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# Impact of Spatial Interpolation Methods on Digital Elevation Models Quality

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**Abstract**: The main aim of the research presented in this paper is to evaluate the impact and influence of different interpolation methods on the quality of the derived digital elevation model (DEM). The main factors affecting the quality of the DEM are: the data sampling method, data density, terrain complexity, and the interpolation method and interpolation parameters. This paper is set answer two main questions: what is the best interpolation method that could be used to generate a DEM to satisfy the accuracy level required for a certain application? Upon what criteria an interpolation method could be chosen? To answer such questions an investigation was carried out on digital elevation models generated from different data sources using different interpolation methods. Three data sets and three interpolation methods were used in the investigation. The results clearly revealed the role of the interpolation method selection on the quality of the generated DEM, in general and in particular DEMs generated from data sets of low density and biased distribution. The investigation also showed the important role of the interpolation parameters in the performance of the interpolation method.

***Keywords:*** *Digital elevation model; Spatial interpolation; Terrain complexity; Sampling; Model quality.*

## 1. INTRODUCTION

A Digital Elevation Model (DEM) is a digital mathematical representation of an existing or virtual object and its environment. As defined by the U.S. Geological Survey, a grid DEM is the digital cartographic representation of the elevation of the land at regularly spaced intervals in *x* and *y* [1]. It is precisely with this meaning that the term DEM is used in this paper. The diverse possibilities offered by digital cartography makes it possible to exploit these DEMs in order to obtain quantitative and qualitative information of great use in hydrological analyses, natural resources management, transport planning, determination of the environmental impact of an activity, calculating the risk of floods in urban zones, military applications, and analysis of the potential erosion of agricultural soil [2], [3] and [4].

Interpolation is an approximation problem in mathematics and an estimation problem in statistics. Interpolation in digital terrain modeling is used to determine the height value of a point by using the known height of neighboring points. There are two implicit assumptions behind Interpolation techniques: (a) the terrain surface is continuous and smooth and (b) there is a high correlation between the neighboring data points [5]. There is a wide range of interpolation techniques, which may be used in any application areas where the phenomenon of interest is continuously distributed over space and can therefore only be measured at sample locations on this surface. Although there are variant types of interpolation techniques, but they can be categorized according to different criteria. Table (1) shows a simple classification of interpolation techniques. For comprehensive review of all interpolation techniques see [6] and [7]. The underlying principle of the interpolation process is that the surfaces to be estimated can be assumed to possess certain characteristics which can be mathematically represented by an interpolator's algorithm [8].

There are many interpolation methods that can be used to generate digital elevation models (DEMs). However, most producers and providers of digital elevation models didn't mention the interpolation algorithms used to generate DEMs and their influence on the quality of DEMs produced. Unfortunately none of the interpolation techniques is universal for all data sources, geomorphologic phenomenon or purposes. Due to this fact, tests were carried out to investigate the effects of the interpolation methods on DEMs quality. Comparison tests which were executed, in this study, between interpolation methods were meant to help producers and users of DEMs select the best interpolation method that can be adopted in their future works, taking into consideration terrain complexity, sample data density and distribution. The best chosen interpolation algorithms used with variant data sources should not differ from the nominal ground that is the idealization of the desired model and which is commonly similar to actual earth's surface.

**Table 1**. Classification of interpolation techniques

| Criteria | Interpolation Techniques |
|---|---|
| Size of area for interpolation | Point based, area based |
| Exactness of the surface | Exact fitting, best fitting |
| Smoothness of the surface | Linear, nonlinear |
| Continuity of the surface | Step, continuous |
| Preciseness of function | Precise, approximate |
| Certainty of the problem | Functional, stochastic |
| Domain of interest | Spatial, spectral (i.e frequency) |
| Complexity of the phenomenon | Analytical, numerical iteration |

The major objectives of the research presented in this paper can be summarized as follows:

- To determine the relative accuracies of the interpolation methods.
- To evaluate the impact of interpolation methods on the quality of digital elevation models (DEMs).
- To assessment of the Cartographic quality of the contour maps which were drawn from the produced DEMs using different interpolation methods.

In this paper, a framework has been prepared for accuracy assessment of DEMs produced from various sources of elevation data sets using different types of interpolation methods. Quantitative statistical tests were performed on three spatial data sources for different terrain configurations. The paper is organized in the following manner; Section two describes the sites chosen for the study. Section two is dedicated to a description of the materials and methodology adopted for study. Section four presents a discussion of the results of the GIS and geospatial processing methods employed. Finally, in section five the conclusions drawn are presented.

## 2. MATERIALS AND METHODS

### 2.1 Data Source

The first set of data source consisted of four topographic map sheets at the scale of 1:100,000. The study sites were selected as shown in Table 2. The maps were based on the UTM projection (zones: 35 and 36) on Clark 1880 Ellipsoid and had a contour interval of 10 m/20 m (depending on the ground surface roughness). These maps were compiled by Sudan Survey Department (SSD) and United Kingdom Ordnance Survey Department (U.K OSD) during 1970’s and 1980’s. The used maps were digitized and converted to points with triplet coordinates (E, N, H). The second set of data is a topographic map of Toti Island at the scale of 1:2500 and had a contour interval of 0.25 m. This map has been compiled and produced by Sudan Engineering and Digital Information Centre (SEDIC) in 2004. The topographic map was based on the UTM projection (Zone 36) on Clark 1880 Ellipsoid. The third set of elevation data is captured by using electronic tachometry and spirit leveling for Aljiniana study area. The instruments used for acquiring the elevation data were spirit levels and total stations. Interval of elevation sample points ranges from 50 m to 100 m along road centre lines. In addition, heights of points along changes of slope, along ridge lines, tops of hill, and along break-lines such as the base of water courses, have been determined. The accuracy of elevation data set is about ±1cm per point. Since roads are, almost, not running in parallel and they are crossing water courses or passing through areas of rugged terrain, the distribution of elevation data sample is of irregular pattern. The data set was based on the UTM projection (Zone 35) on Clark 1880 Ellipsoid. Boundary coordinates of the study area site are shown in Table (3).

### 2.2 Materials

Two major software packages were employed for the processing of data captured from the two sources and the visualization and analysis of the results. These included the ArcGIS 9.2 and Microsoft Excel.

### 2.3 Methodology

The methodology adopted in this study may be summarized in the following:

- data preparation
- Determination of the relative vertical accuracy of different interpolation methods.
- Assessment of the Cartographic quality of the contour lines drawn from the digital elevation models generated by using these interpolation methods.

***Data preparation*:** Processing of topographic maps used in this study was performed firstly by scanning paper hard-copy topographic maps using A0 scanner. Geo-referencing was performed by selecting three or more control points located at intersections of grid lines representing Longitude/Latitude values. The selected control points were evenly distributed and covering all study area. Due to the fact that the resulted scanned map was an image, any further processing cannot be performed before converting it into a digital form. The conversion of the scanned maps into a digital form was performed by using arc scan toolbox available in ArcGIS 9.2.

On screen digitization (semi-automatic) of contour lines was executed by following each contour line using a curser. The attribute table of the digitized contour lines showed up identification numbers (IDNs) of each contour line separately, but contour height values were not shown up. To insert contour height value to its corresponding IDN in the attribute table, a new column was added to the attribute table, and then height value of each contour line was inserted manually. Digitized contour lines were converted into points by using feature vertices to point tool. The corresponding attribute table at this stage presented only discrete points located with their heights along contour lines, but did not contain or show their corresponding spatial coordinates (E, N). To visualize the coordinates of these discrete points together with their heights (E, N, Z) on the attribute table, a tool named Add XY was used. The elevation data obtained through all the above mentioned steps were in an irregular or random distribution form. In order to convert this type of data into a regular type, gridding technique was used. Gridding was carried out by selecting one of the ArcGIS interpolation methods. The interpolation methods used, in this study, to generate DEMs were natural neighbor (NN), inverse distance weighting (IDW) and Kriging.

