Volume Calculation Through Using Digital Elevation Models Created By Different Interpolation Methods

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Keywords: Digital elevation model; Interpolation methods; Volume calculation; Surfer Software

SUMMARY

The digital elevation model is a model which defines the surface of land three-dimensional and has been created through the elevation data of the land. The digital elevation model has been widely used in the fields of application such as, preparation of road projects, excavation-filling-related volume calculations, land arrangement studies, etc. The volume calculations which is the subject of this study and have been used in a variety of engineering services, have often been used in the reserve determination of mine sites, in the determination of splitting and filling soil removal works of the sites such as, road, airport, tunnels etc. Since the amount of the calculated volume burdened financially great expenses to employer, the calculations must be made in a precise manner. The aim of this study is to make and compare the volume calculations with different grid ranges and different interpolation methods. In this study, grid ranges were selected as 50 m, 100 m, 150 m and 200 m. The interpolation methods used are Inverse Distance to a Power (k=1 and k=2), Point Kriging, Minimum Curvature, Modified Shepard's Method, Natural Neighbor, Nearest Neighbor, Polynomial Regression (simple planar surface), Multiquadratic Radial Basis Function, Triangulation with Linear Interpolation. The volume calculation methods used are Trapezoidal rule, Simpson's rule, Simpson's 3/8 rule. The digital elevation models were prepared in the "Surfer 8" program. The surface modelling of the land is made through the chosen different interpolation methods and the grid extended files of these resulting surfaces were created. Afterwards, the volumes of these surfaces with reference to the selected reference surface, Z = 0, were determined with different methods and were compared.

ÖZET

Sayısal yükseklik modeli, bir arazi yüzeyini üç boyutlu olarak tanımlayan ve araziye ait yükseklik verilerinden elde edilmiş bir modeldir. Sayısal yükseklik modeli, yol projelerinin hazırlanmasında, kazı-dolgu ile ilgili hacim hesaplarında, arazi düzenleme çalışmalarında vb. uygulama alanlarında yaygın olarak kullanılmaktadır. Bu çalışmaya konu olan ve çeşitli mühendislik hizmetlerinde kullanılan hacim hesaplamaları maden sahalarının rezerv tespitinde, yol, havaaalanı, tünel vb. sahaların yarma ve dolgu toprak hafriyatlarının belirlenmesinde sıkça kullanılmaktadır. Uygulamalarda hesaplanan hacim miktarının işverene maddi bir külfet yüklediği için, hesaplamaların hassas bir şekilde yapılması gerekmektedir. Bu çalışmanın amacı farklı grid aralıkları ve farklı enterpolasyon yöntemleri ile hacim hesaplarının yapılması ve karşılaştırılmasıdır. Bunun için; grid aralığı, 50 m, 100 m, 150 m ve 200 m olarak seçilmiştir. Enterpolasyon yöntemleri olarak, Inverse Distance to a Power (k=1

ve k=2), Point Kriging, Minimum Curvature, Modified Shepard's Method, Natural Neighbor, Nearest Neighbor, Polynomial Regression (simple planar surface), Multiquadratic Radyal Basic Function, Triangulation with Linear Interpolation kullanılmıştır. Hacim hesaplama yöntemleri olarak Trapez kuralı, Simpson Kuralı, Simpson 3/8 kuralı uygulanmıştır. Sayısal yükseklik modelleri "Surfer 8" programında hazırlanmıştır. Secilen farklı enterpolasyon yöntemleriyle arazinin yüzey modellemesi yapılmış, elde edilen bu yüzeylerin .grd uzantılı dosyaları oluşturulmuştur. Ardından bu yüzeylerin seçilen Z=0 referans yüzeyine göre hacimleri farklı yöntemlerle belirlenmiş ve karşılaştırılmıştır.

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INTRODUCTION

The volume calculations are important requirement of the construction and mining industry. The accurate volume estimation is important in many applications, for example road project, mining enterprise, geological works and building applications. The traditional methods such as the trapezoidal method (rectangular or triangular prisms), traditional cross sectioning (trapezoidal, Simpson, and average formula), and improved methods (Simpson-based, cubic spline, and cubic Hermite formula) have been used in volume computing. The main elements of these methods are to collect the points that appropriate distribution and density. These methods needs more mathematical processes and take more time. The difficulties have been overcome by developments in computer technologies. The corrections of volume is direct proportional with the presentations of land surface in a best representation of land surface in best form is depend on the number of certain X,Y,Z coordinate points. The total station instrument has been used to determine the certain coordinate for land surface [1].

A digital elevation model (DEM) is a numerical representation of topography, usually made up of equal-sized grid cells, each with a value of elevation. Its simple data structure and widespread availability have made it a popular tool for land characterization. Because topography is a key parameter controlling the function of natural ecosystems, DEMs are highly useful to deal with ever-increasing environmental issues [2].

An elevation model can be represented as regular or irregular point clouds formed into a mathematical model. In order to represent the continuous Earth surface these point clouds should form into the shape of the surface. There are various methods for doing this and Triangulated Irregular Network (TIN) is one of the most popular models [3].

DEM quality is a function of (i) the quality of the individual data points within the surface, (ii) the density of data points used to represent the surface, and (iii) the distribution of data points within the surface. Both (ii) and (iii) are related to the field sampling strategy and to the hardware used to collect the data [4].

