Assessment of Spatial Prediction Techniques Accuracy for Elevation Determination in Akure South Local Government, Ondo State Nigeria

Victor A. Ijaware, and Adebayo T. Adeboye

Abstract—The Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) is a cooperative effort between NASA and Japan's Ministry of Economy Trade and Industry (METI), with the collaboration of scientific and industry organizations in both countries. The ASTER instrument provides a more robust remote sensing imaging capability when compared to the older Landsat Thematic Mapper. This paper deals with the accuracy assessment of elevation data obtained using ASTER from each of the eleven (11) selected extrapolation/interpolation algorithms: Inverse Distance Weighting, Natural Neighbor, Spline Regular, Spline Tension, Universal Krigging, Empirical Bayesian Krigging, Topo to Raster, global (trend surface), local polynomial, kernel interpolation with barriers and radial basis functions in Digital Elevation Model (DEM) surface creation. The data was compared with reference to ground control points of differential GPS measurements in the study area. The error statistics was generated between DGPS measurements and Extracted elevation data from each selected interpolation method. It was observed that Spline Regular Interpolation show the best overall accuracy of ±11.520m when elevation data extracted from Inverse distance weighting, Natural Neighbor, Spline T, Topo to Raster, Universal Krigging, Empirical Bayesian krigging, Global polynomial interpolation (GPI), local polynomial interpolation (LP), Radial basis function and Kernel interpolation of ±15.170, ±14.340, ±12.336, ±13.551, ±14.707, ±13.711, ±15.363, ±13.964, ±13.590 and ±15.376 respectively when compared with elevation values from GPS method. The study recommends capacity building of point elevation data to DEM.

Index Terms—ASTER, Interpolation Methods, Extrapolation Methods, Root Mean Square Error, Elevation.

I. INTRODUCTION

Elevation is a vital component in any geographic study utilized as a concrete measurement of the Earth’s surface above the sea level. Teams of surveyors historically collected elevation measurements, performing what is known as geodetic leveling [6]. Geodetic leveling measures the relative elevation from one area (usually the ocean or benchmark) to the area of interest. Today, time-intensive and rather imprecise process has been reduced to a series of fly-overs from remote, passive or active sensors to acquire the measurements [5]. Currently, it is possible to obtain Digital Elevation Model (DEM) information for free, without financial costs of almost every region of the earth surface. Although these DEMs are dense and generally have good spatial distributions, the accuracy of their elevation information might not be suitable for many applications. A way of alleviating this problem is to combine the available DEM data along with other information, coming from reliable sources and having better quality, in the data modeling processes [2].

Interpolation of a spatially continuous variable from point samples is a significant field in spatial analysis and surface models for geosciences [3]. Spatial interpolation permits the representation of a surface and predicts values of other unknown areas in an endeavor to create a continuous surface [4]. According to [1], spatial interpolation can be divided into two methods namely Deterministic (Spatial) and Geostatistics (or stochastic). Deterministic method involves using mathematical formula to form weighted averages of nearby known values, and it also provides no assessment of errors with predicted values. Meanwhile, stochastic method includes using weighted averages and also probability models to make predictions, the assessment of prediction errors is also obtainable with estimated variances.

The use of remote sensing data (especially elevation) requires ground truth data for validation. The integration of ground-based measurements with remote sensing data provides adequate data coverage to the generation of a reliable DEM to show the surface topography. Therefore, for this work, Differential Global Positioning System (DGPS) points within the study area was combined with the Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) datasets for accurate Digital Elevation Model (DEM) generation.

