AN ASSESSMENT OF DIGITAL ELEVATION MODELS (DEMs) FROM DIFFERENT SPATIAL DATA SOURCES

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Key words: **Digital Elevation Model (DEM), Google Earth image, SRTM, spot height**

SUMMARY

Digital Elevation Model (DEM) represents a very important geospatial data type in the analysis and modelling of different hydrological and ecological phenomenon which are required in preserving our immediate environment. DEMs are typically used to represent terrain relief. DEMs are particularly relevant for many applications such as lake and water volumes estimation, soil erosion volumes calculations, flood estimate, quantification of earth materials to be moved for channels, roads, dams, embankment etc. In this study, three different sources of spatial data in the generation of DEMs (Shuttle Radar Topography Mission SRTM 30, Digitized Topographical map and Google Earth Pro.) were compared with field measured data from Total Station Instrument, the field data were used to generate a Digital Elevation Models DEMs from 495 radial points over the test site. The accuracy of generated DEMs were assessed statistically by comparing (1) estimates of some topographic attributes(slope and aspect), (2)overall spot height estimation performance and, (3) independence of spot estimation errors and the magnitude of field measured height. From the results obtained it was concluded that the DEMs from the satellite imagery (SRTM 30) does not perform well in collecting data for topographic works. The digitized topographic map gives a good result but the variation from the reference in this study may be as a result of human activities and erosion that has occurred from when the topographic map was produced and also the quality of the topographic map. The Google Earth pro was also concluded to perform far better than the SRTM 30 data. Finally, it was recommended that Real Time Kinematic GPS combine with total station can be tested for speed and accuracy and also SRTM data and other global terrain data sources i.e., GTOPO, Microsoft Visual Earth and NASA World Wind can also be examined for suitability of their application over larger assessment area.

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1.0 INTRODUCTION AND BACKGROUND

Digital Elevation Model is the continuous representation of elevation values over a topographic surface by a regular array of z-values, referenced to a common datum. Digital Elevation Models (DEMs) are useful in many geoscience applications, such as topographic mapping, earth's deformation, hydrological and biological studies.

It is of immense significance to distinguish between DEMs and other form of terrain representation; the two most closely used and confused with DEMs are Digital Terrain Model (DTM) and Digital Surface Model (DSM). DTM is considered as a continuous usually smooth surface which, in addition to height values (as DEMs) also contains other element that describes a topographic surface; slope, aspect, curvature, gradient, and others. Like Digital Terrain Models, Digital Surface Models contain the spatial elevation data of the terrain in digital format which is usually presented as a grid with natural and artificial features such as vegetation, buildings etc. A filtered DSM result to DTM and a DEM is considered the most important component of DTM (Li, 1994; Maume et al., 2001; Li et al., 2005; Jobin, 2010).

A wide range of application is now drilling the requirement for increased details in Digital Elevation Models (DEMs). Details in this instance are defined by the horizontal sample spacing and vertical accuracy of the measurement. DEM is also an important utility of Geographic Information System (GIS). Using DEM/3D modelling, landscape can be better visualized leading to a better understanding of certain relation in the landscape. Many relevant calculations, such as lakes and water volumes, Soil Erosion Volumes, quantities of earth to be moved for channels, dams, roads, embankments etc (ESRI, 2009).

The derivation of topographic attributes relies on digital elevation data sets that may be acquired from satellite imagery, digitizing the contour lines on topographic maps, or conducting ground surveys (Wilson and Gallant, 2000). Digital elevation data are typically compiled and stored in one of three data structures: (1) point elevation data on a regular grid, (2) point elevation data in triangulated irregular networks, and (3) digitized contour line data.

The popularity of square grid DEMs is owed to their visual simplicity and ease of computer implementation (Moore et al., 1991; Wilson and Gallant, 2000). These square grids are arranged in rows and columns and each grid point represents the elevation at that location. Square grids have been criticized because they contain superfluous data in flat areas and they are unable to handle abrupt changes in elevation easily. The choice of a smaller grid size would increase the first and reduce the second problem. Another undesirable result of using square grids is that the computed upslope flow paths will frequently zigzag across the landscape in unrealistic ways (Wilson and Gallant, 2000).

The second structure used to store digital elevation data is triangulated irregular networks (TINs). These networks are based on triangular elements or facets with vertices at the sample points (Moore et al., 1991; Wilson and Gallant, 2000). Three adjacent points on a plane are connected to form triangular elements. TINs can easily model sharp features such as peaks and ridges, and they can also incorporate discontinuities (Wilson and Gallant, 2000). TINs are more efficient from the point of view that the number of sample points and triangles can be varied to match the surface roughness. Computer storage space is less using TINs compared to regular grids. Calculating topographic attributes is sometimes more difficult than with square grids due to the irregularity of the TIN structure; for example, it may be more difficult to trace the upslope connections of a facet and therefore more difficult to estimate the upslope contributing area at different points in the landscape (Moore et al. 1993).

The final structure is the contour-based network consisting of small, irregularly shaped polygons bounded by adjacent contour lines and streamlines (lines drawn orthogonal to the contour lines). This type of structure is difficult to implement but is nevertheless popular in hydrological applications because it can reduce complex three-dimensional flow equations into a series of coupled one-dimensional equations in areas of complex terrain (Moore and Foster, 1990).

The provision of gridded elevation data sets by many national mapping agencies (e.g. United States Geological Survey (USGS) at http://www.usgs.gov) coupled with the development and wide distribution of methods for converting contour elevation data to square grids (see Hutchinson 1989 for one such method) have contributed to the popularity of gridded elevation data sets and grid-based topographic attributes . Table (1) presents a list of grid-based topographic attributes and their connotations.

