



Landscape Modeling with the Use of Ground Surveying Spot Elevation Measurements at Bare Lands

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Abstract: Landscape modeling is considered as a main objective of any terrain investigation operation that is usually performed through qualitative and quantitative analysis of the earth's surface. Quantitative studies of the terrain landscape demands acquisition of extensive high-resolution topographic data for the extraction of the earth's surface parameters and the landscape components through exploitation of the main products of the topographic data namely; the Digital Elevation Models (DEMs) as inputs. Engineering surveying methods can provide high quality digital elevation measurements that can be utilized in the creation of the DEMs necessary for landscape modeling processes. Different factors such as; the data source, the original point data density, the spatial resolution and interpolation scheme determines the quality of the generated DEM which intern affects the process of the landscape modeling. This research is focused towards investigating the effects of the spatial resolution on the quality of the DEM as a main input in landscape modeling operations. Real elevation measurements collected from a test site close to Cairo, Egypt have been used in creation of DEMs with varying resolutions. Qualitative and quantitative analysis have been applied on that DEMs through the application of 3D visual analysis, the statistical analysis of residual DEMs, analysis of contour-line maps generated from the residual DEMs, profiling at mild terrain landscapes and finally profiling at rough terrain landscapes. The analysis has shown decrease in terrain corrugations and landscape details with the decrease in grid resolution. In addition, coarser tone and coarser texture 3D views have been obtained from lower resolution DEMs. The statistical analysis of the residual DEMs has indicated decrease in the ranges of elevation residuals and increase in the mean standard errors of the residual DEMs due to degradations of the DEM resolution. Analysis of the residual contour-line maps generated from the residual DEMs has shown decreases in the residual contour-line concentrations with the decrease in the DEM resolutions. Additionally, there has been increasing deterioration in the extracted profiles with increasing the size of the grid cells which makes the profiles to be increasingly stepped. Moreover, degradations in the DEM grid resolution have produced bigger deteriorations of the extracted profiles at rough terrain landscapes than that at mild terrain landscapes.

Keywords: Landscape Modeling, DTM/DEM/DSM, 3D Visualization, Spatial Resolution, Terrain Analysis, Topographic Mapping

1. Introduction

Landscape modeling constitutes a main concern of topographic mapping of the earth's surface applications including determining the terrain shapes and terrain irregularities in addition to mapping and analysis of the widely varied above ground features comprising the main components of the earth's landscape [1], [2]. Landscape shapes and types vary considerably across the earth's surface starting from landscapes of mountainous terrains with very rough textures to flat plain landscapes with flat surface and

very smooth textures [3], [4], [5]. Landscape modeling is considered as main objective of any terrain investigation and land surface analysis operations which are usually performed through qualitative and quantitative studies of the earth's surface [1], [6]. Quantitative studies of the landscape usually require acquisition of extensive high-resolution topographic data for the extraction of the earth's surface parameters which constitute the backbone of any terrain analysis and landscape modeling operations through exploitation of the

main products of the topographic data namely; the Digital Elevation Models (DEMs) as inputs [4], [6]. Engineering surveying methods such as ground surveying and GPS technologies can provide high accuracy digital elevation data that can be utilized in creation of good quality DEMs [7]. Although these methods are time consuming in addition to their high labor demands which is directly reflected on the final cost of the project, engineering surveying techniques are very frequently used in collecting data necessary for creation of high quality DEMs employed in many environmental and engineering applications including landscape modeling [8], [9], [10]. Other alternative sources for ground Surveying digital elevation data are remote sensing technologies which provide great advantage to the production of DEMs especially in large extended areas, where these areas can be mapped by fewer people in less time at highly competitive costs [7], [10] but of course lower quality DEMs can be obtained compared to the qualities of the DEMs created from ground surveying or GPS data [11]. However, different sources and different qualities of the digital elevation data give great advantages to the expanding the DEM areas of applications that appear in the widespread use of the DEM in many engineering and environmental applications including the main concern in the paper; the landscape modeling applications [10], [11], [12]. Since DEM has been the main format for representing and extraction of topographic data, it may be useful to note here that in addition to the DEM format for representing topographic data, this data can be represented and stored in other different continuous surface representations including; Triangulated Irregular Network (TIN) as well [13], [14], [15]. However, the DEM format enjoys more popularity over the TIN format that may be due to the smaller storage required by the DEM in a raster format compared to the storage required by the TIN in a vector format [12] [15].

Different landscape modeling applications require different quality DEMs. Thus, for involvement of a DEM in a specific landscape modeling application it is important to assess its quality and investigate the different factors that control the DEM quality so that the DEM can efficiently serve its purpose and give expected quality of the landscape modeling outputs. 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 [16], [17], [18]. Investigating the effects of the spatial resolution on topographic modeling has been a main concern for many researchers 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 [19]. Chow and Hodgson, 2009 examined the effect of the spatial sampling in modeling the mean slope from LiDAR data [20]. The results of such study acknowledged that the grid cell size of the DEM has greater effect on the mean slope than the effects from LiDAR posting density [19]. 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 [21]. Such study suggested that for areas with variable terrain complexity it could be useful to generate DEMs and slopes at suitable resolution for each terrain landscape type separately and then merge the results to produce one final layer for the whole area. In addition, such study recommended that this would provide accurate estimates of the elevations and slopes, and subsequently improve the analyses relying on these derivatives [21].

Haile and Rientjes, 2005, [22], carried out a research for investigating the effect of the DEM resolution on flood hazard assessment where they indicated that the society demands accurate and detailed information on the magnitude and likeliness of hazardous flood events for the design of flood mitigation measures [22]. 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. Their study showed that re-sampling to coarser grid elements and averaging across increasingly larger domains has resulted in an increased loss of the detailed topographic and landscape properties that affected flood simulations [22]. Sharma, et al., 2010, carried out a research for studying the combined effects of the interpolation techniques and the grid cell sizes on the DEM quality. They used five interpolators namely triangulation with linear interpolation, inverse distance weighing, thin plate spline, ordinary kriging and topogrid for 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 and landscape complexity in addition they recommended that the accuracy of a DEM generated using a particular interpolator and a particular grid cell size is highly site specific [23].