Surveys to collect data used to create DEMs can be airborne (e.g. photogrammetry, laser scanning and remote sensing, in particular space borne radar interferometry) or ground based (total station, global positioning system, including, most recently, terrestrial laser scanning) depending on the size of the reach and available technology [5, 6].

2. TRIANGULAR IRREGULAR NETWORK (TIN)

Triangular irregular network (TIN) and regular grid DEM are two commonly used terrain models. TIN can dynamically adjust storage terrain data according to terrain fluctuation and address the terrain characteristic curve appropriately to reproduce the actual terrain. The topological relation of GRID terrain data is simple and easy to store. However, data redundancy occurs because of the fixed and single topological relation of terrain data [7].

The irregularly spaced points of the TIN model can provide a more faithful representation of the terrain surface with more points in rugged terrain areas and fewer points in relatively flat areas. The TIN model suits visualization purposes because of the continuous nature that the triangular facets of the model add to the digital representation. Furthermore, not much information can be derived from TIN models because unlike the case for DEM's, a comprehensive analysis framework for triangulated models does not yet exist. In a TIN model, the sample points are simply connected by lines to form triangles, which are represented by planes, which give a continuous representation of the terrain surface. Creating a TIN, despite its simplicity, requires decisions about how to pick the sample points from the original data set, and further how to triangulate them. When it comes to triangulating the sample points, a few triangulation methods are available for producing a TIN. Among the existing triangulation methods that are in use, the Delaunay Triangulation (DT) is very common and popular for its rigorous structure although it produces triangles that are not hierarchical [8].

3. DELAUNAY TRIANGULATION

Delaunay triangulation, a triangular mesh that connects a set of points in a plane, was proposed by Boris Delaunay in 1934. Delaunay triangulation maximizes the minimum angle of the triangles in the triangular mesh; therefore, the skinny triangles can be avoided to produce a better visual effect. Delaunay triangulation has many applications such as 3D object modeling and scatter interpolation.

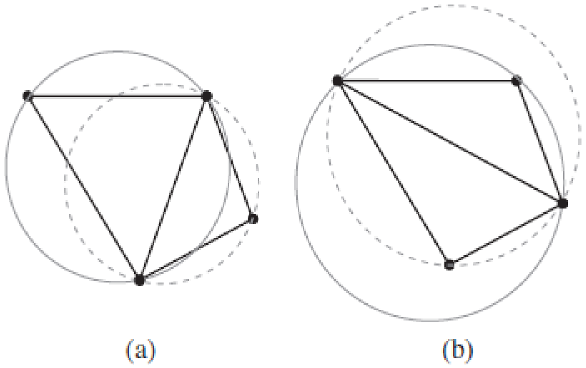

Fig. 1. Circumcircle property of Delaunay triangulation. (a) A Delaunay triangulation. (b) Not a Delaunay triangulation because a circumcircle contains more than three points [9].

Voronoi Diagram is a set of discrete points partitioning the plane into a set of polygon such that all points are nearest to any one site. Voronoi diagram is constructed by the lines of perpendicular bisectors which connect two neighbors. This diagram is approximate representation of nodes in the form of state in near distance or time.
Delaunay Triangulation is used to obtain the two nearest neighboring sites by taking shortest edge in triangulation. It is formed by partitioning a given site into triangles such that circumcircle of sites does not contain each other. Also, Delaunay Triangulation can be constructed by joining the nodes which share a common edge in the Voronoi diagram.

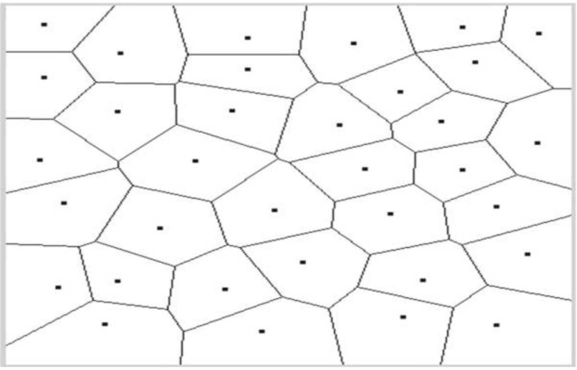

Fig. 2. Voronoi diagram [10].

4. INTERPOLATION METHODS

Data were analysed, interpolated and visualized with Surfer 8.00 [11]. Interpolation methods are briefly described in [12, 2, 13, 14, 15, 16].

5. VOLUME CALCULATIONS

In surfer, three methods are used to determine volumes: Trapezoidal Rule, Simpson's Rule, and Simpson's 3/8 Rule. Mathematically, the volume under a function $f(x, y)$ is defined by a double integral

$$V = \int_{X_{\min}}^{X_{\max}} \int_{Y_{\min}}^{Y_{\max}} f(x,y)dxdy \qquad (1)$$

In Surfer, this is computed by first integrating over X (the columns) to get the areas under the individual rows, and then integrating over Y (the rows) to get the final volume.
Surfer approximates the necessary one-dimensional integrals using three classical numerical integration algorithms: extended trapezoidal rule, extended Simpson's rule, and extended Simpson's 3/8 rule. In the following formula, Δx represents the grid column spacing, Δy represents the grid row spacing and H_{ij} represents the grid node value in row i and column j.
Extended Trapezoidal Rule;

$$A_i = \frac{\Delta x}{2}\left[H_{i,1} + 2H_{i,2} + 2H_{i,3} + ... + 2H_{i,ncol-1} + H_{i,ncol}\right] \qquad (2)$$

$$V \cong \frac{\Delta y}{2}\left[A_1 + 2A_2 + 2A_3 + ... + 2A_{ncol-1} + A_{ncol}\right] \qquad (3)$$

The pattern of the coefficients is {1,2,2,2,...,2,2,1}.

