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Evaluation and Assessment of the Impacts of the Spatial Resolution on the Accuracy of the Digital Elevation Model

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ABSTARCT

Ground surveying methods are main sources for digital elevation data that is usually utilized in the creation of a Digital Elevation Model (DEM). DEM usually is a main input in many Engineering and Environmental applications. The quality of the DEM is a vital issue that controls the qualities of outputs in different applications. Different factors including the data source, the data density, the sampling method, the spatial resolution and the interpolation scheme control the quality of the DEM. This research is focused towards investigating the effects of the spatial resolution of the DEMs generated from ground surveying data on their qualities where digital elevation data has been collected from a test area of corrugated terrain using ground surveying methods. Qualitative and quantitative analyses have been applied on DEMs created from digital elevation data with different resolutions through; visual analysis, statistical analysis, profile analysis and finally accuracy assessments of the extracted elevations using external checkout points. Visual analysis has shown texture smoothing due to degradation of the DEM resolution which has been supported by the statistical analysis results. Also, the analysis using external checkout points has shown deterioration in the accuracy of the elevations extracted from the DEMs due to degradation of the DEM resolution.

Keywords : DEM/DSM/DTM; DEM resolution; DEM grid cell size; Visual analysis; Elevation accuracy; Spatial analysis..

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INTRODUCTION

Engineering surveying methods such as ground surveying and GPS technologies provide high accuracy digital elevation data that can be utilized in the creation of Digital Elevation Model (DEM). Although these methods are time consuming in addition to their high labour demands that is directly reflected on the final cost of the project they are very frequently used for collecting the data from field that is necessary for the creation of high quality DEM that is employed in many environmental and engineering applications [1]. Other alternative sources for the digital elevation data are the remote sensing technologies which provides great advantage to the production of DEMs especially in larger areas where these areas can be mapped by fewer people in less time and at highly competitive costs, but with lower quality DEMs compared to the qualities of the DEMs created from ground surveying or GPS data [2]. Direct positives of the advantages of the different sources and qualities of the digital elevation data appear in the widespread use of the DEM, where it has become the most common source for extracting topographic information that enjoys many engineering and environmental applications. It may be useful to note here that in addition to the DEM format for the representation of the topographic data, this data can be represented and stored in other different continuous surface representations including triangulated irregular network (TIN) as well [3, 4, 5].

Different applications require different quality DEM. For the involvement of the DEM in different applications it is important to assess the quality of the DEM and investigate the different factors that affect the quality of the generated DEM so that the DEM can serve its purpose. There are different factors that affect the DEM quality such as; the data source, the original point data density, the sampling method, the spatial resolution and the interpolation scheme [6]. Investigating the effect of spatial resolution on topographic modeling has been a main concern for many researcher over the last few decades where researches were devoted to exploring the effect of the DEM resolution on terrain characteristics such as slope and aspect [7]. Chow and Hodgson, 2009 examined the effect of the spatial sampling in modeling the mean slope from LiDAR data [8]. The results of this study acknowledged that the grid cell size of the DEM has greater effect on the mean slope than the effects from LiDAR posting density. Ziadat, 2007, investigated the effect of the sampling density used for deriving contours, vertical interval between contours (spacing), grid cell size of the DEM (resolution), terrain complexity, and spatial filtering on the accuracy of the DEM and the slope derivative. The author suggested that for areas with variable terrain complexity it could be useful to generate DEMs and slope at a suitable resolution for each terrain separately and then merge the results to produce one final layer for the whole area. In addition, he recommended that this would provide accurate estimates of the elevations and slopes, and subsequently improve the analyses relying on these derivatives [9].