The aim of this work is to assess spatial prediction techniques accuracy for elevation determination with the following objectives: Determine the elevation values of selected data points from Global digital surface model (ASTER) using adopted interpolation techniques, compare elevation data from adopted interpolation techniques and determine the accuracies of adopted methods of interpolation. To achieve these objectives, answers to the following questions become important: what are the different methods used for height determination and densification? What are the accuracies of height determined from global digital surface model using different interpolation method? What method of interpolation technique will yield optimal result for elevation determination? This study assessed the variation between the interpolation methods provided by Arc GIS in its Spatial
Analyst and Geostatistical Analyst Extensions in order to determine how the varying parameter settings affect the resulting surfaces. The case study will employ eleven (11) interpolation algorithms, including Inverse Distance Weighting, Natural Neighbor, Spline Regular, Spline Tension, Universal Kriging, Empirical Bayesian Kriging, Topo to Raster, global (trend surface), local polynomial, kernel interpolation with barriers and radial basis functions in DEM surface creation. Understanding the extensions’ differences and modifying the parameters in each interpolation algorithm results in statistically reliable elevation surfaces.

I. STUDY AREA

Akure South Local Government covers an area of 331km² and has an area of 331 km² with a projected population of 468,005 as at 2019 based on 2.5% annual population increase. Akure has a tropical climate with significant rainfall most months, and a short dry season. This climate is considered to be Tropical Monsoon according to the Köppen-Geiger climate classification. The average annual temperature is 26.7°C in Akure while the average rainfall is 1455mm. The study area which is of varying undulation covers Akure South Local Government and it lies on the following longitudes and latitudes 5°11'51.4''E, 7°21’15.1’’N; 5°16’24.9’’E, 7°11’34.1’’N; 5°21’50.6’’E, 7°5’34.6’’N; 5°9’33.3’’E, 7°10’10.7’’N and 5°5’2.3’’E, 7°16’41.5’’N.

Fig. 1. Sketch of the study area

II. MATERIALS AND METHODS

One hundred and ninety (190) disperse Ground Control Points (GCP) was established within the study area using DGPS with positional values determined in 3-dimension (X, Y, Z). Existing GCP was also obtained from the Ondo State Ministry of Lands and Housing Akure. The GCPs were distributed within the study area dispersedly and was based on the redundant point’s consideration as shown in Fig 2. The field was visited so as to pre-plan random GCPs and identify the positions of important features to be used for ground-truthing. The established GCPs served as the field work controls as well as the test stations on which the accuracy of height values from adopted approaches was based.

Similarly, the ASTER data that covered Akure-South LGA, Ondo State was downloaded from United State Geological Survey (USGS) website. Height values of the study area were extracted from ASTER data with reference to the established GCPs.

The methodological approach for the assessment interpolation methods using the ASTER data and DGPS measurements is shown in Fig 3.

The Research design was divided into three sections namely data collection, integration/processing and analysis. The data collection involves both primary and secondary sources. The primary data (elevation values) was obtained directly from field survey observation using Differential Global Positioning System (DGPS), while the secondary data was obtained from both the Ondo state Ministry of Land and Housing Akure and United State Geological Survey (USGS) website. Specifically, Akure South Local Government Area was divided into fifteen units and Ground Control Points (GCPs) were established at a minimum of three kilometers interval from each other amounting to eighty-two established GCPs within the study area. The units include: Aponmu, Gbogi, Isikan, Ijomu, Obanla, Oda, Odopetu, Aro, Uro, Oke-Aro, Oja-Oshodi, Owode, Isolo, Imuagun and Oke Lisa.

The procedures for the elevation determination using ASTER require image preprocessing and a thorough ground-truthing process. The elevation values extraction from ASTER was achieved using the spatial analyst tool (extract values to point) where the input point data (vector format) were the planimetric coordinates (Northings and Eastings) of the gridded points which was then loaded alongside the raster format data simultaneously into ArcGIS. Spatial data exploratory analysis of the extracted elevation from ASTER and DGPS elevation was performed while Takeoff trends of the elevations was carried out in other to
create residual stationary information.