**Table 2.** Topographic maps at scale 1:100,000 compiled by SSD and OSD

| Map Name | Sheet No. | Date | Lat. Min Deg N | Lat. Max Deg N | Lon Min Deg E | Lon Max. Deg E | Min Elev., m | Max Elev , m | Elev Rang, m | Check-points No. | Terrain classification |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Almased | 388 | 1975 | 15 | 15.5 | 32.5 | 33 | 364 | 415 | 51 | 73 | Flat |
| Omdurman | 358 | 1975 | 15.5 | 16 | 32 | 32.5 | 374 | 519 | 145 | 169 | Gentle slope |
| Jabalawlya | 387 | 1975 | 15 | 15.5 | 32 | 32.5 | 373 | 498 | 125 | 65 | Gentle slope |
| Habila | 590 | 1990 | 11.5 | 12 | 30 | 30.5 | 500 | 1200 | 700 | 188 | Steep |
| Toti | | | | | | | 372.3 | 382.4 | 10.1 | 347 | Gentle slope |

**Table 3**. Aljinaina study area

| Corner id | E(m) | N(m) |
|---|---|---|
| SW | 652788.81 | 1482783.91 |
| NW | 652788.81 | 1491400.34 |
| SE | 666203.25 | 1482783.91 |
| NE | 666203.25 | 1491400.34 |

**Table 4.** Number of control ground stations

| Test area | No. of control stations |
|---|---|
| Almased | 73 |
| Omdurman | 169 |
| Jabalawlya | 65 |
| Habila | 188 |
| Toti | 314 |
| Alginaina | 437 |

***Data Tests*:** The tests carried out in the investigation were based on the comparison of the generated DEM with a set of reference ground control stations for each study area. Three DEMs were generated using the three interpolation methods adopted for the investigation. photo-control stations of planimetric accuracy of ± 10m and height accuracy between 1.6m to 4.4m were used to test the 1/100,000 scale topographic maps data[9].Four 1/100000 scale sheet data sets were used in the investigation (Almaseed, Omdurman, Jabel Awlia and Habilla). The 1/2500 scale map data (Toti area) was tested by control stations derived from the contour lines. Aljinaina study area data set was tested using control stations captured by electronic tacheometer. The number of control ground stations used in each of the three study areas is presented in table-4 below. For further processing, visualization technique was also performed. This technique was carried out by superimposing contour lines which were drawn from DEMs elevation data set over the original ones.

## 3. RESULTS AND DISCUSSION

The results of the statistical measures or quantitative accuracy assessment of DEMs were presented in Table (5) and the results of visualization or qualitative assessment were shown in Figs (1-36).

### 3.1 Analysis of the accuracy results for Toti

As shown in Table (5) and referring to the Figs (1-4), the obtained results of Toti study area showed that NN-Discussing and analyzing the obtained results of Toti study area (see Table 5) and referring to the Figs (1- 4); the results showed that NN-Interpolation method performed a little bit better than the other two interpolation methods, but in general, all the three interpolation techniques performed well, irrespective of the elevation data set extracted from contour lines (biased distribution). This performance was attributed to the fact that the elevation data extracted from the contour lines were of high density and contour lines were very close to each other (study area was almost flat and the contour interval was small). Visualization results of comparing performance of different interpolation methods for Toti study area were depicted in Figs (5-10). By inspecting the profiles which were drawn from the elevation data set of the generated DEMs using different interpolators, it was found that there were minor discrepancies between the profiles.

