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Analysis of Elevation Models for Nigerian 2D Cadastre Height Determination

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ABSTRACT

In Nigeria, the spatial requirements of cadastral map for the purposes of land registration are based on 2D planimetric boundary coordinates without consideration for the elevation component of geometric space. Whereas, recent development in technology and practises in many countries requires the inclusion of elevation component into the cadastre. The specific objectives of this study are to determine elevation values for existing 2D cadastre of the study area from different data sources and to analyze those elevation values using statistical means. Data were sourced from both primary and secondary sources; secondary data include a 30m by 30m resolution Global Digital Elevation Model (GDEM), Shuttle Radar Topographic Mission Data (SRTM), 1:50,000 topographic map and existing Digital Elevation Model (DEM) of the study area. Ten ground control points were established at 250m grid with Global Positioning System in differential mode and elevation data were obtained accordingly. Elevation values of selected existing planimetric controls (33) were also determined from adopted data sources and were compared using both the standard deviation and the Root Mean Square Error (RMSE). The vertical accuracy obtained from Topographic map data, existing DTM, ASTER data and SRTM data were ± 1.860, ± 3.450, ± 5.309 and ±4.573 respectively relative to elevation values obtained from GPS observation of corresponding selected existing 2D planimetric controls. The degree of association between elevation values obtained from adopted data sources was strong and positive as shown from the regression analysis. The study established that only topographic map elevation data would presently fit GPS elevation data for 3D cadastre implementation for the study.

Keywords :

3D cadastre, Digital Elevation Model
Global Digital Surface Model
Shuttle Radar Topographic Mission

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1. INTRODUCTION

Cadastre is a parcel based, and up-to-date land information system containing a record of interests in land; for instance, rights, restrictions and responsibilities (Dabiri, 2013). It usually includes a geometric description of land parcels linked to other records describing the nature of the interests, the ownership or control of those interests, and often the value of the parcel and its improvements (Stoter *et al,* 2004). Increase in population density has made land use more intense. Stoter *et al,* (2004) opined that the trend in population density growth has caused a growing importance of ownership of land, which has changed the way humans relate to land. For instance, the economic use of land above space as well as underground space in complex construction of buildings with underground parking lot, engineering projects where the use of underground spaces is required for mining or underground transportation, areas that require 3D registration and have become a major concern both in the developed and the developing countries. The interests associated with complex land and people relationship as it relates to land and property right, restrictions and responsibilities (RRR) are major challenges faced in urban cities of Nigeria. 3D cadastral practice is seen as the immediate solution to these land interest and land use complexities in populated cities because of its capability of storing, updating, analyzing, manipulating, quarrying and visualizing RRR (Babalola *et al,* 2015).

The first publication on 3D cadastre was released in 1998 as the output of the Working Group of International Federation of Surveyors (FIG) Commission 7 with the mandate to identify trends in cadastral fields and to suggest a direction to which the cadastre might go for another twenty years (1994-2014); hence the name "Cadastre 2014" (FIG, 2014); consequently, 3D cadastre was proposed with for countries of the world. Nigeria over the years has experienced significant development ranging from rapid population growth to physical and infrastructural developments mostly emanating from urban renewal programmes of the government.

However, most physical developments witnessed are noticed to be in the horizontal direction thereby cornubating most of our country's cities and towns. Studies by Dabiri (2013) and Babalola *et al* (2015) have shown that spatial consideration for cadastral purposes of land registration in Nigeria is based on 2D planimetric boundary coordinates without consideration for the elevation component of geometric space. Recent development in technology and practises in developed countries recommend the exploration of elevation component. This justifies the need for Nigeria as a country to migrate from the present 2D cadastre policies fraught with a number of limitations to 3D cadastre practice. Most important of these limitations is horizontal delineation of land rights and ownership. 3D cadastre practice encourages flexible vertical space registration for both private and public lands and properties particularly in the country's mega cities like Lagos, Ibadan, Kano and Port Harcourt where land demand is noticeably under pressure.