Haile and Rientjes, 2005 Carried out a research for investigating the effect of the DEM resolution on the flood hazard assessment where they indicated that the society demands accurate and detailed information on the magnitude and likeliness of hazardous flood events for design of flood mitigation measures [10]. They generated DEM of 1.5 m grid cell size from LIDAR data that served as a base for various flood simulations and re-sampled DEM where DEMs of decreasing resolutions up to 15 m were generated in order that they serve as inputs to the flood simulations. The study showed that re-sampling to courser grid elements and averaging across increasingly larger domains has resulted in an increased loss of the detailed topographic properties that affected flood simulations. Sharma, et al., 2010, carried out a research for studying the combined effects of the interpolation technique and the grid cell size on the DEM quality. They used five interpolators namely triangulation with linear interpolation, inverse distance weighing, thin plate spline, ordinary kriging and topogrid for the creation of DEMs of 30m, 45m, 60m, 75m and 90m resolutions where the relative accuracies of these DEMs were evaluated. Their results showed decreased DEM quality with increasing terrain complexity and the accuracy of DEM generated using a particular interpolator and a particular grid cell size is highly site specific [11].

MATERIALS AND METHODS

This study aims at investigating the effect of the spatial resolution of the DEM generated from point data files collected using ground surveying techniques on the quality of the produced DEMs and on the accuracy of the elevations extracted from these DEMs. In this context, digital elevation data has been collected from a test site of corrugated terrain close to Cairo, Egypt, where a total station instrument has been used. DEMs have been generated from these data with different resolutions starting from 1m tell 100m grid cell size using the spatial analysis and 3D analyst working under the Arcview GIS package. The Inverse Distance Weighting (IDW) technique have been used for the creation of the DEMs. All the factors of the IDW necessary for DEM interpolation have been kept unchanged except the grid resolution factor; the factor under consideration, which have been allowed to change from 1m to 100m for the creation of DEMs of different resolutions. Analysis of the generated DEMs has been qualitative using 2D visual analysis basing on clear visual interpretation criteria. Also, quantitative analysis of the DEMs has been untaken using statistical analysis of the elevations stored in the DEMs. Additionally, investigation of profiles generated from the different resolution DEMs has been performed. Finally, Accuracy analysis for the elevations extracted from the DEMs has been undertaken using a handful of external checkout points measured from the test site at the same time of collecting the elevation data using the same ground surveying technique, but they have not been used in the creation of the DEMs.

Test Site and the Digital Elevation Measurements

Spot elevation measurements have been collected from field using a total station instrument in a test site formed of a hilly corrugated terrain and located near to Cairo, Egypt have been exploited in the analysis. The sample data covers an area of about 900 by 700 metres and consists of about 3000 spot elevation measurements forming a density of an elevation measurement for every 210 m2 and an average spacing between spot elevations of about 14.50m. The data covers an area of about 630000m2, which is of a very frequently used size of area for medium sized projects which needed to be surveyed and processed by the Geomatics Engineers on daily basis, especially if they use ground Surveying techniques for collecting digital elevation data for medium sized projects. The maximum elevation of data is 138.57m and the minimum elevation is 116.73m above the mean sea level giving a range of elevations of 21.84m. The mean elevation is 128.76m while the standard deviation of the mean is ±4.322m, which is quite high value referring to highly varied terrain.

Visual Analysis of the Digital Elevation Models

2D visual analysis employs visual interpretation criteria for investigating the differences occurring in the DEM due to changing the spatial resolution. The criteria utilized in this analysis include the shape, size, 2D locations of the colour patches in addition to the changes in the tones/colours within the DEM. Also, the texture which expresses the arrangement and repetition of the tones; smooth, intermediate or rough in addition to the pattern which is the arrangements of the spatial objects on the ground are other criteria that can be evaluated in this analysis [12, 13].

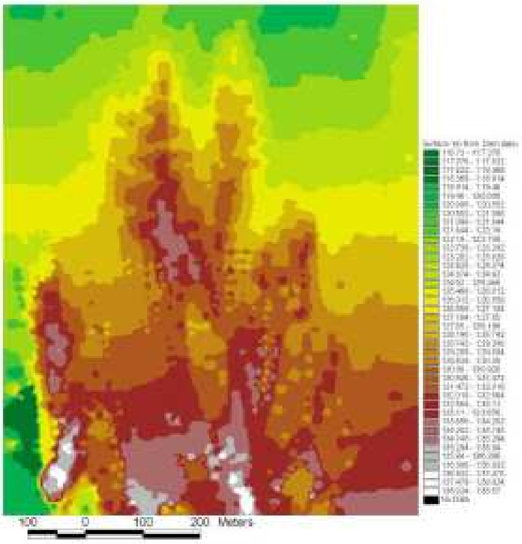

Figure 1. DEM generated from digital elevation data with 1.0 m grid resolution.