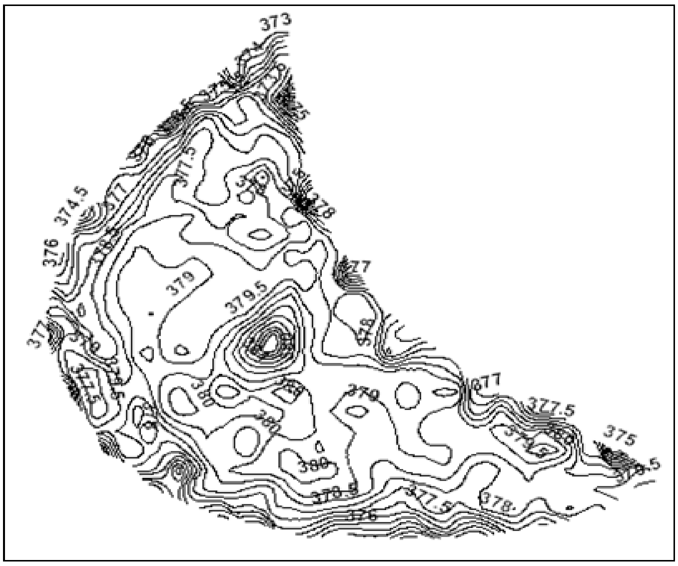


**Fig. 1**. Original contour map for Toti


**Fig. 2**. NN -contour map vs. original contour map for Toti

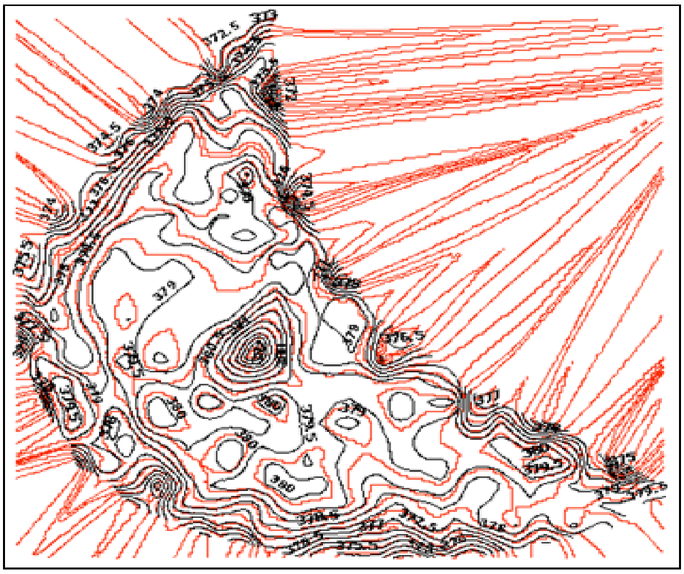

**Fig. 3.** IDW-contour map vs. original contour map for Toti

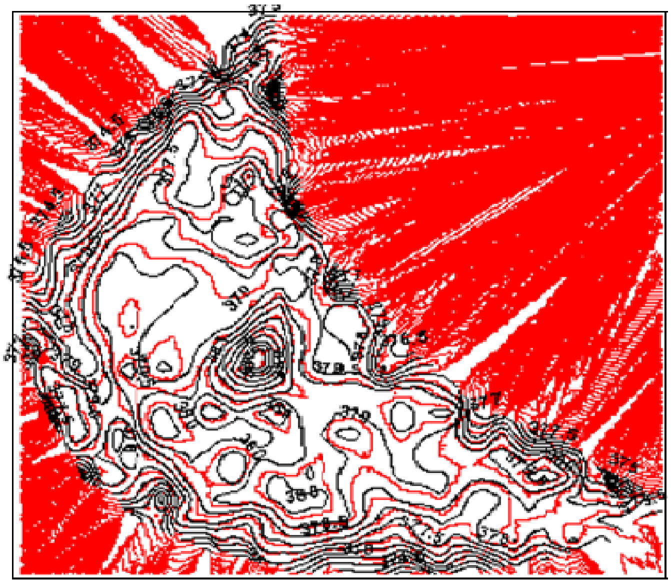

**Fig. 4**. Krig-contour map vs. original contour map for Toti

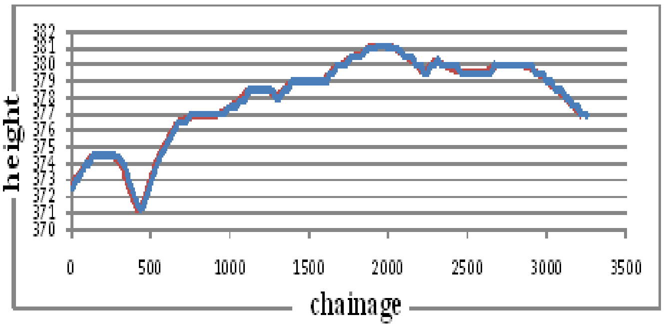


**Fig. 5.** NN versus IDW and power unit of 2 (Toti)

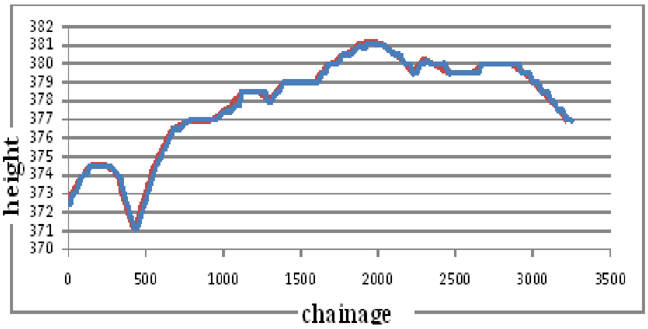


**Fig. 6.** NN versus IDW and power unit of 3 (Toti)

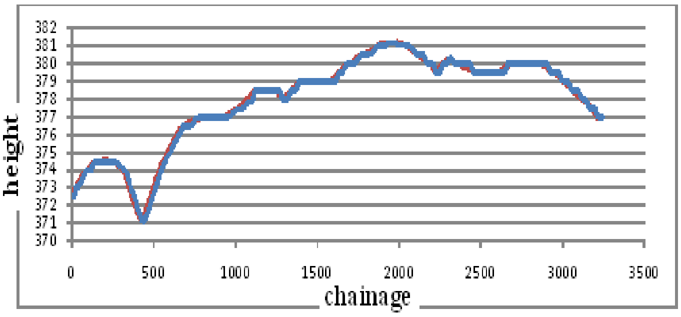


**Fig. 7**. NN versus IDW and power unit of 4 (Toti)

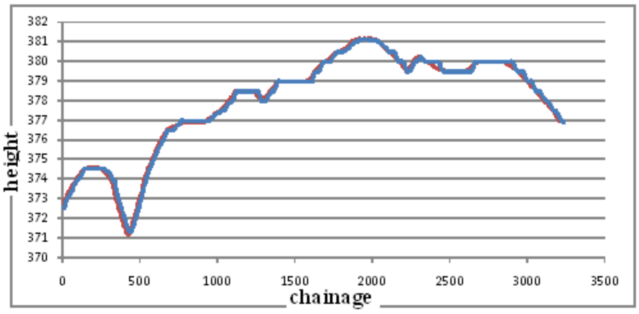


**Fig. 8**. NN versus Krig Exponential (Toti)

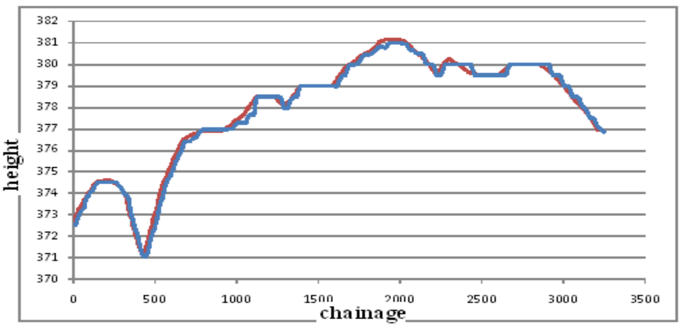


**Fig. 9**. NN versus Krig Circular (Toti)

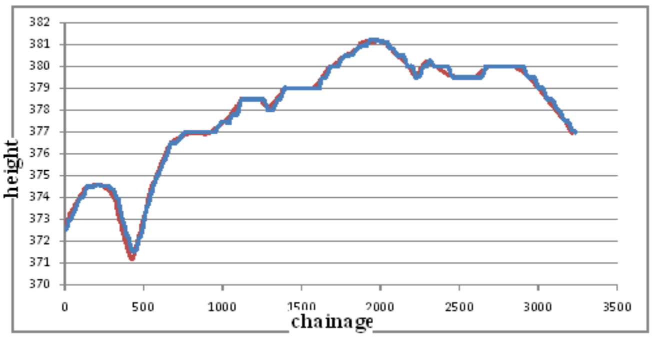


**Fig. 10**. NN versus Krig Spherical (Toti)

**Table 5.** Results of the interpolation methods

| Study Area | Interpolation method | RMSE | Data Source |
|---|---|---|---|
| | N.N | ±0.302 | 1:2500 |
| Toti | IDW | ±0.454 | Contour |
| | KRIG | ±0.324 | map |
| | N.N | ±7.648 | 1:100000 |
| Jabal Awlya | IDW | ±13.020 | Topographic |
| | KRIG | ±12.023 | map |
| | N.N | ±9.716 | 1:100000 |
| Omdurman | IDW | ±21.720 | Topographic |
| | KRIG | ±14.798 | map |
| | N.N | ±16.954 | 1:100000 |
| Habilla | IDW | ±23.422 | Topographic |
| | KRIG | 18.456 | map |
| | N.N | ±2.663 | 1:100000 |
| Almaseed | IDW | ±4.151 | Topographic |
| | KRIG | ±3.951 | map |
| | N.N | ±0.338 | Electronic |
| Aljinaina | IDW | ±0.549 | tachometry |
| | KRIG | ±0.324 | |

This result was verified by comparing the contour maps derived from the constructed DEMs and the original one. The results of this comparison showed that there were also minor discrepancies between contour lines having the same value. Another test was carried out to investigate the influence of the alteration of the interpolation method parameters on the quality of the constructed DEM. For example, in IDW interpolation method, the power of weighting has been changed (power equal 2, 3 and 4) whereas different types of Kriging models were used (exponential, spherical and circular models). As presented in Figs (5-10), it was noted that similar results were obtained. Referring again to the obtained results of visualization, and from cartographic quality point of view of contour maps, we conclude that, the contour maps derived from the generated DEMs using three interpolation methods have good cartographic quality. Hence, any of these interpolation methods could be adopted for the generation of DEMs from elevation data set extracted from contour maps with small contour interval, using high density of sample data and while the general slope is flat and gentle.

### 3.2 Analysis of the Accuracy Results for Jabal Awlya

Discussing and analyzing the obtained results of Jabal Awlya study area (see Table 5); it was found that NN-interpolator performs better than IDW and KRIG interpolators. The worst RMSE value was obtained using IDW-interpolator. Visual comparisons of the derived contour maps were also carried out in the same way used for Toti study area (see Figs 11 and 12). The poor results of IDW and KRIG–interpolators are attributed to the biased and uneven distribution of elevation data extracted from contour lines. This is due to the fact that there is a high density of sampling along the contour lines

