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INVESTIGATION OF THE ROBUSTNESS OF DIFFERENT CONTOUR INTERPOLATION MODELS FOR THE GENERATION OF CONTOUR MAP AND DIGITAL EVELATION MODELS

KUTA Abdullahi Ahmed, AJAYI Oluibukun Gbenga, OSUNDE Tochukwu Juliet, IBRAHIM Pius Onoja, DADA David Oluwatomi and AWWAL Abdulqudus Ayo
Department of Surveying and Geoinformatics, Federal University of Technology, Minna.

This research seeks to investigate the robustness of ten different methods for contour interpolation in Surfer10.0 software namely: Inverse distance to weighting power (IDP), Kriging (KRG), Minimum Curvature (MC), Nearest Neighbor (NENE), Polynomial Regression (PR), Radial Basis Function (RF), Modified Shepard's Methods (MSM), Natural Neighbor (NANE), Triangulation with Linear Interpolation (TWLI) and Local Polynomial (LP). Hi Target Differential Global Positioning System (GPS) receiver was used for the spatial data (x, y, z) acquisition within the study area which was used for gridding and generation of contour maps and DEMs using each of the investigated interpolation method. From the surface models generated, twenty sample points were selected and their heights verified on the ground using a DGPS receiver. Comparative evaluation reveals that minimum curvature (236.4269m) and kriging (236.4674m) had the closest value to the observed value while MSM gave a value that is far higher than the observed height (236.8585m). Statistical investigations were carried out and the results also revealed that minimum curvature and kriging do have the best topographic representation of the study area, which is also supported by the low values of their RMSE of 0.2806 and 0.3109 respectively, while the modified shepard's method produced the highest RMSE value of 0.9100.

Keywords: contour interpolation, contour maps, digital elevation models, topographic representation.

INTRODUCTION

Interpolation is a method or mathematical function that estimates the value at locations where no measured values are available (Azpurua and Ramos, 2010) using nearby known data point (Vohat et al., 2013). Contour is the most commonly used method for relief mapping (Hiremath and Kodge, 2010), it is an imaginary line drawn on the map by joining points of equal elevation which are generated through contour interpolation. The method for converting discrete points collected into a continuous surface is called interpolation. Contour interpolation is a ubiquitous phenomenon (Guttman and Kellman, 2004), used to calculate unknown height of points by referring to the elevation information of neighboring point (Yang et al., 2006). Contours are of great importance in many fields or disciplines such as engineering works where they play vital roles in site location, cut and fill formation level of road or railways, location of catchment areas, dams, reservoirs, etc. Many other professionals such as Geologists, Agricultural scientists, Geographers, Archaeologists, Town planners, Architects, among others also find contour very useful in their various fields. Contour maps are also used in environmental statistics and applied spatial statistics to display estimates of continuous surface (Bolin and Lindgren, 2017), as source of data for the production of digital surface model such as digital elevation model (DEM) (Sharma et al., 2009), Digital terrain model (DTM) and Triangular irregular network (TIN) which are used in representing the earth's surface in 3 Dimensions, as well as in the rectification of aerial photographs or satellite imaginary, creation of relief maps, terrain analysis, precision farming, among others.

ogbajayi@gmail.com

Kuta, et al., (2018). **INVESTIGATION OF THE ROBUSTNESS OF DIFFERENT CONTOUR INTERPOLATION MODELS FOR THE GENERATION OF CONTOUR MAP AND DIGITAL EVELATION MODELS.** Contemporary Issues and Sustainable Practices in the Built Environment. School of Environmental Technology Conference, SETIC, 2018

Data used for contouring can be sourced directly from the field using ground survey, photogrammetry (Ali, 2004), satellite imageries (Ozah and Kufoniyi, 2006) or from existing topographic maps which could be in the form of point data or image. The direct ground surveying method is usually used for relative small size area which involves measurement carried out on the ground using surveying equipment to acquire point data in XYZ. Some of such equipment used includes theodolite, tacheometer, total station, level instrument and differential global positioning system (DGPS) receivers. Among all these ground survey equipment, DGPS receivers are highly sophisticated instruments, which provides a means for acquiring accurate and reliable data over a relatively open area in a short time, with significant accuracy.

The capability to easily create digital contours using commercial software has existed for decades (Tyler and Greenlee, 2012). The contour interpolation methods have significant impacts on the accuracy of the map (Shen et al., 2017) especially for a small area of land which are usually required for engineering works. There are various methods used for contour interpolation using different software packages. Some software for contour interpolation includes ArcGIS, Map source, AUTOCAD, ArcGrid, Surfer etc. Among the various contour interpolating software is SURFER. Surfer software is developed by US Golden Company and it is a grid based contour interpolation software used for 3D representation and visualization of the earth's surface. It provides various methods for contour interpolation. For this paper, Surfer 10.0 version is used and the methods explored includes, Inverse distance to power (IDP), Kriging (KRG) Local Polynomial (LP) Minimum Curvature (MC), Modified Shepard's Methods (MSM), Natural Neighbor (NAN), Nearest Neighbor (NN), Polynomial Regression (PR), Radial Basis Function(RBF) and Triangulation with Linear Interpolation (TWLI). The choice was random and also based on the most popular interpolation method used by land surveyors and other geospatial scientists.

The main aim of this paper is to investigate the robustness of these contour interpolation models which are all available in Surfer 10.0 software, for the accurate generation of contour maps and digital elevation models which will be a guide to the professionals who uses contour interpolation in choosing the right and most appropriate method.

Some Methods of Contour Interpolation In Surfer 10.0

Surfer is a grid based contour software which uses observed data from the field which are in the form of XYZ data file to create and calculate data points on a regularly spaced grid (a Grid [GRD] file). At points where no original data exists in respect to the observed data, interpolation schemes estimates the value of such points and then produces contour maps from the grid. The gridding method in Surfer 10 can be divided into 2 categories; exact and smoothing interpolators.

Exact interpolators honor exactly the data point on the condition that the data point falls completely on a grid. In other to reduce the possibility of not honoring original data points, there is a need to increase the number of grid lines in the X and Y direction which increases the chance of the data point to coincide with the grid nodes. For a weight average interpolator, this simply means that the data that coincides with the grid node has weight of 1.0 while every other data has a weight of 0.0. When the data measured cannot be trusted, the smoothing interpolator is employed. The smoothing interpolators makes little changes to the weighing factor in such a way that a smoother surface will be generated such that even when data points are exactly coincident with the grid node, smoothing interpolators do not assign weight of 1.0 to any data point. This however doesn't mean that the surface generated is not an accurate representation of the data (Http://crack.seismo.unr.edu/ftp/pub/louie/class/333/contour/surfer.pdf, n.d.).

Inverse Distant to Power (IDP)

This is a weighted average interpolator and can either be an exact or a smoothing interpolator. Inverse distance weighting models use the notion that observations further away should have a lower contribution than those which are near the point of interest (Griffiths, 2010). In this method, during interpolation, data is weighted such that point with greater distance from the grid node has lesser influence than those closer to the grid node. The power parameter controls how the weighting factor drops off as distance from a grid node increases. Closer points are assigned higher fraction of overall weight while other points are assigned lower weight fraction. Therefore, points closer to the unknown points are used to interpolate

the value for that point. It is a very fast method for interpolation however, it has the tendency of generating the "bull eye" effect

Kriging (KRG)

The Kriging interpolation method also known as space autoco-variance best interpolation method was proposed by a South African geological engineer D. G. Krige and improved by French mathematician G. Matheron (Chen et al., 2014). The method is known to produce visually pleasing contour from irregularly spaced data. Kriging is a stochastic method that estimates the value of a natural phenomenon in unmeasured sites using an unbiased linear combination of neighboring measures of the phenomenon with a minimum variance (Le Conte, 2006). Kriging can be an exact interpolator or a smoothing interpolator (Vohat et al., 2013) depending on the user's specified parameters. The core idea behind Kriging is that different sample points are weighted in their importance on the basis of their spatial location as well as their degree of correlation such that the estimation error is minimized. This method is widely used in calculation of mineral reserves, remote sensing data processing, geology, hydrology, environmental science, agriculture, and forestry science (Chen et al., 2014).