Most of the algorithms for calculating topographic attributes have been proposed have been implemented inside a GIS and are well documented in different literatures (e.g., Florinsky, 1998; Dunn and Hickey, 1998; Qiming and Xuejun, 2004; Zhou and Liu, 2004; Shi et al., 2007). This state of affairs introduces two new challenges in particular, the need to learn more about the performance of these different algorithms in different settings to maximize the likelihood that the algorithm best suited to the application and landscape at hand. And also, the need to ascertain the performances or reliability of the different data sources for generation of grid based DEMs in view of increasing number of global data set and the demand for such products. The former challenge is left for other studies while this paper ponders discussion on the latter.

This paper presents the result of an experiment to test the accuracy of DEMs that are generated from two global data sets sources (Shuttle Radar Topography Mission(SRTM 30), and Google Earth Pro), digitized topographic map and the reference DEM generated by ground surveys for the study area. Useful results for the evaluated techniques and the achieved accuracies are presented herein.

Table 1: *Primary topographic attributes calculated from DEM data (after Moore et al. 1991).*

Attributes	Definition	Significance
Altitude	Elevation	Climate, vegetation, potential energy
Aspect	Slope azimuth	Solar insolation, evapotranspiration, flora and fauna distribution and abundance
Catchment area	Area draining to catchment outlet	Runoff volume

Catchment length	Distance from highest point to outlet	Overland flow attenuation
Catchment slope	Average slope over the catchment	Time of concentration
Dispersal length	Distance from a point in the catchment to the outlet	Impedance of soil drainage
Dispersal slope	Mean slope of dispersal area	Rate of soil drainage
Elevation percentile	Proportion of cells in a user-defined circle lower than the center cell	Relative landscape position, flora and fauna distribution and abundance
Flow path length	Maximum distance of water flow to a point in the catchment	Erosion rates, sediment yield, time of concentration
Plan curvature	Contour curvature	Converging/diverging flow, soil water content, soil characteristics
Profile curvature	Slope profile curvature	Flow acceleration, erosion/deposition rate, geomorphology
Slope	Gradient	Overland and subsurface flow velocity and runoff rate, precipitation, vegetation, geomorphology, soil water content, land capability class
Specific catchment area	Upslope area per unit width of contour	Runoff volume, steady-state runoff rate, soil characteristics, soil water content, geomorphology
Tangential curvature	Plan curvature multiplied by slope	Provides alternative measure of local flow convergence and divergence
Upslope area	Catchment area above a short length of contour	Runoff volume, steady-state runoff rate
Upslope height	Mean height of upslope area	Potential energy
Upslope length	Mean length of flow paths to a point in the catchment	Flow acceleration, erosion rates
Upslope slope	Mean slope of upslope area	Runoff velocity

2.0 MATERIALS AND METHODS

2.1 Elevation from ground survey

Total station instrument was utilized in the ground survey exercise. The total station gives directly the reduced 3-D coordinates, provided the orientation coordinates, height of the instrument, height of the target of back sight station were inputted before work begins.

After the orientation of the instrument has being made, sufficient number of scattered points (495 points) were observed at the site to define the topography of the site. Figure (1) depicts the 495 scattered points in the study area situated around a valley in the main campus of The Ahmadu Bello University, Nigeria. The dimension of the site is measured to be about $1.5km \times 1.5km$.

2.2 Elevation from SRTM imagery

The NASA Shuttle Radar Topographic Mission (SRTM) has provided digital elevation data (DEMs) for over 80% of the globe. This data is currently distributed by USGS and is available for download from the National Map Seamless Data Distribution System, or the USGS ftp site. The SRTM data is available as 3 arc second (approx. 90m resolution) DEMs. A 1 arc second data product was also produced, but is not available for all countries. The vertical error of the DEM's is reported to be less than 16m. The data currently being distributed by NASA/USGS (finished product) contains "no-data" holes where water or heavy shadow prevented the quantification of elevation. These are generally small holes, which nevertheless render the data less useful, especially in fields of hydrological modelling.

The DEM files of SRTM have been mosaiced into a seamless near-global coverage (up to 60 degrees north and south), and are available for download as 5 degree x 5 degree tiles, in geographic coordinate system - WGS84 datum. These files are available for download in both Arc-Info ASCII format, and as GeoTiff, for easy use in most GIS and Remote Sensing software applications. In addition, a binary Data Mask file is available for download, allowing users to identify the areas within each DEM which has been interpolated. In order to extract height information from SRTM 30 imagery for the study area, the 3-D coordinates from the ground survey in Universal Transverse Mercator (UTM) coordinates system were converted to Geographical Coordinates (longitude and latitude) and were plotted on the imagery on ArcGIS 9.2 software. The corresponding elevation values attributed to each pixel were read and recorded. The extracted elevations were further converted from WGS84 reference height to the Nigerian local system to correspond with elevations obtained later from the ground survey. Figure (2) depicts the downloaded SRTM 30 data file.

2.3 Elevation from digitised topographic map

The topographical map (figure 3) for the test site was scanned and then imported into the ILWIS 3.3 environments for the digitizing. The topographic map was first geo-referenced using three coordinates of the edges of recognized features on the map. A domain was created by inputting the minimum and maximum values of contour of the topographic map. A segment was also created so that all the digitized contours and their height values will be recorded. The contour value of each contour line was inputted by right clicking after digitizing the line.