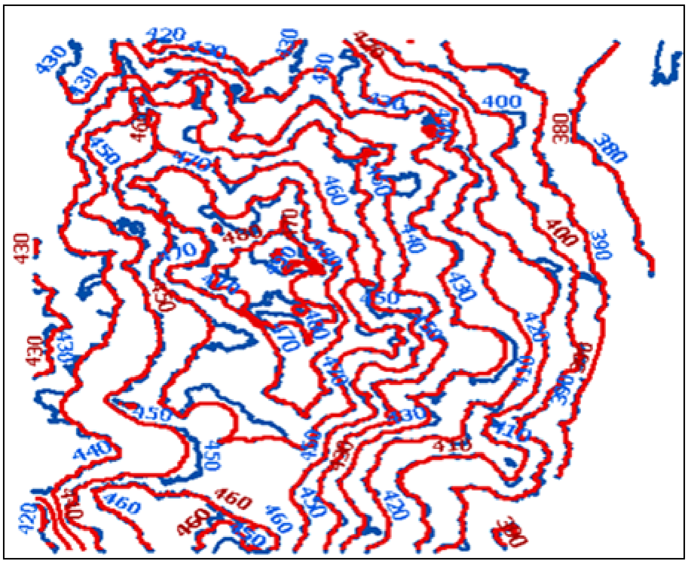

**Fig. 11.** NN contour map vs. original contour map for Jabal Awlya

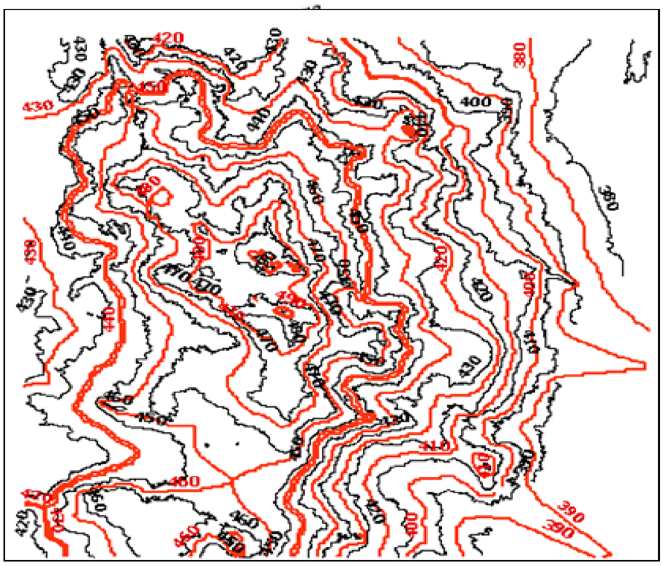

**Fig. 12**. Krig contour map vs. original contour map (Jabal Awlya)

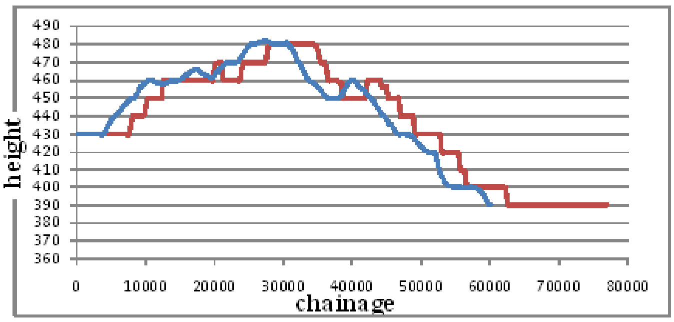


**Fig. 13.** NN versus IDW and power unit of 2 (Jabal Awlya)

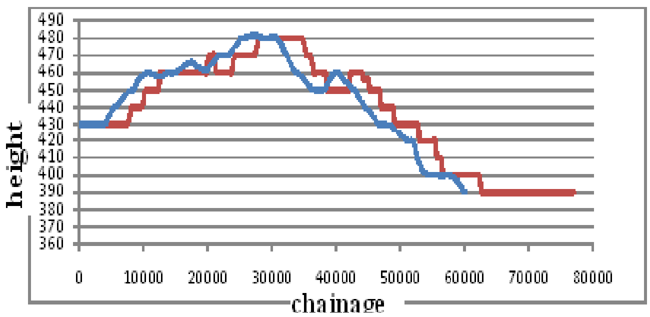


**Fig. 14.** NN versus IDW and power unit of 3 (Jabal Awlya)

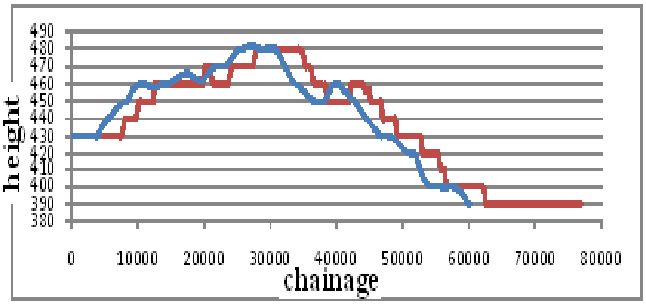


**Fig. 15.** NN versus IDW and power unit of 3 (Jabal Awlya)

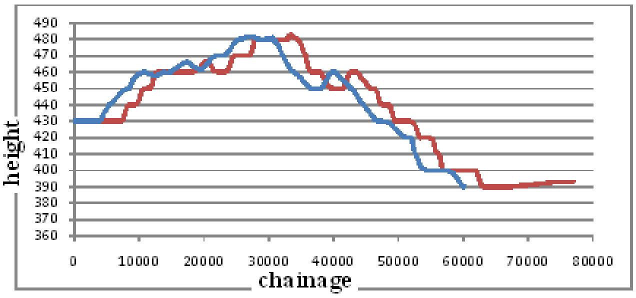


**Fig. 16.** NN versus IDW and power unit of 4 (Jabal Awlya)

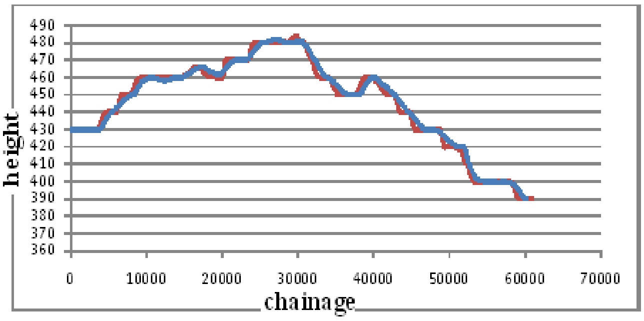


**Fig. 17.** NN versus Krig-Exponential (Jabal Awlya)

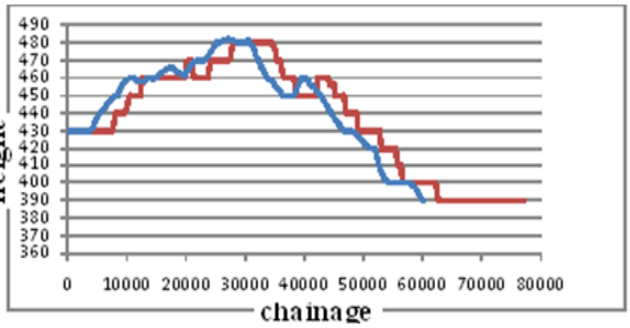


**Fig. 18**. NN versus Kriging – Exponential (Jabal Awlya)

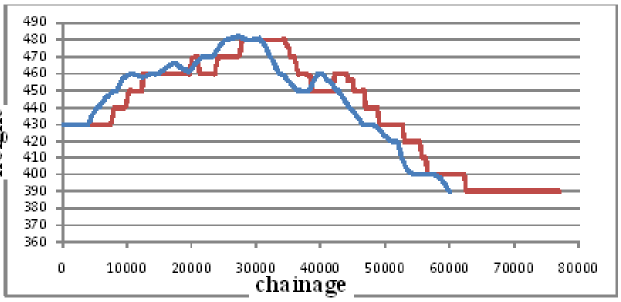


**Fig. 19**. NN versus Kriging- Circular (Jabal Awlya)

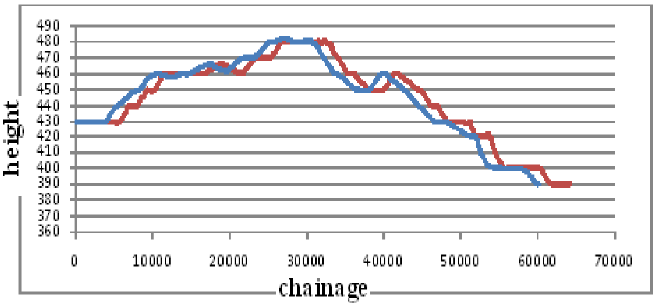


**Fig. 20**. NN versus Kriging- Spherical (Jabal Awlya)

methods. However, in contrast, there is a complete lack of elevation data between contour lines. In addition, Jabal Awlya study area consisted of flat/gentle and steep slope terrain. Referring to the profiles in Figs (11-20), it was observed that a little improvement was made in the shape of the profiles when altering parameters of IDW and KRIG interpolation.