For the processing, Geostatistical Analyst and Spatial Analyst Tools, within ArcGIS 10.3, provides extrapolation/interpolation methods for generating interpolated surfaces from discrete spatial data measurements. In this work, eleven techniques of Extrapolation/interpolation were applied one after another but not all interpolation algorithms such as spline, Topo to Raster and Natural neighbor are available within the Geostatistical Wizard which are then accessed using the arc ToolBox.

The Ground control points and the extracted elevation values were added in ArcMap environment. Deterministic methods, geostatistical methods, and Interpolation with barriers were the methods explored by the Geostatistical Wizard to create a Digital Elevation Model as shown in Figure 4 for the Empirical Bayesian Kriging (EBK), located under Geostatistical Methods.

![Image](image-url)

Fig. 4. Empirical Bayesian Krigging (Elevation model)

These steps were repeated for the other extrapolation/interpolation methods. However, for the analysis, Spline Regular and Spline Tension generated results when Spatial Analyst tool was used while the algorithms of Topo to Raster and Natural Neighbor are not accessible via the geostatistical wizard but through the spatial analysis tool under the arc ToolBox. Using an independent sample set of DGPS elevation points, validations and analysis of the resulting maps using statistics and root mean square deviation metrics were subsequently performed.

III. RESULTS AND DISCUSSION

Table 1 depicts the descriptive statistics of the elevation data. It was clear that the calculated statistical indicator like mean error, standard deviation, sample variance, maximum and minimum values from the approaches adopted are relatively closer to one another. Also, values from ASTER data source are relatively same using geospatial method of interpolation (Kriging) with the exception of the spatial interpolation methods (Natural, Spline and Topo to Raster) which does not have errors associated with the predicted points.

![Table](table-url)

| Method  | Minimum (m) | Maximum (m) | Mean Error (m) | RMSE (m) | Mean Standardized Error (m) | RMS (m) | Processing Speed (Secs) | Average Standard Error (m) |
|---------|-------------|-------------|----------------|----------|-----------------------------|---------|------------------------|--------------------------|
| IDW     | 241         | 490         | 0.84           | 16.309   | -                           | -       | 3.2                    | 31.398                   |
| NATURAL | 243.39      | 487.17      | -              | -        | -                           | -       | 3.17                   | 28.331                   |
| SPLINE R| -765.10     | 1527.51     | -              | -        | -                           | -       | 4.39                   | 180.179                  |
| SPLINE T| 239.85      | 502.62      | -              | -        | -                           | -       | 3.87                   | 35.165                   |
| TOPO RAST| 238.43     | 488.39      | -              | -        | -                           | -       | 15.10                  | 32.018                   |
| KRIGG   | 241         | 490         | 0.18           | 15.603   | 0.006                       | 0.961   | 4.40                   | 17.11                    |
| EBK     | 246.98      | 478.37      | -0.01          | 15.310   | -0.004                      | 0.948   | 11.98                  | 16.232                   |
| GPI     | 296.94      | 377.95      | 0.00           | 27.478   | -                           | -       | 0.58                   | 15.463                   |
| LPI     | 251.36      | 445.62      | -0.27          | 17.072   | -                           | -       | 1.27                   | 26.218                   |
| RBF     | 251         | 490         | 0.01           | 0.363    | -                           | -       | 1.35                   | 31.398                   |
| KERNEL  | 247.86      | 461.82      | -0.03          | 15.410   | -0.001                      | 0.978   | 3.42                   | 15.747                   |

It was observed that Global Polynomial Interpolation (GPI) has the lowest mean error (0.002) among the adopted methods while using ASTER data. The summary of the results of regression analysis for all adopted techniques under investigation is shown in table 2.