The cost, time and resources required for fresh survey on old parcels (existing parcels in planimetric system) warrants alternative methods (non-conventional methods of survey) of elevation data determination. From the foregoing, it is expedient to examine the reliability and suitability of these alternative methods and data sources (SRTM, ASTER, Topo map and existing DTM) for the integration of elevation values to existing 2D cadastre with a view to enhancing Land Administration System.

Considering the large nature of the country and the volume of existing 2D cadaster data, this paper evaluates the relative accuracies of different alternative approaches of height determination as a step to facilitating 3D cadastre practice in Nigeria using the Moremi housing estate, Ile-Ife belonging to the Osun State Property Development Corporation as a prototype. The study also examined the performance of individual approaches under investigation to determine the best approach that fits quick migration from 2D to 3D (geometric space) cadastral practice for the study area. This study finally proposed policy guidelines in helping to solve some of the problems associated with the country's horizontal space growth for sustainable land governance.

2. HEIGHT DETERMINATION FROM ADOPTED DATA SOURCES

The Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) is a cooperative effort between National Aeronautics and Space Administration (NASA) and Japan's Ministry of Economy Trade and Industry (METI), with the collaboration of scientific and industry organizations in both countries. ASTER provides a more robust remote sensing imaging capability at 15 meter, 14 band multispectral resolutions. It has a wide range of application including change detection, land surface studies, global change-related application areas, including vegetation and ecosystem dynamics, hazard monitoring, geology and soils, land surface climatology, hydrology, land cover change, and the generation of digital elevation models (DEMs) (Abd-Elmotaal, 2009). According to Arun *et al* (2016) ASTER shows DEM accuracy of about 7m to 14m while each ASTER frame covers an area of 60km by 60km with an output DEM resolution at 30m.

However, the Shuttle Radar Topography Mission (SRTM) 30m resolution was flown aboard the space in February, 2000. This mission used single-pass interferometer, which acquired two signals at the same time by using two different radar antennas. The satellite based DEM such as SRTM and ASTER are freely and widely available with wide range applications in topography, geomorphology, vegetation cover studies, tsunami assessment, and urban studies (Arun *et al* 2016).

Comparatively SRTM provides the most complete highest resolution absolute horizontal and vertical accuracies of 20m (circular error at 90% confidence) and 16m (linear error at 90% confidence) (Manuel, 2004), relative to other methods like contour lines, topographic maps, field surveying using automatic level, total station, GPS, photogrammetry techniques, radar interferometry and laser altimetry. Arun *et al* (2016) stated that the vertical accuracy is significantly better than the 16 m while Rabus *et al* (2002) confirmed that it is closer to ±10 m.

Ozah and Kufoniyi (2008) carried out a study to investigate the accuracy of contour interpolation from Shuttle Radar Topographic Mission (SRTM 90m) and existing 1:50,000 topographical maps. The various processing tasks executed were based on the 90m resolution SRTM elevation data, a 1:50,000 topographic map of the test site and GPS data of the study area. The study recommended that 90m resolution SRTM elevation data can be used as a substitute for existing 1:50,000 topographic maps with the condition that the former be processed prior to topographic information extraction for 1:25,000 topographical mapping. The analysis of the results from the approach used for processing the SRTM data prior to contour interpolation was basically qualitative; thus a more robust statistical approach may be required to further establish the claims. However, the emergence of a more reliable SRTM data at 30m resolutions invalidates the claims of Ozah and Kufoniyi (2008).

Isioye and Jobin (2011) assessed the reliability of elevation data used in the generation of DEMs from ground surveys, SRTM of 30m resolution and Google Earth pro with existing topographic map for the test site. In the study, DEM from ground survey using total station proves to be a very efficient method compared to other methods considered; however, the efficiency and the accuracy of the method in terms of cost benefits and operational time was not established in the research. The paper further opined that the ground survey method for generating DEMs requires a rigorous field work in capturing detailed terrain data. The study concluded that it is important that accuracy of elevation data for generation of DEMs be properly understood before they are utilized in varying applications; and thus recommended the need to validate all available global elevation dataset in Nigeria, to ascertain their suitability.