Local Polynomial (LP)

The Local Polynomial method assigns values to grid nodes by using a weighted least squares fit, with data within the grid node's search ellipse and works best with data sets that are relatively smooth within search neighborhoods (support.goldensoftware.com).

Minimum Curvature (MC)

This was developed by W.H.F. Smith and P. Wessel in 1990, It is not an exact interpolator, however while attempting to honor original data, minimum curvature generates the smoothest possible surface. The speed of computation is high, hence a suitable method for a large number of points *XYZ*. The disadvantage of this method is that, it has a complicated algorithm and cannot conserve extrapolation trends (Dressler, 2009).

Modified Shepard's Method (MSM)

This method uses an inverse distance weighted least square method. Therefore, it is similar to the inverse distance to power interpolator. But the bull's eye effect present in the inverse distance to power method is reduced in this method by the use of least squares. Shepard's method can either be an exact or smoothing interpolator.

Natural Neighbor (NAN)

The Natural neighbor works based on Voronoi tessellation which can be defined as "the partitioning of a plane with *n* points into *n* convex polygons such that each polygon contains exactly one point and every point in a given polygon is closer to its central point than to any other" (Dressler, 2009). This simply means that the natural neighbor uses a weighted average of the neighboring observations to interpolate an unknown value and thus generates contour lines. The Natural Neighbor method does not extrapolate the Z grid values outside the range of data and it does not generate nodes in areas without data.

Nearest Neighbor (NN)

In this method, the value of the nearest datum point is assigned to each grid node. This method comes in handy when the data is already in grid but however, needs to be converted to surfer grid file, or in a case where the data are nearly on grid with few missing values, this method helps in filling in the missing values.

Polynomial Regression (PR)

Polynomial regression does not predict unknown elevation values. It is not really an interpolator. It is used to define large scale trends and pattern in the data.

Radial Basis Function (RF)

Radial Basis Function interpolation is a diverse group of data interpolation method considered by many to be the best due to its ability to fit source data and to produce a smooth surface (Vohat et al., 2013; Yang et al., 2004). All of the Radial Basis Function are Multiquadric method and exact interpolators which attempt to honor every available data (Yang et al., 2004), and it is similar to Kriging due to it is flexible and ability to generate an

exact interpretation of most data sets. It can also produce a smooth surface as well as handle large data sets (support.goldensoftware.com).

Triangulation with Linear Interpolation(TWLI)

This method is historically one of the first methods used before the intensive development of computers (Dressler, 2009). This is an exact interpolator. This method works by drawing lines between data points to create triangles. The observed data points are connected such that no triangle edge is intersected by other triangles. This method is most effective when the observed data is evenly distributed over the grid area. It is a very fast algorithm but its limitations includes the fact that, the domain of the function is limited to the convex envelope of the points *XYZ*, the resulting surface is not smooth and isolines consists of line segments.

RESEARCH METHOD

Study Area

Minna is the capital city of Niger State, which is located at the North central region of Nigeria. The study area for this research is situated in the Federal University of Technology, permanent site, Gidan –Kwano, Minna, Niger State. The Institution is located along the Minna-Katerigi-Bida road which is about 12 km from Minna township. The study area (Figure 1) covers an approximate area of Eleven (11) hectares and it is located at the western part of the campus.

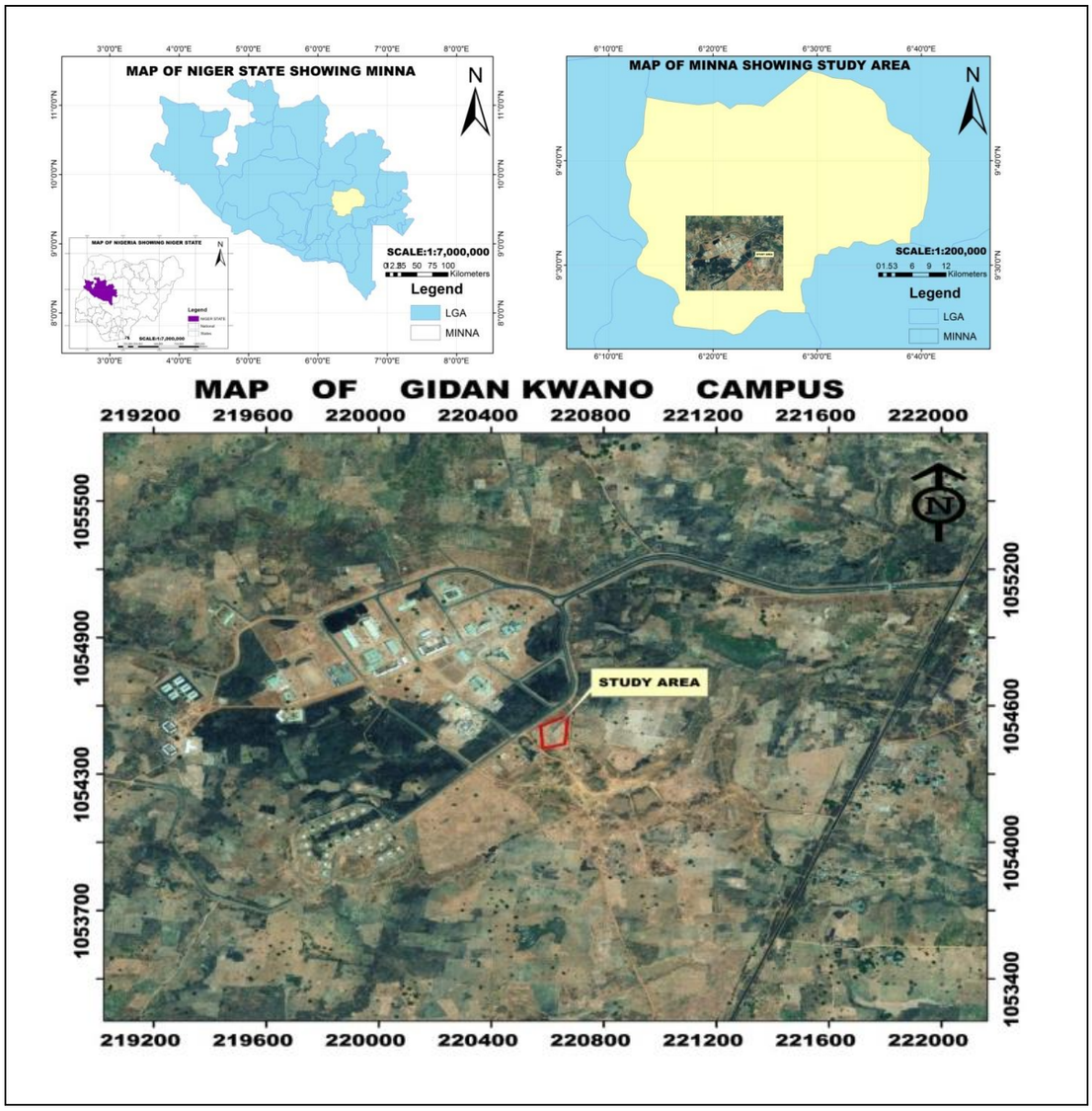


Figure 1: Study area

Data acquisition and pre-processing

The boundary of the study area was carved out and demarcated using iron pegs and perimeter survey was carried out using High-target V30 DGPS receiver to coordinate the pegged points defining the boundary, acquiring their Northing, Easting and height coordinate data. The spot heights of various points were randomly picked across the study area using the same DGPS receiver and the measured data was saved on the instrument's data logger. Approximately 560 sample points covering the total area of about 11 hectares were observed. The saved data was later converted to excel format (xlsx) before importing same into Surfer 10.0 software environment, in preparation for contour interpolation and generation of contour maps and DEMs.

Contour Interpolation and generation of DEMs

Since the data were not captured in gridded format (at a regular interval), The randomly selected ten (10) interpolation methods were used to grid the data into regular intervals. These methods are: Inverse Distance to Weighting Power (IDP), Kriging (KRG), Minimum Curvature (MC), Nearest Neighbor (NENE), Polynomial Regression (PR), Radial Basis Function (RF), Modified Shepard's Methods (MSM), Natural Neighbor (NANE), Triangulation with Linear Interpolation (TWLI) and Local Polynomial (LP). From the gridded data, contour surfaces were generated, depicting the topography of the study area. Since ten (10) different methods for interpolation were investigated for this research, ten (10) different contour maps were generated. Figures 2, 3, and 4 are the contour maps generated for each interpolation method used. The gridded data from each of the interpolation method was also used for the generation of DEM which is a 3-dimensional representation of the study area. Figures 5, 6, and 7 are the DEMs generated from the different interpolation method.