The current study aims at investigating the effects of the spatial resolution, on the quality of the DEM, as a main input in any landscape modeling operation. The research is mainly focused towards studying the effects of the spatial resolution on the DEMs generated from point data files observed using ground surveying techniques, such as spirit leveling and total station technologies, in addition to assessment of the effects of the DEM resolutions on the quality of the extracted elevations from these DEMs for the purpose of terrain analysis and landscape modeling. In this context, digital elevation data has been collected from a test site of corrugated terrain, where a spirit level and a total station instruments has been used. DEMs have been generated from these data with different resolutions starting from 1m till 100m grid cell size using the spatial analysis and 3D analyst working under the ArcView GIS package. The Inverse Distance Weighting (IDW) interpolation technique has been exploited in creation of the tested DEMs. All the factors of the IDW necessary for DEM generation have been kept unchanged except the grid resolution factor; the factor under consideration, which have been allowed to change from 1m

to 100 m giving DEMs of different resolutions. Analysis of the generated DEMs has been qualitative using 3D visual analysis basing on clear visual interpretation criteria. Also, quantitative analysis of the DEMs has been undertaken using statistical analysis residual DEMs that have been generated through subtracting a DEM of a specific resolution from a reference DEM generated with a resolution of 0.25 m. Moreover residual contour-line maps have been generated from the different resolution residual DEMs and analyzed. Furthermore, investigations of profiles generated from the different resolution DEMs in different terrain landscapes; mild terrain landscape and rough terrain landscape have been performed.

2. Test Site and the Spot Elevation Measurements

Spot elevation measurements have been collected from field using a spirit level and a total station instruments in rural area as a test site that is mostly formed of hilly corrugated terrains and located near to Cairo, Egypt and 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 14.50 m. The data covers an area of about 630000 m², 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 measurements for medium sized projects. The maximum elevation of data is 138.57 m and the minimum elevation is 116.73 m above the mean sea level giving a range of elevations of about 21.84 m. The mean elevation is 128.76 m while the standard deviation of the mean is ± 4.322 m, which is quite high value referring to highly varied terrain.

3. 3D Visualization of the Different Resolution DEMs

3.1. 3D Visual Interpretation Criteria

Since 3D views of the DEM constitute images of raster formats, then, the elements of digital image interpretation namely; shape, size, 3D locations of the color patches in addition to changes in the tone/color are main criteria that can be exploited in visual interpretation of the 3D views generated from the DEMs [24], [25]. Also, the texture which expresses the arrangements and repetitions of the tone; smooth, intermediate or rough adding to the pattern which is the arrangements of the spatial objects on the ground are other criteria that can be performed in such analysis. Moreover, the height/depth of objects and the shadow of objects are main criteria for the analysis of the 3D view generated from a DEM [24], [25], [26].

3.2. Analysis of the DEM 3D Views

Figures from figure 1 to figure 8 represent 3D views generated from DEMs of resolutions 1.0 m, 2.0 m, 5.0 m, 10.0 m and 15.0 m, 20m, 25 m, and 30 m respectively. Little differences between figure 1 which is a 3D view generated from a DEM of 1.0 m grid cell size and figure 2 which is a 3D view generated from a DEM of grid cell size of 2.0 m are visually interpretable. Both figures show wide variations of the tones with considerable numbers of different color patches reflecting that significant amount of details are represented and highly corrugated surfaces are obtained. With increasing the grid cell size differences are observables when comparing figure 3 which is a 3D view generated from DEM of 5.0 m cell size and figure 4 which is a 3D view generated from DEM of 10.0 m cell size with figures 1 and 2. Changes from figures 1 and 2 in the tones are interpretable in figures 3 and 4 where the sizes of different color patches 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, some details are lost in figures 3 and 4 and the 3D views have become smoother. Differences are wider in figure 5 and figure 6 which are 3D views generated from DEMs of grid cells of 15.0 m and 20.0 m sizes respectively, where the cell squares are distinguishable in these two figures reflecting increasing in the amount of detail losses where coarser tone 3D views and less corrugated surfaces are obtainable.

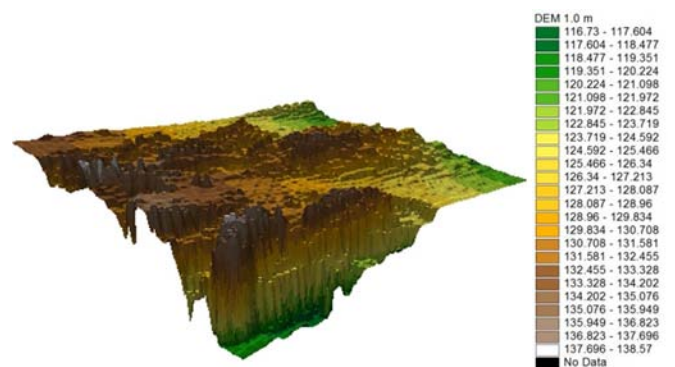


Figure 1. 3D view generated from DEM of 1.0 m grid resolution.

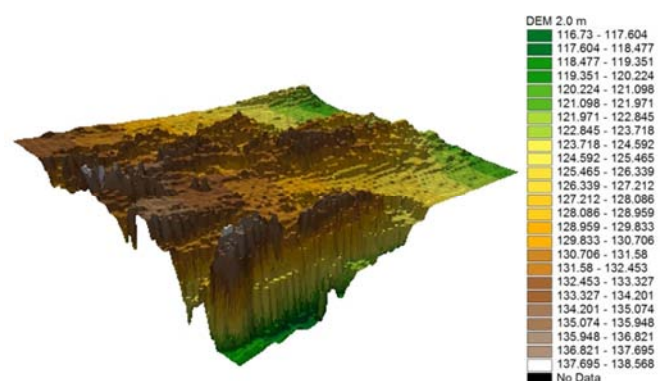


Figure 2. 3D view generated from DEM of 2.0 m grid resolution.