### 3.3 Analysis of the Accuracy Results for Omdurman

Discussing and analyzing the obtained results using the same interpolators for Omdurman study area (see Table 5); it was found that NN-interpolator performed better than IDW and KRIG interpolators. The lowest RMSE value was obtained using IDW-interpolator. These results of IDW and KRIG–interpolators are attributed to the biased and uneven distribution of elevation data extracted from contour lines. This is due to the same reasons mentioned for Jebel Awlya study area. In addition, Omdurman study area consisted of flat/gentle and steep slope terrain. In addition, visual comparisons were made between the contour lines drawn from the derived DEMs using these three interpolation methods and their corresponding contour lines depicted in the

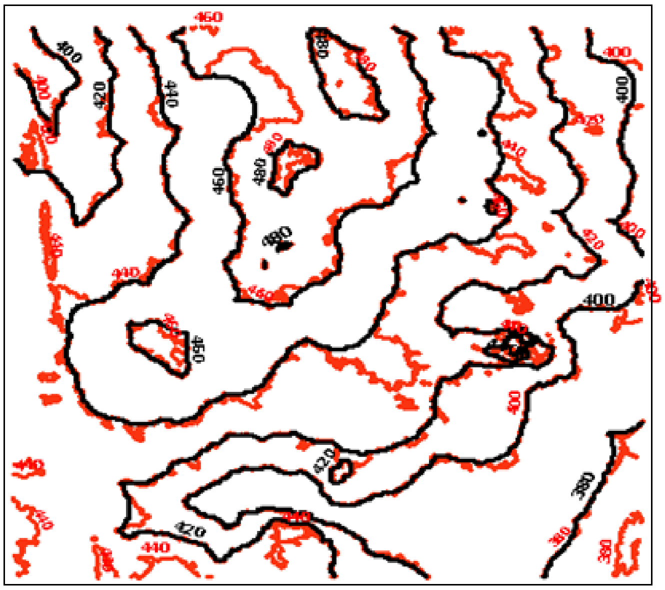

**Fig. 21.** NN contour map vs. original contour map (Omdurman )

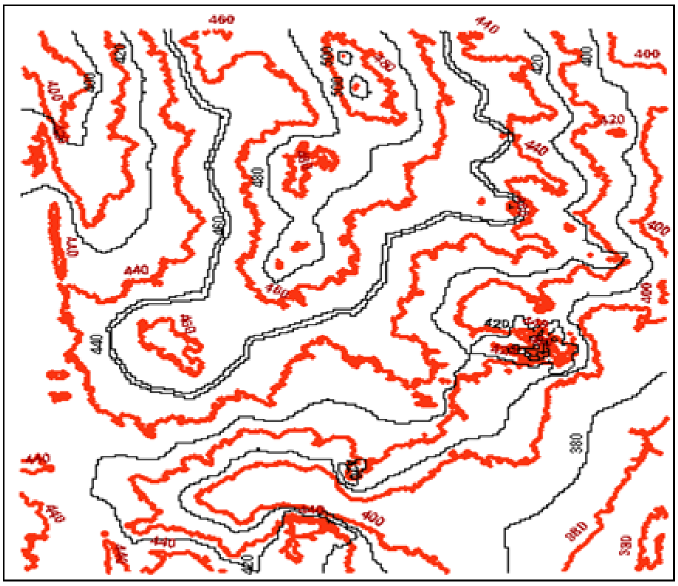

**Fig. 22.** IDW contour map vs. original contour map (Omdurman)

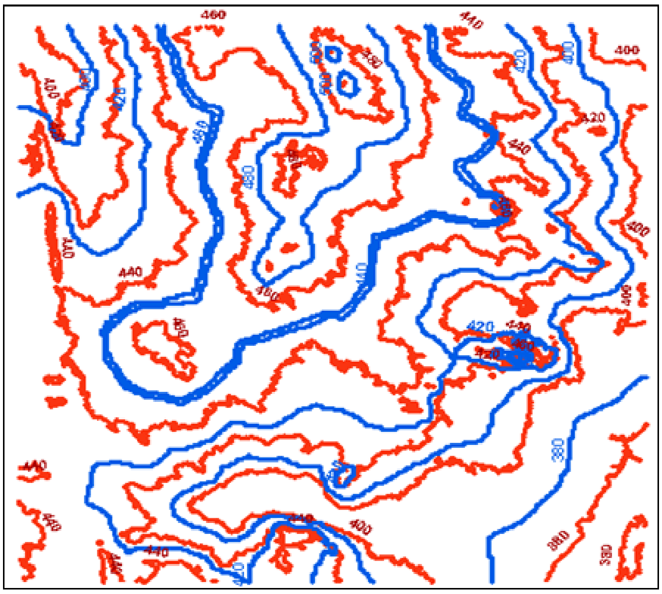

**Fig. 23**. Krig contour map vs. original contour map (Omdurman)

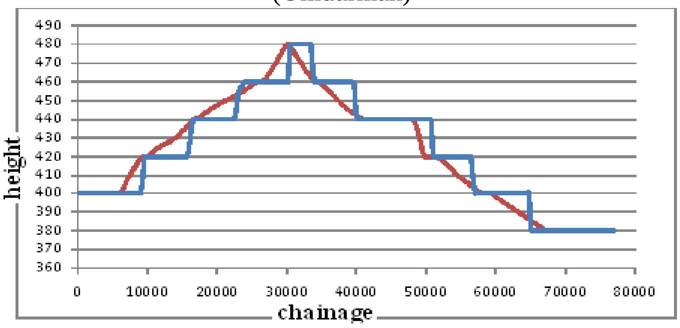


**Fig. 24.** NN versus IDW and power unit of 2 (Omdurman)

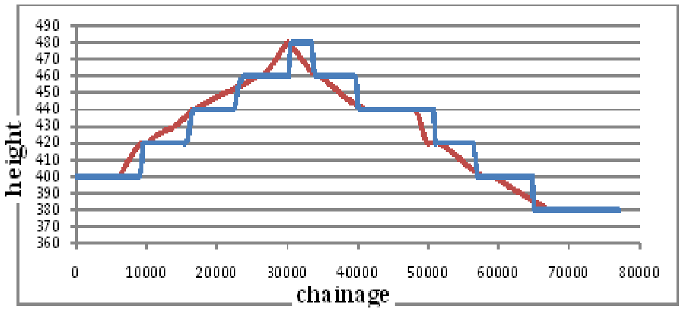


**Fig. 25**. NN versus IDW and power unit of 3 (Omdurman)

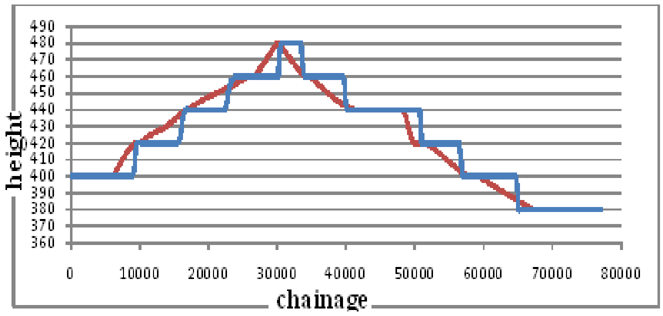


**Fig. 26**. NN versus IDW and power unit of 4 (Omdurman)

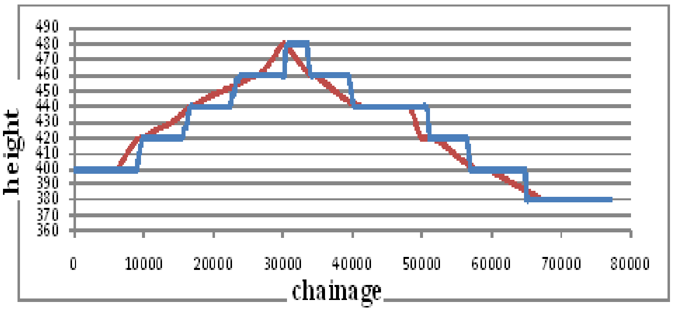


**Fig. 27.** NN versus Krig-Exponential(Omdurman)

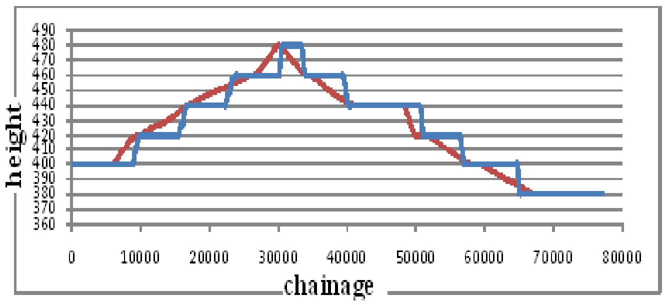


**Fig. 28.** NN versus Krig-circular (Omdurman)

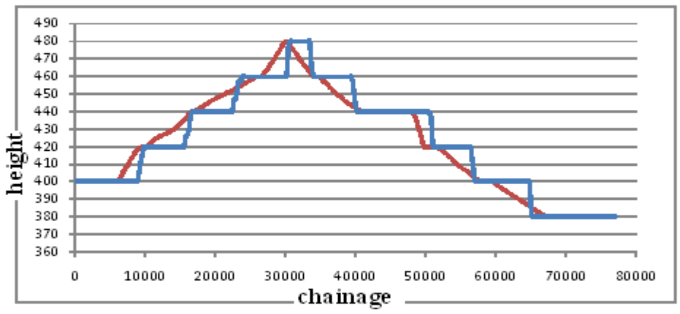


**Fig. 29.** NN versus Krig-spherical (Omdurman)

topographic map. Contour maps drawn from NN, IDW, and KRIG –DEM were superimposed over original contour maps. Referring to Figs (21-23) and inspecting superimposed contour lines, the authors noted that NN-contour lines pass very close to their corresponding ones in the original map. In contrast, it was noted that there were some discrepancies between IDW and KRIG contour lines and their corresponding ones depicted in the original topographic map. But, in general, they were running parallel to the contour lines presented in the original maps. Referring to the profiles presented in Figs (24-29), it was observed that a little improvement was made in the shape of the profiles when altering parameters of IDW and KRIG interpolation methods.