Extended Simpson's Rule;

$$A_i = \frac{\Delta x}{3}\left[H_{i,1} + 4H_{i,2} + 2H_{i,3} + 4H_{i,4} + ... + 2H_{i,ncol-1} + H_{i,ncol}\right] \tag{4}$$

$$V \cong \frac{\Delta y}{3}\left[A_1 + 4A_2 + 2A_3 + 4A_3 + ... + 2A_{ncol-1} + A_{ncol}\right] \tag{5}$$

The pattern of the coefficients is {1,4,2,4,2,4,2,...,4,2,1}.

Extended Simpson's 3/8 Rule;

$$A_i = \frac{3\Delta x}{8}\left[H_{i,1} + 3H_{i,2} + 3H_{i,3} + 2H_{i,4} + ... + 2H_{i,ncol-1} + H_{i,ncol}\right] \tag{6}$$

$$V \cong \frac{3\Delta y}{8}\left[A_1 + 3A_2 + 3A_3 + 2A_3 + ... + 2A_{ncol-1} + A_{ncol}\right] \tag{7}$$

The pattern of the coefficients is {1,3,3,2,3,3,2,...,3,3,2,1} [11, 17, 1].

6. MATERIALS AND METHODS

6.1. Study area

In practice, geodetic network with 1175 points, which was established in Konya, was used. x,y coordinates of these points were measured by GSP and the orthometric heights of which, were measured by levelling method. Minimum and maximum orthometric heights of these reference points were 1034.541 m and 1671.294 m, moreover, the topographical structure of the land was indicated in the form of three dimensional surfaces in Figure 3 and in the form of wireframe in Figure 4. The range in x and y directions of Gauss-Krüger projection system coordinates of these reference points were determined as Δx= 486.562 m and Δy=487.116 m.