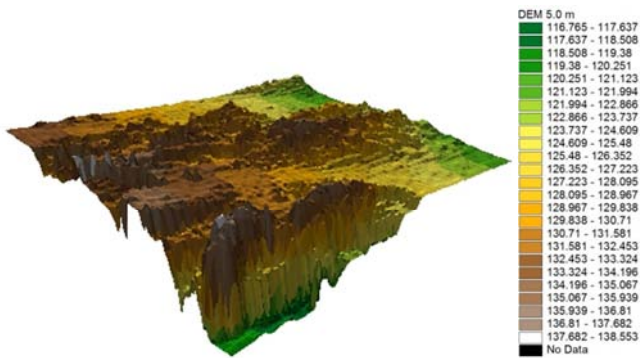


Figure 3. 3D view generated from DEM of 5.0 m grid resolution.

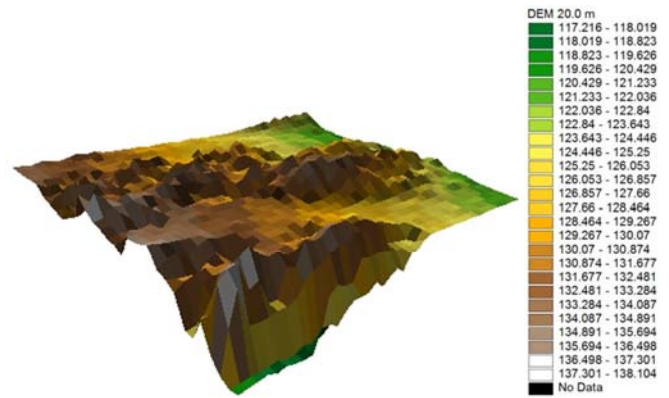


Figure 6. 3D view generated from DEM of 20.0 m grid resolution.

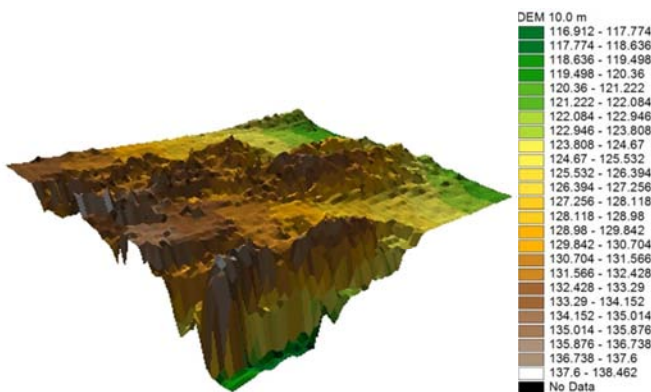


Figure 4. 3D view generated from DEM of 10.0 m grid resolution.



Figure 7. 3D view generated from DEM of 25.0 m grid resolution.

In figure 7 and figure 8 which are 3D views generated from DEMs of grid cell sizes of 25.0 m and 30 m respectively the squares of the cells are much clearer as they are bigger and much of fine details are lost while only big size details the only what are left reflecting high degree of surface smoothing and elevation approximating. Also, the tones and textures are increasingly much coarser reflecting higher degree of terrain smoothing and approximating. 3D Visual analysis gives clear and sensible idea on how the characteristics of the 3D views and consequently the DEMs deteriorate with the degradation of the DEM grid resolution.

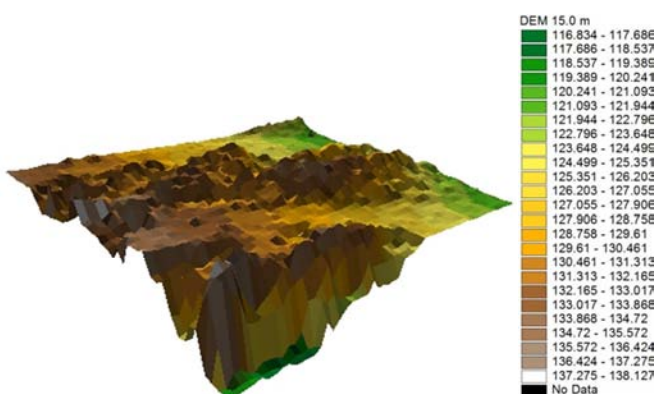


Figure 5. 3D view generated from DEM of 15.0 m grid resolution.

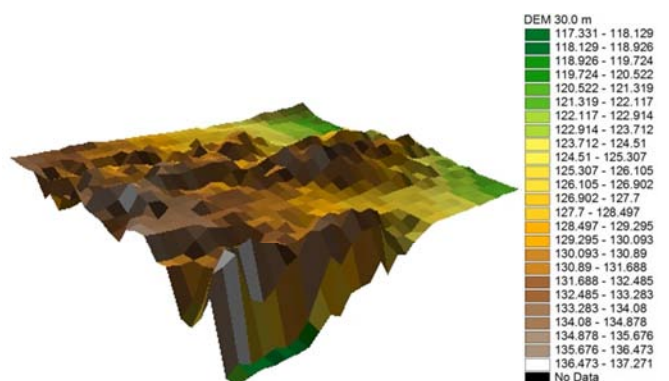


Figure 8. 3D view generated from DEM of 30.0 m grid resolution.

4. Statistical Analysis of the Residual DEM at Different Resolutions

The idea of the test depends on creation of a reference DEM of as small grid cell size as possible, then the surface analysis map calculator application tools are exploited for calculating a residual DEM as a result from subtracting the reference DEM from the generated DEM at a specific grid cell size. In this operation, the resulting DEM will be of cell size similar to that of the coarser DEM. In this analysis a reference DEM has been generated with a selected grid cell of 0.25 m, the residual DEMs have been created as results from subtracting this reference DEM from the DEMs generated with grid cell sizes of 1.0 m, 2.0 m, 5.0 m, 10.0 m, 15.0 m, 20.0 m, 25.0 m, 30.0 m, 50.0 m, and 100.0 m. Thus

the resulting residual DEMs will of grid cell sizes of 1.0 m, 2.0 m, 5.0 m, 10.0 m, 15.0 m, 20.0 m, 25.0 m, 30.0 m, 50.0 m, and 100.0 m. The statistical properties of each of the resulting residual DEM have been calculated and depicted in tables 1a and 1b. From tables 1a and 1b it is noticeable that the no. of rows, the no. of columns and the count no. (total no. of cells in the DEM) of the resulting residual DEM from the map calculation operations are similar to the DEM of lower size grid cell in subtracting operation as stated before.