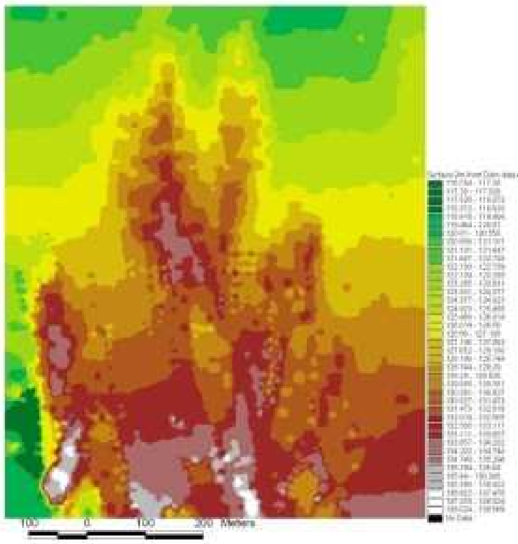

Figure 2. DEM generated from digital elevation data with 2.0 m grid resolution.

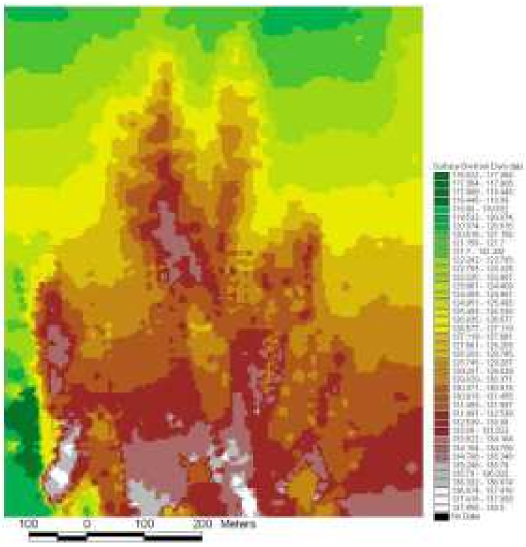

Figure 3. DEM generated from digital elevation data with 5 m grid resolution.

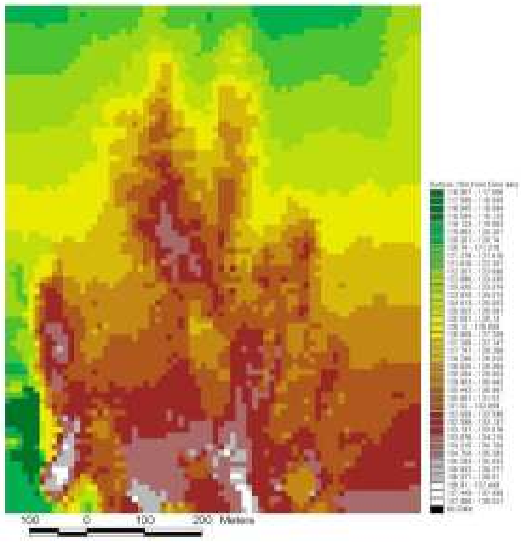

Figure 4. DEM generated from digital elevation data with 10 m grid resolution.

Figures from figure 1 to figure 8 represent digital elevation models generated from the test digital elevation data with grid resolutions of 1.0m, 2.0m, 5.0m, 10.0m and 15.0m, 20m, 25m, and 30m respectively. Little differences between figure 1 which is a DEM generated with 1.0m cell size and figure 2 which is a DEM generated with cell size of 2.0m are visually interpretable. There is clear in the big variations of the tone within these DEMs and the considerable numbers of different colour patches reflecting that significant amount of details are represented in the two DEMs. With increasing the cell size of the DEM differences are observables when comparing figure 3 which is a DEM of 5.0m cell size with figures 1 and 2. Clear changes in the tones are interpretable where the sizes of patches of different colours in addition to the texture of the DEM have become coarser reflecting increasing in terrain elevation smoothing due to degradation of the DEM resolution, in addition, much of details are lost in figure 3. Differences are wider in figure 4 which is a DEM generated using grid cell of 10.0m where the grid cell squares are distinguishable with increasing in the amount of detail losses and a coarser tone DEM is obtainable. In figures starting from figure 5 which is a DEM generated using grid cell size of 15.0m till figure 8 which is a DEM generated using cell size of 30.0m the 2D views have become worse. This appears in the increasingly blurring views and the increasingly missing of the ground surface details. Also, the tones and textures are increasingly much coarser reflecting higher degree of terrain smoothing and approximating. Visual analysis gives a clear idea on how the characteristics of the DEM deteriorate with the degradation of the DEM grid resolution.