![Table](table-url)

| Method  | R | R² | Adjusted R² | Significance Value | Standard Deviation of Error of Estimate | Constant | Unstandardized Coefficient (B) |
|---------|---|----|-------------|--------------------|----------------------------------------|----------|-------------------------------|
| IDW     | 0.89| 0.79 | 0.79       | P=0.0<0.05         | 5.8487              | 83.070   | 0.775                         |
| NATURAL | 0.87| 0.75 | 0.75       | P=0.0<0.05         | 5.5634              | 40.535   | 0.871                         |
| SPLINE R| 0.90| 0.81 | 0.80       | P=0.0<0.05         | 5.1725              | 15.386   | 0.948                         |
| SPLINE T| 0.92| 0.84 | 0.837      | P=0.0<0.05         | 4.9160              | 9.765    | 1.016                         |
| TOPO RAST| 0.92| 0.84 | 0.837      | P=0.0<0.05         | 4.7351              | 1.815    | 0.980                         |
| KRIGG   | 0.84| 0.71 | 0.700      | P=0.0<0.05         | 5.8304              | 61.008   | 0.814                         |
| EBK     | 0.88| 0.78 | 0.773      | P=0.0<0.05         | 5.3257              | 31.772   | 0.897                         |
| GPI     | 0.94| 0.89 | 0.883      | P=0.0<0.05         | 3.8521              | 6.505    | 0.962                         |
| LPI     | 0.88| 0.78 | 0.770      | P=0.0<0.05         | 5.8456              | 3.969    | 0.977                         |
| RBF     | 0.87| 0.75 | 0.740      | P=0.0<0.05         | 5.3107              | 60.060   | 0.817                         |
| KERNEL  | 0.91| 0.83 | 0.830      | P=0.0<0.05         | 4.4964              | 26.531   | 0.906                         |

Although, the regression model predicted that all method investigated are of good fit for GPS data. Moreover, the positional accuracy of each adopted method was determined using the United National Standard for Spatial Data Accuracy of 2016. In this work, horizontal and vertical accuracies were determined based on the distributed data points reported at the 95% confidence level (p-value in the ANOVA outcome was also less than α = 0.05). As
horizontal accuracy is of little importance to this work, only vertical accuracy of adopted methods was investigated.

The study also revealed that the accuracy assessment of the absolute vertical accuracy of the adopted prediction methods using the ASTER data were within the allowable limit values of ±16m as for GDSM data specification using GPS elevations as a reference as seen in Table 3. The vertical accuracy obtained from ASTER indicates that both methods are suitable for elevation data determination.

| Method      | Minimum Residual (m) | Maximum Residual (m) | Mean Residual (m) | RMSE (m) | Accuracy Degree (m) | Accuracy allowable limit (m) |
|-------------|----------------------|----------------------|-------------------|----------|---------------------|-----------------------------|
| IDW         | -10.382              | 9.286                | -19.927           | 7.740    | 15.170              | ±16.00                      |
| NATURAL     | -18.669              | 1.531                | -4.709            | 7.317    | 14.340              | ±16.00                      |
| SPLINE R    | -9.618               | 9.696                | -2.968            | 5.878    | 11.520              | ±16.00                      |
| SPLINE T    | -13.73               | 6.16                 | -4.077            | 6.294    | 12.336              | ±16.00                      |
| TOPO RASTER | -15.84               | 3.572                | -5.142            | 6.914    | 13.551              | ±16.00                      |
| KRIGG       | -13.454              | 11.067               | -4.464            | 7.504    | 14.707              | ±16.00                      |
| EBK         | -12.856              | 7.073                | -4.554            | 6.996    | 13.711              | ±16.00                      |
| GPI         | -11.949              | 2.55                 | -6.868            | 7.838    | 15.363              | ±16.00                      |
| LPI         | -13.221              | 7.697                | -4.270            | 7.124    | 13.964              | ±16.00                      |
| RBF         | -12.226              | 10.922               | -4.166            | 6.933    | 13.590              | ±16.00                      |
| KIB         | -14.4                | 5.68                 | -6.427            | 7.845    | 15.376              | ±16.00                      |

This work also shows that the Vertical accuracy with respect to the United Nation spatial standard revealed that elevation data extracted from Inverse distance weighting, Natural Neighbour, Spline R, Spline T, Topo to Raster, Universal Krigging, Empirical Bayesian krigging, Global polynomial interpolation (GPI), local polynomial interpolation (LPI), Radial basis function and Kernel interpolation were ±15.170, ±14.340, ±11.520, ±12.336, ±13.551, ±14.707, ±13.711, ±15.363, ±13.964, ±13.590 and ±15.376 respectively, but when compared with elevation values from GPS Spline Regular Interpolation method show the best overall accuracy result of ±11.520m.