2.4 Elevation from Google Earth Image

The height from the Google Earth imagery (figure4) was generated online by converting the plannimetric coordinates in Universal Transverse Mercator (UTM) system obtained from total station instrument into Geographical Coordinates (longitude and latitude) and was plotted on imagery. The corresponding height values for the planimetric coordinates were read and recorded.

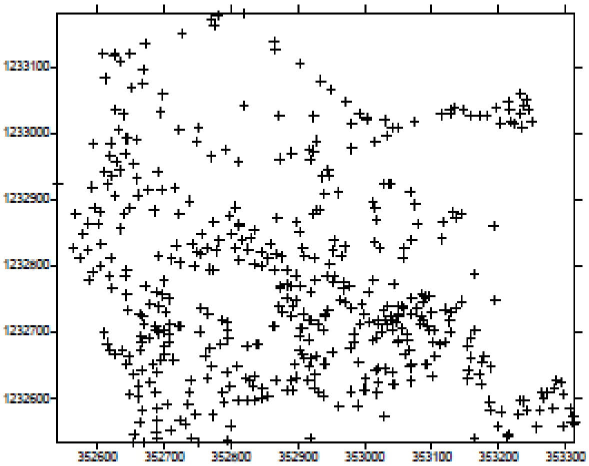

Figure. 1: Data points from Total station measurement for the test site

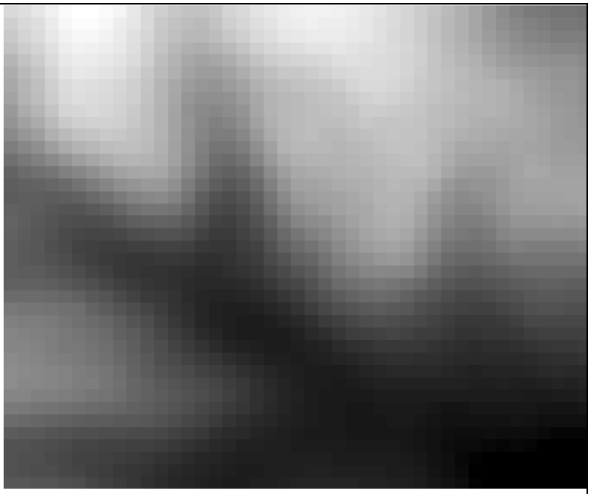

Figure. 2: SRTM 30 image for the test site

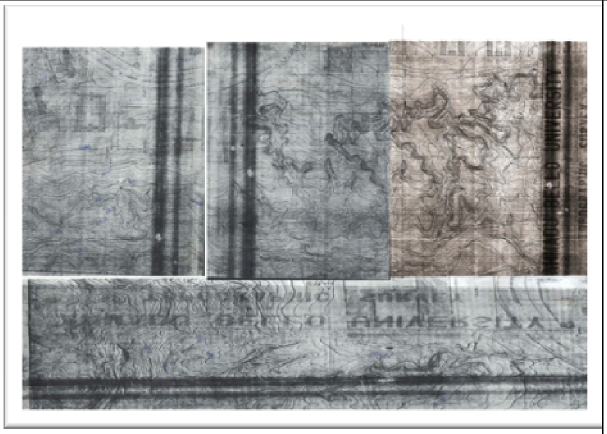

Figure. 3: Digitised topographical map for the test site

Figure. 4: Google Earth Pro image for the test site.

Generating DEMs from elevations

The three dimensional coordinate from the various spatial data sources were plotted by gridding using Kriging method in ArcGIS 9.2 to produce the DEM, . Figures (5)-(8) shows the Digital Elevation Models DEMs with colours representing different ranges of elevation values.

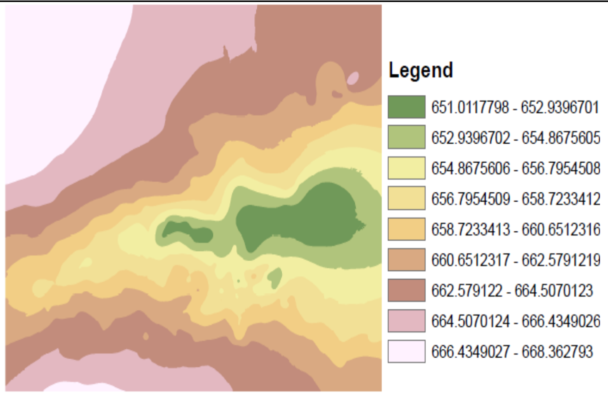

Figure. 5: DEM from total station measurement for the test site

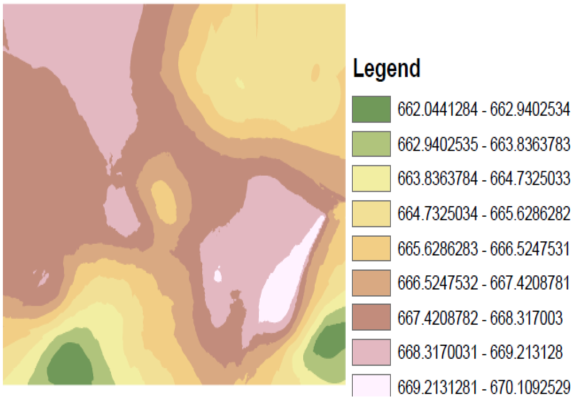

Figure. 6: DEM derived from SRTM 30 for the test site.