From tables 1a and 1b, also it is noticeable that the no. of cells (count) of the residual DEM and consequently the sum of the residual elevations stored in the DEM decrease with the increase in the grid cell size as expected. Moreover, with neglecting the sign of the residual elevation it is observed that the values of maximum residuals and those of the minimum residual decrease considerably with increasing the grid cell size (i.e. deterioration in the DEM resolution) referring high degree of elevation smoothing due to increase

in the grid cell sizes. Additionally, tables 1a and 1b show that the DEM grid cell size does not have a dramatic effect on the mean residual elevations which in most cases of the analysis have the same values. However, the range of the residual elevations in different resolution DEMs decrease considerably with the decrease in the DEM resolution while the standard deviations of the residual elevations in the DEM decreases dramatically with the decrease in the grid resolution. This is again may be explained as the decrease in the grid resolution results in an increase in surface smoothing with loosing of surface details. This is much clearer in figure 9 where the standard error of the residual elevations decreases dramatically with the increase in the grid resolution referring to smoothing in the surface. On the other hand, figure 10 is a plot of the standard error of the mean residual elevation against the grid cell size that shows increases in the standard error of the mean residual elevations with increasing the grid cell size.

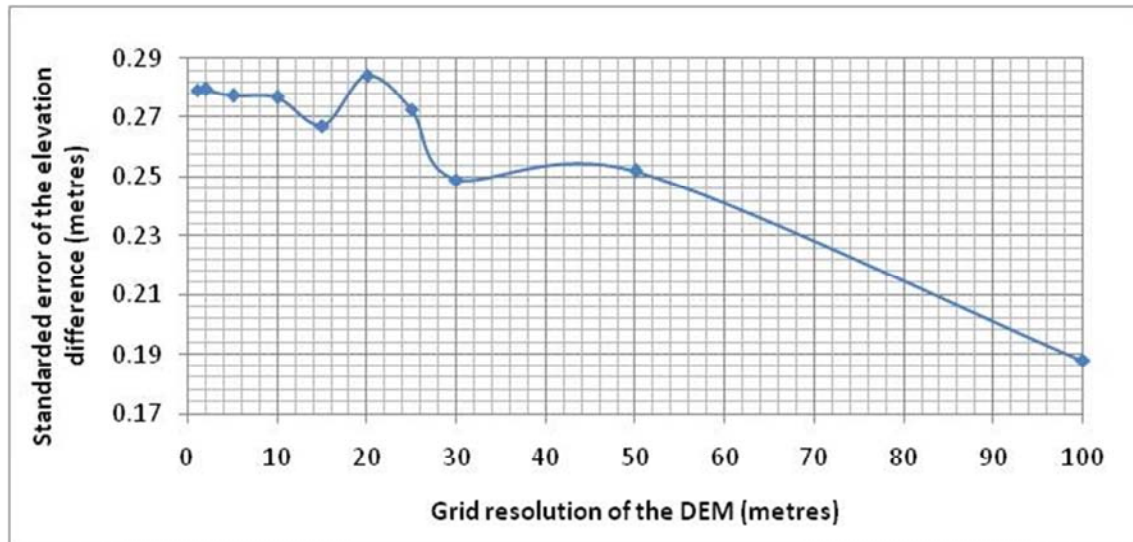


Figure 9. The effects of the DEM spatial resolution on the standard error of the residual elevations.

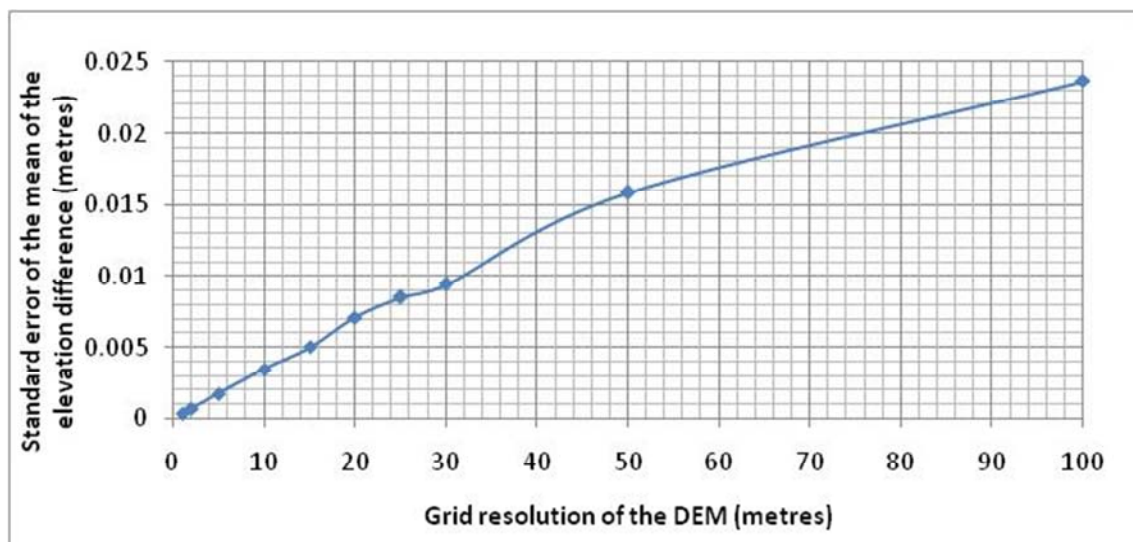


Figure 10. The effects of the DEM spatial resolution on the standard error of the mean residual elevation.

Table 1a. Statistical analysis of the residual DEMs generated using different grid resolutions.