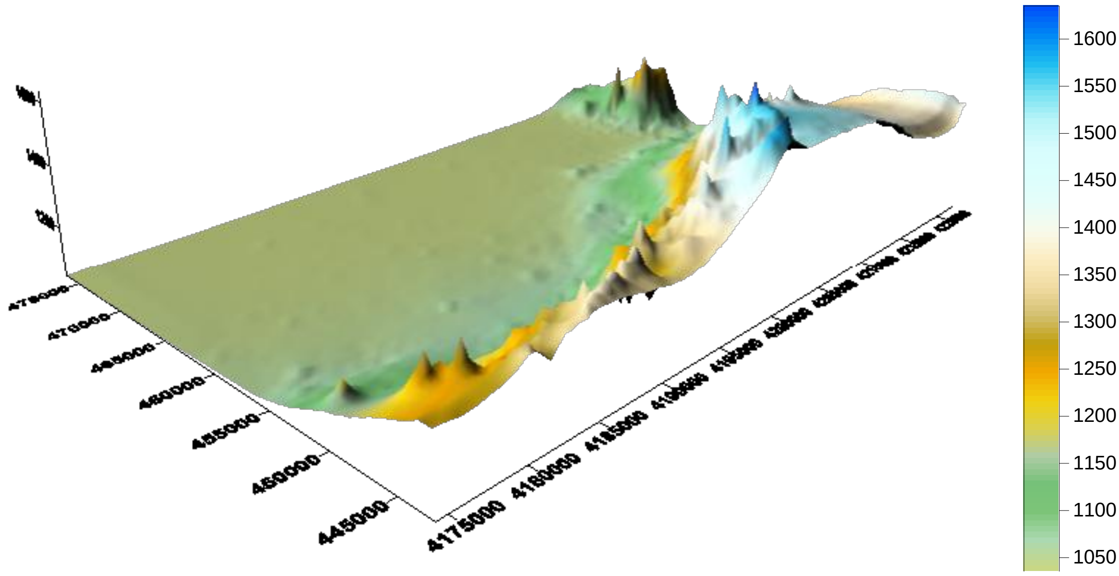

Fig. 3. Three-dimensional surface view of the study area

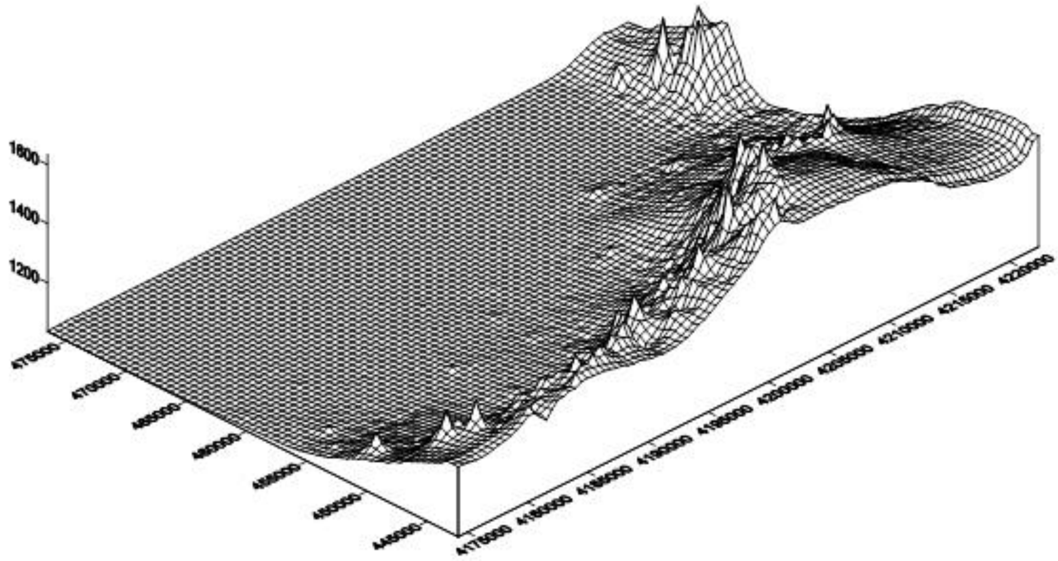

Fig. 4. Three-dimensional view of the study area by the wireframe method

6.2. Volume Calculations

The real volume of the land was calculated through NETCAD5.0 software package program [18]. Following the triangulation process covering the land had been performed through AP program, regarding the volume calculation made by using Delaunay triangles, since the volume was calculated directly by using the coordinates of the reference points without applying interpolation, the result was accepted as the value of the actual volume. Real volume was determined as 1436639831721.4 m^3.

Then, without making any change in the standard settings of the Surfer program;

- The grid ranges were selected as 50 m, 100 m, 150 m and 200 m.
- Interpolation methods: The surface modeling was carried out within the limits we specified using the interpolation methods including Inverse Distance to a Power (k=1 and k=2), Point Kriging, Minimum Curvature, Modified Shepard's Method, Natural Neighbor, Nearest Neighbor, Polynomial Regression (simple planar surface), Multiquadratic Radial Basis Function, Triangulation with Linear Interpolation

and *.grid extended files of these resulting surfaces were created. The volume values of these surfaces, which were resulted by making surface modeling, with respect to specific reference surface, Z=0, were calculated according to the rules given below :
Trapeze (Terminal areas method) Rule, Simpson's Rule, Simpson's 3/8 Rule
The results of the volumes calculated with different volume calculation methods depending on the different interpolation methods and grid ranges applied are given in Table 1, and the differences of these results from the actual volume and the calculated relative errors wıth respect to these differences are given in Table 2.
Relative Error is given by (8)

$$E_{relative} = \frac{V_{estimated} - V_{actual}}{V_{actual}} \tag{8}$$

where $E_{relative}$ is relative error; $V_{estimated}$ is estimated volume; V_{actual} is actual volume.

Table 1. The results of the volumes calculated with different volume calculation methods depending on the different interpolation methods and grid ranges

Interpolation methods	Grid ranges (m)	Volume calculation methods		
		Trapezoidal rule (m^3)	**Simpson's rule (m^3)**	**Simpson 's 3/8 rule (m^3)**
Inverse Distance to a Power (k=1)	50	1873063892573.60	1873053304065.40	1873064832869.50
	100	1873059712549.10	1873031819106.40	1873063854823.70
	150	1873047910977.70	1873044834373.50	1873038277428.80
	200	1873118855689.20	1873077533053.40	1873075626208.90
Inverse Distance to a Power (k=2)	50	1874988732022.50	1874983517357.80	1874989438476.00
	100	1874983336793.00	1874968392886.10	1874983630882.30
	150	1874979095000.20	1874975664864.80	1874975645025.50
	200	1875021088515.50	1875008182482.70	1875012230840.70
Kriging	50	1890669126848.40	1890664648539.00	1890669499593.70
	100	1890660938849.80	1890665785794.20	1890658667976.40
	150	1890663981903.90	1890651355131.90	1890660994133.80