Accuracy assessment

Determination of the accuracy of interpolation methods is necessary in geosciences due to the developments in computer science and technology, and many different spatial interpolation algorithms which have been adopted in the software for surface modeling and GIS (Gogovi et al., 2014). In order to assess the accuracy of each of the contour interpolation methods, 20 sample points were selected on the same roll and column for the 10 different interpolation methods from the grid node editor in the Surfer 10.0 software environment. The Northing and Easting coordinates and the spot heights of the 20 sample points were extracted and recorded. The 20 sample points were also tracked on the ground by inputting their coordinates (Northing and Easting) into the data logger and using the DGPS rover to stake out the points on the ground. The spot heights of the staked-out points were then measured directly using the DGPS receiver. The sampled spot heights extracted from the ten interpolation methods were later compared with the spot heights of the same sample points measured directly by the DGPS receiver. Table 1 shows the interpolated sample spot heights and the spot heights measured directly by the DGPS receiver. The accuracies of the surfaces generated were evaluated using visual and statistical analysis. Using visual analysis, the spot height of each of the 20 sample points extracted from the ten-interpolation method was compared with the height measured directly to see which interpolation method gives a closer value to the measured spot height. The computed misclosures are shown Table 2. For adequate statistical analysis, the root mean square error (RMSE), Standard error, Scatter graph and correlation coefficient were examined to calculate the error for interpolated height values and to show the relationship that exists between interpolated and observed values.

Root Mean Square Error (RMSE)

From the computed misclosure, Root Mean Square Error (RMSE) was computed for each method using the formula given in equation 1. The computed RMSE for each of the methods investigated are shown in Table 3.

$$RMSE=\sqrt{\frac{1}{N}\sum_{i=0}^{n}(X_I-\chi_I)^2} \quad (1)$$

For every interpolation method used, there is a grid report automatically computed by the system software stating information such as, time taken for a method to grid the data, the standard deviation and standard error, Table 4 shows the information for each method.

Correlation

The correlation coefficient is a number between -1 and +1 which shows the strength of the linear relationship that exists between two variables. +1 shows a very strong positive linear relationship between the variables, 0 shows no relationship exists and -1 shows a very strong negative relationship between the variables. Table 5 and 6 respectively shows correlation coefficient between the interpolated height with observed height values and correlation coefficient of all the methods.

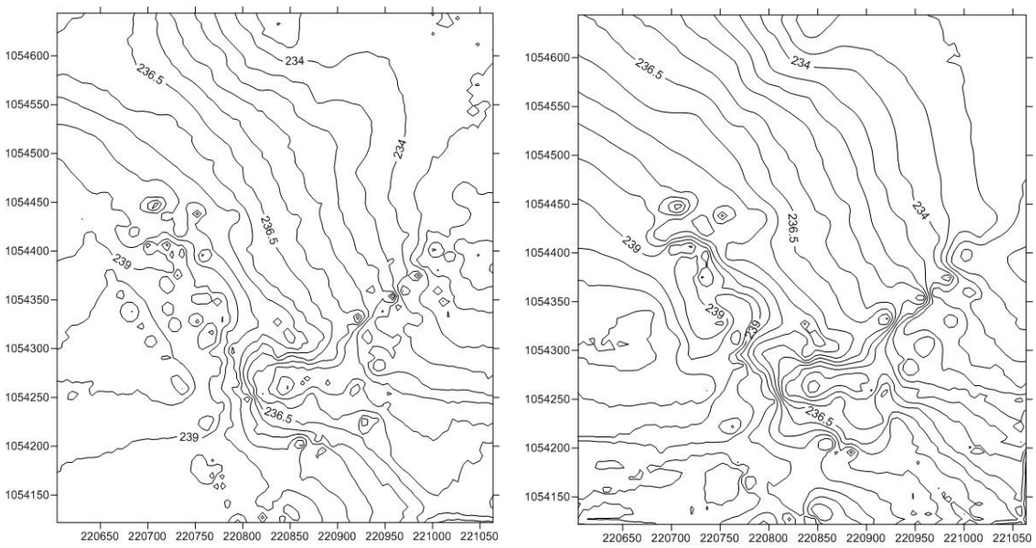
Scatter Point Graph

Scatter point graphs were also used to indicate the direction of the relationship for the heights interpolated for each method on the X axis against the observed method on the Y axis. Figures 8, 9, and 10 are the scatter point graphs for each method plotted against the observed data.

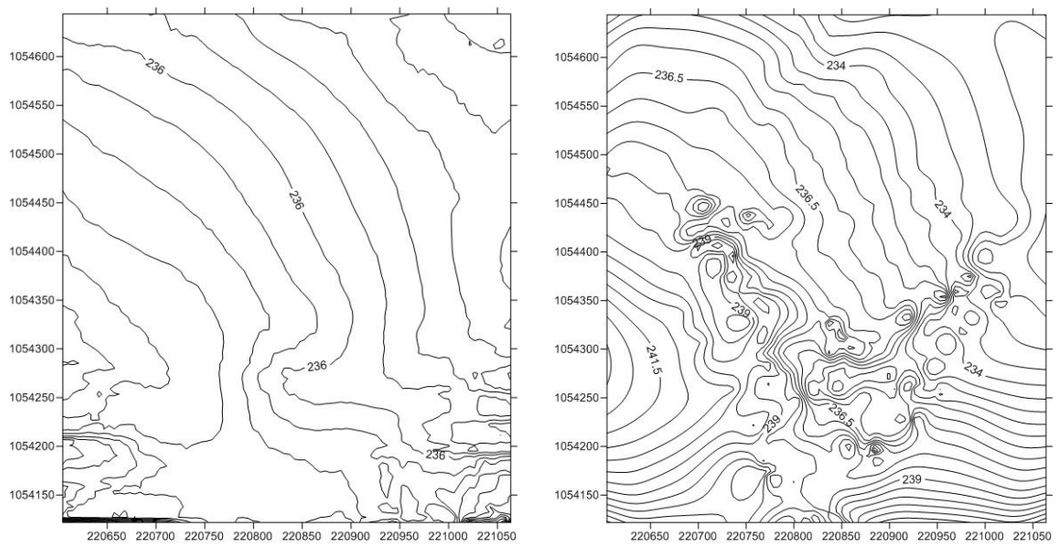
FINDINGS AND DISCUSSION OF RESULTS

Generated Contour Maps

Figures 2 A -D shows contour maps generated by Inverse distance to power (IDP), Kriging (KRG, Local Polynomial (LP) and Minimum Curvature (MC) methods respectively. The maps generated by IDP, Kriging and MC are more similar, and they gave a closer representation of the study area compared to LP although, Kriging and MC are more visually similar. Kriging is known to produce visually pleasing contours from irregularly spaced data using an unbiased linear combination of neighboring measures of the phenomenon with a minimum variance (Le Conte, 2006), and can be an exact interpolator or a smoothing interpolator in SUFER depending on the user's specified parameters. Also, the Minimum Curvature attempt to honor original data, and as such, generates the smoothest possible surface that exactly fit the dataset which makes it have a more similar visualization with kriging. The IDP contour lines are sparse and even sparser in Local polynomial generated contour map. This is due to the fact that IDP tends to generate bull's eye patterns which can be reduced by smoothing the interpolated grid. The LP has smooth curve and less dense contour lines. This is because LP fits the specified order (zero, first, second, third, and so on) polynomial using points only within the defined neighborhood. The LP also assumes that; the samples were taken on a grid (that is, the samples are equally spaced), and the data values within the searching neighbourhood are normally distributed.