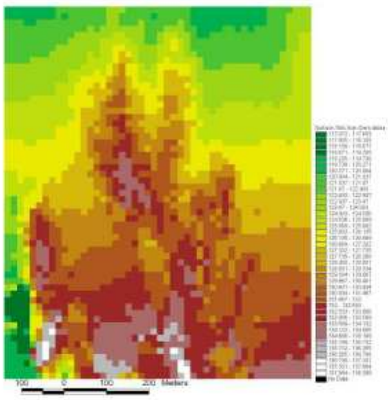

Figure 5. DEM generated from digital elevation data with 15 m grid resolution.

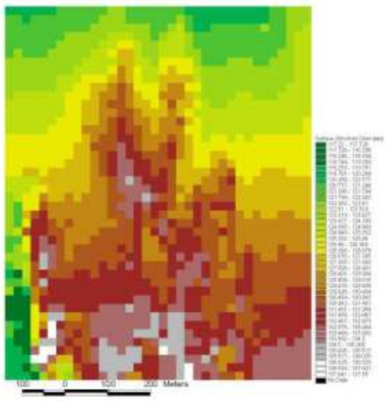

Figure 6. DEM generated from digital elevation data with 20 m grid resolution.

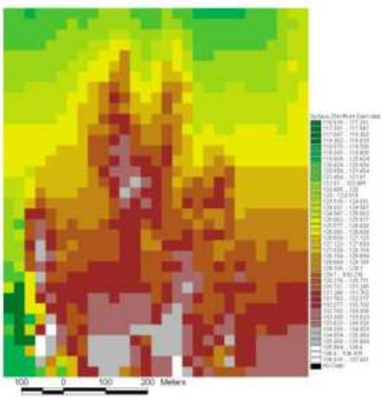

Figure 7. DEM generated from digital elevation data with 25 m grid resolution.

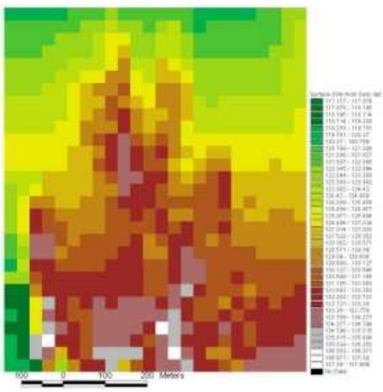

Figure 8. DEM generated from digital elevation data with 30 m grid resolution.

RESULT AND DISCUSSION

Statistical Analysis of DEM

Table 1. Statistical analysis of DEMs generated with different grid resolutions.