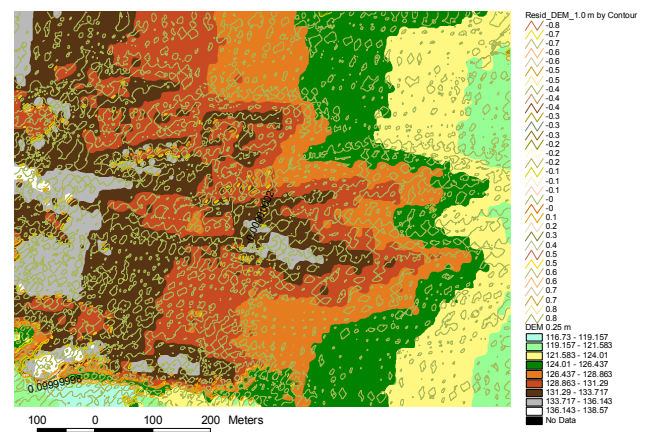
Statistical Value	Residual DEM of 1.0m resolution	Residual DEM of 2.0m resolution	Residual DEM of 5.0m resolution	Residual DEM of 10.0m resolution	Residual (DEM of 15.0m resolution)
No. of rows	882	441	176	88	59
No. of columns	722	361	144	72	48
Count	636804	159201	25344	6336	2832
Sum of residual elev. (m)	8849.5	2211.8	355.97	63.424	40.845
Min. of residual elev. (m).	-4.790	-4.493	-3.342	-3.567	-2.422
Max. of residual elev. (m).	6.029	5.878	3.679	3.734	3.601
Mean of residual elev. (m).	0.014	0.014	0.014	0.010	0.014
Range of residual elev. (m).	10.818	10.371	7.021	7.300	6.023
Standard error of residual elev. (m).	0.279	0.279	0.277	0.277	0.267
Standard error of mean residual elev. (m).	0.0003	0.0007	0.0017	0.0035	0.0050

Table 1b. Statistical analysis of the residual DEMs generated using different grid resolutions.

Statistical Value	Residual DEM of 20.0m resolution	Residual DEM of 25.0m resolution	Residual DEM of 30.0m resolution	Residual DEM of 50.0m resolution	Residual DEM of 100.0m resolution
No. of rows	44	35	29	18	9
No. of columns	36	29	24	14	7
Count	1584	1015	696	252	63
Sum of residual elev. (m)	15.248	11.01	-2.111	12.241	0.671
Min. of residual elev. (m).	-2.411	-2.544	-1.820	-1.234	-0.948
Max. of residual elev. (m).	2.807	1.666	1.473	1.489	0.612
Mean of residual elev. (m).	0.009	0.011	-0.003	0.049	0.011
Range of residual elev. (m).	5.218	4.21	3.293	2.723	1.560
Standard error of residual elev. (m).	0.284	0.273	0.249	0.252	0.188
Standard error of mean residual elev. (m).	0.0071	0.0086	0.0094	0.0159	0.0237

5. Residual Contour-Line Generation from Different Residual DEMs

Residual contour-line maps have been created from the residual DEM resulting from subtracting a reference DEM, generated with 0.25 m grid cell from each individual DEM of different grid cell size. Figures from 11 to 18 are residual contour-line maps produced from residual DEMs of 1.0 m, 2.0 m, 5.0m, 10.0m and 15.0m, 20m, 25m, and 30m respectively. The residual contour-line maps have been generated with a unified contour interval of 0.25 m then draped over the DEM of 1.0 m in order to help better interpretation of the residual contour-line maps. Figures 11, 12 and 13 which are residual contour-line maps generated from the residual DEMs of 1.0 m, 2.0 m and 5.0 m grid cell sizes indicate that at mild terrain there is high concentration of residual contour lines but the individual residual contour lines are still distinguishable from each other.

**Figure 11.** Residual contour-line map generated from residual DEM of 1.0 m cell size and viewed over a digital elevation model of 0.25 m grid resolution.

The situation is different at rough terrain areas where clouds of residual contour lines are obtainable where separate

contour lines come very close to each other. This refers to higher errors in the segmentation process at corrugate terrains than those occur at milder terrains. When moving to figure 14 which is a residual contour-line map generated from the residual DEM of 10.0 m grid cell, it can be noticed the concentration of the residual contour lines has become smaller than those in figures 11, 12 and 13 and again with higher concentration at rough terrain areas.

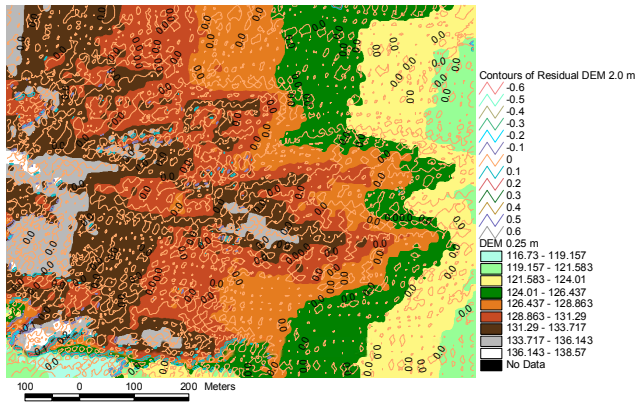


Figure 12. Residual contour -line map generated from residual DEM of 2.0 m cell size and viewed over a digital elevation model of 0.25 m grid resolution.

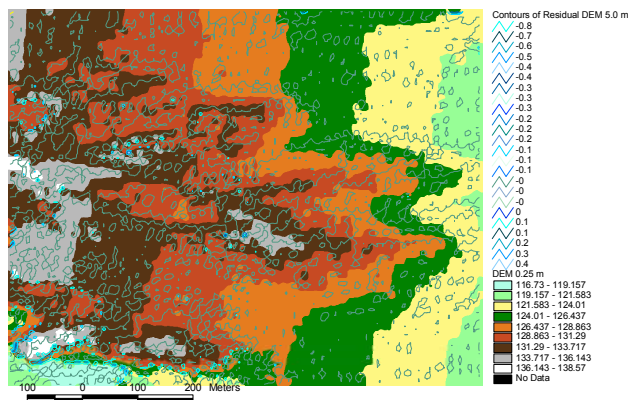


Figure 13. Residual contour -line map generated from residual DEM of 5.0 m cell size and viewed over a digital elevation model of 0.25 m grid resolution.

