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HORIZONTAL AND VERTICAL VALIDATION OF DAR ES SALAAM DTM USING ABSOLUTE AND RELATIVE TAREF11 AND OTHER GPS CONTROLS

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BSc Geomatics

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HORIZONTAL AND VERTICAL VALIDATION OF DAR ES SALAAM DTM USING ABSOLUTE AND RELATIVE TAREF11 AND OTHER GPS CONTROLS

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A Dissertation Submitted to the Department of Geospatial Science and Technology in Partial Fulfillment of the Requirements for the Award of Degree of Bachelor of Science in Geomatics (BSc. GM) of the Ardhi University.

CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the Ardhi University dissertation titled ***"*Horizontal and Vertical Validation of Dar es Salaam DTM Using Absolute and Relative TAREF11 and other GPS Controls*"*** in partial fulfillment of the requirements for the award of degree of Bachelor of Science in Geomatics at Ardhi University.

……………………………………..

Ms. REGINA V. PETER

(Supervisor)

Date………………………..

DECLARATION AND COPYRIGHT

I, MBAGA YONAZA declare that this research is my own original work and that to the best of my knowledge, it 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.

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DEDICATION

I would like to dedicate this research to my loving parents. Their unwavering support financially, encouragement, and sacrifices have been the driving force behind my academic journey. Their belief in my abilities and their constant reassurance have kept me motivated during challenging times. This research is a reflection of their love, guidance, and unwavering dedication to my education.

ABSTRACT

The aim of this research was to validate the Dar es salaam DTM horizontally and vertically using the absolute and relative TAREF11 GPS controls so that its accuracy and performance can be known for application.

The horizontal accuracy of the Dar es salaam DTM was done by extracting the (x, y) coordinates from the DTM to be used for comparison with the GGCPs coordinates. The accuracy was assessed basing on the Mean Error, RMSE and SD for both x-coordinates and y-coordinates. The results for the positional horizontal accuracy were as follows for x-coordinates the Mean Error, RMSE and SD were -0.17m, 0.18m and 0.19m. Also, For the y-coordinates the Mean Error, RMSE and SD were -0.20m, 0.22m and 0.22m. The results when combined provides overall horizontal Mean error, RMSE and SD of -0.36m, 0.40m and 0.41m. Thus, with minor positional shifts the Dar es salaam DTM horizontal accuracy proves to be closely matched with the reference GPS controls.

For the vertical validation using absolute approach the Dar es salaam DTM was assessed basing on statistical analysis at 99% confidence level of the height differences between the GGCPs and the DTM. The results for Mean, Standard Deviation (SD), and Root Mean Square (RMS) were 0.7m, 0.98m and 1.2m. The value of mean, SD and RMS respectively shows that the DTMs is accurate and that the DTM is much closer to the TAREF11 GPS controls. The Dar es salaam DTM can be applicable for various purposes including river engineering and drainage assignments, infrastructure developments and environmental analysis due to its accuracy and performance.

For the vertical validation using relative approach, the statistical analysis of the difference of change in orthometric heights between GGCPs and DTM at a 99% confidence level provided the Mean, Standard deviation and RMS of -0.1m, 1.1m and 1.1m. Vertical validation using relative approach in terms of mean, root mean square and the standard deviation the Dar es salaam DTMs vertical accuracy shows it can be applicable for construction projects and environmental analysis.

Keywords: TZG13, TAREF11 GPS Controls, Dar es salaam DTM, Horizontal and Vertical validation, Absolute and Relative approach.

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ABBREVIATIONS AND ACCRONMYS

DEM	Digital Elevation Model
DSM	Digital Surface Model
DTM	Digital Terrain Model
GCP	Ground Control Point
GDEM	Global Digital Elevation Model
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
InSAR	Interferometric Synthetic Aperture Radar
LiDAR	Light Detection and Ranging
RMS	Root Mean Square
RMSE	Root Mean Square Error
SD	Standard Deviation
TAREF11	Tanzania Reference Frame 2011
TZG13	Tanzania Geoid Model of 2013
WGS84	World Geodetic Reference System

CHAPTER ONE
INTRODUCTION

1.1 Background

Digital terrain model (DTM), is a digital representation of the elevation of the surface and other geographical elements and natural features, such as rivers, ridgelines, etc. Digital Terrain Models (DTMs) are important tools for mapping and analyzing the topographic surface of an area. Accurate DTMs are crucial for various applications such as land use planning, environmental analysis, and infrastructure development. However, the accuracy and precision of DTM can vary widely depending on the quality of the data used to create them and the methods used to process and validate them (Balasubramanian, 2017).

Digital elevation models (DEMs) are quantitative measurements of Earth's elevation with respect to any reference datum. DEMs provide a three-dimensional view of Earth's topography and can be used to derive additional attributes such as slope, aspect, and curvature which used for various application (Athmania & Achour, 2014). DEMs can be created from ground surveys, digitizing existing hardcopy topographic maps or by remote sensing technique which includes photogrammetry, airborne and space borne Interferometry Synthetic Aperture Radar (InSAR) and Light Detection and Ranging (LIDAR) (Balasubramanian, 2017). DEMs are widely used in numerous activities in the world including; hazard monitoring, natural resources exploration, agricultural management, groundwater modeling, estimation of the volume of proposed reservoirs, determining landslide probability and flood prone area mapping *(ibid).* Also, in Geomatics field, DEM are used to provide height information which used for precise gravimetric geoid determination (Abbak, 2014). In some countries, a DTM is actually synonymous with a DEM. This means that a DTM is simply an elevation surface representing the bare earth referenced to a common vertical datum. In United States and other countries, a DTM has a slightly different meaning. A DTM is a vector data set composed of regularly spaced points and natural features such as ridges and break lines. A DTM augments a DEM by including linear features of the bare earth terrain.

Variety of these data sources for elevation models signifies that it will become easy to fill data gaps for areas with little data over remote regions, the most basic representation of elevation model is a map which can show elevation, slope, reflectance, or contours. Elevation model is a raster dataset that is available globally or regionally depending on the manufacturer's preference, it can be free or commercial, with a structure organized in a square digital elevation grid, Triangular Irregular Network (TIN), and a set of digital line graph contours or random points, and its accuracy depends on the region of study, the nature of the environment, algorithm development methods, input data, data processing, and sensor resolution. It is critical to assess and compare the quality of these data in order to determine which elevation model best fits the area of interest (Apeh, 2019). Examples of the elevation models are DEM, DSM, and DTM.

Digital Surface Models (DSMs), is a digital representation of the elevation of the surface and features both natural and man-made such as power lines, trees, vegetation, towers, and buildings. The laser scanner is mounted on the aircraft and sends pulses of light to the Earth and then reflects to the sensor, the time of reflection and difference of reflection provide elevation data. However, DSM can also be obtained automatically from stereoscopic satellite images, as well as from stereoscopic digital aerial photographs with different resolutions.