Statistical Value	DEM of 1m Gird resolution	DEM of 2m Gird resolution	DEM of 5m Gird resolution	DEM of 10m Gird resolution	DEM of 15m Gird resolution	DEM of 20m Gird resolution	DEM of 25m Gird resolution	DEM of 30m Gird resolution	DEM of 50m Gird resolution	DEM of 100m Gird resolution
No. of rows	**882**	**441**	**176**	**88**	**59**	**44**	**35**	**29**	**18**	**9**
No. of columns	**722**	**361**	**144**	**72**	**48**	**36**	**29**	**24**	**14**	**7**
Count	**636804**	**159201**	**25344**	**6336**	**2832**	**1584**	**1015**	**696**	**252**	**63**
Sum of elevations	**81548682**	**20387169**	**3245918**	**811478**	**362614**	**202862**	**130005**	**89200**	**32251**	**8039**
Minimum elevation	**116.730**	**116.734**	**116.822**	**116.967**	**117.072**	**117.220**	**116.816**	**117.157**	**117.331**	**117.220**
Maximum elevation	**138.570**	**138.570**	**138.500**	**138.530**	**138.400**	**137.549**	**137.430**	**137.908**	**137.606**	**134.998**
Mean elevation	**128.059**	**128.059**	**128.074**	**128.074**	**128.042**	**128.070**	**128.084**	**128.161**	**127.980**	**127.610**
Range of elevation	**21.840**	**21.835**	**21.678**	**21.560**	**21.326**	**20.330**	**20.614**	**20.751**	**20.274**	**17.7780**
Standard error of elevation	**4.29061**	**4.29058**	**4.28563**	**4.28157**	**4.30611**	**4.27668**	**4.25601**	**4.23546**	**4.34527**	**4.40968**
Standard error of the DEM mean elevation	**0.0053767**	**0.0107533**	**0.026920**	**0.053789**	**0.080917**	**0.10746**	**0.13359**	**0.16054**	**0.27372**	**0.555567**

Table 1 depicts the results of the statistical analysis of the digital elevation models generated from the digital elevation data at different resolutions starting from grid cell size of 1.0m till grid cell size of 100m. From the table it is noticeable that the no. of cells (count) and consequently the sum of elevations in the DEM decreases with the increase in the grid cell size as expected. The maximum, minimum, mean elevation criteria do not determine a specific trend of increase or decrease with the increase in the grid resolution. However, the range of elevations in the different DEMs decrease considerably with the decrease in the DEM resolution while the standard deviation of elevations in the DEM shows slight decrease with the decrease in the grid resolution. This may be explained as the decrease in the grid resolution results in an increase in smoothing of the DEM that appears in the results of the range of elevations and the standard error of elevations in the DEM. Referring to figure 9, the standard error of the elevations in the DEM decreases with the increase in the grid resolution referring to smoothing in the surface which is affected by the decrease in the number of cells in the DEM. Figure 10 is the plot of the standard error of the DEM mean elevation against the grid cell size. From the figure it is noticeable that the standard error of the mean elevation increases with increasing the grid cell size that is also affected by the number of cells in the DEM.

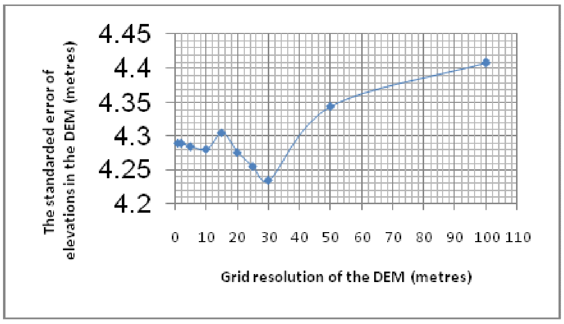

Figure 9. The effects of the DEM spatial resolution on the standard error of the DEM elevations.

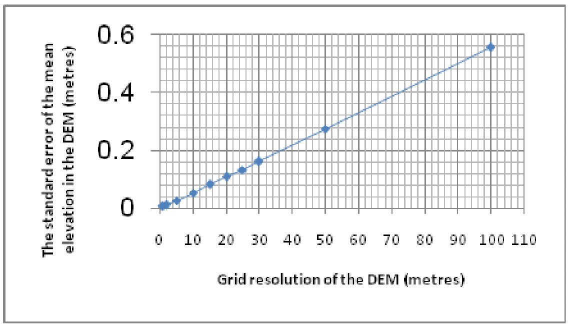

Figure 10. The effects of the DEM spatial resolution on the standard error of the DEM mean elevation.