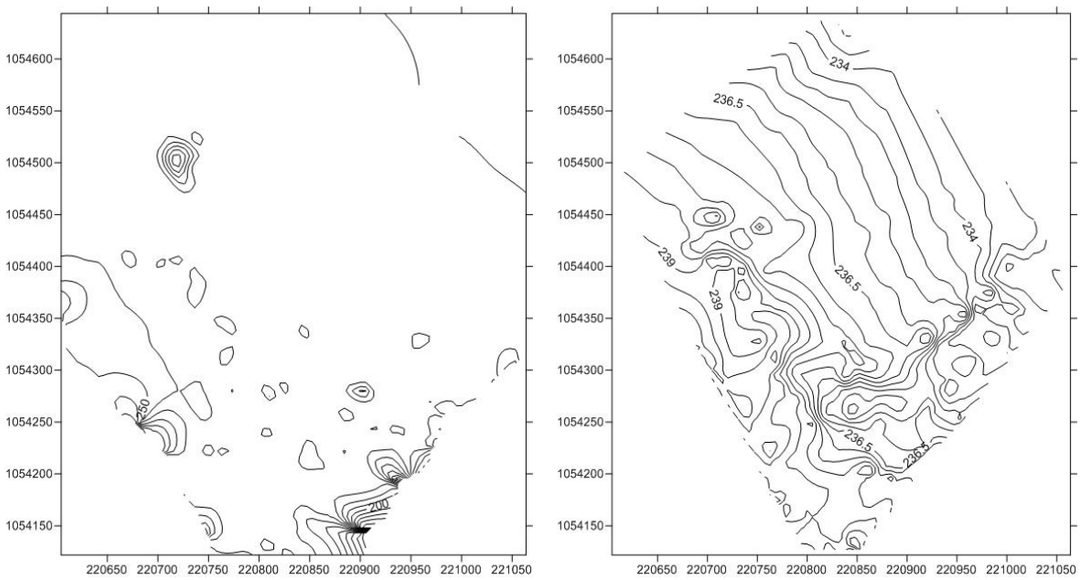
A = IDP B = kriging



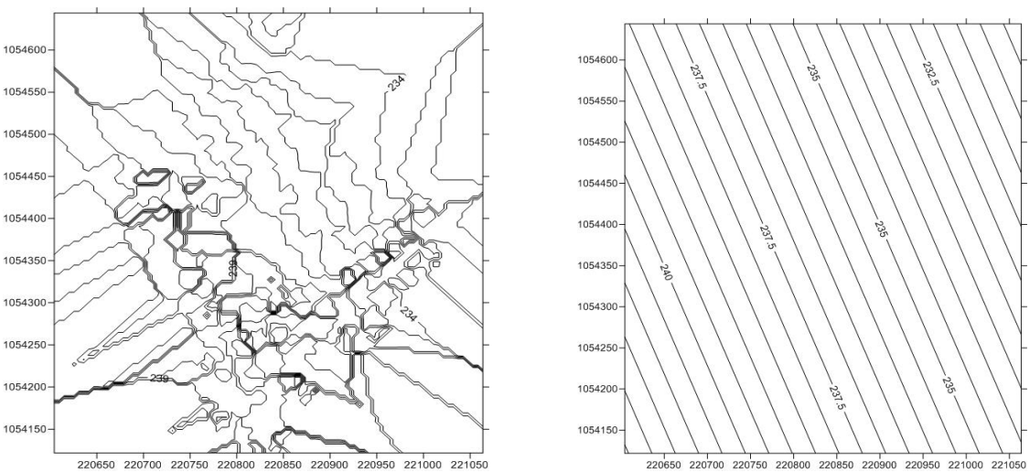
C = LP D = MC

Figure 2: Contour maps generated by Inverse distance to power A), Kriging B), Local polynomial C), and Minimum Curvature D) methods.

Figures 3 A-D are contour maps from Modified Shepard, Natural neighbor, Nearest Neighbour and Polynomial regression methods respectively. MSM and NAN shows contour covering only the boundary of the study area because both methods are exact although smoothing could be specified for MSM. Also, the Natural Neighbor method does not extrapolate contours beyond the convex hull of the data locations (Yang et al., 2004) while MSM gives a poor visualization of the study area using local least squares estimation. It generates fewer artifacts and can provide extrapolation. On the other hand, NN generated bulky contours with sharp edges because it is most useful for almost complete datasets (e.g. grids with missing values) and does not provide extrapolation. PR represents the area as a very flat terrain which is false as the study area is fairly rugged. The poor result obtained from PR is because it is not really an interpolator and it does not attempt to predict the value of elevation but rather, it defines large scale trends and pattern in the data.



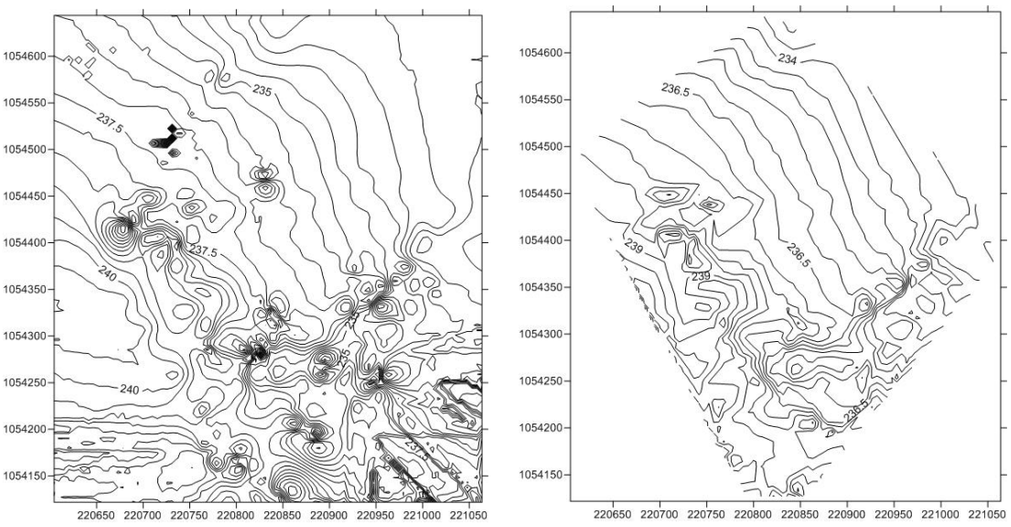
A= MSM **B= NAN**



C= NN **D= PR**

Figure 3: Contour maps generated by Modified Shepard Method A), Natural neighbor B), Nearest neighbor C), Polynomial regression D) methods.

Figures 4A and B shows contour maps generated from Radial Basis Function and Triangulation with Linear Interpolation methods respectively. RBF generated contours are closely packed, though they cover the entire region while TWLI contours covers only the boundary of the study area just like MSN and NAN. Both the RBF and TWLI are exact interpolators, and they honor the provided data as seen from the result in Figure 4 A and B, the representation of the topography are similar. The major difference is that the BWLI uses the original data to define the triangles. The data are honored very closely with the tilt and elevation of the triangle determined by the three original data points, defining the triangle hence, it fit into the boundary of the study area.



A= RBF **B=TWLI**

Figure 4: Contour maps generated by Radial Basis Function A), Triangulation with Linear Interpolation B) methods.

Derived Digital Elevation Models (DEM)

Figures 5 A-D presents the digital elevation model from triangulation with linear interpolation, Inverse Distance to Power, kriging and Local Polynomial methods respectively. Kriging and IDP DEMs are similar in their terrain depiction of the study area. Just like the contour it generated, the TWLI DEM only covers the boundary of the area while LP generated a DEM that represents the study area as a gentle slope terrain.