	200	1890656510689.50	1890650019559.00	1890637786303.80
Minimum Curvature	50	1887255486394.60	1887252201199.40	1887252202665.40
	100	1883970464527.90	1883963925645.10	1883963896059.80
	150	1876261658283.20	1876254349189.40	1876255619304.20
	200	1880519658141.10	1880506202368.30	1880504208000.60
Modified Shepard's Method	50	1695389648358.00	1695414183124.80	1695397784210.80
	100	1695419879930.40	1695457080993.70	1695419061048.00
	150	1695394176404.30	1695271395651.00	1695503792596.10
	200	1695347759194.40	1695585380221.40	1695293885257.30
Natural Neighbor	50	1431232295188.70	1431264700544.10	1431270420902.90
	100	1426287826183.50	1426384070515.50	1426252849094.70
	150	1421137309559.90	1421355816146.20	1421183594979.40
	200	1416440820929.10	1416514253713.80	1416561413218.10
Nearest Neighbor	50	1882348910460.40	1882347606946.50	1882348121508.00
	100	1882364418326.70	1882348305723.30	1882389499454.90
	150	1882351613301.90	1882435927709.10	1882371998262.00
	200	1882398585456.00	1882361662497.80	1882364937768.50
Polynomial Regression	50	1848148187924.90	1848148187924.90	1848148187924.90
	100	1848148187924.90	1848148187924.90	1848148187924.90
	150	1848148187924.90	1848148187924.90	1848148187924.90
	200	1848148187924.90	1848148187924.90	1848148187924.90
Radial Basis Function	50	1895047179544.60	1895038765860.20	1895046695774.50
	100	1895051043047.00	1895058190116.80	1895046343354.30
	150	1895046555132.40	1895019253479.40	1895047703609.50
	200	1895036682491.70	1895031171674.10	1895007245275.10
Triangulation with Linear Interpolation	50	1436555123600.20	1436634127195.00	1436616258308.90
	100	1436336475464.00	1436560750795.30	1436491325418.90
	150	1436145696855.70	1436454584369.30	1436620300762.60
	200	1435565412824.90	1436354350787.70	1436015289880.00

Table 2. Differences between actual volume and volumes calculated with different volume calculation methods depending on the different interpolation methods and grid ranges, and the calculated relative errors wıth respect to these differences

Interpolation methods	**Grid ranges (m)**	**Trapezoidal rule**		**Simpson's rule**		**Simpson 's 3/8 rule**	
		Differences (m^3)	**Relative error**	**Differences (m^3)**	**Relative error**	**Differences (m^3)**	**Relative error**
Inverse Distance to a Power (k=1)	50	436424060852.20	0.304	436413472344.00	0.304	436425001148.10	0.304
	100	436419880827.70	0.304	436391987385.00	0.304	436424023102.30	0.304
	150	436408079256.30	0.304	436405002652.10	0.304	436398445707.40	0.304
	200	436479023967.80	0.304	436437701332.00	0.304	436435794487.50	0.304

Inverse Distance to a Power (k=2)	50	438348900301.10	0.305	438343685636.40	0.305	438349606754.60	0.305
	100	438343505071.60	0.305	438328561164.70	0.305	438343799160.90	0.305
	150	438339263278.80	0.305	438335833143.40	0.305	438335813304.10	0.305
	200	438381256794.10	0.305	438368350761.30	0.305	438372399119.30	0.305
Kriging	50	454029295127.00	0.316	454024816817.60	0.316	454029667872.30	0.316
	100	454021107128.40	0.316	454025954072.80	0.316	454018836255.00	0.316
	150	454024150182.50	0.316	454011523410.50	0.316	454021162412.40	0.316
	200	454016678968.10	0.316	454010187837.60	0.316	453997954582.40	0.316
Minimum Curvature	50	450615654673.20	0.314	450612369478.00	0.314	450612370944.00	0.314
	100	447330632806.50	0.311	447324093923.70	0.311	447324064338.40	0.311
	150	439621826561.80	0.306	439614517468.00	0.306	439615787582.80	0.306
	200	443879826419.70	0.309	443866370646.90	0.309	443864376279.20	0.309
Modified Shepard's Method	50	258749816636.60	0.180	258774351403.40	0.180	258757952489.40	0.180
	100	258780048209.00	0.180	258817249272.30	0.180	258779229326.60	0.180
	150	258754344682.90	0.180	258631563929.60	0.180	258863960874.70	0.180
	200	258707927473.00	0.180	258945548500.00	0.180	258654053535.90	0.180
Natural Neighbor	50	-5407536532.70	-0.004	-5375131177.30	-0.004	-5369410818.50	-0.004
	100	-10352005537.90	-0.007	-10255761205.90	-0.007	-10386982626.70	-0.007
	150	-15502522161.50	-0.011	-15284015575.20	-0.011	-15456236742.00	-0.011
	200	-20199010792.30	-0.014	-20125578007.60	-0.014	-20078418503.30	-0.014
Nearest Neighbor	50	445709078739.00	0.310	445707775225.10	0.310	445708289786.60	0.310
	100	445724586605.30	0.310	445708474001.90	0.310	445749667733.50	0.310
	150	445711781580.50	0.310	445796095987.70	0.310	445732166540.60	0.310
	200	445758753734.60	0.310	445721830776.40	0.310	445725106047.10	0.310
Polynomial Regression	50	411508356203.50	0.286	411508356203.50	0.286	411508356203.50	0.286
	100	411508356203.50	0.286	411508356203.50	0.286	411508356203.50	0.286
	150	411508356203.50	0.286	411508356203.50	0.286	411508356203.50	0.286
	200	411508356203.50	0.286	411508356203.50	0.286	411508356203.50	0.286
Radial Basis Function	50	458407347823.20	0.319	458398934138.80	0.319	458406864053.10	0.319
	100	458411211325.60	0.319	458418358395.40	0.319	458406511632.90	0.319
	150	458406723411.00	0.319	458379421758.00	0.319	458407871888.10	0.319
	200	458396850770.30	0.319	458391339952.70	0.319	458367413553.70	0.319
Triangulation with Linear Interpolation	50	-84708121.20	0.000	-5704526.40	0.000	-23573412.50	0.000
	100	-303356257.40	0.000	-79080926.10	0.000	-148506302.50	0.000
	150	-494134865.70	0.000	-185247352.10	0.000	-19530958.80	0.000
	200	-1074418896.50	-0.001	-285480933.70	0.000	-624541841.40	0.000

Relative errors regarding the differences between actual volume value and volume values obtained with different volume calculation methods according to the different interpolation methods and grid spacing are shown in Fig. 5, Fig. 6, Fig. 7 and Fig. 8 with bar graphs.