DEM errors are generally categorized as either systematic, blunders, or random. Systematic errors result from procedures or systems of DEM generation and cause bias or artifacts in the final product such as vertical elevation shifts, fictitious features, and improper interpretation of terrain surfaces due to effects of trees, buildings, and shadows. Blunders errors are vertical errors that exceed the maximum absolute error permitted caused by misreading contours, transposing numeric values, erroneous correlations, or careless observations during the data collection process. After removing systematic and blunders errors, the remaining errors are known as random errors. The result owing to accidental and unknown combinations of causes beyond the control of the observer. These various errors often produce cell or groups of cell values that are artificially lower/higher in altitude than their surrounding cells (Moawad & Aziz, 2018).

Digital Elevation models are very useful in various applications such as land-use planning, infrastructural project management, hazard monitoring, soil science, hydrology, Rendering 3D visualizations, flood risk assessment, flight planning, hydrology, and land use planning. In geomatics, DEMs are applicable in the provision of elevation data which are useful in gravity field modeling, and precise gravimetric geoid determination (Abbak, 2014). Engineering for designing infrastructure projects like roads, bridges, and buildings, it's crucial to understand the terrain's elevation and slope. In hydrology, DTMs are essential for studying water flow patterns, catchment areas, and flood modeling. In environmental analysis, DTM help in analyzing terrain suitability for land use planning, natural resource management, and habitat modeling. Visualizations DTMs are used to create realistic 3D visualizations and terrain representations for simulation. Regarding the Dar es salaam digital terrain model the following information is provided below.

Dar es salaam digital terrain model, is a continuous digital terrain model covering the whole Dar es salaam area. It was created on 1st December 2017. The Dar es salaam DTM have a spatial resolution of 5 meters. The DTM contains elevation information about the terrain, all objects above the terrain level such as buildings and trees are removed. However, the Horizontal and vertical accuracy of the Dar DTM is not known apart from the known spatial resolution of 5 metres. The Dar es Salaam digital terrain model lacks the horizontal accuracy thus it is validated horizontally.

Horizontal validation of a Digital Terrain Model (DTM) refers to the process of assessing the accuracy and positional reliability of the model in the horizontal dimension. It involves comparing the coordinates (x, y) of specific points or features in the DTM with their corresponding coordinates in a reference dataset, such as ground control points (GCPs) obtained from Global Navigation Satellite Systems (GNSS) or other accurate surveying techniques. (Xiong & Tang, 2022). The DTM also needs to be validated vertically to understand the vertical accuracy of the Dar es Salaam DTM.

Vertical validation of Digital Terrain Models (DTMs) involves evaluating the accuracy and reliability of the elevation data in the vertical dimension. It aims to assess how well the DTM represents the actual elevation values of the Earth's surface. The validation process typically compares the elevations from the DTM with ground-truth reference data obtained through precise surveying methods, such as Global Navigation Satellite Systems (GNSS) or accurate leveling. (Blomley, Fisher, & Wood, 2016). This is important to ensure that the DTM can be used for accurate spatial analysis, mapping and other applications that require accurate elevations, such as flood and landslide risk assessment, hydrological modeling, or 3D visualization.

Additionally, the study uses the term "validation" which is the process of evaluating a system or its component(s) with the intent to determine that it satisfies its required needs and specifications (Liu, 2019). In GIS and remote sensing, validation of digital elevation models (DEMs) is crucial to ensure the data is accurate and reliable for the intended applications (Jin, 2018)

In Tanzania validation studies have been conducted on the GDEMs and other DEMs in regions or even for the country as a whole, but there is very limited research that specifically addresses the unique geographical and topographical characteristics of Dar es Salaam region. The validation of the Dar es salaam digital terrain model is going to be relevant due to the city's economic significance, urban planning needs, and vulnerability to environmental hazards. Accurate terrain information from the DTM is crucial for various applications such as infrastructure development, flood modeling, and disaster preparedness.

In Tanzania especially at Ardhi University validation of many public GDEMs has been going on for almost two decades (Peter, 2018). This has been done to search for the GDEM which will best fit the GGCPs so as to be used in different development activities and applications. The following from researches conducted in Tanzania on validation of public GDEMs;

i. Assessment of vertical accuracy of ASTER-1"-v2, ALOS-1"-v2, SRTM- 1"-v3 and ASTER-1"-v3 using GPS ground control points in Tanzania. Basing on the SD value, the results showed that ALOS-1"-v2 is much closer to GPS controls compared to ASTER- 1"-v3, ASTER-1"-v2 and SRTM-1"-v3. Also basing on the smallest value of mean, ASTER- 1"-v2 was the best GDEM compared to the other GDEMs (Agustino, 2020).
ii. Validation of SRTMv3-1", Jdef DEM and SRTMv3-1" using Tanzania 2nd order geodetic control network and its comparison to SRTM- 3 CGIAR-CSI v4.1 was conducted in which the results show that SRTMv3-1" performed much better than JdeF DEM and SRTM-3 CGIAR-CSIv4.1 (Mwansasu, 2016).

Depending on the research conducted on validation of the public GDEMs, the DEMs which have shown to perform better are SRTM -1"-v3 (Ulotu, 2017) and ALOS-1"-v2 (Agustino, 2020) Since there are DEMs like NASADEM and ALOS-1"-v3.1.Therefore, this research will validate the horizontal and vertical accuracy of the new Dar es Salaam DTM using absolute and relative TAREF 11 and other GPS controls for the determination of its accuracy and reliability.

1.2 Statement of the Problem

The accuracy of digital terrain models (DTMs) is important for various applications such as land use planning, environmental analysis, and infrastructure development. However, it is not clear whether the Dar es Salaam DTM accurately represents the actual terrain of the region. The results of the horizontal and vertical validation will help to determine the overall accuracy of the DTM and identify any biases or errors that may affect its reliability and usefulness.

1.3 Objectives

1.3.1 Main Objective

The main objective of the research is to validate horizontally and vertically the Dar es Salaam digital terrain model (DTM) using the TAREFF11 GPS controls.

1.3.2 Specific objectives

1. To compare the Dar es Salaam digital terrain model (DTM) to TAREF11 GPS ground controls.
2. To assess the accuracy of the DTM using both absolute and relative approach of validation.
3. To determine the overall accuracy of the DTM.

1.4 Hypothesis

The Dar es salaam digital terrain model have a good horizontal and vertical accuracy than the public DEMs.

1.5 Significance of the Research

The significances of this study are as follows;

i. After the Dar es salaam DTM is validated, it will be more useful for various applications such as land use planning, environmental analysis, and infrastructure development.
ii. Validating DAR DTM can help to identify any biases or errors that may affect its reliability and usefulness. This is important for ensuring that the DTM is accurate and can be trusted for various applications.
iii. The results of the validation may also provide insights into the effectiveness of different validation techniques in assessing the accuracy of DTMs. This information could be useful for other researchers who are working on DTMs for other regions.
iv. By identifying and addressing any issues with the Dar es Salaam DTM, the research may contribute to the overall quality and reliability of DAR DTM as a tool for mapping and analyzing terrain. This could have significant implications for various fields that rely on.

1.6 Beneficiaries

The people and organizations who rely on accurate DTMs, such as government agencies, civil engineers, environmental scientists, researchers and geographers. Validated accuracy of the DTM will likely make it more useful and reliable for various applications such as land use planning, environmental analysis, and infrastructure development.