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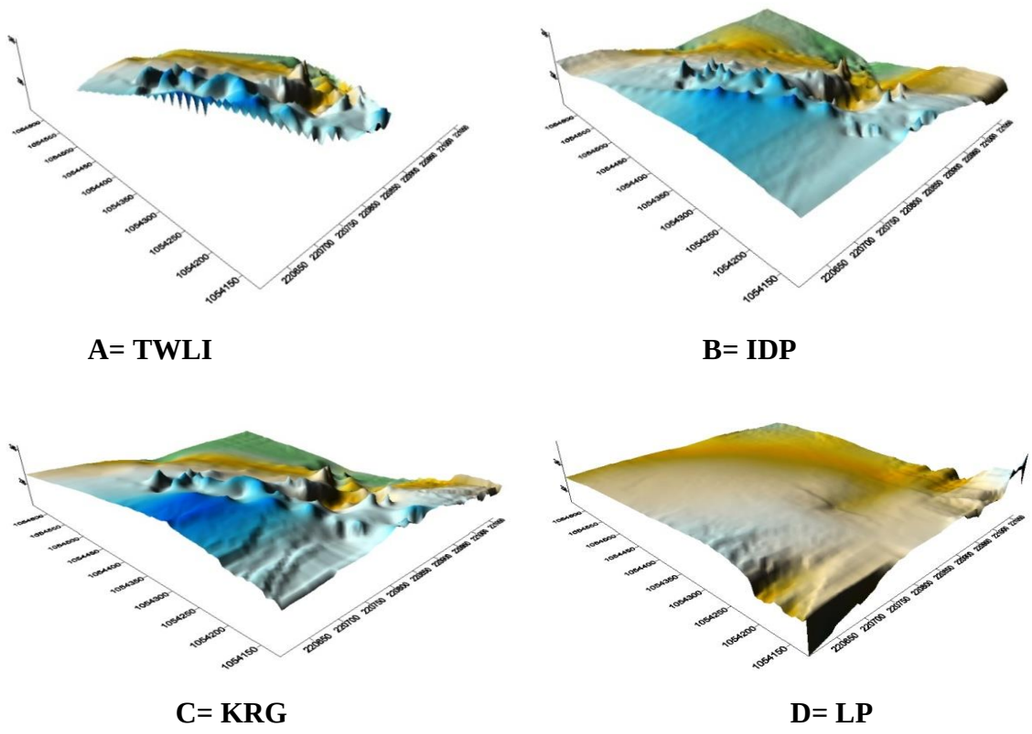


Figure 5: Digital elevation model from triangulation with linear interpolation A), Inverse Distance to Power B), kriging C), and Local Polynomial D) methods.

Figures 6 A-D is the digital elevation model from Minimum curvature, Modified Shepard, Natural Neighbor and Nearest Neighbor methods respectively. The worst of the DEMs generated is observed in the Modified Shepard method which generated a DEM that completely shows the opppsite of how the terrain configuration is, showing depression instead of elevation. NN DEMs had bulky edeges just as its generated contour map.

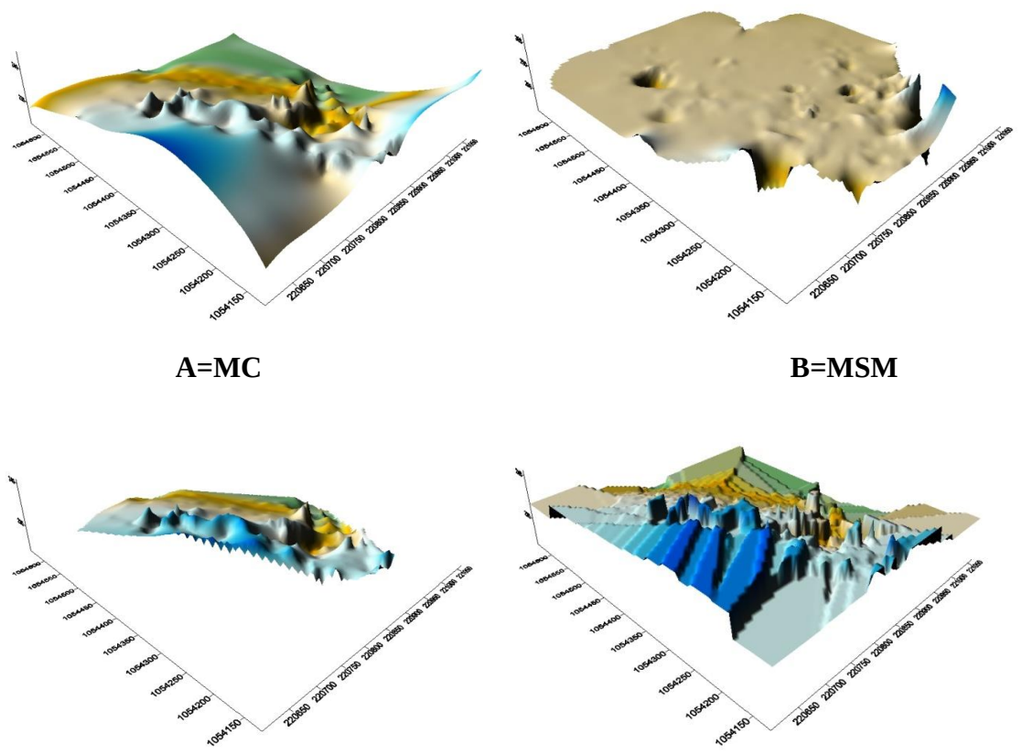
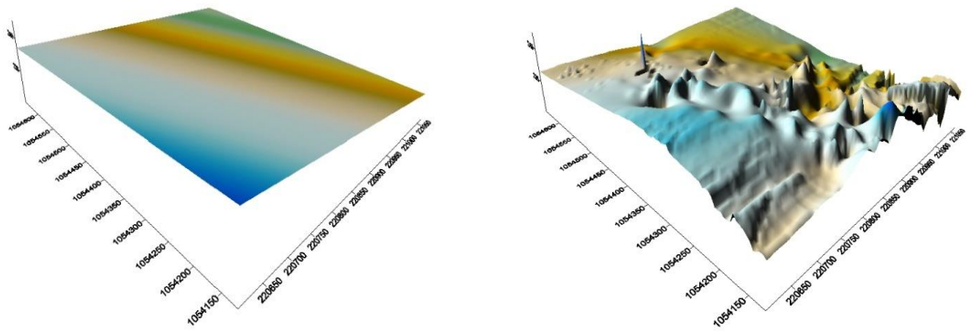


Figure 6: Digital elevation model for Minimum Curvature A), Modified Shepard B), Natural Neighbor C) and Nearest Neighbor D) methods.

Figure 7A-B shows the digital elevation model for Polynomial Regression and Radial Basis Function respectively. Polynomial regression generated DEMs shows the study area as a smooth flat terrain with no variation in height because the model is not really an intepolator.



A=PR **B= RBF**

Figure 7: Digital elevation model for Polynomial Regression A), Radial Basis Function B)

Interpolated sampled heights and Misclosures between interpolated heights and observed heights

Table 1 shows the spot heights of the 20 sampled points extracted from each of the ten interpolation methods and the spot heights of the same 20 sampled points measured directly on the ground using the DGPS receiver (shown in red). The interpolated heights were subtracted from the observed height to derive their misclosures which is shown in Table 2. High level of discrepancies can be observed in spot heights extracted from MSM, PR, RBF, TWLI and LP in comparison with the measured heights. Table 1: Interpolated sampled heights from different methods of contour interpolation in Suffer 10 and observed height from DGPS receiver