Alatawi and Abushandi (2015) compared ASTER satellite imagery with topographic map and GPS datasets. Although there is an agreement between GPS and topographic map data sets in terms of positive correlation, the study revealed that ASTER data values are higher than GPS and topographic map values. The observed discrepancies between ASTER DEM and GPS data set show the error magnitude of ASTER DEM. The result of comparison from Pearson Correlation Coefficient shows that there exist significant linear positive relationships between ASTER Data with GPS and Topographic map elevation data.

3. STUDY AREA

Ile-Ife is a major town in Osun state, Southwestern Nigeria. It is one of the ancient and probably the oldest town of the Yoruba people; the socio-cultural group is the Yoruba ethnic group, one of the largest ethnic groups in Africa (Levison, 1998; Oloukoi, 2014). Geographically, Ile- Ife lies within latitudes 7^{0} 28' N and 7^{0} 46' N, and longitudes 4^{0} 36' E and 4^{0} 56' E (Figure 1.1); to her west lies Ibadan, and to the east lies Akure, and it is about 200km NE of Lagos (Oloukoi, 2014). Ile-Ife is home to the prestigious Obafemi Awolowo University, about 40km to Osogbo, the Osun state capital.

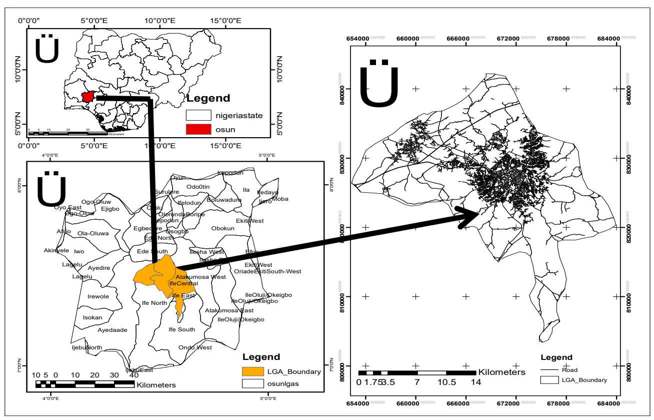

Figure 1: Map of the study area
Source: Office of the Surveyor General Osun State, (2018)

4. DATA TYPES AND SOURCES

4.1. Primary data and Sources

The primary data (elevation values) were obtained from field observations using Differential Global Positioning System (DGPS). This entails height determination of selected thirty three (33) existing property pillars used for accuracy analysis. The orthometric heights of existing property pillars were extracted from the topographic map and transformed into ellipsoidal heights of World Geodetic System 1984 (WGS 84).

4.2. Secondary data and source

Data required are basically positional data (X, Y and H) in 3D geometric space required for full implementation of 3D cadastre. The secondary data was obtained from the following secondary sources:

i. Existing topographic map (contour map) of the study area (1:50,000) obtained from African Institute for Geospatial Information Science and Technology (AFRIGIST) for the purpose of orthometric height extraction.

ii. GDEM (SRTM and ASTER) 30m by 30m resolution of the study area obtained from the USGS website for the purpose of ellipsoidal height extraction

iii. Google earth imagery of the study area for office reconnaissance

iv. Ortho-rectified aerial photograph of the study area obtained from Office of the Surveyor General of Osun State, Osogbo for the purpose of planimetric data extraction (Northings and Eastings of existing cadastre for ground truthing).

5. INSTRUMENT USED FOR SPATIAL DATA COLLECTION

Both hardware and software were used for spatial data collection and processing. The hardware includes Hand held GNSS receiver for reconnaissance survey, Differential Global Positioning System (DGPS) and large format (A0) scanner. The software includes ArcGIS 10.2, Global Mapper version 15, SPSS version 16.0 and Suffer 12.0. Selected point were observed using Trimble 1800 surveying GPS receiver at Real Time Kinematic (RTK) technique taking PBG 1111 with 828862.7mN, 668073.566mE and 253.232mH as a fixed reference base and the rover was used to observe the required points. Both planimetric and altimetric values of these existing positions (point data) were thus determined in WGS84 reference system using stop and go mode of operation.

