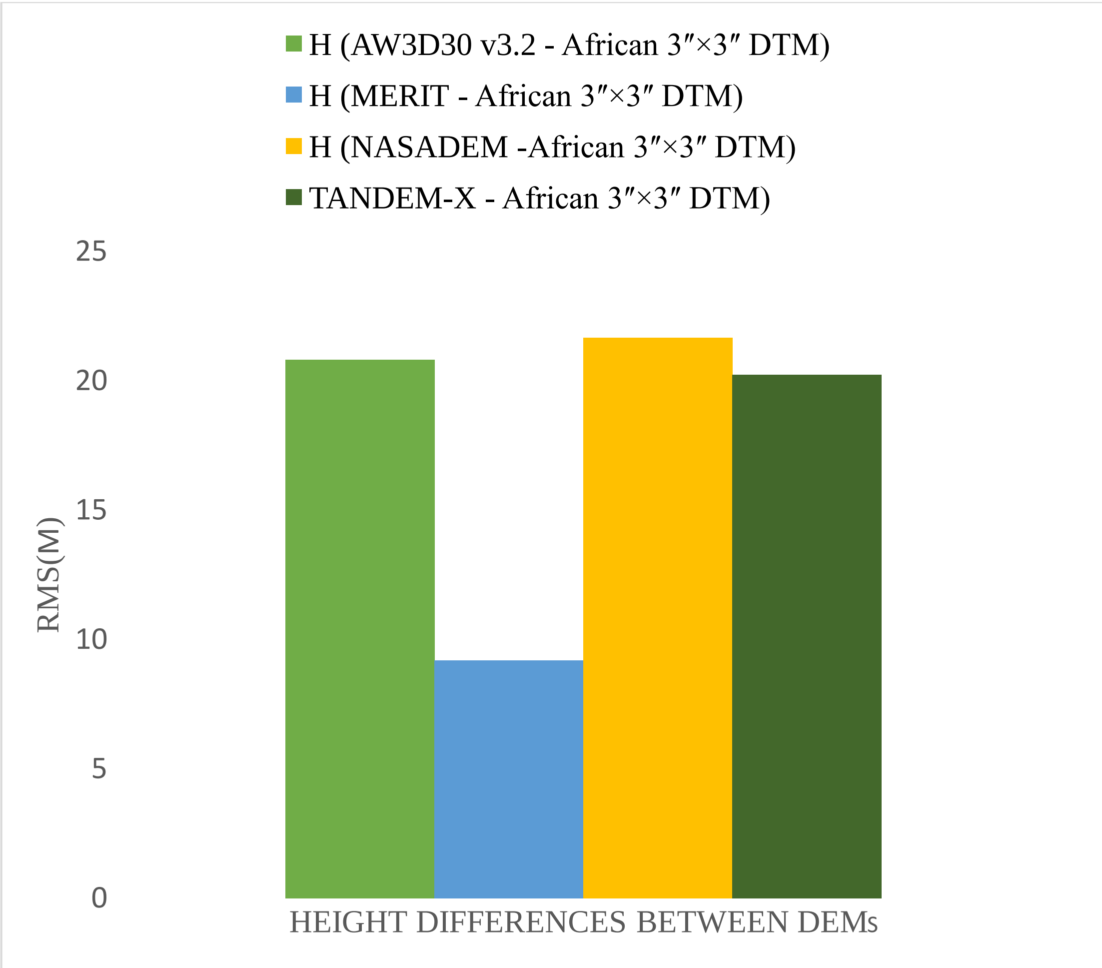

Figure 4.2: Statistical height differences between DEMs countrywide.

Performance level of height difference between GDEMs in twelve land covers based on their values of mean, SD and RMS as presented in figure 4.3. Generally, from the figure 4.3 the height difference between ALOS-v3.2 ″ vs Africa 3″×3″ DTM show better agreement in most land cover compared to all other GDEMs.