1.7 Scope and Limitations

The study area is limited to the Dar es Salaam region. The research will focus mainly on horizontal and vertical validation of the Dar es Salaam digital terrain model (DTM) using the available TAREF 11 GPS controls as shown in the Figure (1.1) below;

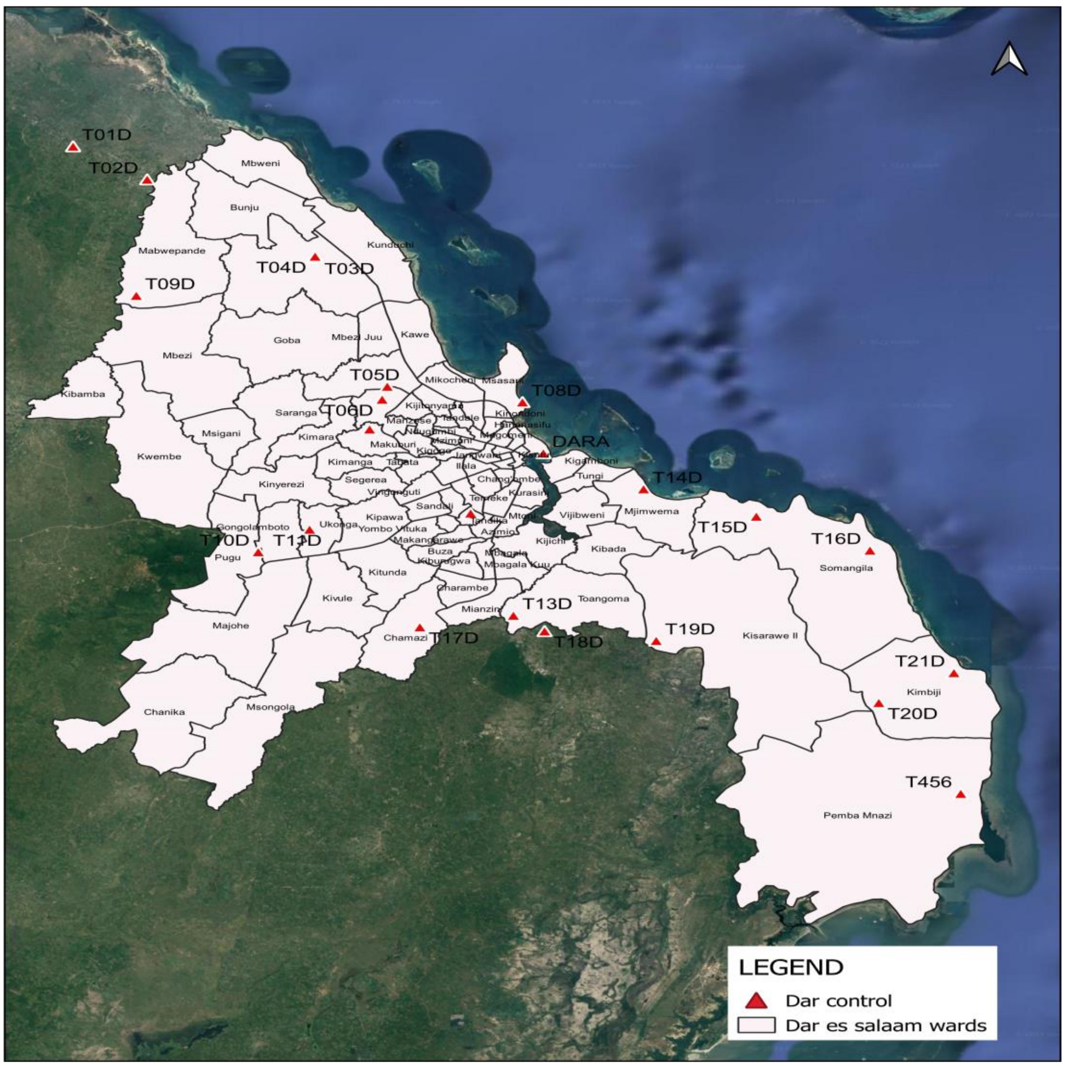

Figure 1.1: Distribution of control points in Dar es salaam region

1.8 Structure of Dissertation

There are five chapters in this research. Chapter one introduces the study by explaining the background of the study, statement of the problem, main objective, research hypothesis, significance, beneficiaries of the research and scope of the research. Chapter two is all about literature review concerning the method of assessment of vertical performance of DEM, method of analysis of the result and the method selected to be used in this research. Chapter three details the methods used, data acquisitions, data descriptions, data preparations, mathematical models used in computations and software used in this research. Chapter four gives the results and discussions of the results. Chapter five consists of conclusion drawn from this study and recommendations for the future related researches.

CHAPTER TWO

LITERATURE REVIEW

Digital Terrain Models (DTMs), is a digital representation of the elevation of the surface and other geographical elements and natural features, such as rivers, ridgelines, etc, most of the time it is defined according to the area of interest for example in USA they are defining it as a synonym of DEM and in other areas they as a vector data set consisting of dots at regular intervals and natural features such as mountain ridge and breaking lines (a line in the model showing a marked cut in the slope of a surface, such as road or a stream).

Digital Surface Models (DSMs), is a digital representation of the elevation of the surface and features both natural and man-made such as power lines, trees, vegetation, towers, and buildings. The DSM is different from the DEM and DTM because of its ability to capture both man made and natural features.

DEM is a digital representation of the earth's surface elevation. DEMs can be created from ground surveys, digitizing existing hardcopy topographic maps or by remote sensing technique which includes photogrammetry, airborne and space borne Interferometry Synthetic Aperture Radar (InSAR) and Light Detection and Ranging (LIDAR) (Athmania & Achour, 2014).

2.1 Methods for DEM Creation Using Remote Sensing Techniques

Light detection and ranging (LiDAR) is the remote sensing technique that involves emitting pulses of laser light from an aircraft or satellite towards the ground and measuring the return time LiDAR-equipped aircraft carries a pulsing laser, airborne GPS for determining sensor location, an inertial measuring unit for measuring orientation of the sensor to the ground, a high accuracy clock to process data in real-time and data storage equipment. LiDAR is among the best remote sensing technique that is capable of capturing remote and other inaccessible locations, collecting data at any time of day or night, and the ability to penetrate vegetation hence, one pulse can produce multiple returns reflected off different surfaces (Ravibabu & Kamal, 2008). LiDAR appears to be incredibly fast, however, it is very technical.

Radar is shortened version of Radio Detecting and Ranging which determines the range, angle, or velocity objects, there are two kinds of radar types in general use which are dual antenna radar (Topography Mission (SRTM) use two radar images simultaneously captured antennas to create elevation models and single-antenna radar. Radar has a long wavelength and it is possible to measure the phase of received signal together with information on the aircraft's flying height, this phase information can be combined with ground control data and used to calculate the elevation of the underlying ground surface, particularly where overlapping radar images are available for the same study area.

Photogrammetry is the science of taking measurements from aerial photographs or other remotely sensed data. The principle of elevation measurement in photogrammetry is very similar to that of stereo vision, where an object is viewed from two different angles simultaneously allowing a distance ratio to be calculated by trigonometry. In photogrammetry two different views of an object are provided by two images taken from different positions. This may be two successive, overlapping frames taken during an airplane or satellite or even two images taken months apart, providing the land surface has not altered over the intervening period. The output vector data are points and/or contour polylines. Aerial photography uses photographs taken from at least two different points with photogrammetry. (Martin, Wright, & Treves, 2018).