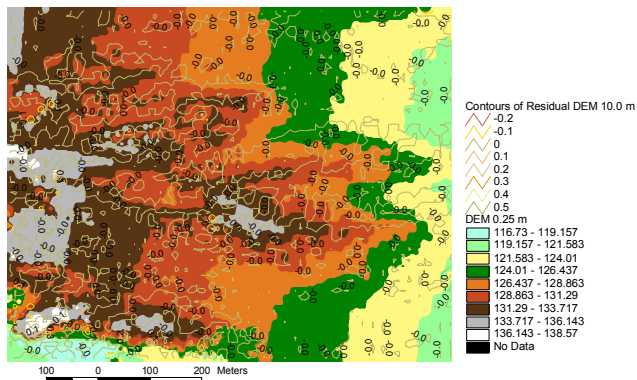


Figure 14. Residual contour -line map generated from residual DEM of 10.0 m cell size and viewed over a digital elevation model of 0.25 m grid resolution.

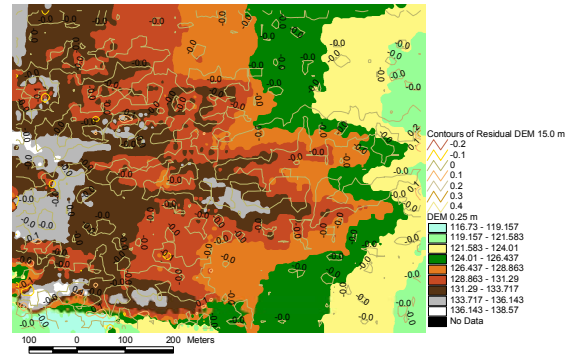


Figure 15. Residual contour -line map generated from residual DEM of 15.0 m cell size and viewed over a digital elevation model of 0.25 m grid resolution.

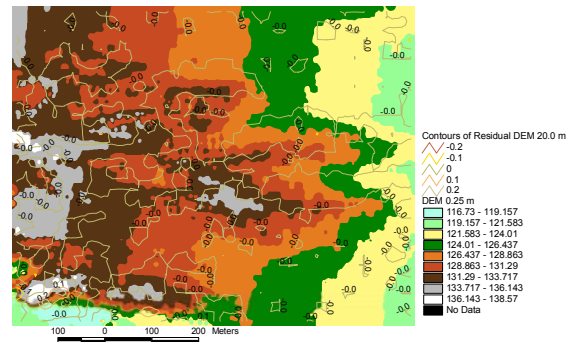


Figure 16. Residual contour -line map generated from residual DEM of 20.0 m cell size and viewed over a digital elevation model of 0.25 m grid resolution.

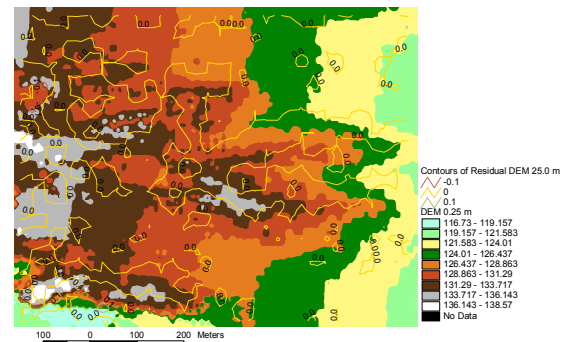


Figure 17. Residual contour -line map generated from residual DEM of 25.0 m cell size and viewed over a digital elevation model of 0.25 m grid resolution.

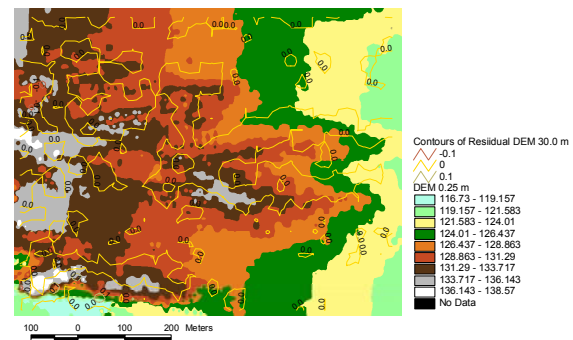


Figure 18. Residual contour -line map generated from residual DEM of 30.0 m cell size and viewed over a digital elevation model of 0.25 m grid resolution.

With increasing the grid cell size the concentration of the contour lines of the residual elevations become smaller with relatively higher concentrations of contour line in rough terrain than those in the mild terrain area. This is clear in figure 15, 16, 17, and 18 which represent residual contour-line maps generated from DEMs of 15 m, 20 m, 25 m and 30m grid cell size respectively. From this analysis two concrete results may be extracted; the first one is that the quality of the generated DEM in rough area is usually less than that of the DEM generated in milder terrain areas. The second result is that smoothing of the DEM increases with increasing the grid cell sizes. It has been clear that there is a decrease in the contour line of residual elevations concentration due to decrease in the DEM resolution due to increase in DEM smoothing.

6. Analysis of the Profiles Extracted from Different Resolution DEMs

6.1. Profile Extraction at Mild Terrain Landscapes

Figure 19 represents profiles extracted across the line A-

B from DEMs of different resolutions at mild terrain area. The profiles generated from the DEM of 0.25 m records the minimum deviation from the actual terrain as it has been extracted from the highest resolution DEM so it is expected to run continuously with clear corrugations as close as possible to the natural ground surface and consequently this profile will be considered as a reference profile in this analysis. From figure 19, the profiles generated from the DEMs of 1.0 m, 2.0 m and 5.0 m run close to the reference profile with some deviations from the reference DEM can be of about 0.25 m that increases as the resolution of the DEM decreases. With increasing the grid cell size the deviation from the reference profile increases and can be more than 0.50 m in the case of the profiles from the DEM of 20.0 m grid cell size while the amount of deviation is reaching more than 1.0 m in the case of the profile from the DEM of 50.0 m grid cell size. This clarifies how much DEM resolution contributes to the error budget induced in the extracted elevations from that DEM. Also, with deterioration in DEM resolution the extracted profiles become stepped with step size is directly proportion to corresponding grid cell size.