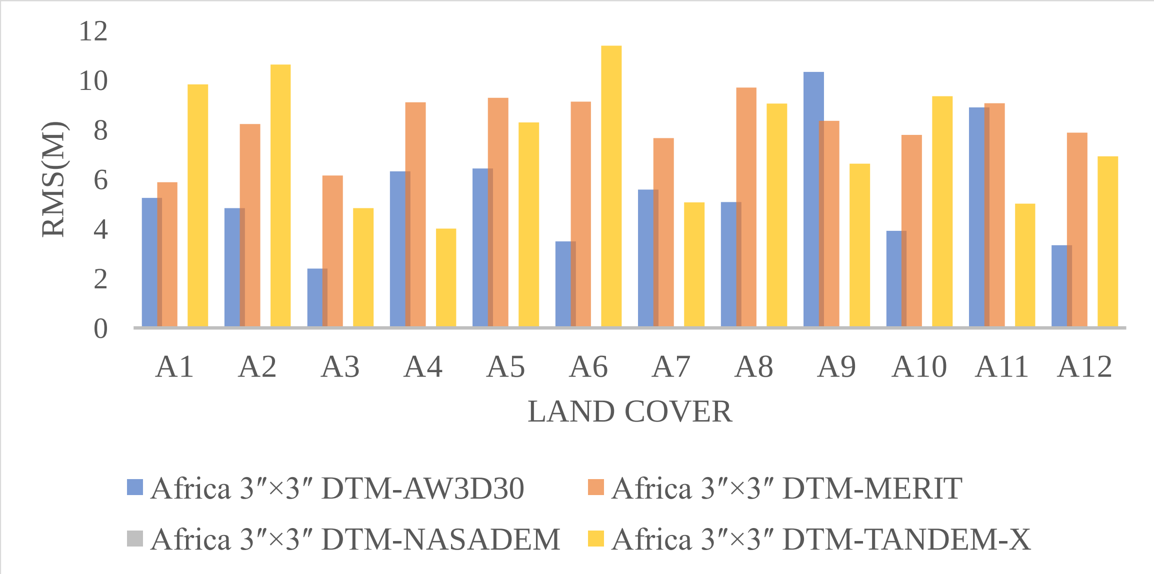

Figure 4.3: Statistical height differences between DEMs in land covers.

4.2.3 General Performance of Africa 3″×3″ DTM

The performance of Africa 3″×3″ DTM in countrywide is inferior to ALOS-v3.2 ″, NASADEM-3″ as well as MERIT 3″. The overall fit of Africa 3″×3″ DTM to the GPS ground controls is about 4m while for other three is around 3m except for TANDEM-X-3″ which is around 5m. Performance of Africa 3″×3″ DTM is best in flat and slightly terrain, where STD is 1m and RMS is 3.4m relative to GPS controls. Its performance is worst in flat and forested coastal terrain, where the STD and RMS are 9.8 and 11m respectively. Therefore, it can be said that, in general, the Africa 3″×3″ DTM performs better in flat and slightly terrain and its performance weakens in coastal forested terrains.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The objective of this research was to assess Africa 3″×3″ DTM and compare it with other DEMs which are; NASADEM-1″, MERIT 1″, TANDEM-X-3″ and ALOS-v3.2 ". The results showed that the performance of Africa 3″×3″ DTM in Tanzania is inferior compared to ALOS-v3.2 " and NASADEM-3″ which has mean 2.594, SD 1.889 as well as RMS of 3.506. Also, general performance of ALOS-v3.2 " was more superior with statistical mean of 1.814m, SD 1.367m and RMS 2.271m on which Africa 3″×3″ DTM had a mean of -0.899m, SD 4.605m and RMS 4.692m countrywide.

According to (Abd-Elmotaal, et al. 2017), the Africa 3″×3″ DTM was compared with the available point reference-checking data on land areas for a set of about 200 thousand points and most differences were below 20m and for the case of this research the differences obtained countrywide based on mean, SD and RMS were -0.899m, 4.605m and 4.692m respectively. Hence, the results obtained on this research follow under 20m as the results discussed by (Abd-Elmotaal, et al. 2017).

Based on these results, it is obvious that ALOS-v3.2 " offers higher accuracy and reliability for elevation data in Tanzania, highlighting its suitability for various applications. The performance comparison emphasizes the need to consider ALOS-v3.2 " or NASADEM-3″ as preferred choices over Africa 3″×3″ DTM in the context of elevation-related studies and projects."

5.2 Recommendation

Further assessment of Africa 3″×3″ DTM should be done by considering other land covers apart from those which have been used on this research, this will help to assess the performance of Africa 3″×3″ DTM in different terrains covering large part of Tanzania.

Further assessments of Africa 3″×3″ DTM should be done using other GDEMs apart from those which have been used on this research, this may involve newly released GDEMs (ALOS-v4.0 ").

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