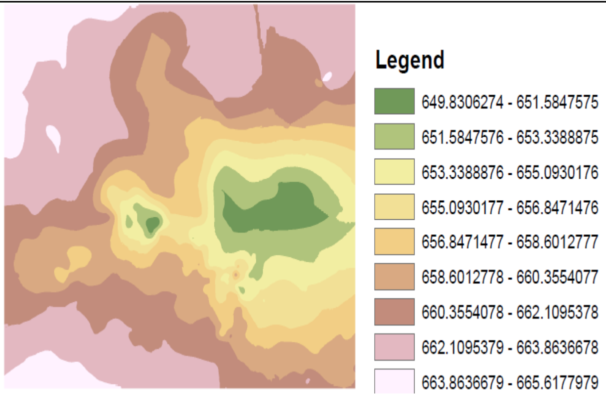

Figure. 7: DEM from derived topographical map for the test site

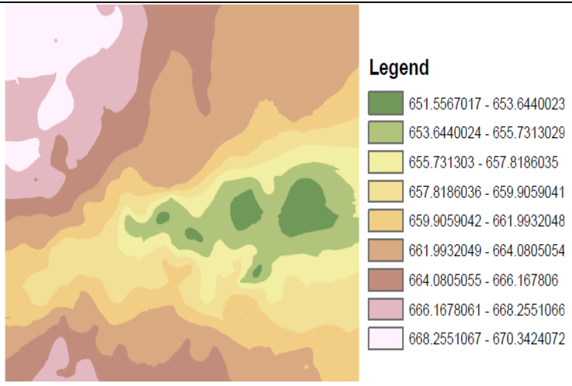

Figure. 8: DEM derived from Google Earth Pro for the test site.

3.0 RESULT AND DISCUSSIONS

3.1 Overall spot heights estimation performance

The spot heights for 495 points was obtained from the different sources of spatial data generated from (Shuttle Radar Topography Mission SRTM 30, Digitized Topographical map and Google Earth Pro.) and were compared with field measured data from Total Station Instrument.

Table (2) depicts the descriptive statistics for spot heights from which it is obvious that the calculated standard error, standard deviation and sample variance from the topographic map and Google earth imagery are closer to those of the total station(ground survey) than those of the SRTM. The descriptive statistics for the spot heights as presented in Table (2) clearly show the poor relationship of the SRTM data source when compared to other data sources under investigation.

Figure (9) represents the scattered plot of spot height from the various sources of data and it is clear that the topographic map data and Google earth imagery overlap the reference source more than any other.

Table 2: Descriptive Statistics for Spot Heights

STATISTICS	*total station*	*SRTM*	*topographic map*	*Google earth*
Mean	660.9786	666.9042	659.5831	661.3879
Standard Error	0.1775	0.1044	0.1874	0.1560
Median	661.181	667.532	660.1765	661
Mode	660.259	668.015	658.5515	660
Standard Deviation	3.9494	2.3220	4.1690	3.4712
Sample Variance	15.5979	5.3915	17.3807	12.0491
Range	17.397	10.484	21	16.0635
Minimum	650.988	660.256	649.6585	650
Maximum	668.385	670.74	665.722	671
Confidence Level (95.0%)	0.3488	0.2051	0.3682	0.3065