6. METHODOLOGY FOR ELEVATION DATA EXTRACTION

The locations of several existing cadastral pillar (planimetric stations) in the study area were accessed using the layout survey plan. A geodetic control (PBG 1111) which was 1km away from the study area was used as a reference as well as the base for established GCPs for this study. Existing Digital Terrain Model of 25cm Ground Sampling Distance (GSD) data of the study area was obtained from Office of the Surveyor General of Osun State, Osogbo.

The height values of the existing thirty three (33) cadastral property pillars were extracted from the topographic map, existing DEM data as well as GDEM (SRTM and ASTER) data. GPS observations were carried out on the property pillars on which the accuracy of height values from adopted approaches was based. The GDEM data was converted from raster format into vector data format. Extracting elevation values from GDEM was achieved using the spatial analyst tools “extract values to point” on ArcGIS 10.2 version.

7. DATA ANALYSIS

7.1. Vertical accuracy assessment

The vertical accuracy was determined using the RMSE of observed elevation data obtained from different data sources as shown in equation 1.0

$RMSE_z = SQRT\ [\Sigma\ (Z_{obsi}-Z_{standi})^{\wedge 2}/n]$ … (1.0)

Where Z_{obsi} are the coordinates of the *i*th check point in the dataset, and Zstandi are the coordinates of the *i*th check point in the independent source of higher accuracy. Where n is the number of check points tested, *i* is the integer ranging from *1 to n*. The values of $Zobsi - Zstandi$ as used in this study is referred to as residuals for each of the adopted methods. $Zobsi$ are elevation data obtained from adopted method (data sources) of determining elevation data while $Zstandi$ are GPS observed elevation data. Vertical accuracy at the 95-percent confidence level was determined as expressed by United National Standard for Spatial Data Accuracy (SSDA) of 2016 as:

$$Accuracy_z = 1.9600 * RMSE_z \ldots (2.0)$$

The observed stations were corresponding stations whose elevation values have earlier been determined from other adopted techniques of determining elevation data. Regression analysis was used in comparing elevation values from adopted sources. The regression model (equation 3.0) is as shown.

$$Yi = \beta_0 + \beta_i X_i + ei \ldots (3.0)$$

Where β_0 is constant of the unstandardised coefficient

β_i is the unstandardised regression coefficient and *ei* is the error term

Yi is the observed elevation (predicted) value

Xi is standard elevation value (GPS).

In the analysis, GPS elevation data were made constant throughout and it serves as standard base for accuracy assessment of adopted techniques. After the proportion of variation was established, the correlation coefficient 'r' was used to further test the significant relationship from the Pearson's Correlation coefficient (r) using the hypothesis regarding *p*, the population correlation coefficient was adopted, such that:

H_0: ρ = 0 and H_a: ρ ≠ 0. $r\sqrt{(n-2)/(1-r^2)}$ will assumes a *t-distribution* with (n-2) degree of freedom if the null hypothesis is true then the null hypotheses is rejected if $r\sqrt{(n-2)/(1-r^2)}$ is considered greater than the critical *t value*.

8. RESULTS AND DISCUSSIONS

In table 1.0, the correlation between the GPS values and topo map values is given as 0.794, the proportion of variance R^2 (63.1% degree) as shown indicates how much of the total variation in the topographic map extracted elevation values can be explained by the GPS elevation values (Table 1.0). Furthermore, the correlation between the GPS values and existing DEM values is given as 0.922 (Table 1.0). Here, the correlation of elevation values derived from both sides is very high. The proportion of variance R^2 as shown in the table indicates how much of the total variation in the existing DEM extracted elevation values, can be explained by the GPS elevation values, a total of 85.1% degree of variation is noticed based on the result shown.