The steps that are encountered during the generation process of each DEM, regardless of which technology, can introduce errors to the final DEM. *(ibid).* This led to assessments of the DEM's accuracy in many different locations throughout the world for improving of the next generation of GDEMs (Suwandana, 2014). The assessment of GDEMs provide the quality of each DEM which involves the measure on an absolute and relative accuracy. Absolute accuracy accounts for all effects of systematic and random errors and relates the modeled elevation to the true elevation with respect to an established vertical datum (geo-referenced). Relative accuracy is a measure of the point-to-point vertical accuracy within a specific dataset (Luebke, 2019).

Elevation dataset for specific region around the global have been analyzed in numerous studies, one commonly used method is to compare the DEM with high quality ground control points (GCPs). The GCPs can be located using different methods, some of them are through topographic map, global navigation satellite system (GNSS) and high-quality radar altimetry data such as ICESat/GLASS.

2.2 Methods for DEM Validation

Vertical accuracy of elevation data is the possible height difference between the modelled height and the actual height of the land. There are different methods of creating elevation data, such as

LiDAR, photogrammetry or radar, which produce different levels of accuracy. Also, there are various public dataset of DEMs with numerous versions and the required DEM is the one which is most accurate than the rest. The determination of the DEM with best accuracy is performed in the world using different method for DEM assessment. The following are the method for the assessing the vertical accuracy of the DEM.

2.2.1 Validation Using the GGCP

The method involves the assessment of DEM's elevations using the GGCPs elevation. Before the assessment is undertaken, the vertical datum of the DEMs must be identified and that of the reference data (Luebke, 2019). The geometric heights of the GGCPs have to be converted to Orthometric height by subtracting the geoid height of the GGCPs points so that to make the uniformity between the elevations (Agustino, 2020). Vertical accuracies of GDEM are assessed by comparing the difference between the GGCP elevation and the corresponding DEM value. Since the GGCPs are not directly in accord with a DEM point location, for every control point location, the corresponding DEM elevation is extracted through the bilinear interpolation. Positive differences mean the interpolated DEM elevation is correct, the elevation of the DEM is lower than that of the GGCP. Negative differences represent the locations where the DEM elevation is higher than the GGCP elevation. After the error estimation the statistical maximum and minimum, mean, standard deviation and root mean square are estimated to portray the accuracy of the DEM relative to the GGCPs. This method is preferable due to the accuracy of ground control points since they are fixed, so has high accuracy which increase the spatial accuracy of the data. Although the GGCPs are not available in areas where there is dense forest and areas with rough/mountainous terrain due to the difficult of provision of the GCPs, hence the method is not more preferable to such kind of areas (Ulotu, 2017).

2.2.2 Validation Using ICESATS/GLAS

ICESat is a satellite mission which has launched in 2003 to measure ice sheet mass balance, cloud and aerosol heights as well as land topography and vegetation characteristics. GLAS is a space based full waveform LIDAR and sole instrument onboard ICESat. The Instrument records a full waveform for each laser pulse to reach the earth surface and return back to the receiver to obtain ICESat elevation data. ICESATs land elevation data is a valuable source for assessment of DEM vertical accuracy particular in areas where there are limited ground control points due to difficult weather conditions (Pagnutti & Ryan, 2009). In this method an algorithm was developed to determine the vertical accuracy of a given DEM using the ICESat GLAS data product as a reference, using MATLAB software. The algorithm reads a given DEM and performs an elevation assessment of DEM using the ICESat GLAS data product. Bi-linear interpolations are performed to locate the ICESat GLAS laser shot on to the given DEM. The same analysis used to validate the ICESat GLAS product described above is used to determine the accuracy of a given DEM. This method is more usefully in the areas where there is inadequate of GGCPs but its disadvantages is it may lead accuracy assessment problems when comparing DEM created from old air photos with recent ICESAT data. This leads to the vertical shift due to the temporal gap between the photo and ICESAT.

2.2.3 Validation Using Topographic Maps.

Topographic map shows the shape of the land surfaces of the Earth and provides the spots height as well as contour line which are used as a secondary data for evaluating the vertical accuracy of DEM (Mapunda, 2019). Topographic map elevation is represented by contour lines and spot heights produced by ground surveying techniques and aerial photographs and other sources, the contour lines or spot height are interpolated to create the DEMS (Ravibabu & Kamal, 2008). Collection of the spot levels from the topographic map as reference elevation is done in Arc GIS (Agustino, 2020). The SPOT elevation values are subtracted from the elevation values in the topographic DEM to create residual surfaces (Ravibabu & Kamal, 2008). This method is not commonly used since the maps are old because most of them were produced in 1960's to 1980's.

2.2.4 Validation Using Other Dems

The method involves the assessment of the differences in elevation between the GDEMs all over the area of interest to check their agreement or disagreement at the common grid intersection (Zhihua & Peng, 2017). This approach has been used in China where the vertical accuracy of ASTER GDEM version 1 data was validated by comparing it with CGIAR-CSI SRTM Version 4.1. The analysis of result using statistical approach is then performed by comparing the one with small RMS and Standard deviation.

2.2 Method for Result Analysis

2.2.1 Statistical Analysis

A low standard deviation implies that the values tend to be close to the set's mean, whereas a high standard deviation shows that the values are spread out over a wider range. The root mean square (RMS) of a set of measurements is a measure of their magnitude. It demonstrates the number's average size, regardless of whether it is positive or negative. RMS is capable of including both random and systematic error. They also assess the quality of the surface and reveal the distribution of deviations on each side of the mean value. The majority of studies have compared the RMS and standard deviation. (Jin, 2018)

2.3 Methods for Horizontal Accuracy Assessment

Horizontal validation of a DTM involves assessing the accuracy of the DTM's horizontal or planimetric coordinates, which represent the X and Y coordinates on the Earth's surface. It aims to determine how well the DTM matches the actual ground surface. This validation is essential to ensure that the DTM is reliable for various applications, such as engineering design, flood modeling, and geographic information system (GIS) analysis (Yu & Li, 2012)

Horizontal validation of Digital Terrain Models plays a crucial role in determining the reliability of topographic data for various applications. This literature review highlights the importance of using ground control points, resampling techniques, Monte Carlo simulations, and geostatistical analysis to assess horizontal accuracy. It also emphasizes the need to account for interpolation methods and terrain characteristics during validation. Here are some methods related to horizontal validation of DTMs:

2.3.1 Validation Using Ground Control Points (GCPs) Method

The GCPs method is one of the most widely used approaches for horizontal validation. It involves selecting several well-distributed reference points on the ground with known and accurate coordinates. GCPs are surveyed points with known and accurate coordinates on the ground. These GCPs serve as benchmarks to compare the corresponding points in the DTM. The differences between the DTM and GCP coordinates are analysed using statistical metrics, such as Root Mean Square Error (RMSE), mean error, and standard deviation. They serve as reference points to compare the corresponding coordinates in the DTM. Using GCPs is a common method for horizontal validation (Olsen, 2011).