IDP	KRIGING	MC	MSM	NANE	NENE	PR	RBF	TWLI	LP	OBSERVED HEIGHT
236.4389	236.4674	236.4269	236.8585	236.4584	236.4964	236.1231	236.7159	236.4463	236.4722	236.4024
239.4287	239.7456	239.8900	239.5734	239.5405	240.1317	237.9893	239.6970	239.2892	238.8993	240.4663
234.7186	234.5543	234.5395	234.5756	234.5641	234.7760	234.2390	234.5391	234.5320	234.6282	234.5388
234.9440	234.8880	234.8918	234.9264	234.8796	234.9560	234.9130	234.9103	234.8826	234.6752	234.8183
234.6788	234.1609	234.1220	233.0443	234.0377	234.4565	233.7564	234.1427	234.0112	234.0270	234.0536
235.8095	235.8303	235.8001	235.8136	235.8183	236.0465	235.7388	235.8009	235.8062	235.7621	235.8420
235.0581	234.9726	234.9853	235.6167	234.9531	235.0096	234.5018	234.9900	234.9674	234.8499	234.8822
235.5124	235.5442	235.5313	235.5702	235.5461	235.5512	235.0184	235.5669	235.5469	235.3953	235.4673
236.8298	236.8613	236.8452	236.8757	236.9065	236.7395	236.6701	236.8387	236.9194	237.3381	236.7737
236.6134	237.3875	237.2829	237.3200	237.4020	236.7580	236.8309	237.2814	237.3972	237.6294	236.8173
236.4140	236.6556	236.4003	236.3022	236.9515	235.5697	237.7157	236.5252	237.1880	237.1242	236.4002
236.3545	236.7094	236.7433	236.4731	236.8091	236.8242	237.6013	236.6472	236.6157	236.7032	237.2284
236.4341	236.6083	236.5522	238.7436	236.5352	236.4543	237.0972	237.0738	236.4976	236.6400	236.2808
235.2590	234.7960	234.8904	234.2234	234.8947	234.9211	236.3858	234.4458	234.7671	235.5460	234.6149
236.4126	236.7555	236.8026	236.8259	236.7175	236.4563	235.9496	237.1409	236.7449	236.0814	236.8299
237.2381	236.9627	236.8745	236.6226	237.0054	236.6911	236.1785	237.1658	237.0383	236.9316	236.7476
238.4585	237.7424	237.8058	235.5386	237.8620	236.9709	237.9785	236.9083	237.8818	238.5179	237.1216
239.3147	239.7135	239.4814	237.3590	239.7220	240.5351	238.7239	238.9598	239.9940	239.4455	239.4413
235.8248	235.7038	235.6269	236.0027	235.7329	235.7809	236.2374	235.6321	235.8127	236.2800	235.8173
234.5545	234.3469	234.4236	234.2708	234.3408	234.4143	235.0094	234.2035	234.3390	235.0738	234.1314

Table 2: Misclosures between interpolated heights and observed heights

IDP DIFF	KRIGING DIFF	MC DIFF	MSM DIFF	NANE DIFF	NENE DIFF	PR DIFF	RBF DIFF	TWLI DIFF	LP DIFF
-0.0365	-0.0650	-0.0245	-0.4561	-0.0560	-0.0940	0.2793	-0.3135	-0.0439	-0.0698
1.0376	0.7207	0.5763	0.8929	0.9258	0.3346	2.4770	0.7693	1.1771	1.5670
-0.1798	-0.0155	-0.0007	-0.0368	-0.0253	-0.2372	0.2998	-0.0003	0.0068	-0.0894
-0.1257	-0.0697	-0.0735	-0.1081	-0.0613	-0.1377	-0.0947	-0.0920	-0.0643	0.1431
-0.6252	-0.1073	-0.0684	1.0093	0.0159	-0.4029	0.2972	-0.0891	0.0424	0.0266
0.0325	0.0117	0.0419	0.0284	0.0237	-0.2045	0.1032	0.0411	0.0358	0.0799
-0.1759	-0.0904	-0.1031	-0.7345	-0.0709	-0.1274	0.3804	-0.1078	-0.0852	0.0323
-0.0451	-0.0769	-0.0640	-0.1029	-0.0788	-0.0839	0.4489	-0.0996	-0.0796	0.0720
-0.0561	-0.0876	-0.0715	-0.1020	-0.1328	0.0342	0.1036	-0.0650	-0.1457	-0.5644
0.2039	-0.5702	-0.4656	-0.5027	-0.5847	0.0593	-0.0136	-0.4641	-0.5799	-0.8121
-0.0138	-0.2554	-0.0001	0.0980	-0.5513	0.8305	-1.3155	-0.1250	-0.7878	-0.7240
0.8739	0.5190	0.4851	0.7553	0.4193	0.4042	-0.3729	0.5812	0.6127	0.5252
-0.1533	-0.3275	-0.2714	-2.4628	-0.2544	-0.1735	-0.8164	-0.7930	-0.2168	-0.3592
-0.6441	-0.1811	-0.2755	0.3915	-0.2798	-0.3062	-1.7709	0.1691	-0.1522	-0.9311

0.4173	0.0744	0.0273	0.0040	0.1124	0.3736	0.8803	-0.3110	0.0850	0.7485
-0.4905	-0.2151	-0.1269	0.1250	-0.2578	0.0565	0.5691	-0.4182	-0.2907	-0.1840
-1.3369	-0.6208	-0.6842	1.5830	-0.7404	0.1507	-0.8569	0.2133	-0.7602	-1.3963
0.1266	-0.2722	-0.0401	2.0823	-0.2807	-1.0938	0.7174	0.4815	-0.5527	-0.0042
-0.0075	0.1135	0.1904	-0.1854	0.0844	0.0364	-0.4201	0.1852	0.0046	-0.4627
-0.4231	-0.2155	-0.2922	-0.1394	-0.2094	-0.2829	-0.8780	-0.0721	-0.2076	-0.9424

It can be observed that minimum curvature and kriging gave lower discrepancies from the observed data in centimeters and millimeters ranges which are tolerable in surveying and engineering works. But in other methods, the difference in some points are in meters. For example, the modified shepard method had misclosures ranging from 1 to 2 meters which are known to be too high and intolerable in surveying.

Statistical Analysis

Root mean square error was calculated for each method and the result is shown in Table 3. From the RMSE results, minimum curvature gave the least root mean square value (0.2806) which means that on the average, minimum curvature generated heights are errorneous by 0.280m (Forkuo, 2008). Kriging gave a RMSE that is very low too though a little higher than Minimum curvature (0.3108), while the highest root mean square value is seen in modified shepard (0.9099).

Table 3: Root Means Square Error for different methods of contour interpolations

S/N	INTERPOLATION METHOD	RMSE VALUE(m)
1	Minimum curvature	0.280561288
2	Kriging	0.310865356
3	Radial basis function	0.356979
4	Natural neighbor	0.3617
5	Nearest neighbor	0.377381
6	Triangulation with linear interpolation	0.438779
7	Inverse distance to power	0.509658367
8	Local polynomial	0.667918
9	Polynomial regression	0.887015
10	Modified shepard	0.909980786

Elapsed time for gridding data, standard deviation and standard error values were obtained from the grid report for each method used and the results are displayed in Table 4. The result obtained from the elapsed time for gridding data shows that some grid data interpolation methods are faster than the others. The longest expended time is seen in radial basis function method with a processing time of 172.5 seconds while the shortest processing time was recorded by Polynomial regression method (0.02 seconds) which is in agreement with the work of Yang et al. (2004). Modified Shepard has the highest value for standard deviation (7.84684) and standard error (0.094152), while the lowest standard deviation is recorded by Natural neighbor interpolation method (1.98344), and the lowest standard error is recorded by Inverse distance to power method (0.02239).

Table 4: Time elapsed, standard deviation and standard error of each of the interpolation methods

S/N	INTERPOLATION METHOD	TIME ELASPED FOR GRIDDING DATA (seconds)	STANDARD DEVIATION	STANDARD ERROR
1	Minimum curvature	1.10	2.61369	0.02786
2	Kriging	8.33	2.31768	0.02471
3	Radial basis function	172.5	2.40811	0.02567
4	Natural neighbor	0.32	1.98344	0.02850
5	Nearest neighbor	0.16	2.27459	0.02425
6	Triangulation with linear interpolation	0.03	2.00485	0.02848
7	Inverse distance to power	1.01	2.10038	0.02239
8	Local polynomial	1.31	2.54558	0.02714
9	Polynomial regression	0.02	2.73362	0.02914
10	Modified shepard	0.13	7.84684	0.094152

Table 5 shows the coefficient correlation for each of the interpolation method against observed data. The result reveals that they are all closely related, however, the closest relation is seen in minimum curvature and Kriging while the least relation is observed in modified Shepard and polynomial regression methods. Table 6 shows the detailed result of coefficient correlation for all the methods.