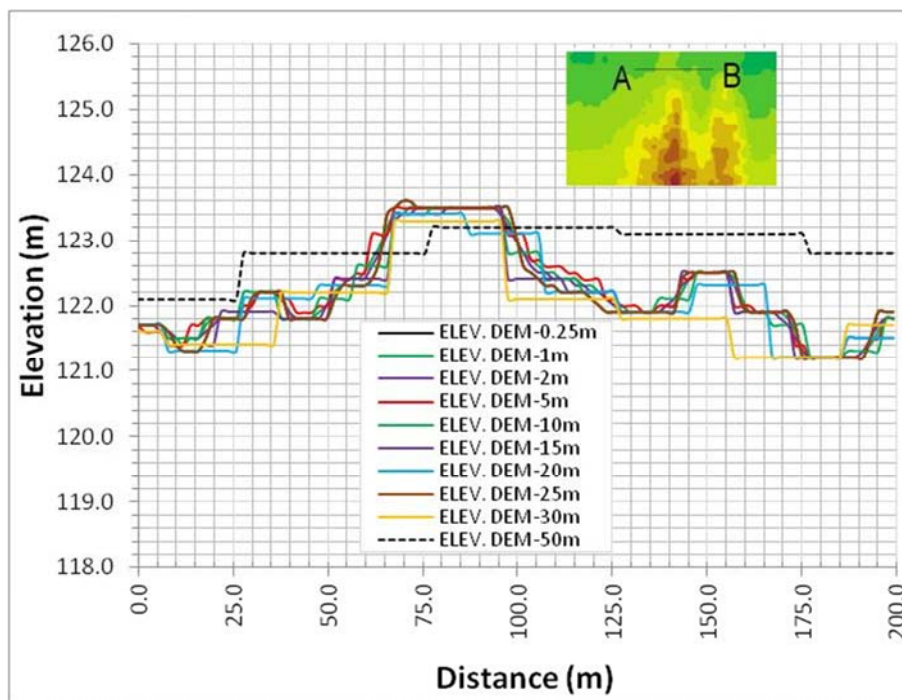


Figure 19. Profiles A-B extracted from DEMs generated with different grid resolution at mild terrain landscape.

6.2. Profile Extraction at Rough Terrain Landscapes

Figure 20 depicts profiles extracted along the line C-D from DEMs of different resolutions at rough terrain. Again the profiles extracted from the DEM of 0.25 meters is expected to record 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 so it is considered here as a reference profile in this analysis. The profiles produced from the DEMs of 1.0 m, 2.0 m and 5.0 m run close to the reference profile with deviations

from the reference DEM can be less than 0.5 m, however as the resolution of the DEM decreases the amount of deviation from the reference profile increases. With increasing the grid cell size the deviation from the reference profile increases that can be more than 1.0 m in the case of the profiles from the DEM of 20.0 m cell size where the profile is stepped with steps are equal to the grid cell size while the amount of deviation is reaching more than 2.0 m in the case of the profile from DEM of 50.0 m grid cell size. This means that the DEM resolution have direct effect on the induced errors in the

extracted elevations from the DEM. The accuracy of the extracted elevations from a DEM is expected to be much smaller in rough terrain compared to that accuracy in the case

of the mild terrain areas. Also, with increasing the DEM cell size the produced profile become stepped with steps sizes directly proportion to the DEM cell size.

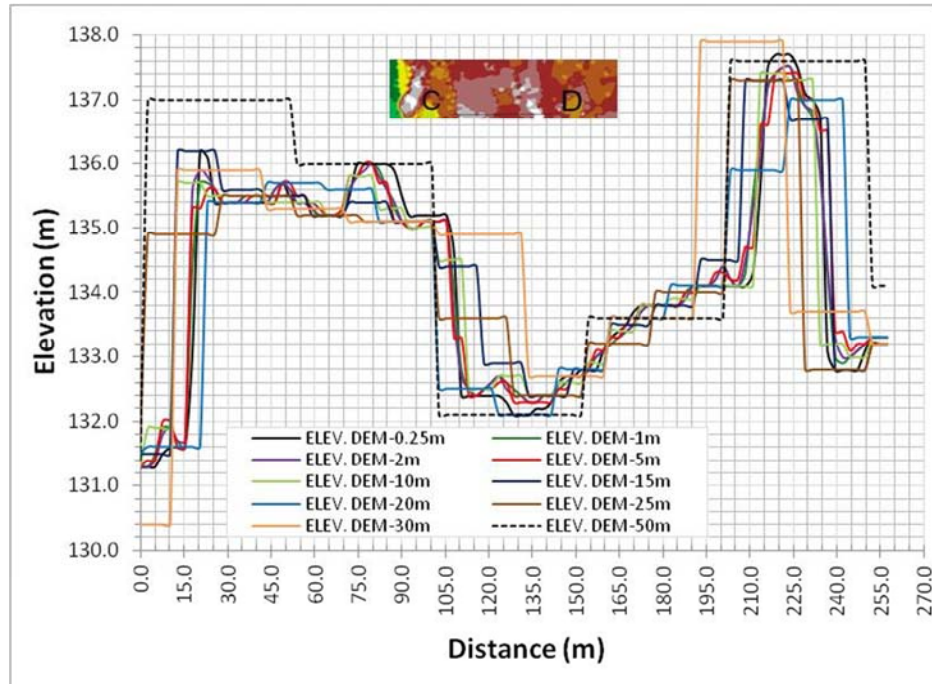


Figure 20. Profiles C-D extracted from DEMs generated with different grid resolution at rough terrain landscape.