2.3.2 Resampling and Cross-Validation Techniques

In certain cases, DTMs are derived from remote sensing data or aerial imagery, leading to grid-based representations. In such scenarios, resampling techniques, such as bilinear or cubic interpolation, are employed to transform the DTM to match the GCPs' coordinate system. Cross-validation techniques, including k-fold cross-validation, are also utilized to assess the robustness of the validation results by dividing the GCPs dataset into subsets for testing and validation. (Glick & Devin, 2016)

2.4 Statistical Analysis for the Horizontal Accuracy Assessment

Root Mean Square Error (RMSE) is a widely used metric to evaluate the horizontal accuracy of a DTM. It calculates the differences between the DTM and GCP coordinates, squares the differences, takes the mean, and then computes the square root. The lower the RMSE value, the better the horizontal accuracy of the DTM. Mean Error represents the average difference between the DTM coordinates and the corresponding GCP coordinates. A mean error close to zero indicates a good horizontal accuracy. Standard Deviation (SD) measures the dispersion or spread of the differences between the DTM and GCP coordinates. A lower SD suggests a more accurate DTM (Rawat, 2012)

2.5 Method Selected for this Research

The method selected for validation of the DTM is by using the TAREF11 GPS control, they have a great precision which increases the spatial accuracy of the DTM. The DTMs vertical accuracy is measured by comparing the difference between the GGCP elevation and corresponding DTM value. The horizontal accuracy is done by comparing the GGCPs coordinates with the corresponding DTMs coordinates whereby the positional accuracy is determined for validating the Dar es salaam DTM. Also, the statistical analysis for both horizontal and vertical accuracy is assessed and validated.

CHAPTER THREE

METHODOLOGY

This research focuses on the validation of Dar es salaam DTM using the TAREF 11 GPS ground control points. Therefore, this section focuses on the methods, procedures and data collections carried out in this research.

3.1 Horizontal Validation

Horizontal validation was done by first obtaining the x, y coordinates from DTM. The GGCPs (x, y) coordinates were overlayed on the DTM to extract the (x, y) coordinates by points in the QGIS software.

3.1.1 Horizontal Differences of the GGCPS and DTM Coordinates.

The difference of the coordinates between the GGCPs and DTM was done to verify the position of features on the DTM match the actual location on the earth's surface this was done using the Equation (3.1) and (3.2) below;

$\Delta X^{GGCP,DTM} = X^{GGCP} - X^{DTM}$……………………………………………………………..(3.1)

$\Delta Y^{GGCP,DTM} = Y^{GGCP} - Y^{DTM}$…………………………………………………………...(3.2)

Where;

$\Delta X^{GGCP,DTM}$ is the difference in eastings coordinates between the GGCPs and the DTM

$\Delta Y^{GGCP,DTM}$ is the difference in northings coordinates between the GGCPs and the DTM

X^{GGCP} is the eastings coordinates of the GGCPs

Y^{DTM} is the northings coordinates of the DTM

3.1.2 Statistical Measures on the Horizontal Differences Between GGCPs and DTM.

a) Mean Error

Used to compute the mean of differences between GGCPs and DTM coordinate points. Mean is obtained through the mathematical relation in Equation (3.3) and (3.4) below;

$\Delta X_{mean} = \frac{\sum \Delta X}{n}$..(3.3)

$$\Delta Y_{mean} = \frac{\sum \Delta Y}{n} \qquad (3.4)$$

Whereby;

ΔX_{mean} is the mean of the difference in eastings coordinates

ΔY_{mean} is the mean of the difference in northings coordinates

ΔX is the difference in eastings coordinates of the GGCPs and DTM

ΔY is the difference in northings coordinates of the GGCPs and DTM

n is the number of GGCPs

b) Root Mean Square Error

The root mean square between the value differences between the GGCPs and DTMs coordinate points. The RMS is obtained through the mathematical relation below

$$RMSE_x = \sqrt{\frac{\sum(\Delta X)^2}{n}} \qquad (3.5)$$

$$RMSE_y = \sqrt{\frac{\sum(\Delta Y)^2}{n}} \qquad (3.6)$$

$$RMSE = \sqrt{RMSE_x^2 + RMSE_y^2} \qquad (3.7)$$

c) Standard Deviation

Standard deviation is the measure of amount of variation or dispersion of a set of values. A 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. The Standard deviation is obtained through the Equation (3.7) and (3.8) below;

$$SD_x = \sqrt{\frac{\sum(\Delta X)^2}{n-1}} \qquad (3.8)$$

$$SD_y = \sqrt{\frac{\sum(\Delta Y)^2}{n-1}} \qquad (3.9)$$

3.2 Vertical Validation Using Absolute Approach

The following are the procedures for vertical accuracy validation using the absolute approach as described below;

3.2.1 Conversion of GGCPs to TZG13 Orthometric Height

TAREF 11 GPS ground control points are the ellipsoidal heights, they are converted to orthometric height by using GNSS levelling equation so as to have the same format as the heights of DTM. Therefore, by using the geoidal height from TZG13, GGCPs ellipsoidal height are converted to orthometric height. This is done through Equation (3.1) below.

$$H_{TZG13}^{GGCP} = h^{GGCP} - N_{TZG13} \quad \text{(3.10)}$$

Where;

H_{TZG13}^{GCCP} is the orthometric height of GGCPs based on TZG13

h^{GGCP} is the ellipsoidal height of GGCPs

N_{TZG13} is the geoidal height of TZG13

Through mathematical relation above orthometric height is computed then it is compared with the DTM orthometric heights.

3.2.2 Dar es salaam DTM Orthometric Heights Extraction

The Dar es salaam DTM orthometric heights were obtained using the golden surfer software whereby the elevation information was extracted from the DTMs grid using the GGCPs latitude and longitudes as shown in Figure (3.1).