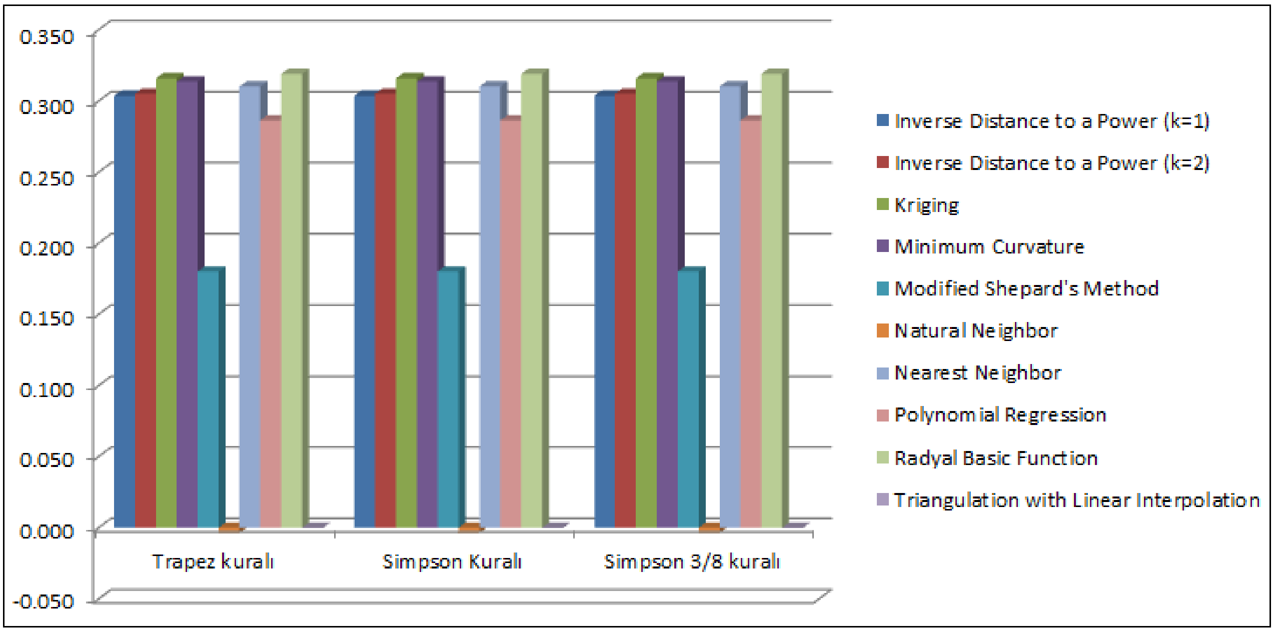

Fig. 5. Variation of relative errors according to 50 m grid range

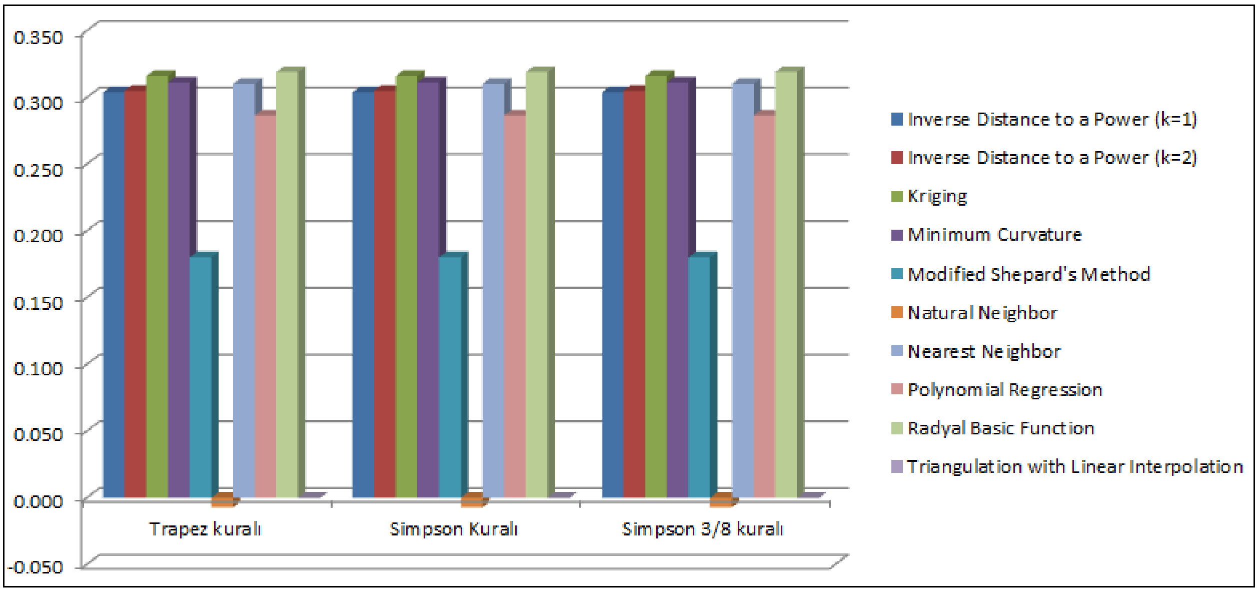

Fig. 6. Variation of relative errors according to 100 m grid range

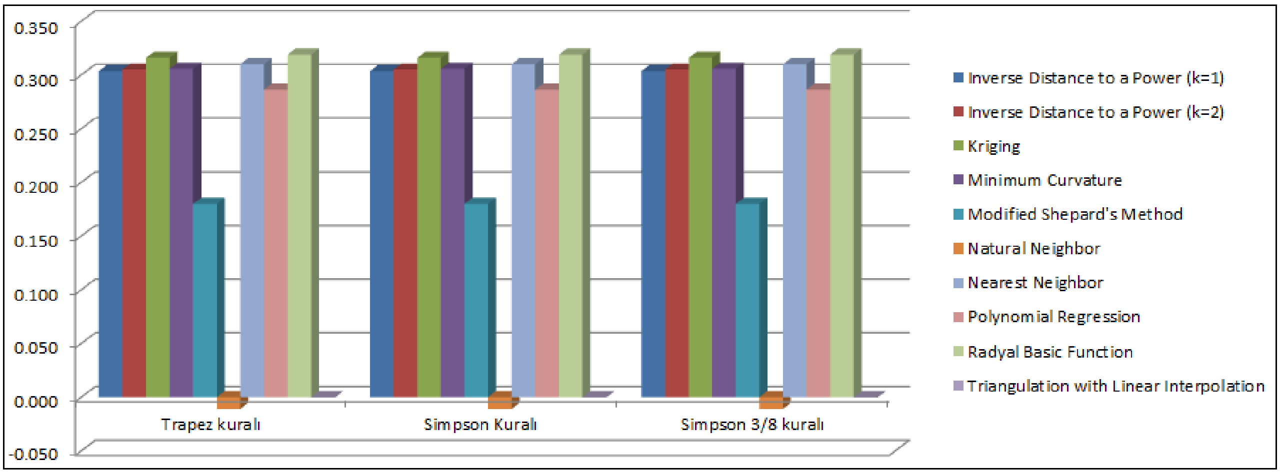

Fig.7. Variation of relative errors according to 150 m grid range

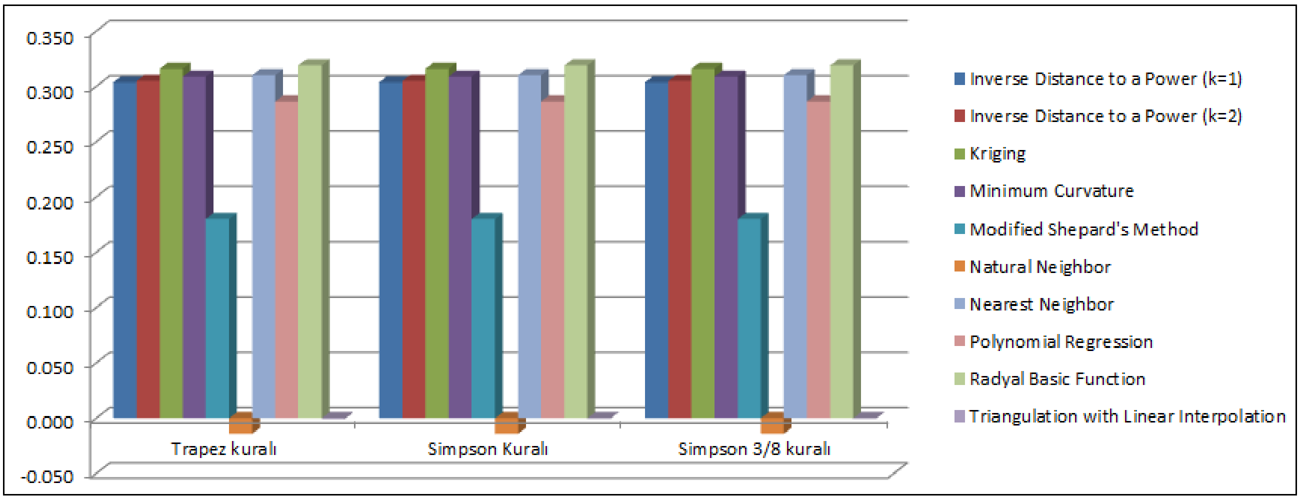

Fig. 8. Variation of relative errors according to 200 m grid range

7. CONCLUSIONS

The volume calculations were made through Surfer8 program. The effects of the parameters such as, grid range, interpolation methods, volume calculation methods on the volume calculation was investigated in the study. Moreover, the discussions made taking into account the amount of relative errors are as follows:

- When the relative errors examined (see Table 2, Figure 5-6-7-8), it was seen that the most appropriate interpolation model was triangulation with linear. When the relative errors calculated with other interpolation methods examined, it was seen that the most appropriate interpolation models were respectively, from smaller to larger, Natural Neighbor, Modified Shepard's Method, Polynomial Regression, Inverse Distance to a Power (k=1), Inverse Distance to a Power (k=2), Nearest Neighbor, Kriging, Radial Basis Function.
- It was seen in the interpolation methods used including minimum curvature, natural neighbor that the relative errors changed depending on the different grid ranges. In other methods, the change in grid ranges didn’t affect the relative error.
- Changing the volume calculation methods didn’t affect the relative error. The amount of relative error wasn’t changed with changing the method of volume calculation.