However, the result indicates that the regression model predicts the dependent variable significantly well for topo map elevation data. The statistical significance of the regression model is such that $p < 0.0005$, which is less than 0.05, also the F-ratio in the ANOVA (Table 1.0) indicates that, overall, the regression model (GPS data variables) statistically significant at $F(1,30) = 51.235$, $p < 0.0005$. This implies that elevation data extracted from topographic maps is a good fit for the GPS data. The ANOVA just as in the case of topo map elevation revealed statistical significance for the regression model at $p < 0.0005$ for existing DEM which is less than 0.05. It thus indicates that, overall, the regression model significantly shows that though elevation data extracted from existing DEM has a strong correlation with GPS data, however, the F ratio value ($F(1, 30) = 171.149$, $p < 0.0005$) also indicated that it's a good fit for the GPS data. Similarly, the same results were generated for both SRTM and ASTER data as shown in the summary of regression analysis for all adopted techniques under investigation (Table 1.0).

Table 1.0: Model summary for adopted techniques

Methods	R	R^2	Adjusted R^2	Significance value in ANOVA	Remark on *F*-ratio
Topographic map	0.794	0.631	0.618	P <0.05	Good fit for GPS data
DTM	0.922	0.851	0.846	P < 0.05	Good fit for GPS data
SRTM	0.875	0.766	0.758	P < 0.05	Good fit for GPS data
ASTER	0.901	0.813	0.806	P < 0.05	Good fit for GPS data

Source: Authors' field work (2019)

From table 2.0, the values of $r\sqrt{(n-2)/(1-r^2)}$ exceeds the t -value (1.697) for all the methods, therefore, the null hypothesis is rejected. The student *t-test* of significance (Table 2.0) and the regression test (Table 1.0) agreed to the result of studies by Arun *et al* (2016), Isioye and Jobi (2011) comparing SRTM data, the topographic map data and Google Earth imagery.

Table 2.0: Test for Significant Relations between elevation values

Methods	R	$r\sqrt{(n-2)/(1-r^2)}$	*t-value* at 95% Confidence level
Topographic map	0.794	7.154	1.697
DTM	0.922	13.043	1.697
SRTM	0.875	9.899	1.697
ASTER	0.901	11.376	1.697

Source: Author's field work (2019)

Although, the regression model predicted that all methods investigated are good fit for GPS data, the model did not reveal the level of accuracy of each of the methods investigated. Hence, the standard deviation of error of estimate (RMSE) and the United National Standard for Spatial Data Accuracy (SSDA) of 2016 was used to establish the vertical accuracy of all the adopted methods based on the distributed data points reported at the 95% confidence level (Equation 2.0). The result for the distribution of the residual of elevation data (Figure 3.0 and 4.0) shows that the elevation values extracted from existing DEM is at a wide variance with other adopted methods having highest magnitude of residuals values in positive direction on the geometric space but in similar pattern of progression for all adopted methods. The wide variation in the origin may be as a result of wrong of inaccurately defined datum for its spatial referencing.