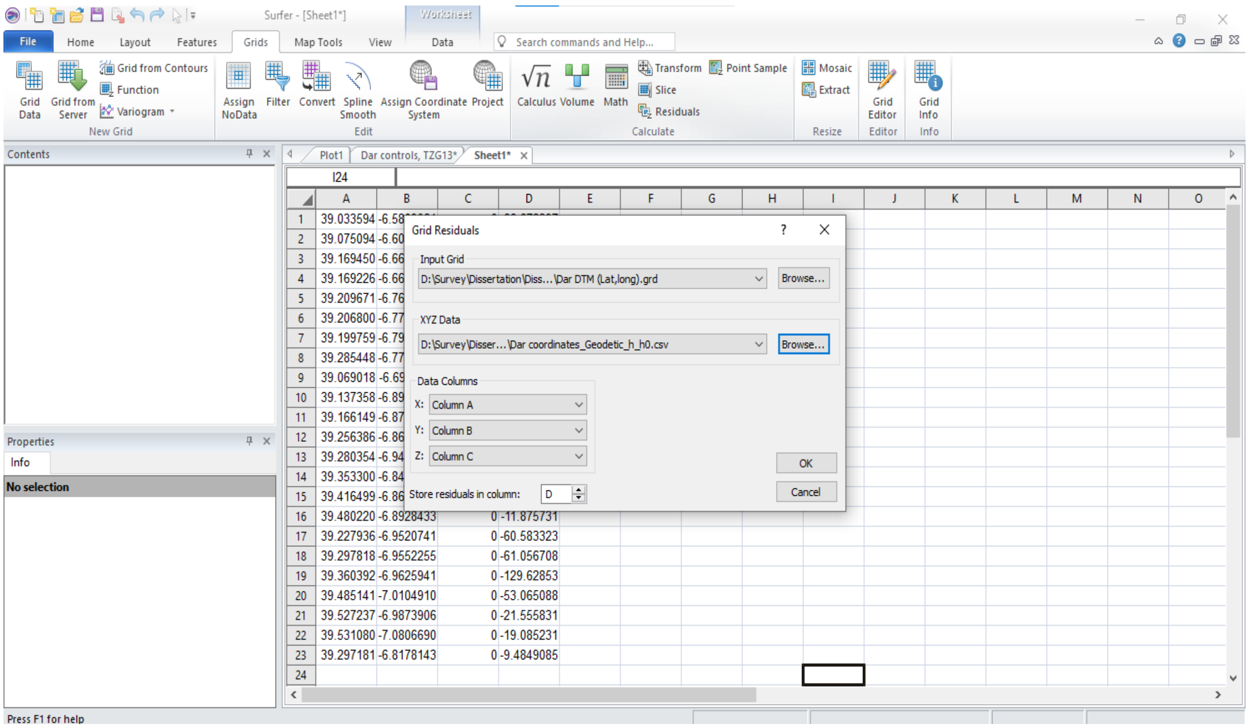

Figure 3.1 Shows the e*xtraction of the orthometric heights from the DTM*

3.2.3 Validation of the Dar es salaam DTM Using GGCPs

This involves taking the orthometric height differences between DTM and GGCPs obtained in mathematical relation below;

$$\Delta H_i^{GGCP,DTM} = H_i^{GGCP} - H_i^{DTM} \quad \ldots\ldots(3.11)$$

$\Delta H_i^{GPS,DTM}$ is height difference between GGCPs and DTM.

H_i^{GGCP} is the orthometric height of the GGCPs

H_i^{DTM} is the orthometric height of grid intersection of respective DTM

3.2.4 Statistics of Vector Differences Between the DTM and the GGCPs

The orthometric height differences between DTMs and GGCPs obtained in Equation (3.10) are used in the following mathematical relationship.

a) Mean Difference Between the GGCPs and DTMs

Used to compute the mean of height differences between DTM and GPS ground control points. Mean is obtained through the mathematical relation in Equation 3.11

$$\Delta H_{mean} = \frac{1}{n}\sum_{i=1}^{n} \Delta H_i^{GGCP,DTM} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.12)}$$

Where n is the number of GGCPs

b) Standard Deviation of the Height Difference Between the GGCPs and DTMs.

Standard deviation is the measure of amount of variation or dispersion of a set of values. A 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. The Standard deviation is obtained through the Equation (3.12) below;

$$\text{SD} = \pm\sqrt{\sum_{i=1}^{n} \frac{(\Delta Hi^{GGCP,DTM} - \Delta Hmean)^2}{n-1}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.13)}$$

c) The root mean square between the value differences in elevation between the GGCPs and DTMs. The RMS is obtained through the mathematical relation below;

$$\text{RMS} = \sqrt{\sum_{i=1}^{n} \frac{(\Delta Hi^{GGCP,DTM})^2}{n}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.14)}$$

3.3 Vertical Validation Using Relative Approach

The vertical validation was done by finding the change in elevation for the GGCPs but also change in elevation of the DTM. Then the difference of change in orthometric heights between the GGCPs and the DTM was performed using the mathematical relations below;

3.3.1 Difference in Change of Orthometric Heights Between the GGCPs and DTM

$$\Delta H^{GGCP} = H_A - H_B \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.15)}$$

$$\Delta H^{DTM} = H_A - H_B \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.16)}$$

$$\Delta H_i^{GGCP,DTM} = \Delta H_i^{GGCP} - \Delta H_i^{DTM} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.17)}$$

Whereby;

ΔH^{GGCP} is the orthometric height difference between two GGCP points

ΔH^{DTM} is the orthometric height difference between two points on the DTM.

$\Delta H_i^{GGCP,DTM}$ is the difference of the change in orthometric height between GGCP and the DTM

3.3.2 Statistical Analysis of the Relative Approach

a) Mean

$$\Delta H_{mean} = \frac{1}{n}\sum_{i=1}^{n} \Delta H_i^{GGCP,DTM} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.18)$$

b) Root Mean Square

$$\text{RMS} = \sqrt{\sum_{i=1}^{n} \frac{(\Delta Hi^{GGCP,DTM})^2}{n}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.19)$$

c) Standard Deviation

$$\text{SD} = \pm\sqrt{\sum_{i=1}^{n} \frac{(\Delta Hi^{GGCP,DTM} - \Delta Hmean)^2}{n-1}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.20)$$

3.4 Data Requirement, Description and Preparation

This includes the process of gathering and organizing data required for analysis. The dataset needed for this research are Da es salaam DTM dataset, TAREF 11 GPS Control Points and TZG13. They were obtained from various sources as follows below;

3.4.1 TAREF11 GPS Controls

They were obtained from Ministry of Lands Housing and Human Settlement Development (MLHHSD) through Surveying and Mapping Division (SMD). There are about 23 TAREF11 GPS controls points, these control points cover the Da es salaam region and are used in this research for validation of the DTM, they are in form of DAT (XYZ) containing northings, eastings and elevations.

3.4.2 Tanzania Geoid Model (TZG13)

The Tanzania Geoid model of 2013 were obtained from the Department of Geospatial Science and Technology (GST) at Ardhi University. The geoidal undulation obtained were used in conversion of the ellipsoid heights of GGCPs to TZG13 orthometric heights.

3.4.3 Dar es salaam DTM Dataset

The dataset was downloaded from the http://geonode.resilienceacademy.ac.tz the data were in form of TIF file format and so they were required to be converted into X,Y,Z format for further processing in the golden surfer software. Below is Figure (2.2) showing the Dar es salaam DTM view in Global mapper software.