### 3.4 Analysis of the accuracy results for Habilla

As shown in Table (5), the obtained results of Habilla study area revealed that that NN-interpolator performed better than IDW and KRIG interpolators. The lowest RMSE value was obtained when using IDW-interpolator. These results are attributed to the same reasons mentioned for Omdurman and Jebel Awlya study areas. For further quality assessment, three contour maps were drawn using the DEMs, then a comparison was made between these contour maps and the original ones as shown in Figs (30--32). It was observed that NN-contour lines follow closely the corresponding the original contour lines. In contrast, there was some significant discrepancy between contour lines which were drawn from IDW-DEM/KRIG-DEM elevation data sets and the original contour lines depicted in the topographic map.

### 3.5. Analysis of the Accuracy Results for Almaseed

As shown in Table (5), the results of Almaseed study area revealed that performance of NN, IDW and KRIG interpolators was almost the same. Irrespective of the biased distribution of elevation data set, better results were obtained when compared with the results of other study areas discussed in the previous sections. This unexpected result may be attributed to the fact that Almaseed study area was of flat and gentle slope terrain.

### 3.6. Analysis of the Accuracy Results for Aljinaina

As shown in Table (5), the obtained results of Aljinaina study area revealed that performance KRIG-Interpolation method was better than the performance of the other two methods. In general, the performance of the three interpolation methods proved to be reasonable. This performance was attributed to the fact that the elevation data set was evenly distributed (composite sampling) with high density and high accuracy (±0.005 m). For further analysis, three contour maps were drawn from the constructed DEMs, and then a visual comparison was carried out. The results of comparisons showed that corresponding contour lines were similar in their general shape where the elevation data sample was of regular form and high density. In contrast, the corresponding contour lines passing through areas of irregular and low density sample elevation data were different. Moreover, it was found that NN interpolation method restricted its working area within the limits of sample data, and the working areas of other two methods covered areas larger than the area of sample elevation data set as shown in Figs (33-36).