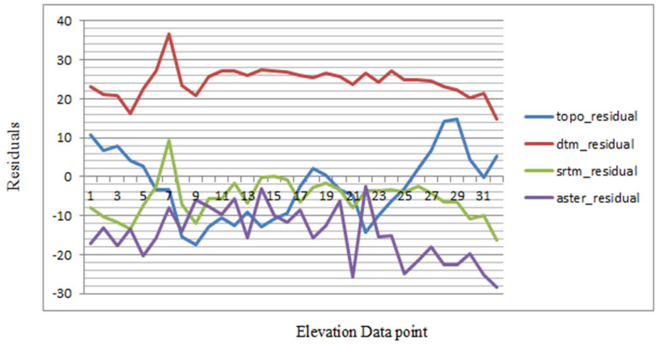

Figure 3.0: Surface distribution of residuals

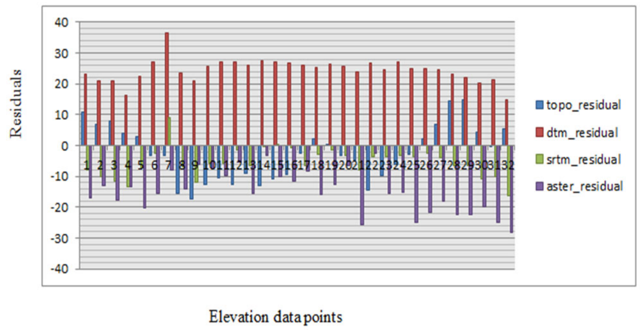

Figure 4.0: Distribution of residuals in vertical direction

The reliability of determined elevation data was based on statistical measures of precision and accuracy, the precision of elevation data obtained from adopted sources was measured from standard deviation while accuracy was measured using Root Mean Square Error (RMSE). The accuracy assessment of the results (Tables 3.0, 4.0 and 5.0) revealed that the absolute vertical accuracy for GDEM data were within the allowable limit values of ±16m specification. The vertical accuracy obtained from both existing DTM and topographic data (≃ +4.0m and ≃ +7.0m respectively) indicates that both methods are suitable for elevation data determination. The accuracy obtained from the STRM and ASTER (≃ +9.0m and ≃ +10.0m) respectively has large tolerance for 3D cadastre implementation. GDEM data used may be relevant when purpose for height determination does not take accuracy as an important consideration. Though all the methods have similar vertical progression (Figure 3.0), the results further affirmed the earlier suggestion concerning the possibility of a fundamental error in the datum used for the existing DEM during the project.

Table 4.0 Accuracy Estimation from Residuals

Method	Mean	RMSE	SSDA Accuracy	Accuracy limit
Topo map	-2.451	± 1.806	± 3.540	Not available
Existing DTM	24.400	± 3.450	± 6.762	Not available
ASTER	-14.790	± 5.309	± 10.406	± 16.00
SRTM	-5.509	± 4.573	± 8.963	± 16.00

Source: Authors' field work (2019)

Table 5.0: Precision Estimation of Extracted Elevation Data

Method	Mean	Std. Deviation
Topo map	264.371	2.924
Existing DTM	291.220	8.789
ASTER	252.030	12.066
SRTM	261.310	9.299

Source: Authors' field work (2019)

Table 6.0 Overall Performances of Extracted Elevation Data in Comparison to GPS Data

Method	Accuracy in comparison to GPS data	Precision of extracted elevation values
Topographic map	Very good	High
Existing DTM	Good	Moderate
SRTM	Fairly good	Moderate
ASTER	Fairly good	Low over all

Source: Author's field work (2019)

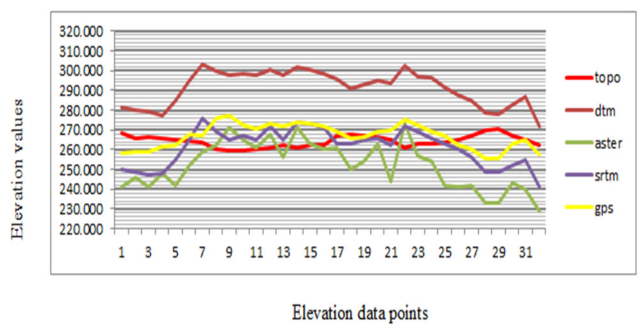

Figure 5.0: Comparison of GPS data and adopted methods

Sources: Author's field work (2019)

9. FITNESS OF ADOPTED METHODS FOR 3D CADASTRE APPLICATION

Statistical analysis for model comparison of each of the methods under investigation shows different levels of performance of elevation data extracted. However, investigation revealed that elevation data from topographic map has the best performance. However, a fundamental consideration for incorporating elevation data into existing 2D cadastre is cost, time and accuracy. While all the methods have shown the capability of providing elevation data for cadastral applications, the cost of each of the methods varies a great deal. Except for the GDEM which is an open source data readily available, both topographic map (1:50,000) of the test site and GDEM though already existing would require more financial capital for any cadastral application. Cadastral survey requires accurate delineation of boundaries for both 2D and 3D practices, accuracy obtained from both GDEM cannot be tolerable for cadastral application. This is because the standard height as stated in building codes of Nigeria is 4.5m. Results shows accuracy values of tolerance far beyond the maximum height required for residential building (Table 4.0). Products from GDEM may be used for other applications outside cadastral mapping.