Furthermore, the standard deviation, average, minimum and maximum height values that were extracted from elevation data are as shown in Table 4. The IDW prediction method has highest standard deviation while Radial Basis Function prediction method gave the least standard deviation from the GPS data.

| Method     | Minimum             | Maximum             | Mean              | Std Deviation |
|------------|---------------------|---------------------|-------------------|---------------|
| TOPO RASTER| 320.974             | 366.140             | 346.710           | 11.748        |
| IDW        | 320.308             | 370.003             | 346.621           | 12.605        |
| KRIGG      | 320.589             | 369.774             | 347.388           | 10.640        |
| KIB        | 319.565             | 364.342             | 345.426           | 10.909        |
| GPI        | 323.281             | 369.036             | 344.984           | 11.240        |
| LPI        | 319.817             | 370.191             | 347.582           | 12.190        |
| SPLINE T   | 317.935             | 374.762             | 347.174           | 12.181        |
| SPLINE R   | 327.237             | 368.080             | 348.884           | 11.605        |
| EBK        | 319.186             | 364.538             | 347.298           | 11.174        |
| NATURAL    | 321.162             | 369.180             | 347.142           | 11.044        |
| RBF        | 320.547             | 372.157             | 347.687           | 10.405        |

**IV. CONCLUSION**

The present study was an attempt to assess the accuracy of the selected extrapolation/interpolation methods in elevation determination using ASTER as the data source. The research revealed that Global Polynomial Interpolation (GPI) requires minimal interactive modeling and also allows for exact predictions (unbiased model) of elevation with a mean error of 0.002m. The adopted techniques have been proven to be reliable for quick integration and determination of elevation data in the study area with the Spline Regular interpolation method suggested to be the optimal interpolation method for elevation determination with a ±5.878m and ±11.520m of Root mean square error and degree accuracy respectively based on the Global Positioning data used as the controls.

**ACKNOWLEDGMENT**

V. A. Ijaware and Adeboye appreciate Ademag & Associates for their support in data collection. Credit also goes to the entire staff and students of the Department of Surveying and Geoinformatics, Federal University of Technology Akure, Ondo State, Nigeria.

**REFERENCES**

[1] P. A. Burrough, P. F. Van Gaans, J. Wilson and A. J. Hansen, GIS and Geostatistics: Essential Partners for Spatial Analysis, 2001.

[2] C. A. Felgueiras, E. C. Camargo, and J. Ortiz, Exploring Geostatistical Methods to Improve the Altimetry Accuracies of Digital Elevation Models, 2015.

[3] T. Hengl, B. Bajal, D. Blagojevic, H. I. Reuter, Geostatistical modeling of topography using auxiliary maps, Computers & Geosciences, p. 1886-1899, 2008.

[4] N.S.N. Lam, Spatial Interpolation Methods: A Review. The American Cartographer, Vol. 10, No. 2, 129-149, 1983.

[5] R. R. Rodriguez, Integration of Topographic and Bathymetric Digital Elevation Model using ArcGIS Interpolation Methods: A Case Study of the Klamath River Estuary, 2015.

[6] J. M. Stoker, H. K Heidemann, G. A. Evans and S. K Greenlee., “A conceptual prototype for the next-generation national elevation dataset”. Open-File report2013-1023, U.S. Geological Survey, 2013.

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