REFERENCES

[1] Fawzy, H.E. (2015) The Accuracy of Determining the Volumes Using Close Range Photogrammetry. IOSR Journal of Mechanical and Civil Engineering 2015; 12, Issue 2 Ver. VII, PP 10-15, DOI: 10.9790/1684-12271015.

[2] Chaplot, V., Darboux, F., Bourennane, H., Leguédois, S., Silvera, N. and Phachomphon, K. (2006) Accuracy of Interpolation Techniques for the Derivation of Digital Elevation Models in Relation to Landform Types and Data Density. Geomorphology, **77**, 126–141, DOI:10.1016/j.geomorph.2005.12.010.

[3] Bandara, K.R.M.U., Samarakoon, L., Shrestha, R.P. and Kamiya, Y. (2011) Automated Generation of Digital Terrain Model Using Point Clouds of Digital Surface Model in Forest Area. Remote Sensing, 3, 845-858, DOI:10.3390/rs3050845.

[4] Heritage, G.L., Milan, D.J., Large, A.R.G. and Fuller, I.C. (2009) Influence of Survey Strategy and Interpolation Model on DEM Quality. Geomorphology, 112, 334–344, DOI:10.1016/j.geomorph.2009.06.024.

[5] El-Ashmawy, K.L.A. (2015) A Comparison between Analytical Aerial Photogrammetry, Laser Scanning, Total Station and Global Positioning System Surveys for Generation of Digital Terrain Model. Geocarto International, 30, No. 2, 154–162, http://dx.doi.org/10.1080/10106049.2014.883438.

[6] Schwendel, A.C., Fuller, I.C. and Death, R.G. (2012) Assessing Dem Interpolation Methods For Effective Representation of Upland Stream Morphology for Rapid Appraisal of Bed Stability. River Research And Applications, 28, 567–584, DOI: 10.1002/rra.1475.

[7] Zhang, T., Xu, X. and Xu, S. (2015) Method of Establishing an Underwater Digital Elevation Terrain Based on Kriging Interpolation. Measurement, 63, 287–298, http://dx.doi.org/10.1016/j.measurement.2014.12.0250263-2241.

[8] Ali, T. and Mehrabian, A. (2009) A Novel Computational Paradigm for Creating a Triangular Irregular Network (TIN) from LiDAR Data. Nonlinear Analysis, 71, 624-629, DOI:10.1016/j.na.2008.11.081.

[9] Hong, W., Chen, T.S. and Chen, J. (2015) Reversible Data Hiding Using Delaunay Triangulation and Selective Embedment. Information Sciences, 308, 140–154, http://dx.doi.org/10.1016/j.ins.2014.03.030.
[10] Sangwan, A. and Singh, R.P. (2015) Survey on Coverage Problems in Wireless Sensor Networks. Wireless Pers Commun, 80, 1475–1500, DOI 10.1007/s11277-014-2094-3.
[11] Surfer 8 software handbook, (2006).
[12] Yanalak, M. (2003) Effect of Gridding Method on Digital Terrain Model Profile Data Based on Scattered Data. Journal of Computing in Civil Engineering, 17, No. 1, DOI: 10.1061/(ASCE)0887-3801(2003)17:1(58).
[13] Bogusz, J., Kłos, A., Grzempowski, P. and Kontny, B. (2014) Modelling the Velocity Field in a Regular Grid in the Area of Poland on the Basis of the Velocities of European Permanent Stations. Pure and Appied Geophysics, **171,** 809–833, DOI 10.1007/s00024-013-0645-2.
[14] Yilmaz, H.M. (2007) The Effect of Interpolation Methods in Surface Definition: An Experimental Study. Earth Surface Processes and Landforms, 32, 1346–1361, DOI: 10.1002/esp.1473.
[15]Yang, C.S., Kao, S.P., Lee, F.B. and Hung, P.S. (2004) Twelve Different Interpolation Methods: A Case Study of Surfer 8.0. International Society for Photogrammetry and Remote Sensing (ISPRS), Volume XXXV, Part B2, Pages 778-785, Istanbul.
[16] Vohat, P., Gupta, V., Bordoloi, T.K., Naswa, H., Singh, G. and Singh, M. (2013) Analysis of Different Interpolation Methods for Uphole Data Using Surfer Software. 10th Biennial International Conference & Exposition, Society of Petroleum Geophysicists, India.
[17] Yakar, M. and Yilmaz, H.M. (2008) Using in Volume Computing of Digital Close Range Photogrammetry. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXVII. Part B3b. Beijing 2008.
[18] NETCAD5.0 Software, (1989) NETCAD YAZILIM A.Ş.: NETCAD 5.0 GIS for WINDOWS, http://www.netcad.com.

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