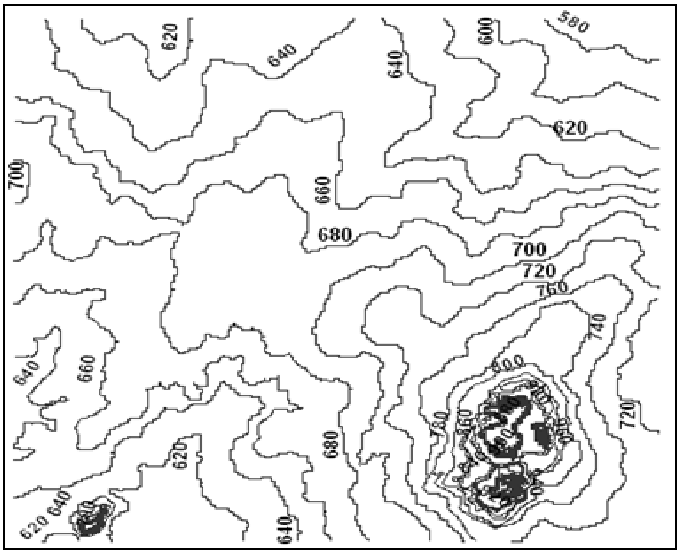


**Fig. 30.** IDW- contour map (Habilla)

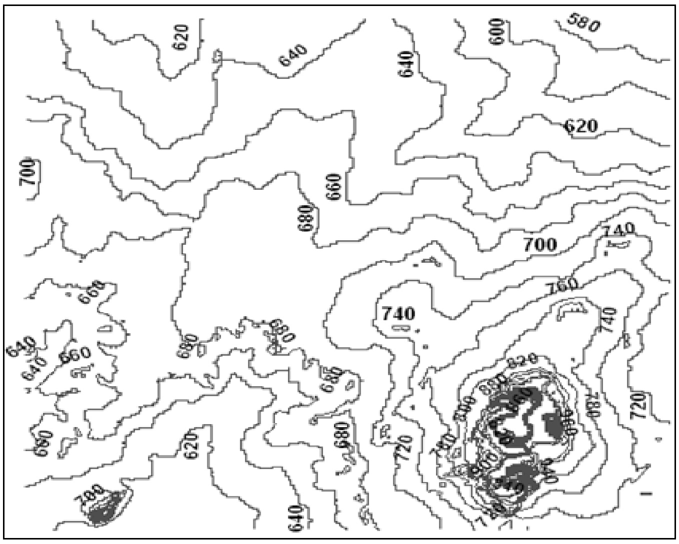


**Fig. 31**. KRIG-contour map (Habilla)

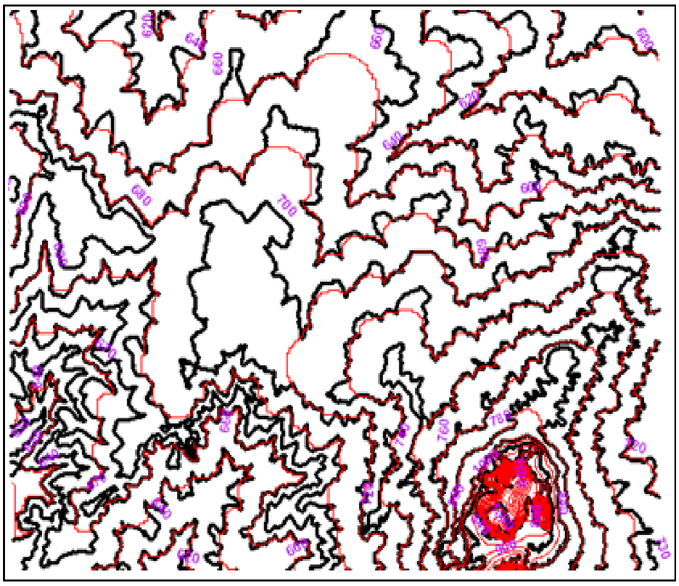

**Fig. 32**. NN- contour map vs. original contour map (Habilla)

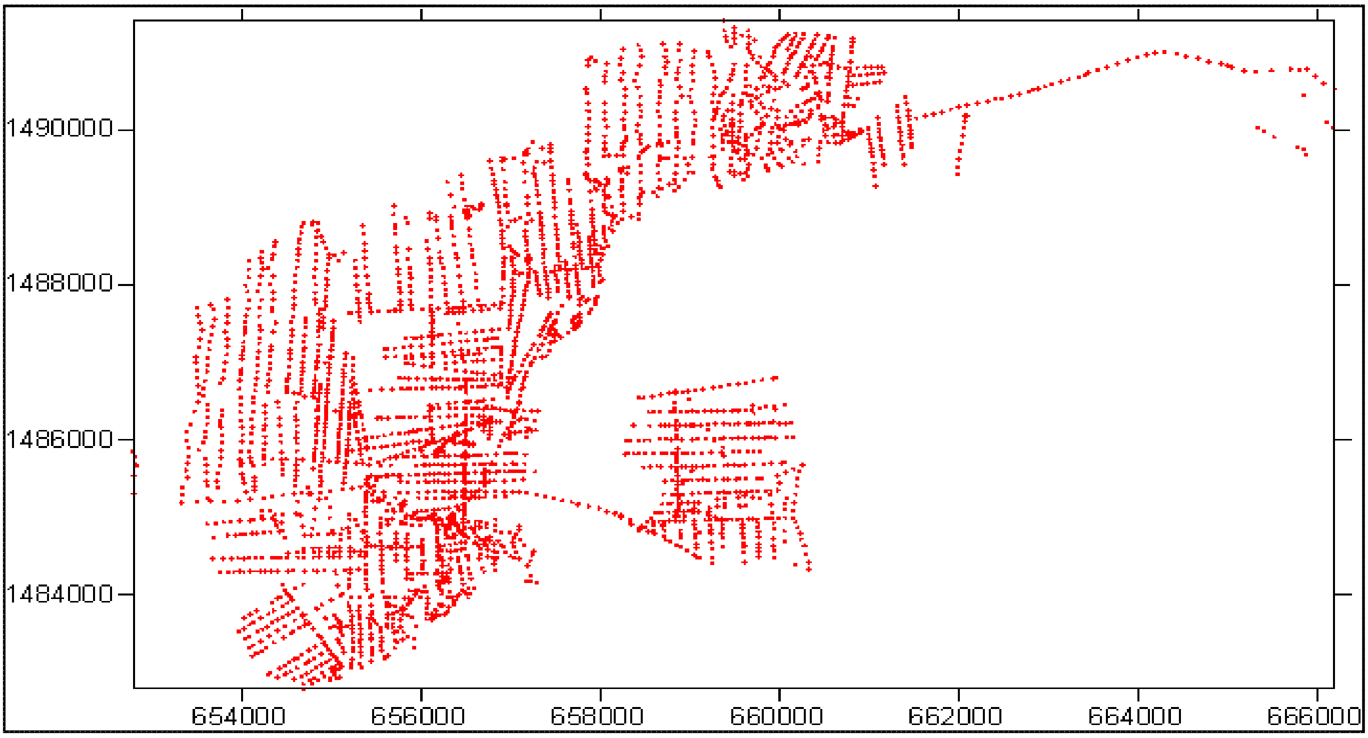


**Fig. 33**. Sample elevation data set (Aljiniana)

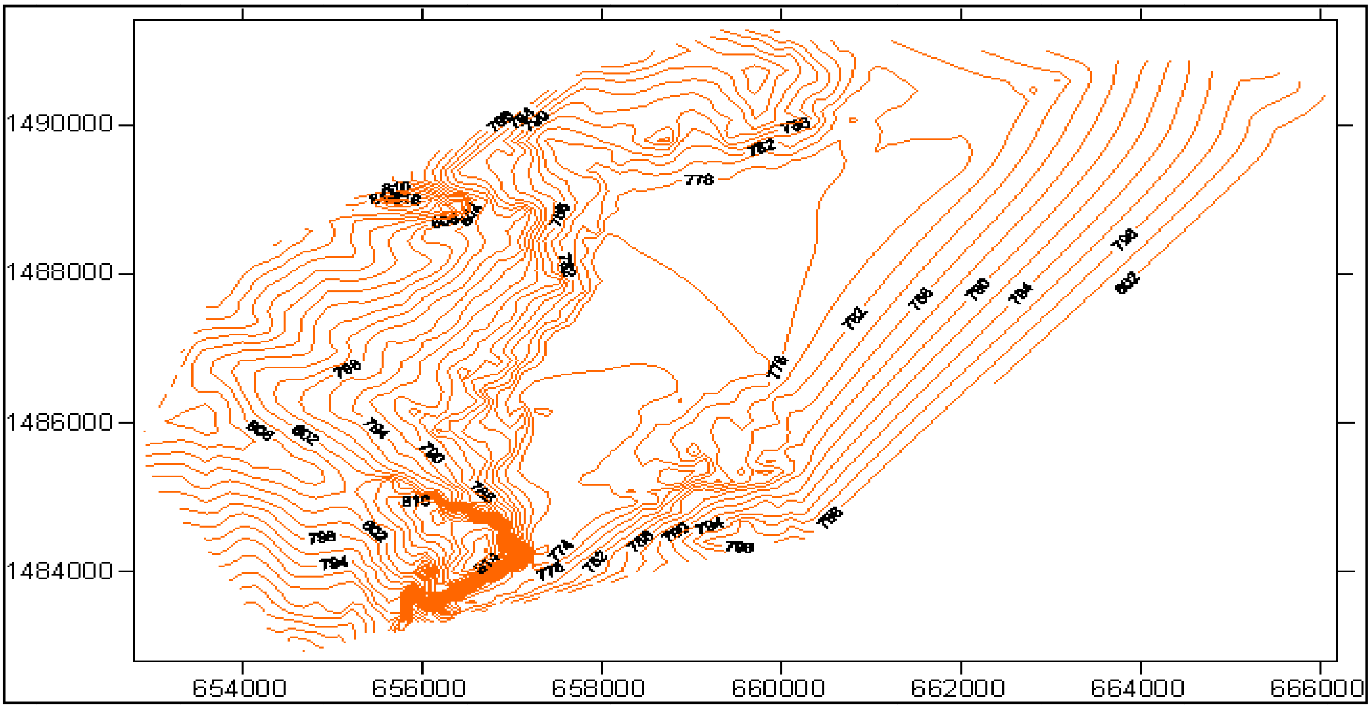


**Fig. 34.** NN-contour map (Aljiniana)

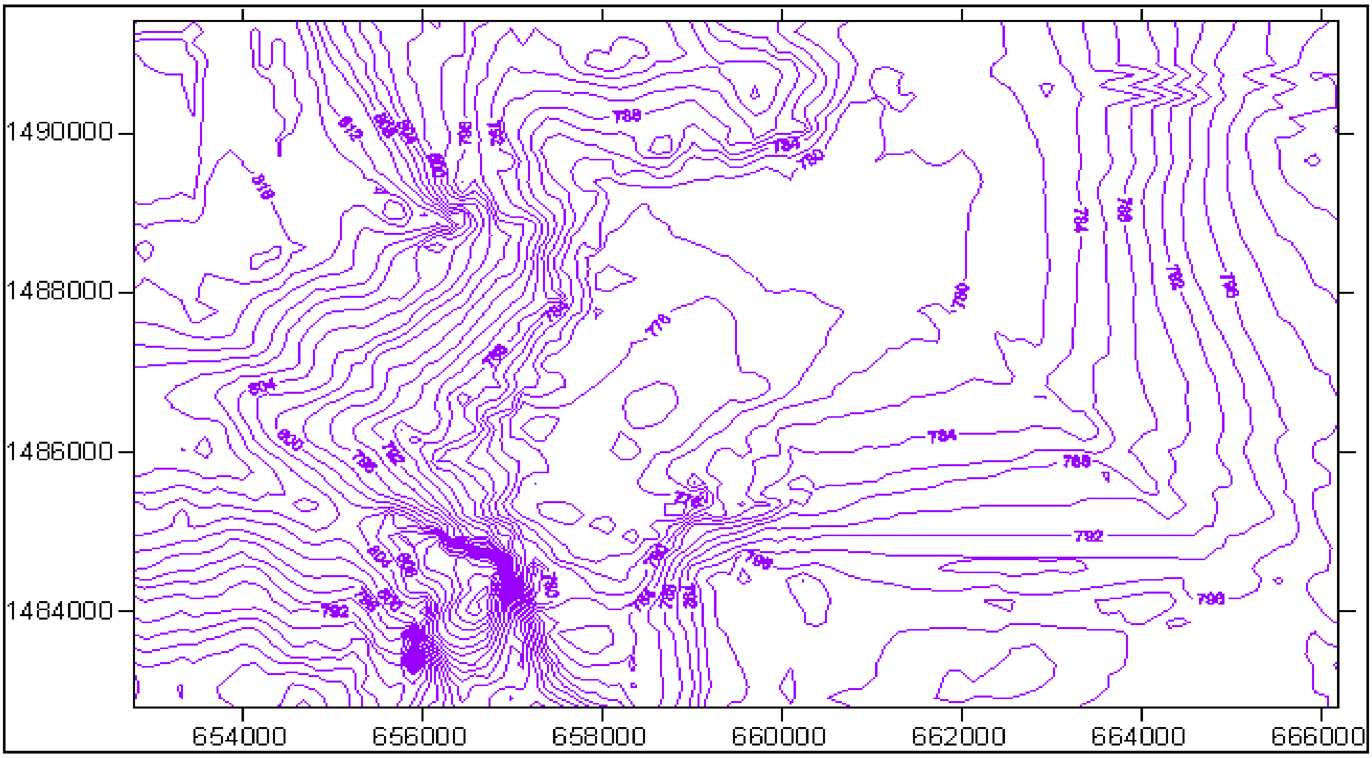


**Fig. 35.** IDW-contour map (Aljiniana)

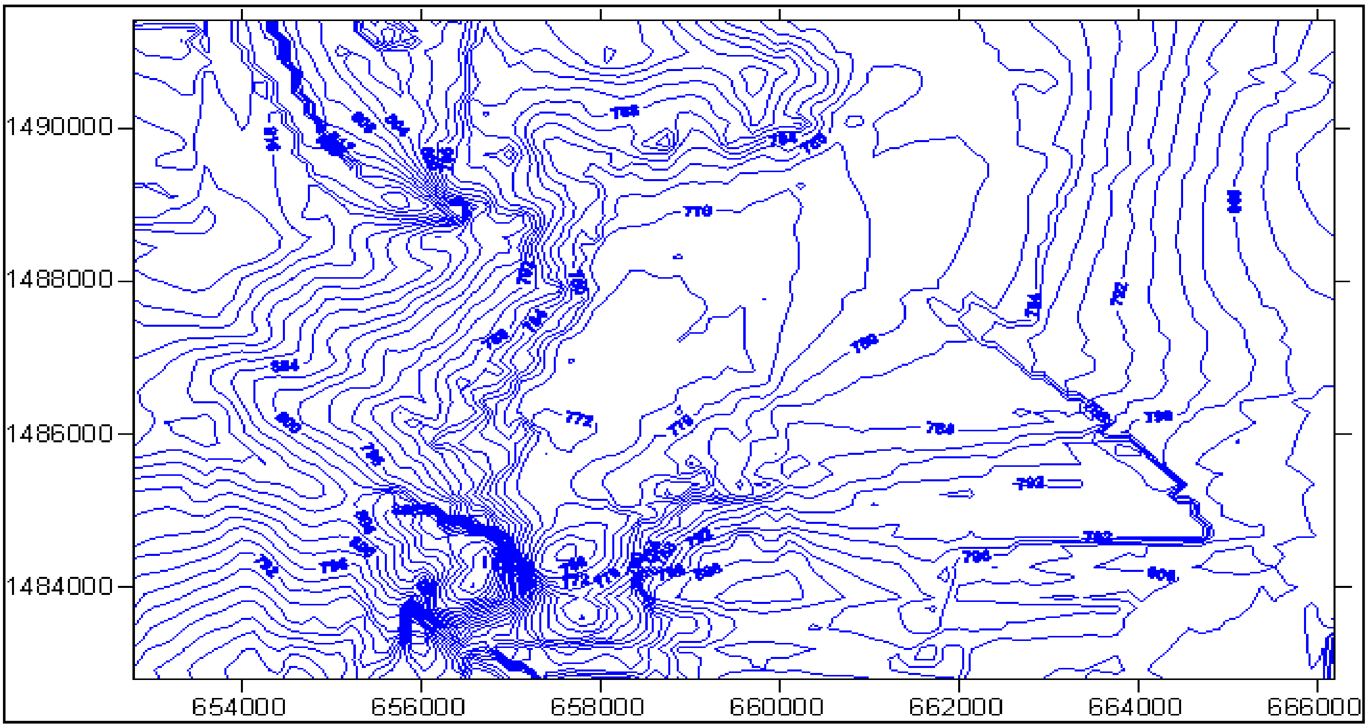


**Fig. 36.** KRIG-contour map (Aljiniana )

### 3.7 Summary Analysis of the Accuracy Results for All Study Areas

In summary, the results obtained for all study areas using three interpolation methods NN, IDW and KRIG; it was found that the performance of the three interpolators depends on the distribution and density of the sample elevation data. It was also noted that the performance of NN interpolator was better than the other two methods when the distribution of elevation data was of biased nature (Omdurman, Jabal Awlya and Habilla study areas). Due to this result, it is preferable for producers and users of DEMs to be aware of the use of the default interpolation methods to generate DEMs for areas consisted of rugged terrain and /or the elevation data set was of biased distribution Unfortunately, there was no standard interpolation method that can be used to generate DEMs for all types of terrain. This is due to the continuity and complexity of terrain surface, density and distribution of sample data. In addition, interpolation methods are mathematical models; that can not generate DEM which represent the terrain surface exactly. The shape of the error frequency histograms, observed in the study, were similar to the shape of the error normal distribution curve (frequency of errors having negative sign is equal to the frequency of errors having positive sign). Thus, these errors can't be corrected or minimized.