Table 5. Coefficient correlation for each method against observed data

	IDP	KRIGING	MC	MSM	NAN	NN	PR	RBF	TWLI	LP
Obs value	.952	.983	.986	.831	.976	.972	.831	.976	.963	.914
N	20	20	20	20	20	20	20	20	20	20

Table 6: Correlation coefficient for all method

		Obs_Value	IDP	KRIGING	MC	MSM	NANE	NENE	PR	RBF	TWLI	LP
Obs_ Value	Pearson Correlation	1	.952	.983	.986	.831	.976	.972	.831	.976	.963	.914
	Sig. (2-tailed)		.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
	N	20	20	20	20	20	20	20	20	20	20	20
IDP	Pearson Correlation	.952	1	.977	.979	.734	.976	.944	.853	.937	.970	.958
	Sig. (2-tailed)	.000		.000	.000	.000	.000	.000	.000	.000	.000	.000
	N	20	20	20	20	20	20	20	20	20	20	20
KRIGING	Pearson Correlation	.983	.977	1	.998	.817	.998	.966	.864	.980	.993	.959
	Sig. (2-tailed)	.000	.000		.000	.000	.000	.000	.000	.000	.000	.000
	N	20	20	20	20	20	20	20	20	20	20	20
MC	Pearson Correlation	.986	.979	.998	1	.819	.994	.967	.858	.979	.986	.954
	Sig. (2-tailed)	.000	.000	.000		.000	.000	.000	.000	.000	.000	.000
	N	20	20	20	20	20	20	20	20	20	20	20
MSM	Pearson Correlation	.831	.734	.817	.819	1	.806	.775	.692	.896	.790	.740
	Sig. (2-tailed)	.000	.000	.000	.000		.000	.000	.001	.000	.000	.000
	N	20	20	20	20	20	20	20	20	20	20	20
NANE	Pearson Correlation	.976	.976	.998	.994	.806	1	.953	.885	.974	.997	.969
	Sig. (2-tailed)	.000	.000	.000	.000	.000		.000	.000	.000	.000	.000
	N	20	20	20	20	20	20	20	20	20	20	20
NENE	Pearson Correlation	.972	.944	.966	.967	.775	.953	1	.787	.943	.945	.894
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000		.000	.000	.000	.000
	N	20	20	20	20	20	20	20	20	20	20	20
PR	Pearson Correlation	.831	.853	.864	.858	.692	.885	.787	1	.814	.884	.932
	Sig. (2-tailed)	.000	.000	.000	.000	.001	.000	.000		.000	.000	.000
	N	20	20	20	20	20	20	20	20	20	20	20
RBF	Pearson Correlation	.976	.937	.980	.979	.896	.974	.943	.814	1	.965	.909
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000		.000	.000
	N	20	20	20	20	20	20	20	20	20	20	20
TWLI	Pearson Correlation	.963	.970	.993	.986	.790	.997	.945	.884	.965	1	.969
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000		.000
	N	20	20	20	20	20	20	20	20	20	20	20
LP	Pearson Correlation	.914	.958	.959	.954	.740	.969	.894	.932	.909	.969	1
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	
	N	20	20	20	20	20	20	20	20	20	20	20

Scatter graph

Figure 8A-D is the scatter point graph, linear trend line is shown along with the equation of the curves and R^2 statistics for inverse distance to power, Kriging, Minimum Curvature and Modified Shepard method respectively. This analysis was done to further examine how correlated (fitted) the observed heights are close to the interpolated heights from different contour interpolation methods in a graphical form. The scatter plots and the fit line shows that there is positive correlation between the observed height and the interpolated height for all the four contour interpolation methods because the trend is from left side rising towards the right side. The R^2 values measure the strength of fit between the dependent and independent variables. The independent variables are the observed heights while the dependent variables are the interpolated heights. The closer the R^2 value is to 1, the stronger the fitness. From the results in Figure 8A to D, it can be observed that IDP, KRG and MC all have R^2 values above 0.9 (showing close relationship with observed height) while MSM has the lowest value of 0.69. This result agreed with table 5 showing the correlation coefficient ***r*** of each contour interpolation method where MSM has the lowest value of 0.831. The full ***r*** values (coefficient of correlation) are tabulated in table 5. Also, the graph shows

that the points are more clustered along the fit line in IDP, KRG and MC (indicating stronger correlation) than MSM.

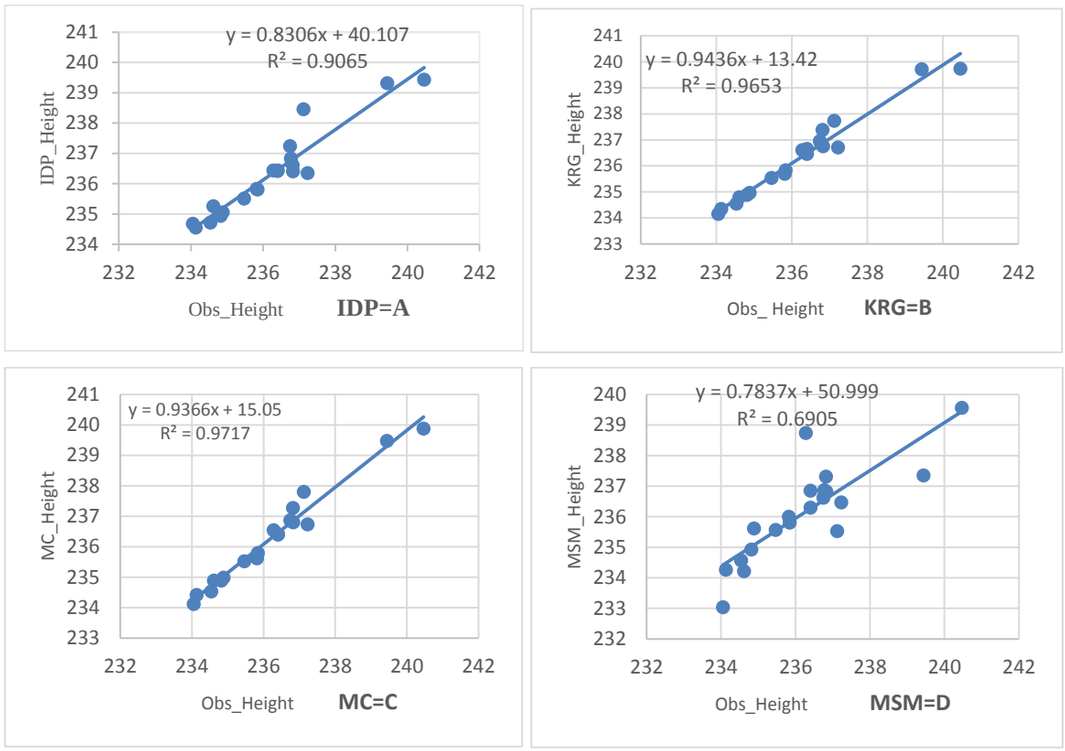


Figure 8: scatter point graph, linear trend line, the equation of the curves and R^2 statistics for Inverse Distance to Power A), Kriging B), Minimum Curvature C), and Modified Shepard method D) methods.

Figure 9A-D is the scatter point graph, linear trend line, the equation of the curves and R^2 statistics for Natural Neighbor, Nearest Neighbor, Polynomial Regression and Radial Basis Function respectively. Just like the results in Figure 8, scatter plots and the fit line shows that there is positive correlation between the observed heights and the interpolated heights for all the four contour interpolation methods. The results show that NAN, NN and BRF all have R^2 values that is above 0.9 (showing close relationship with observed height) while PR has the lowest value of 0.68.The result of correlation coefficient ***r*** in table 5 shows that NAN, NN and BRF have r values above 0.9 while PR has the lowest r values of 0.831. Also, the graph shows that the points are more clustered along the fit line in NAN, NN and PRF (indicating stronger correlation) than PR.