Analysis of the Profile extracted from Different Resolution DEMs

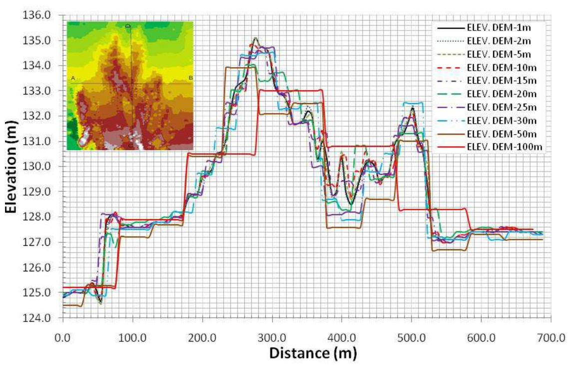

Figure 11. Profiles A-B generated from DEMs generated with different grid resolution. resolutions.

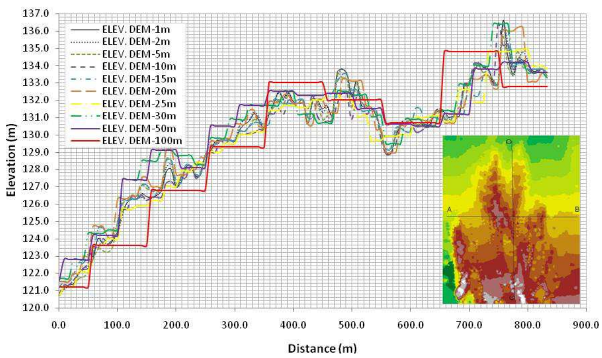

Figure 12. Profiles C-D generated from DEMs generated with different grid resolution. resolutions.

Figure 11 represents profiles extracted across the line A-B from the generated DEMs of different resolutions. Also, Figure 12 depicts profiles generated along the line C-D from the same DEMs. The profiles generated from the DEM of 1.0 metre records the minimum degree of deviation from the actual terrain where the profile run continuously with clear corrugations in a manner that makes it could be close to the natural ground surface. The smoothing effect increases with the decrease in the DEM spatial resolution where at lower resolutions the profiles are stepped where the step size is equal to the grid cell size of the DEM. This is an indication that the smoothing and approximating of the DEM elevations are at their highest values with DEMs of grid cell sizes of 15, 20, 25, 30, 50 and 100 metres. The profile testing as shown in figures 11 and 12, allows interpretation and evaluation of the amount of deviation of the profiles extracted from lower resolution DEMs, from that profile which is extracted from the DEM of 1.0m resolution that is considered close to the natural ground. Consequently this allows the estimation of the amount of deviation of the profiles extracted from different DEMs, from the natural ground.

Accuracy Estimation Using Checkout Points

In this accuracy estimation test a handful of points (about 50 points) have been retained from the original digital elevation data in order to be used for the assessment of the accuracy of the extracted elevations from the different resolution DEMs. These 50 points have not been used in the generation of the DEMs of different resolutions and consequently are considered as external checkout points. The elevations at the positions of the checkout points have been measured from the different DEMs and the residual elevations have been calculated using the following equation [12, 13]:

$$\delta = \text{Elev.checkout} - \text{Elev.DEM} \qquad (1)$$

where: δ = the residual elevations.
Elev.checkout = the elevation of the external checkout point.
Elev.DEM = the elevation from the DEM.

Then, the standard error σ of the residuals can be computed using the following formula:

$$\sigma_{Elev.} = \sqrt{\frac{(\text{Elev.checkout} - \text{Elev.DE}}{(n-1)}} \qquad (2)$$

Where: n = no. of observations (checkout points)

Referring to table 2 it is observed that the accuracy analysis test has been undertaken on ten DEMs of varied grid resolutions; 1.0, 2.0, 5.0, 10.0, 15.0, 20.0, 25.0, 30.0, 50.0 and 100 metres. The count which is the no. of the checkout points is the same for all the DEMs recording 50 points. The

Table 2. Statistical analysis of the residuals of the elevations extracted from the DEMs generated with different grid resolutions.