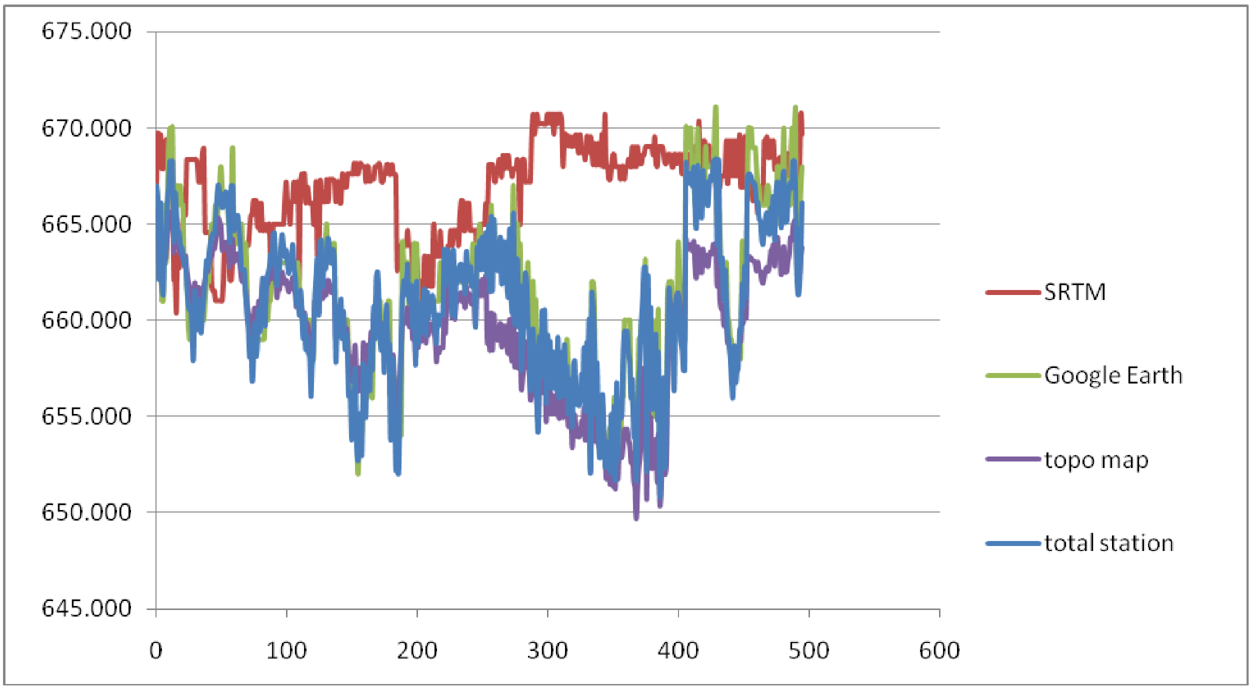

Figure. 9: Scattered Plot of Spot Height from Various Data Sources

Visual inspection and examination of surface maps (see figures 10-13) obtained from the extracted elevations was used to evaluate qualitatively the various data sources when compared to that obtained from the ground survey. Comparing visually between the various surface map representations, Figure.10 represents the terrain of the test site better when compared with reality. Figure.11 gives a poor surface representation of the test site and Figure.12 also performs well but the differences between Figure(12) and Figure(10) may be as a result of erosion and human activities that have taken place from when the topographic map was produced and Figure(13) also performs well.

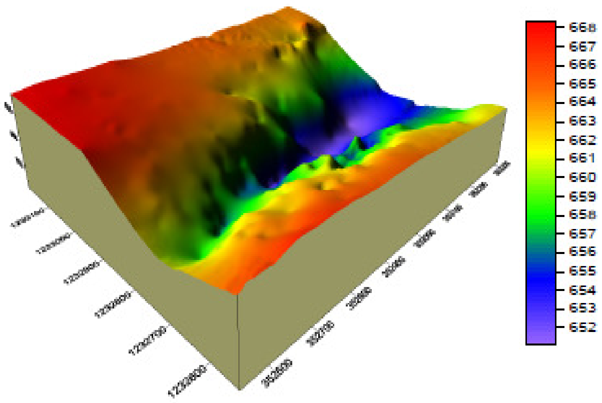

Figure.10 Surface map for the test site from Total Station

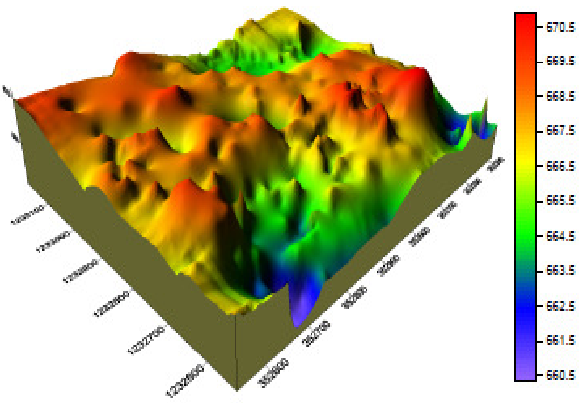

Figure.11: Surface map of the test site from SRTM 30

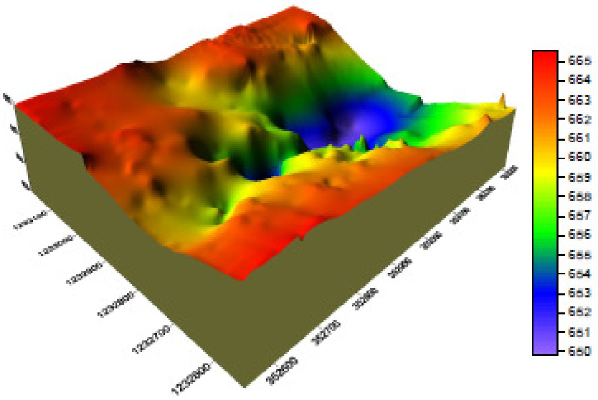

Figure. 12: Surface map of the test site from topographic map

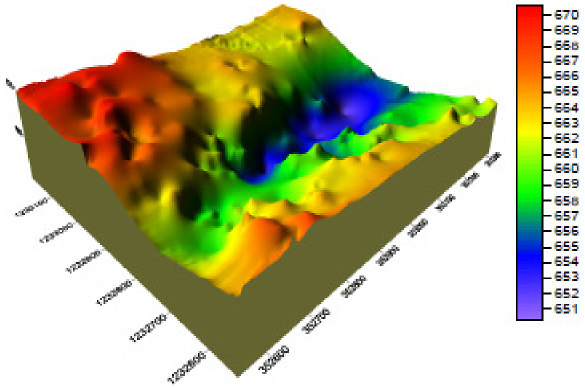

Figure. 13: Surface map of the test site from Google earth pro

3.2 Results of Estimated Topographic Attributes

Two major terrain attributes (slope and aspect) were estimated from the DEMs generated from the different data sources under investigation. Also their corresponding slope maps are presented in figures 14-17. In Table 3, the slope map statistics derived from the SRTM 30 have the lowest minimum and maximum slope value which indicates that the SRTM derived terrain is flatter, while the topographic map with the highest minimum and maximum slope values shows that the terrain is steeper and is also closer to the reference terrain. This is because the lower the slope value, the flatter the terrain; the higher the slope value, the steeper the terrain.

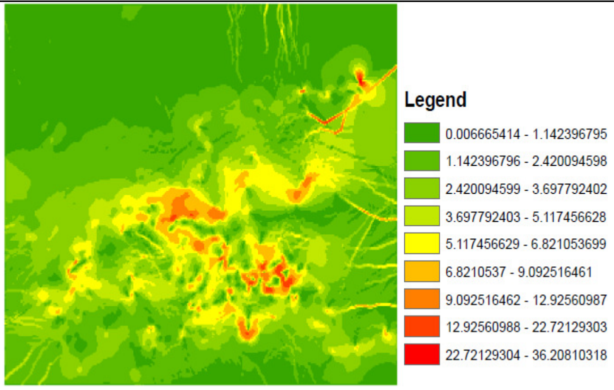

Figure.14: Slope map from total station measurement for the test site.