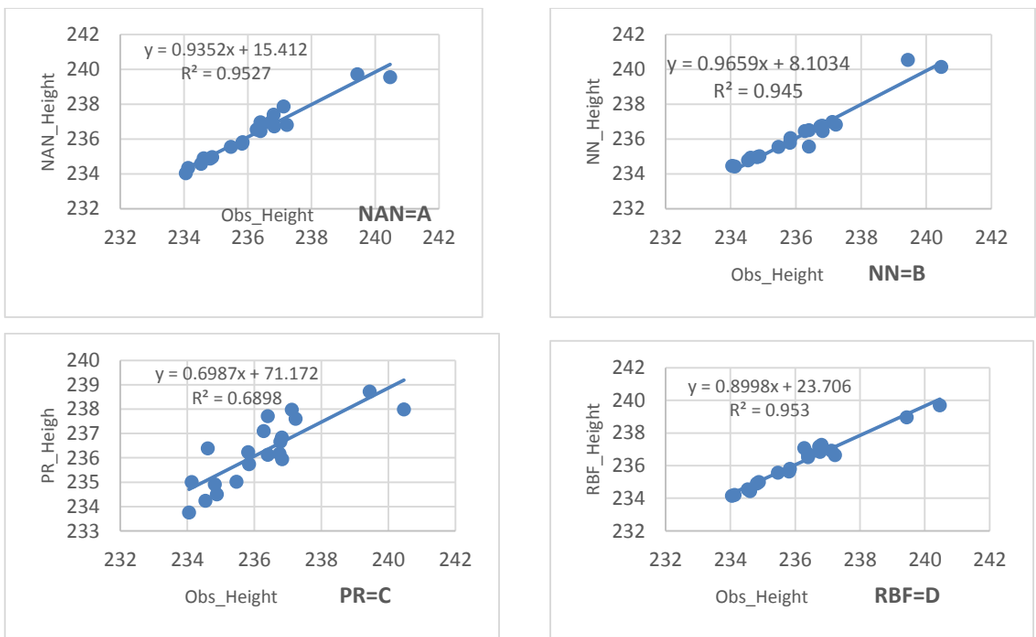
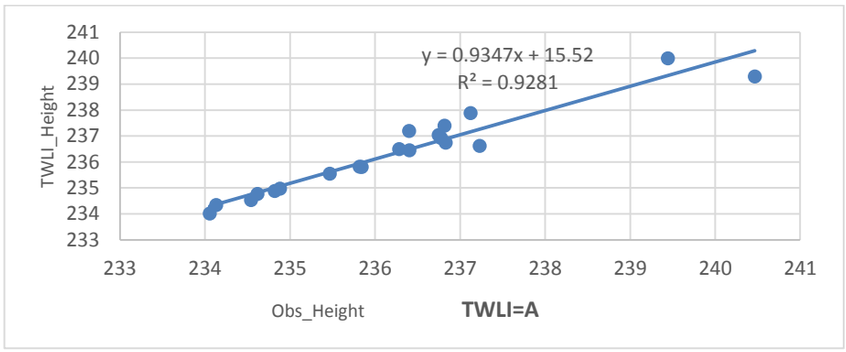


Figure 9: scatter point graph, linear trend line, equation of the curves and R^2 statistics for Natural Neighbor A), Nearest Neighbor B), Polynomial Regression C), and Radial Basis Function D) method.

Figures 10A and B shows the scatter point graph, linear trend line, the equation of the curves and R^2 statistics for Triangulation with Linear Interpolation and Local Polynomial methods

respectively. The scatter plots and the fit line in figure 10 also shows a positive correlation between the observed heights and the interpolated heights for TWLI and LP contour interpolation methods. TWLI has R^2 value that is above 0.9 (showing close relationship with observed height) while LP has R^2 value of 0.84. For correlation coefficient ***r*** in table 5, both TWLI and PL have *r* values above 0.9 indicating strong correlation between observed heights and the interpolated heights generated from the two methods. Also, the graph shows that the points are clustered along the fit line in both methods which indicate strong correlation.



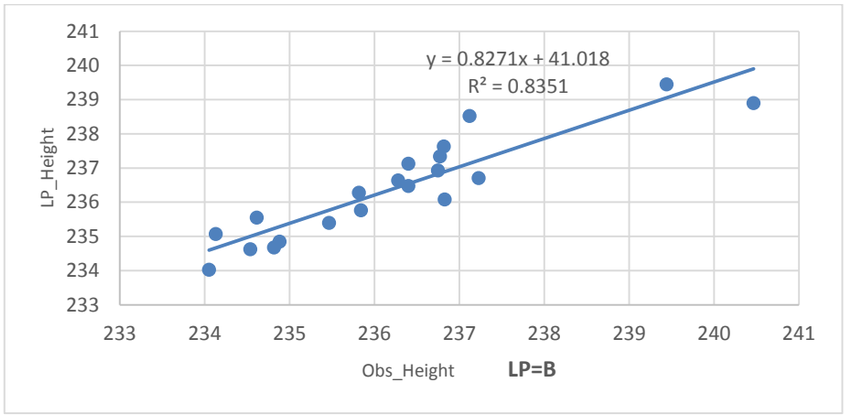


Figure 10: scatter point graph, linear trend line, equation of the curves and R^2 statistics for Triangulation with Linear Interpolation A), Local Polynomial B) method.

CONCLUSION

From the results obtained in this research and their analysis, it can be concluded that minimum curvature and kriging gave the closest estimation to the observed value of the elevation data used. On the other hand, Modified Shepard Method and Polynomial Regression gave the worst estimation to the observed values of elevation data as seen from generated elevation and the results from statistical analysis. It is however important to note that there is no overall best method of interpolation, each method has its advantage and disadvantage and the accuracy for each method depends on the nature of sample data used. Selection of interpolation method should depend on the sample data, expected processing/elapsed time, the type of surface to be generated and tolerance of estimated errors.

REFERENCES

Ali, T.A., 2004. On the Selection of an Interpolation Method for Creating a Terrain Model (TM) from LIDAR Data. Am. Congr. Surv. Mapp. Conf. 2004 1–18.

Azpurua, M., Ramos, K. Dos, 2010. A Comparison of Spatial Interpolation Methods for Estimation of Average Electromagnetic Field Magnitude. Prog. Electromagn. Res. M 14, 135–145.

Bolin, D., Lindgren, F., 2017. Quantifying the Uncertainty of Contour Maps. J. Comput. Graph. Stat. 26, 513–524.

Chen, P., Li, Y., Su, Y., Chen, X., 2014. The improved kriging interpolation algorithm for local underwater terrain based on fractal compensation. Math. Probl. Eng. 2014.

Dressler, M.M., 2009. Art of Surface Interpolation. Kun?` Tát.

Gogovi, G.K., Oduro, F.T., Fosu, G.O., 2014. Performance Analysis of Memorization Rate Models. Geod. Vestn. 3, 1343–1346.

Griffiths, D.W., 2010. Contouring Algorithms With Terrain Mapping Applications.
Guttman, S.E., Kellman, P.J., 2004. Contour interpolation revealed by a dot localization paradigm. Vision Res. 44, 1799–1815.
Http://crack.seismo.unr.edu/ftp/pub/louie/class/333/contour/surfer.pdf, n.d. No Title 1–9.
https://support.goldensoftware.com/hc/en-us/articles/231348728-A-Basic-Understanding-of-Surfer-Gridding-Methods-Part-1#
Le Conte, P., 2006. Parcours Hydrologie-Hydrogéologie Kriging with Partial Di erential Equations in Hydrogeology. University Pierre & Marie Curie.
Ozah, a P., Kufoniyi, O., 2006. Accuracy Assessment of Contour Interpolation From 1 : 50 , 000 Topographical Maps and Srtm Data for 1 : 25 , 000 Topographical Mapping. Archives 1347–1354.
Sharma, A., Tiwari, K.N., Bhadoria, P.B.S., 2009. Measuring the accuracy of contour interpolated digital elevation models. J. Indian Soc. Remote Sens. 37, 139–146.
Shen, J., Han, W.L., Ge, J., Zhang, L.B., Inspection, N.Q., Products, M., Road, L., Method, I., 2017. Digital Elevation Model Interpolation By Fusion of XLII, 18–22.
Tyler, D.J., Greenlee, S.K., 2012. Creation of Digital Contours That Approach the Characteristics of Cartographic Contours.
Vohat, P., Gupta, V., Bordoloi, T.K., Naswa, H., Singh, G., Singh, M., 2013. Analysis of different interpolation methods for uphole data using Surfer software. 10th Bienn. Int. Conf. Expo. 2.
Yang, C., Kao, S., Lee, F., Hung, P., 2004. Twelve Different Interpolation Methods : a Case Study. Proc. XXth ISPRS Congr. 35, 778–785.
Forkuo, E.K. (2008). Digital terrain modeling in a GIS environment. *The International archives of the Photogrammetric, Remote Sensing and Spatial Information Sciences*. Vol. XXXVII. Part B2. Beijing 2008.
Yang, L., Park, B. U., Xue, L. & Hardle, W. (2006). Estimation and testing for varying coefficients in additive models with marginal integration. *J. Amer. Statist. Assoc.* 101, 1212-1227.

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