Statistical Properties	Elevations from DEM of 1.0m grid resolution	Elevations from DEM of 2.0m grid resolution	Elevations from DEM of 5.0m grid resolution	Elevations from DEM of 10.0m grid resolution	Elevations from DEM of 15.0m grid resolution	Elevations from DEM of 20.0m grid resolution	Elevations from DEM of 25.0m grid resolution	Elevations from DEM of 30.0m grid resolution	Elevations From DEM of 50.0m grid resolution	Elevations From DEM of 100.0m grid resolution
Grid cell size (m)	**1**	**2**	**5**	**10**	**15**	**20**	**25**	**30**	**50**	**100**
Count	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**
Max. Residual	**0.546**	**0.517**	**0.619**	**0.85**	**0.619**	**1.238**	**1.268**	**1.059**	**5.179**	**4.011**
Min. Residual	**-0.504**	**-0.575**	**-0.637**	**-0.893**	**-0.994**	**-1.093**	**-0.89**	**-1.164**	**-1.64**	**-2.109**
Mean Residual	**-0.03526**	**-0.0431**	**-0.0161**	**-0.00886**	**-0.08736**	**-0.02694**	**0.04894**	**-0.00816**	**0.2372**	**0.20488**
Range of Residuals	**1.05**	**1.092**	**1.256**	**1.743**	**1.613**	**2.331**	**2.158**	**2.223**	**6.819**	**6.12**
Sum of e Residuals	**-1.763**	**-2.156**	**-0.805**	**-0.443**	**-4.368**	**-1.347**	**2.447**	**-0.408**	**11.86**	**10.244**
Standard Error of Residuals	**0.23501**	**0.23947**	**0.25253**	**0.30385**	**0.36626**	**0.44347**	**0.45056**	**0.45301**	**0.89487**	**0.88642**

maximum residual increases with the decrease of the DEM resolution. The same can be said for the absolute values of the minimum residual which records increasing with the decrease of the DEM resolution. The mean residual decreases with the decrease of the DEM resolution approaching to zero then changes its sign to start increasing in the opposite direction with the decrease in the DEM resolution. The same can be said on the algebraic sum of residuals which decreases approaching to zero then it changes its sign starting to increase in the opposite direction with the decrease in the DEM resolution. The range of the residuals of the extracted elevations increases considerably with the decrease in DEM resolution referring to deterioration of the quality of the extracted elevations from the DEM. This is much clearer in figure 13 which is a chart depicting the relationship between the range of the residuals and the grid resolution. From figure 13, the rate of increasing of the range of residuals becomes bigger after 30 metres grid cell size. The same can be said for the standard error as seen in figure 14 which depicts the relationship between the standard error and the grid cell size, where the values of the standard error of the extracted elevations increase with the decrease in the grid resolution, however, this rate of the standard error decreasing becomes bigger after the grid cell size of 30.0 metres referring to higher rate of accuracy deterioration of the extracted elevation from the DEMs of lower resolution.

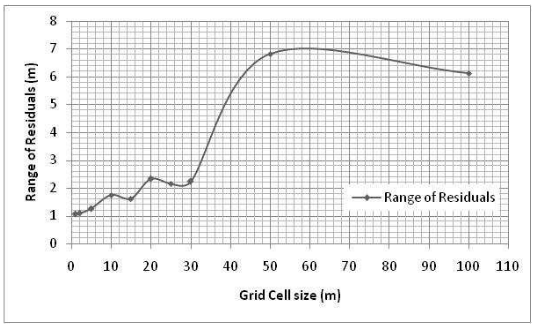

Figure 13. The range of elevation residuals against the grid resolution of the DEM.

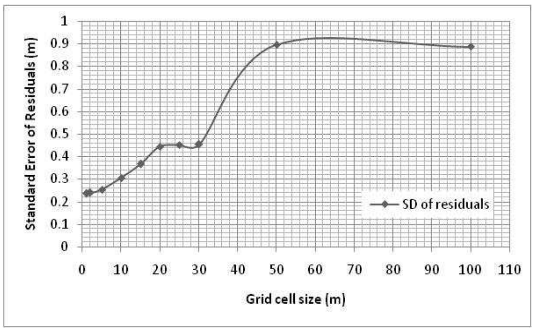

Figure 14. The standard error of the elevation residuals against the grid resolution of the DEM.