However, elevation data extraction from existing DEM of the study area did not give information about data specification; therefore, its reliability is questionable unless information exists about the data sources, reference systems, and methods for model determination (meta data). As shown in the result (Figure 5.0), the variation of approximate 20m between the GPS data and existing DEM necessitates that the discrepancy be reconciled; therefore, the adoption of data from this source will require that the origin of the datum used for spatial referencing for the development of the DEM be investigated and be ensured to truly match WGS84 ellipsoidal height system.

For the study area, few contour lines were seen to pass through the area; hence interpolation was carried out to densify contour points across the area so as to enhance the result of this research. This will likely make the procedure more rigorous, laborious and tasking on a large scale project that will involve the whole country unless the country is ready to carry out topographic mapping at scale between at least 1:5,000 to 1:10,000. Though for the test site, topographic map gives a reasonably high accuracy (Table 4.0), but as it stands, the topographic map in public domain may not serve the purpose of 3D cadastre implementation. A fresh national topographic mapping will requires establishment of sufficient spot heights and densification of both 1st order and 2nd order ground controls; if densification will be done from the present first order country of the country, a unified datum transformation parameters are therefore required to make old survey conform to WGS84 format. These procedures will require many personnel, a lot of time and high cost of project execution.

10. CONCLUSION AND RECOMMENDATION

This study revealed the possibility of generating elevation data from any model that exhibits continuous characteristics of physical surfaces at large, medium and small scale. All analysis are empirical base, and this gives the allowance for a deep insight into quantifying the magnitude, the direction and general behaviour of errors incurred in the process. The results obtained in this study for vertical accuracy assessment further agreed with previous studies by Muller (2005), Arun et al (2016), Ozah and Kufoniyi (2008), Gorokhovich and Voustianiouk (2006), Isioye and obarafo (2010), Alatawi, and Abushandi (2015) that there is usually some agreement (correlations) between GPS data and topographic map dataset with SRTM and ASTER data having accuracy level of ± 16m and that the discrepancy may have a spatial behaviour which is coherent as shown by pattern progression in vertical directions and the characteristics of the terrain modeled.

However, contrary to the claim of Alatawi and Abushandi (2015), the assertion of the possibility that GDEM data values are usually higher than both GPS dataset and topographic map values may be a regional or localized phenomenon. The variation in results from data sources is perceived to be attributed to the quality of dataset used. Direct extraction of elevation data from the topographic map is an indirect method of elevation data determination that required a lot of human effort with relatively small error expectation provided error sources (random, gross and systematic) are eliminated. Moreover, if this errors are eliminated to the bearest minimum, the results of elevation data extracted will have little or no uncertainty.

The reliability of existing DTM data source should be based on availability of metadata that states the source of data acquisition, date of acquisition, reference system and projection method and other vital information required. The GDEM of 30m by 30m resolutions is a technique that may achieve higher accuracy if tested for a large scale application. Hence it's suitability for a small scale survey that requires higher spatial resolution like cadastral mapping may not be guaranteed. This study concludes that the topographic map approaches can be well considered for the choice of suitable alternative method for altimetric data determination for existing 2D planimetric cadastre data in the study area.

This study revealed the need to update the National topographic map. The current topographic map in circulation was produced in January 1965 at 1:50,000 (medium scale). However, to achieve a better accuracy level, large scale topographic map is required between 1:5,000 to 1:10,000. Government agencies and stakeholders should therefore advocate the importance of having topographic data at large scales to promote scale flexibility; this is because, most times, working with analogue topographic maps restricts professionals to a particular fixed scale. More so, it is important also to ensure that all existing 2D cadaster data in analogue format be converted to digital format; this requirement should be achieved within a time frame so as to ensure flexibility in the migration to 3D cadastre.

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13. KEY TERMS AND DEFINITIONS

Cadastre: a cadastre is normally a parcel based, and up-to-date land information system containing a record of interests in land, for instance, rights, restrictions and responsibilities.

Planimetric pillars/controls: Survey pillars used for boundary demarcation defined by Northings and Eastings coordinates only.

Spatial requirements: location data required for defining positions relative to the earth surface