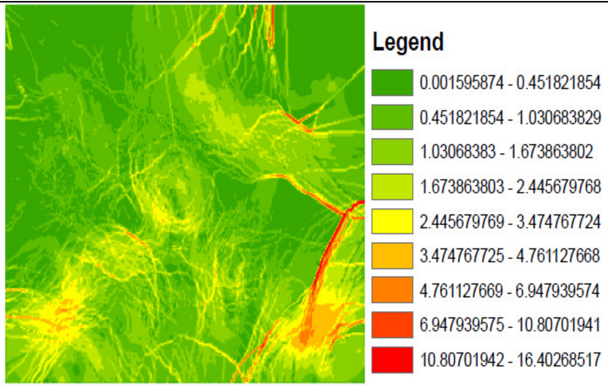

Figure.15: Slope map derived from SRTM 30 for the test site.

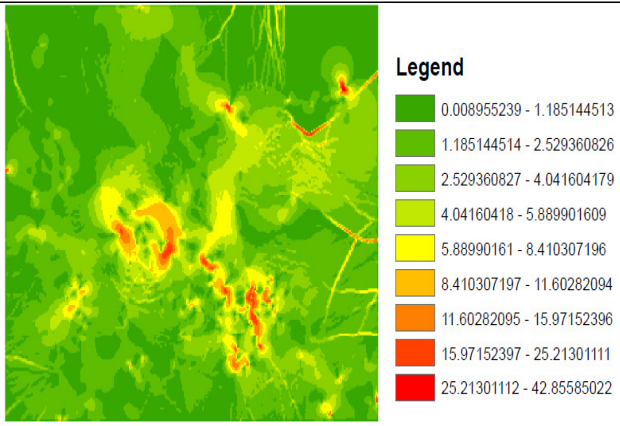

Figure.16: slope map from topographic map for the test site.

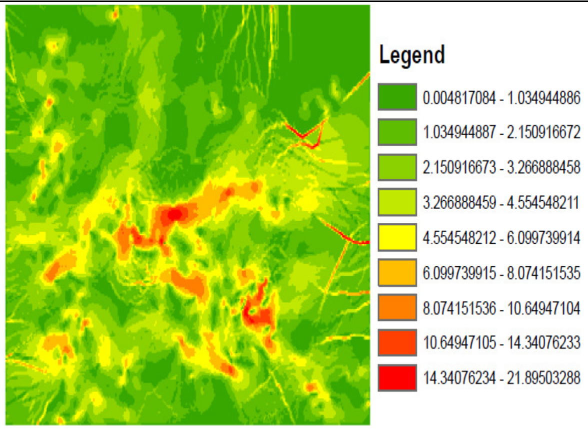

Figure. 17: Slope map derived from Google Earth Pro for the test site.

Table 3: Descriptive statistics for Slope maps from the various spatial data sources

S/no	Statistics	Ground survey in degrees	SRTM 30 in degrees	Topographic Map in degrees	Google earth pro in degrees
1	Minimum	0.0067	0.0016	0.0090	0.0048
2	Maximum	36.2081	16.4027	42.8559	21.8950
3	Mean	2.4683	1.0909	2.3611	2.5903
4	Std dev.	2.0599	1.0898	2.1957	2.0975

Aspect identifies the steepest down slope direction at a point on the earth surface. Table 4, shows the Aspect map (slope's direction) statistics from the various aspect maps. The mean values from the reference indicate that the steepest down slope is in the direction of South-East, while the SRTM 30, Google Earth and topographical map are all in the south direction. Figures.18 -21 shows that the aspect value -1 indicates flat slope and flat slope have no direction. While the red colours in aspect map ranging from (0-22.5) and (337.5-360) shows direction due north.

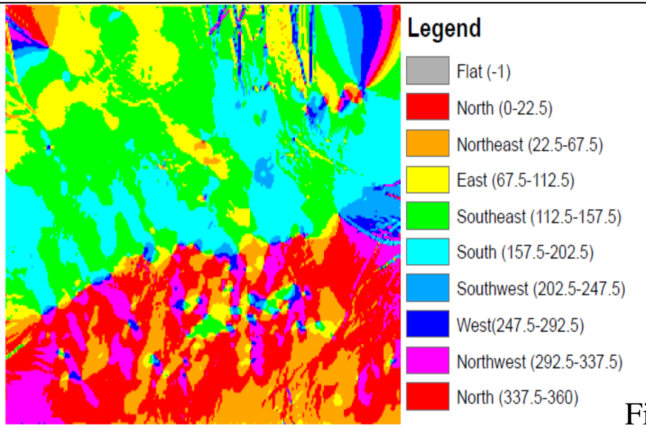

Figure.18: Aspect map derived from total station for the test site.