The analysis of the DEMs generated from digital elevation data using IDW interpolation technique with the application of different grid cell sizes has been perform using four different analysis techniques; visual analysis, statistical analysis of the DEMs, profile analysis, and accuracy analysis of the extracted elevations from the DEMs using external checkout points. The visual analysis test has shown deterioration in the 2D view of the DEMs due to increase in the grid cell size resulting in deterioration in the DEM resolution, where cell squares are distinguishable with increasing the cell sizes. This refers to increasing in smoothing and approximating of the DEM elevations. Also, tinny colour patches referring to much amount of details in the ground surface are interpretable with larger numbers from high resolution DEMs while from lower resolution DEMs these tinny colour patches disappear referring to surface smoothing. These results have been reflected and viewed in numbers from the statistical analysis test results depicted in table 1. The statistical analysis has shown that, with the increase in the grid cell size the number of cells in the DEM decreases and consequently the sum of the elevations stored in the DEM. The mean elevation in the DEMs has not recorded a defined trend of increase or decrease with the degradation of the DEM resolution. The same may be said for the maximum and minimum elevations. However, the range of elevations stored in the DEM decreases with the decrease in the DEM resolution. Additionally, the standard error of the DEM elevations decreases with the increase in the grid cell which is expected as the smoothing of the DEM elevations increases at lower resolutions.

The profile testing has provided a clear view of how much is the DEM resolution affect the representation of the ground surface. The profiles from DEMs at high resolution (small grid cell size) have provided continuously corrugated profile that could be close to the actual terrain. However, with the increase in the grid cell size the profiles tend to be stepped where the step size is equal to the grid cell size of the DEM that increases in the case of lower resolution DEMs. This result clarifies increasing of the smoothing factor allover the area of each grid cell. From the profile testing, the amount of deviations from the actual terrain can be estimated easily for each DEM of specific grid resolution.

Accuracy estimation of the extracted elevations using checkout point test results coincide with the results hat have been obtained from the 2D visual analysis, the statistical analysis and the profile analysis of the DEMs. As the deviation from the actual terrain is clear in the profile testing figures 11 and 12, this is expressed in the maximum and minimum residuals and the range of residual in the accuracy estimation from checkout point tests. The maximum, minimum and range of elevation residuals increase clearly with increasing the grid cell size referring to greater errors embedded in the elevations extracted from DEMs of lower resolutions. The sum and the range of the residuals also, increases with increasing the grid cell size. Additionally, deteriorations in the elevation accuracy increase with increasing the grid cell size (degradation of the DEM resolution) where this is shown in the increase in the standard errors of the residuals of the elevations extracted from the DEMs with increasing the grid resolution referred as deterioration in the DEM resolution .

CONCLUSION

This research aimed at studying the effect of the grid resolution on the quality of the digital elevation models and consequently on the accuracy of the elevations extracted from the DEMs. Qualitative and quantitative analysis have been applied on DEMs created from digital elevation data with different grid cell sizes. Different tests have been undertaken; visual analysis test, statistical analysis test, profile testing and finally accuracy assessments of the extracted elevations using external checkout points. The analysis has shown deterioration in the 2D views of the DEMs due to decrease in the grid resolution with coarser tones and textures of the DEMs of lower resolutions leading to increasing of smoothing and approximating of the digital elevation model due to increasing the grid cell sizes. Also, decreasing in the range of elevations in the DEM and deterioration of the standard error of the stored elevations in the DEM are clear results of the statistical analysis of the different resolution DEMs. Additionally, deterioration in the profiles from the DEMs increases with increasing the grid cell size where the profiles are stepped and the step size increase with increasing the grid cell size leading to increasing in the deviations from the actual terrain. The results obtained before have been reflected on the accuracy of the elevations extracted from the digital elevation models, where increasing the values of the maximum and the minimum residuals of elevation measurements from the DEM of lower resolutions are interpretable. Also, the range of elevation residuals increases with increasing the grid cell size. This has been reflected on the deterioration of the accuracy of the elevations extracted from the digital elevation models of degraded resolutions expressed in the standard error of the residuals of the extracted elevations. Creation of digital elevation models with high resolutions for the production of high quality DEM is usually a requirement for different applications. More investigations may be important for the assessment of the effect of the DEM resolution on the accuracy of the extracted elevations from the DEM with comparison of requirements of the computing systems and their effects on the final cost of the project.

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