7. Discussions

Five analysis tests namely; 3D visual analysis of the DEMs, statistical analysis of the residual DEM, Analysis of residual contour-line maps generated from the residual DEM, profiling at mild terrain and finally profiling at rough terrain have been introduced for evaluation of the quality of DEMs generated from ground surveying data with varying spatial resolutions since the DEM constitutes a main input in any landscape modeling operation and its quality controls the quality of the outputs from such operations. 3D visual analysis of the DEMs depended on creation of 3D views from the different resolution DEMs with employment of visual analysis criteria such as; shape, size, 3D locations of the color patches in addition to changes in the tone/color, texture, pattern, height/depth of objects and the shadow of objects. The 3D visual analysis has indicated that 3D views from the DEMs of higher resolutions show wide variations of the tones with considerable numbers of color patches reflecting significant amount of details have been represented. Additionally, 3D views from higher resolution DEMs have shown corrugated surface that can be close to the natural ground. With increasing the grid cell size of the DEM, the extracted 3D views have become different where the tones and the texture have become coarser and the squares of the individual grid cells have been clearly interpretable. In addition, smoothing of the surface and loss of details expressed in less corrugated surface have increased due to deterioration in DEM resolutions.

In order to examine the results obtained from the 3D visual

analysis test, the statistical analysis of the residual DEM has been performed. In this analysis the no. of rows, the no. of columns and the count no. of the resulting residual DEM from the map calculation operations have been similar to those of the DEM of lower resolution in the subtraction operation which has led to decrease in the sum of the residual elevations stored in the residual DEM due to increase in the grid cell size. Additionally, with neglecting the sign of the residual elevation it has been observed that the values of the maximum residuals and those of the minimum residuals has decreased with increasing the grid cell size (i.e. deterioration in the DEM resolution), which could be due to the smoothing effect in DEM. Moreover, the DEM grid cell size did not have dramatic effects on the mean residual elevations. In the opposite, the ranges and the standard deviation of the residual elevations have decreased considerably with the decrease in the DEM resolution that could be due to increasing in surface smoothing. In the contrary, the standard error of the mean residual elevation has increased with increasing the grid cell size.

Since, the statistical analysis of the residual DEMs has introduced some numbers describing the effects of the grid resolution on the quality of the generated DEMs, the analysis of residual contour-line maps created from the residual DEMs has been another way of determining the effects of the grid resolution on the quality of the DEM. The analysis has shown high concentration of the residual elevation at mild terrain areas while at corrugated terrain area clouds of contour line of residuals are obtainable. With increasing the grid cell size the concentration of the residual contour lines become smaller with relatively higher concentrations of those

residual contour lines in rough terrain than those in the mild terrain areas. From this analysis two concrete results have been obtained; the first one is that a DEM generated in rough area is usually of less quality compared to that of a DEM generated in mild terrain areas. The second result is that there is decrease in the contour line of residual elevations concentration due to decrease in the DEM resolution.

The fourth and fifth tests have been analysis of profiles generated from DEMs of different resolutions at mild and rough terrain areas respectively providing a view of how the DEM resolution affects the representation of the ground surface. The profiles extracted from the DEMs of high resolution (small grid cell size) have provided continuously corrugated profile that could be close to the actual terrain; that is in the both cases of mild terrain and rough terrain. However, with the increase in the grid cell size the profiles tended to be stepped with the step sizes proportional to the grid cell size of the DEM that increases in the case of lower resolution DEMs. This clarifies increasing of the smoothing factor all over 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. In the case of rough terrain the effect of the grid resolution is bigger than that effect in the case of mild terrain.

8. Conclusions

Landscape modeling constitutes a main concern of topographic mapping of the earth's surface applications including determining the terrain shapes and terrain irregularities in addition to mapping and analysis of the widely varied above ground features comprising main components of the earth's landscape [1], [2]. Landscape shapes and types vary considerably across the earth's surface starting from landscapes of mountainous terrains with very rough textures to flat plain landscapes with flat surface and very smooth textures [3], [4], [5]. Landscape modeling is considered as main objective of any terrain analysis and land surface analysis operations which is usually performed through qualitative and quantitative analysis of the earth's surface [1], [6]. The Digital Elevation Model (DEM) constitutes a main input in any landscape modeling operation and consequently the quality of the DEM determines the quality of the outputs from such landscape modeling operations. Engineering surveying methods can provide high quality digital elevation data that can be utilized in creation of high quality DEM. Grid resolution is one of the main factors that control the quality of a DEM. This research aimed at studying the effects of the grid cell size on the quality of the DEM since the DEM constitutes a main input in landscape modeling. Qualitative and quantitative analysis have been applied on DEMs created from digital elevation data with different grid cell sizes through a package of test and analyses namely; 3D visual analysis test, statistical analysis of the residual DEM test, analysis of the contour-line maps generated from the residual DEM, profiling at mild terrain and profiling at rough terrain. The analysis has shown decrease in terrain corrugations in the 3D visual

analysis due to decrease in the grid resolution in addition to coarser tone and coarser texture 3D views have been obtained from lower resolution DEM that could be due to increasing in DEM smoothing and approximating of the surface due to increasing the grid cell sizes. Statistical analysis of the residual DEM has indicated considerable decrease in the range of the residual elevations and the standard errors of the residual DEM due to increasing of smoothing with degradation of the DEM resolution as well. Analysis of residual contour-line maps has shown increasing of terrain smoothing due to degradation of the DEM resolution which is very clear in the decrease in the concentration of the residual elevation contour-lines. Additionally, deterioration in the profiles from the DEMs has increased with increasing the grid cell size where the profiles have been stepped where the step size increase with increasing the grid cell size leading to increasing in the deviations from the actual terrain. The analysis has indicated that the effects of the grid resolution on the quality of the generated DEM in the rough terrain landscapes have been higher than that effect in the mild terrain landscape areas. Creation of DEMs with high resolutions for the production of high quality DEM is usually a requirement for different applications such as landscape modeling applications. Investigations of the optimal grid resolution for generating good quality DEM could be of great benefit for the Geomatics community and landscape modeling researchers.

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