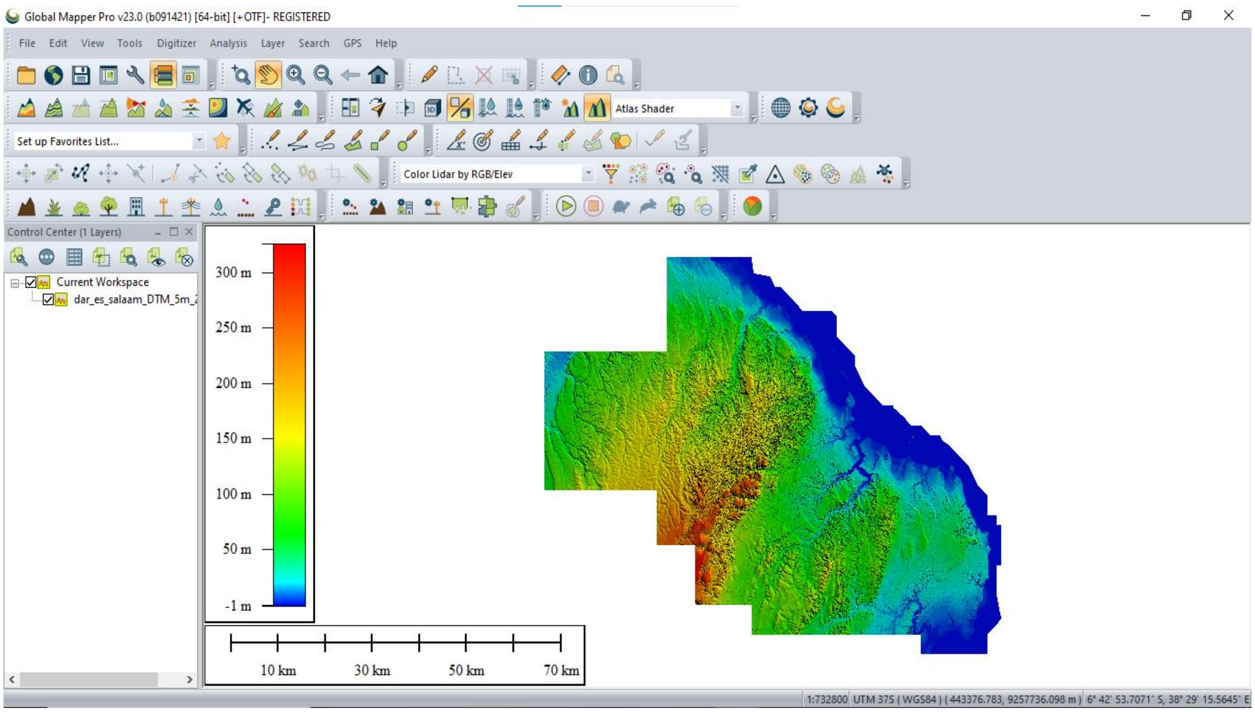

Figure 2.2 Shows the Dar es salaam DTM tile cover over the region

3.5 Software Package

Software that were used are as follows;

i. Golden Surfer

   This is used in conversion of DTMs to list grid format, merging smaller tiles of the DTMs into the area of interest and computations of the statistics required for this research.

ii. Microsoft Office (Excel and Word)

   The programs used mostly are Microsoft word for writing report and Microsoft excel for computing statistics attributes such as standard deviation, root mean square and the mean.

iii. Global Mapper

   This is used to open and convert the DTM from GEOTIFF format to XYZ for processing.

iv. QGIS Software

   This was used in extracting the DTMs coordinate points after the overlay of the GGCPs on the DTM.

CHAPTER FOUR

RESULTS, ANALYSIS AND DISCUSSION

This chapter deals with results obtained in this research and critical discussion of the results for the horizontal and vertical validation of the Dar es salaam DTM using both methods that is absolute and relative approach.

4.1 Results

The results include the statistics of height differences between the GGCPs and the Dar es salaam DTM for the absolute and relative approach. Also, the validation of the Dar es salaam DTM using GGCPs at 99% confidence level. The statistics of height differences include number of values, sum, mean, maximum value, minimum value, Standard deviation and Root Mean Square (RMS). These statistics are used as the measure of accuracy such that the lower the RMS the higher the vertical accuracy.

4.1.1 Horizontal Accuracy Validation Results

The horizontal validation done by finding the difference between the GGCPs and DTMs (x, y) coordinates gave the following results in Table 4.1 below;

Table 4.1 Difference in the (x, y) coordinates of the GGCPs and DTM

Description	Xggcp	Yggcp	Xdtm	Ydtm	Xggcp-Xdtm	Yggcp-Ydtm	$(Xggcp-Xdtm)^2$	$(Yggcp-Ydtm)^2$
T01D	503713.670	9272579.959	503713.794	9272580.076	-0.124	-0.117	0.015	0.014
T02D	508300.945	9269757.978	508301.175	9269758.222	-0.230	-0.244	0.053	0.060
T03D	518728.958	9263072.415	518729.138	9263072.663	-0.180	-0.248	0.033	0.062
T04D	518704.160	9263186.423	518704.304	9263186.598	-0.144	-0.175	0.021	0.031
T05D	523169.738	9252082.855	523169.878	9252083.099	-0.140	-0.244	0.020	0.060
T06D	522852.007	9250974.439	522852.165	9250974.593	-0.158	-0.154	0.025	0.024
T07D	522072.960	9248431.640	522073.153	9248431.818	-0.193	-0.178	0.037	0.032
T08D	531542.828	9250739.960	531543.021	9250740.041	-0.193	-0.081	0.037	0.007
T09D	507627.931	9259843.813	507628.067	9259843.967	-0.136	-0.154	0.018	0.024
T10D	515174.692	9237959.149	515174.849	9237959.325	-0.157	-0.176	0.025	0.031

T11D	518356.132	9239876.713	518356.592	9239877.275	-0.461	-0.562	0.212	0.316
T12D	528326.345	9241256.343	528326.495	9241256.529	-0.151	-0.186	0.023	0.035
T13D	530969.120	9232529.573	530969.357	9232529.810	-0.157	-0.237	0.025	0.056
T14D	539035.244	9243316.148	539035.368	9243316.342	-0.124	-0.194	0.015	0.038
T15D	546016.098	9240975.167	546016.303	9240975.218	-0.205	-0.051	0.042	0.003
T16D	553053.394	9238070.225	553053.480	9238070.423	-0.086	-0.198	0.007	0.039
T17D	525178.440	9231543.111	525178.561	9231543.245	-0.121	-0.134	0.015	0.018
T18D	532897.614	9231190.444	532897.850	9231190.731	-0.236	-0.287	0.056	0.082
T19D	539809.128	9230371.051	539809.332	9230371.219	-0.204	-0.168	0.042	0.028
T20D	553583.752	9225063.711	553583.846	9225063.854	-0.094	-0.143	0.009	0.020
T21D	558236.198	9227612.469	558236.274	9227612.662	-0.076	-0.193	0.006	0.037
T456	558649.062	9217299.941	558649.221	9217300.061	-0.158	-0.120	0.025	0.014
DARA	532836.709	9246380.951	532836.858	9246381.187	-0.149	-0.236	0.022	0.056

Table 4.2 Statistical analysis for the horizontal accuracy

	ΔX (m)	ΔY (m)	(ΔX+ΔY) m
Mean Error	-0.169	-0.195	-0.364
Root Mean Square Error	0.184	0.217	0.401
Standard Deviation	0.189	0.222	0.411

4.1.2 Vertical Accuracy Validation Result for the Absolute Approach

The validation of the Dar es salaam DTM was done by finding the difference in orthometric heights obtained from the GGCPs and the Dar es salaam DTM where by the smaller difference in heights indicate the closeness to the exact value of the GGCP while the large difference shows the deviation from the exact value. The results obtained in Table 4.3 shows the difference in orthometric heights.