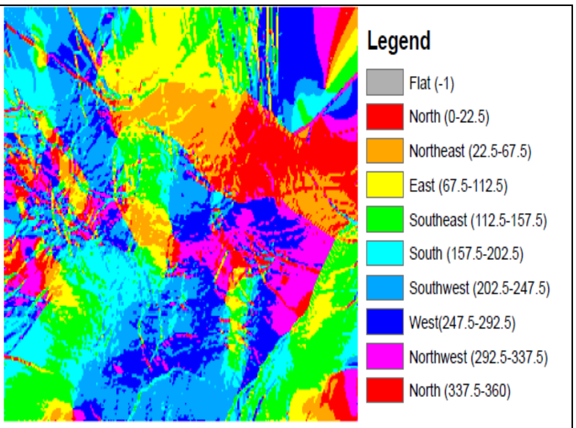

Figure. 19: Aspect map derived from SRTM 30 for the test site.

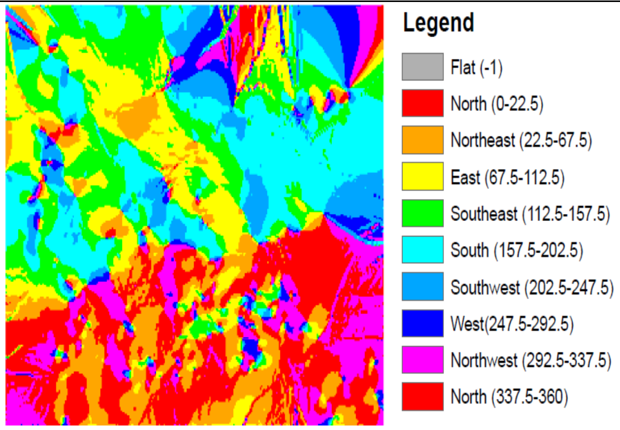

Figure. 20: Aspect map derived from topographic map of the test site.

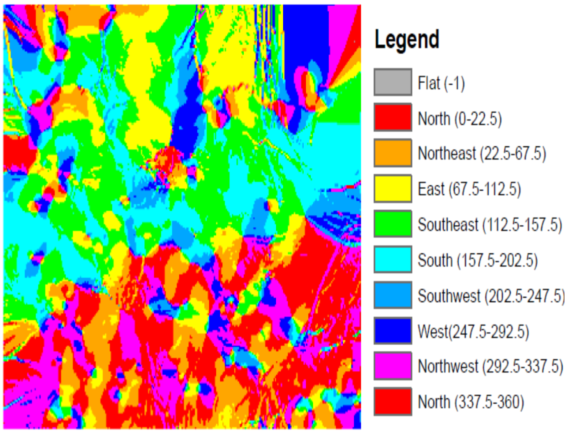

Figure. 21: Aspect map derived from Google Earth pro for the test site

Table 4: Descriptive Statistics for Aspect Maps from the Various Spatial Data Sources.

S/no	Statistics	Total station measurement in degree	SRTM 30 in degree	Topographic Map in degree	Google earth pro in degrees
1	Minimum	0	0	0	0
2	Maximum	359.9964	359.9882	359.9954	359.9918
3	Mean	155.2108	181.6740	163.4916	172.0930
4	Std dev.	102.6856	95.9055	108.2551	106.9118

3.3 Independence of spot height estimation errors and the magnitude of field measured height

Table 5 is the result of the residuals from the various data sources compared with the field measured data. It is obvious from the table that the residual of the spot heights from the SRTM 30 is the lowest having difference of -18m. While the standard error values from Table 5 show that the topographic map has the highest accuracy because of its low value. Figure. 22 is the scattered plot for the residual with topographic map on top, Google earth pro in the middle and SRTM below and far away from others.

Table 5: Descriptive Statistics for Residual of Spot height.

STATISTICS	*SRTM*	*Topographic map*	*Google earth*
Mean	-5.9256	-0.4093	1.3955
Standard Error	0.2277	0.0651	0.0825
Median	-5.175	-0.569	1.3965
Mode	-3.101	-2.2	1.7075
Standard Deviation	5.0670	1.4492	1.8351
Sample Variance	25.6748	2.1003	3.3675
Range	24.335	8.342	10.1395
Minimum	-18.354	-3.608	-4.02
Maximum	5.981	6.5315	4.322
Confidence Level (95.0%)	0.4475	0.1280	0.1621