Interesting results could be obtained if the DEM producers used trial and error technique by altering the parameters of each interpolator (e.g. search radius, number of elevation sample points, weight, semi-variance and variogram), and then compared the obtained results with reference data set. It was, also, noted that simpler interpolation methods, such as NN and IDW, will give satisfactory results so long as the input data are well sampled, whereas sophisticated algorithms such as Kriging, will likely lead to unsatisfactory results if they are applied to the poor data (i.e. data set of biased distribution and density). Some researchers such as [9], [10], [11] and [12] reported that the results of their investigations carried out to generate DEMs came to the same conclusion. These researchers urge less experienced users to focus on the quality of the input data rather than adopting sophisticated interpolation methods to construct DEMs.

## 4. CONCLUSIONS

The following conclusion could be drawn from this study:

- The quality of the DEMs constructed using different interpolation algorithms was likely the same when elevation data set was of high density and of unbiased distribution.
- Performance of interpolation methods was found to be different when the distribution of elevation data set of a biased nature such as the one extracted from contour lines.
- The performance of natural neighbor (NN) interpolation method is better than the performance of IDW and Kriging interpolation methods when the elevation data set used for constructing DEMs was of a biased distribution, but in some cases, different interpolation methods have similar performance irrespective of the source of the data.
- NN, IDW and KRIG interpolation methods could be used for generating DEMs with reasonable accuracy when the interpolation method parameters (e.g. search radii, number of sample elevation data, power of weighting and type of variogram) have been chosen correctly
- Error frequency histograms of all study areas were similar to the curve of errors of normal distribution.

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