Table 4.3 Height difference between the GGCPs and Dar es salaam DTM

Description	Longitude	Latitude	hggcp (m)	N_TZG13 (m)	Hggcp (m)	Hdtm (m)	(Hggcp-Hdtm) (m)
T01D	39.034	-6.581	40.046	-27.001	67.047	66.672	0.374
T02D	39.075	-6.606	12.683	-27.019	39.702	39.533	0.169
T03D	39.169	-6.667	96.609	-27.108	123.717	108.433	15.284
T04D	39.169	-6.666	100.090	-27.110	127.120	112.153	15.047
T05D	39.210	-6.766	73.705	-26.952	100.657	96.876	3.781
T06D	39.207	-6.776	106.193	-26.911	133.104	92.912	40.192
T07D	39.200	-6.799	79.783	-26.821	106.604	105.149	1.455
T08D	39.285	-6.778	-15.866	-27.309	11.443	10.950	0.493
T09D	39.069	-6.696	89.954	-26.719	116.673	116.624	0.048
T10D	39.137	-6.894	116.461	-26.408	142.869	141.747	1.123
T11D	39.166	-6.877	60.094	-26.541	86.635	86.703	-0.068
T12D	39.256	-6.864	25.960	-26.948	52.908	35.489	17.419
T13D	39.280	-6.943	15.586	-26.900	42.486	42.288	0.198
T14D	39.353	-6.846	-12.249	-27.467	15.218	13.619	1.599
T15D	39.416	-6.867	-24.658	-27.716	3.058	3.305	-0.246
T16D	39.480	-6.893	-14.760	-27.968	13.208	11.876	1.332
T17D	39.228	-6.952	34.399	-26.671	61.070	60.583	0.487
T18D	39.298	-6.955	34.678	-26.948	61.626	61.057	0.569
T19D	39.360	-6.963	101.118	-27.192	128.310	129.629	-1.318

T20D	39.485	-7.010	25.316	-27.672	52.988	53.065	-0.077
T21D	39.527	-6.987	-6.179	-27.939	21.760	21.556	0.204
T456	39.531	-7.081	-8.712	-27.873	19.161	19.085	0.075
DARA	39.297	-6.818	22.398	-27.258	49.656	9.485	40.171

The Table 4.4 shows the statistical analysis of the height differences obtained from Table 4.3. The statistical analysis was performed at 99% confidence level and the results show that the Dar es salaam DTM is accurate basing on the assessment of the Mean, SD and RMS obtained in the Table 4.4.

Table 4.4 Statistics of height differences between GGCPs and Dar es salaam DTM

Height Difference	NO	SUM	MIN (m)	MAX (m)	MEAN (m)	SD (m)	RMS (m)
H(GGCP-DTM)	17	11.516	-0.246	3.781	0.677	0.979	1.190

4.1.3 Vertical Validation Results for the Relative Approach

Relative method was done by finding the relative change in of the GGCPs and relative change in height of the DTM. The difference between the change in height of GGCPs and DTM provided the following results in Table 4.5 below;

Table 4.5 Relative height difference between the GGCPs and the DTM

Description	ΔHggcp (m)	ΔHdtm (m)	ΔHggcp-ΔHdtm (m)
T02D-T01D	-27.344	-27.139	-0.205
T03D-T02D	84.015	68.899	15.115
T04D-T03D	3.483	3.720	-0.237
T05D-T04D	-26.543	-15.277	-11.266
T06D-T05D	32.447	-3.964	36.411

T07D-T06D	-26.500	12.237	-38.737
T08D-T07D	-95.161	-94.198	-0.963
T09D-T08D	105.230	105.674	-0.444
T10D-T09D	26.197	25.122	1.074
T11D-T10D	-56.234	-55.043	-1.191
T12D-T11D	-33.727	-51.214	17.487
T13D-T12D	-10.423	6.798	-17.221
T14D-T13D	-27.268	-28.669	1.400
T15D-T14D	-12.160	-10.314	-1.845
T16D-T15D	10.150	8.571	1.579
T17D-T16D	47.862	48.708	-0.845
T18D-T17D	0.555	0.473	0.082
T19D-T18D	66.684	68.572	-1.887
T20D-T19D	-75.322	-76.563	1.241
T21D-T20D	-31.228	-31.509	0.281
T456-T21D	-2.599	-2.471	-0.128
DARA-T456	30.495	-9.600	40.095

The relative height differences were analysed by performing the statistics at 99% confidence level which gave the results in Table 4.6 below;

Table 4.6 Statistics of relative height difference between GGCPs and DTM

Change in height	NO	SUM	MIN (m)	MAX (m)	MEAN (m)	SD (m)	RMS (m)
Δ(GGCP-DTM)	15	-2.089	-1.888	1.579	-0.139	1.111	1.120

4.2 Discussion of the Results

This part discusses the results obtained from the procedures and computations described in the methodology part in chapter three. The results obtained are discussed below;

4.2.1 Vertical Accuracy Validation Results from the Absolute and Relative Approach

For the absolute approach the performance of the Dar es salaam DTM have proved to be accurate having the Mean, SD, and RMS of 0.67m, 0.98m, and 1.19m. For the relative approach the results for Mean, SD and RMS are -0.14, 1.11 and 1.12. Both approaches have shown that the mean and RMS are small indicating they are close to the true value. This have shown that the DTM is accurate and can be used in engineering projects, infrastructure development and environmental analysis.

4.2.2 Horizontal Accuracy Validation Results

Horizontal validation results based on the comparison of the positional accuracy that is the (x, y) horizontal coordinates between the GGCPs and DTM coordinates. The comparison results have shown that the Dar es salaam DTM presents the actual terrain since the variation from the accurate TAREF11 ground control point is so small. The assessment was performed basing on the Mean, Root Mean Square Error and Standard deviation for both the x-coordinates that is the eastings and the y-coordinates that is the northings. The Mean Error, RMSE and SD results for the x-coordinates were -0.17m, 0.18m, and 0.19m. For the y-coordinates the Mean Error, RMSE and SD obtained were -0.20m, 0.22m and 0.22m. Therefore, the general result when combined for the horizontal accuracy of the Dar es Salaam DTM gives the Mean Error of -0.36m, RMSE of 0.40m, and the SD of 0.41m. The results suggest that the horizontal accuracy of the dataset is quite good, as the Mean Errors are close to zero, indicating a minimal overall bias in the observed coordinates. The RMSE values are relatively small, which means that the average positional differences between the observed and reference coordinates are generally low. The standard deviation values are also relatively small, indicating that the observed coordinates are relatively close to the mean value, demonstrating good precision in the dataset.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The main objective of this research was to validate the Dar es salaam DTM horizontally and vertically using absolute and relative TAREF11 GPS controls. From the results obtained and discussion made in chapter four the following conclusion can be made;

1) The horizontal validation of the Dar es salaam DTM using GGCPs has yielded accurate and precise results, with minor positional shifts and good consistency between the observed and reference coordinates. The overall RMSE of 0.40m and SD of 0.41m for the x and y-coordinates are relatively low, indicating that the majority of the DTM points closely matched the reference GPS controls.
2) The vertical validation results for both the Absolute and Relative approaches indicated that the Dar es Salaam DTM achieved a satisfactory level of vertical accuracy. The mean height differences and RMS values fell within acceptable limits, and the standard deviation provided insights into the variability of the DTM's vertical accuracy. The Dar es Salaam DTM reliable and suitable dataset for various applications, such as urban planning, infrastructure development, and environmental modeling.

5.2 Recommendation

Since the approach used in this research based on the validation using TAREF11 GPS controls, I recommend other techniques of validation to be applied so as to assess the accuracy and performance of the Dar es salaam DTM.

Increasing the density of control points, this will provide more precise validation and improve the overall accuracy of the DTM making it more suitable for various applications, including urban planning and infrastructure development in the region.

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