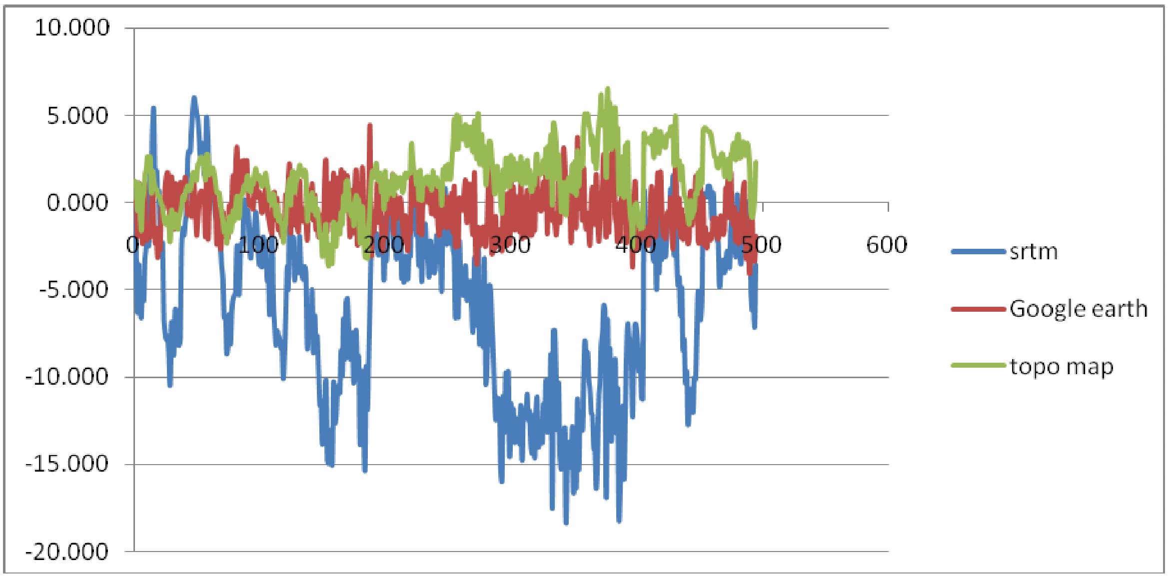

Figure. 22: Scattered plots from the residuals of the various data sources

Finally, three statistical tests (namely Pearson`s correlation coefficient test, covariance test and Spearman`s Ranking test) were conducted to ascertain the strength of the linear relationship between different sets of data and the reference ground survey.

The correlation analysis test examines each pair of measurement variables to determine whether the two measurement variables tend to move together — that is, whether large values of one variable tend to be associated with large values of the other (positive correlation), whether small values of one variable tend to be associated with large values of the other (negative correlation), or whether values of both variables tend to be unrelated (correlation near 0 (zero)). The value of any correlation coefficient must be between -1 and +1 inclusive.

Also, the covariance test examines each pair of measurement variables to determine whether the two measurement variables tend to move together — that is, whether large values of one variable tend to be associated with large values of the other (positive covariance), whether small values of one variable tend to be associated with large values of the other (negative covariance), or whether values of both variables tend to be unrelated (covariance near 0 (zero)). Corresponding covariances are not scaled.

The Spearman rank- correlation coefficient is a measure of the monotonicity of a relationship. The Spearman rank- correlation coefficient ranges from -1.0 to +1.0, with an interpretation similar to that for the sample correlation coefficient.

Table (6) shows the results of the different statistical tests described above. It is evident from the results of the three tests that the Google Earth imagery upholds the most excellent relation with the reference field data. The SRTM data source had a negative correlation coefficient and consequently a negative covariance implying a very meagre relation with the reference field data from the Total station instrument.

Table 6: Relationship between the Various Spot Heights and the Field Measured Data

s/no	Data source	Pearson's Correlation coefficient	Covariance	Spearman's Rank correlation
1	SRTM 30	-0.2555	-2.3380	0.5744
2	Topographic map	0.8855	12.1152	0.9765
3	Google Earth Imagery	0.9377	15.4080	0.9980

To test for a significant relationship from the Pearson's Correlation coefficient (r), the following hypothesises regarding ρ , the population correlation coefficient was adopted

$H_{\circ}: \rho = 0,$ *and* $H_1: \rho \neq 0$

Thus, if $H_{\circ}$ is true, then the value of $r\sqrt{(n-2)/(1-r^2)}$ has a t-distribution with $(n-2)$ degree of freedom. If the value of $r\sqrt{(n-2)/(1-r^2)}$ exceeds t-value from the student statistical t-test table or is less than -t , the null hypothesis $(H_{\circ}: \rho = 0)$ is rejected. A summary of results for the significant test are presented in Table (7).

Table 7: Test For Significant Relation between the Various Spot Heights and the Field Measured Data

Data source	$r\sqrt{(n-2)/(1-r^2)}$	t-value at 95% confidence level
SRTM 30	-5.8668	1.645
Topographical map	59.9159	1.645
Google Earth Imagery	42.3200	1.645

It is obvious that the value of $r\sqrt{(n-2)/(1-r^2)}$ for the SRTM 30 image is less than the corresponding t-value (1.645), we accept the null hypothesis $(H_{\circ}: \rho = 0)$ and conclude that the data from SRTM are not linearly related to the field measured data. The topographic map and Google Earth image had a $r\sqrt{(n-2)/(1-r^2)}$ value of 59.9159 and 42.3200, respectively, exceeding the t-value (1.645), we reject the null hypothesis $(H_{\circ} : \rho = 0)$ and conclude that the data from topographic map and Google Earth image are linearly related to the field measured data.

Finally, the Spearman`s Ranking correlation test, which a non parametric test confirms the results of Pearson`s Correlation test and covariance test which are parametric in nature. The trend of results of the non parametric test agrees well with those of parametric test and as such same conclusions are reached.

4. CONCLUDING REMARKS

In this study we assessed the reliability of elevation data used in the generation of Digital Elevation Models (DEMs) from its parameters generated from four different spatial data sources which are ground surveys using 495 total station radial points, Shuttle Radar Topography Mission (SRTM 30), Google Earth Pro and existing topographic map for the test site. The DEMs, Slope and Aspect map were produced using ArcGIS 9.2, while the 3D models were plotted on SUFFER 9.0. The spot height, slope and aspect were compared using statistical method.

Conclusively, it was observed that the reference DEM from ground survey using total station proves to be a very efficient method for generating DEMs but requires field work in capturing detailed terrain data. The DEM derived from the imagery (SRTM 30) does not perform well in obtaining DEM data. Google earth pro is slightly reliable while DEM derived from the topographical map also gives a good result but its quality depends on the quality of the existing topographic map and consequently the nature of data used in generating it. Finally it is important to point out that accuracy of elevation data for generation of DEMs be properly understood before they are utilised in varying applications. In view of the results obtained herein there is the need to validate all available global elevation data set in Nigeria, to ascertain their suitability or otherwise.

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BIOGRAPHICAL NOTES

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