Local geoid modeling in Azerbaijan using ANN ،ANFIS Methods

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Receive Date: 28 December 2024 Revise Date: 15 January 2025 Accept Date: 27 February 2025

Abstract
In order to measure the height in mapping engineering topics, we need to define the height base level or geoid. In fact, the geoid is one of the earth's equipotential surfaces, which best approximates the mean sea level (MSL) based on the least squares method. The separation between the planar base surface (elliptical) and the geoid is called the height of the geoid (N). By having this quantity, orthometric height (Ho) and normal height (h) can be converted to each other. There are different methods to determine the height of the geoid. In this thesis, the efficiency of machine learning models to determine geoid height locally and using GPS/Leveling measurements is evaluated. In order to do this, the geodetic coordinates of 26 stations of the northwestern network of Iran, whose orthometric height was also measured by the first level alignment by the National Mapping Organization (NCC), were used. In these stations, the orthometric height difference from normal height (h) is considered as geoid height (N). Therefore, the input of ANN, ANFIS models is the geodetic latitude and longitude coordinates of the stations and the corresponding output is the geoid height. The models have been trained using 22 and 19 stations. In other words, the number of training stations is variable in order to provide a more detailed analysis of the accuracy of the models. For a more accurate evaluation, the results are compared with the geoid from the IRG2016 model produced by the country's mapping organization. The evaluations show that in the case of 22 training stations and 4 test stations, the RMSE of ANN, ANFIS models in the test phase are 32.37, 19.83, 34.49, 53.82, respectively. It has become 29.65 cm. However, in the case of 19 training stations and 7 test stations, the error values of the models are equal to 36.63, 58.31, 39.64, 41.29 and 24.68 cm, respectively. Comparison of RMSE shows that ANN model with less number of training stations provides higher accuracy than ANFIS models. The results of this paper show that using ANN and ANFIS models, geoid height can be locally estimated and used with high accuracy.
Keywords: Geoid, ANN, ANFIS

1- Introduction

One of the most basic observations in surveying engineering is the measurement of the quantity of height (absolute - relative). To measure absolute height, a datum (baseline) is needed. This baseline must be defined based on the physical characteristics of the earth. Because surveying measurements are made on the physical surface of the earth. In colloquial terms, the level of the open sea is considered as the elevation base level. However, this level has many fluctuations and loses its application on land. GPS/GNSS satellite positioning systems measure the height of points relative to an ellipsoid. However, in many surveying projects where height and slope are important, height from an ellipsoid is not useful because it is a mathematical surface and is not suitable for large projects where height and slope are important. The correct solution to this problem is to define a physical surface that has the closest shape to the earth. This physical surface is the geoid. The geoid is the elevation reference surface and the elevation of different points is measured relative to it. Therefore, the need for an accurate model for the geoid is clearly felt (Ardalan; 2002).

Various methods have been used to model the geoid and determine it accurately. These methods include: geometric method of determining the geoid, determining the geoid by satellite method, gravity methods of determining the geoid and determining the geoid using GPS/leveling.

2- Research Method

Investigation of the ANFIS network training method

The ANFIS network is an adaptable and trainable network that is completely similar in performance to the fuzzy inference system. For simplicity, we assume that our fuzzy system has two inputs x and y and its output is z, now if the rules are as follows:

(1-2)

$$IF \quad x = A_1 \quad AND \quad y = B_1, \quad Then \quad f_1 = p_1 x + q_1 y + r_1$$

(2-2)

$$IF \quad x = A_2 \quad AND \quad y = B_2, \quad Then \quad f_2 = p_2 x + q_2 y + r_2$$

And if we use the mean center defuzzifier for defuzzification, the output will be as follows:

(3-2)

$$f = \frac{w_1 f_1 + w_2 f_2}{w_1 + w_2} = \overline{w_1} f_1 + \overline{w_2} f_2$$

$$\overline{w_1} = \frac{w_1}{w_1 + w_2} \quad , \quad \overline{w_2} = \frac{w_2}{w_1 + w_2}$$

The equivalent structure of ANFIS will be as shown in Figure (3-6). This structure has five layers, the tasks of each of which are explained below:

•Layer 1: In this layer, the inputs pass through the membership functions.

(4-2)

$$O_{1,i} = \mu A_i(x), \qquad for \quad i = 1,2$$

$$O_{1,i} = \mu B_i(x), \qquad for \quad i = 3,4$$

The membership functions can be any suitable parametric function, and in most cases, Gaussian functions are chosen. For example, the bell function of the general form:

(2-5)

$$\mu A(x) = \frac{1}{1 + \left|\frac{x - c_i}{a_i}\right|^{2b_i}}$$

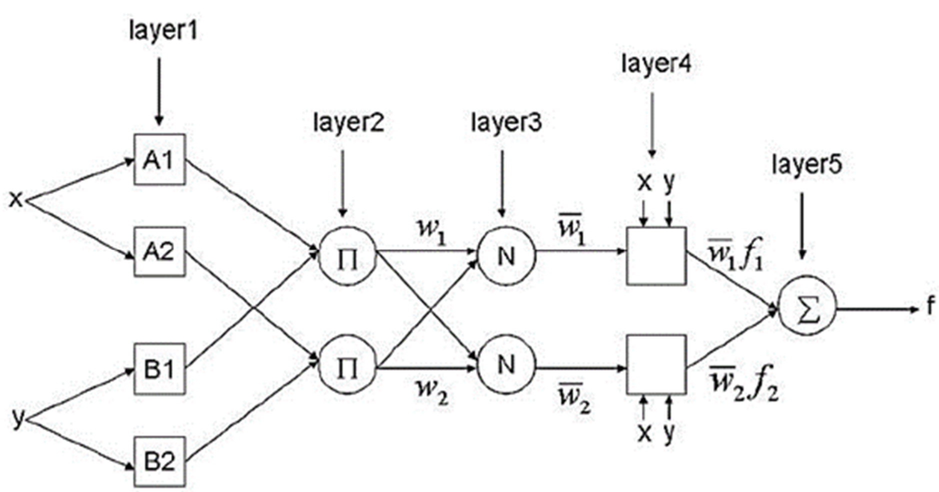


Figure 2-1: ANFIS network structure (Kiamehr et al., 2007).

Now a network has been generated which is equivalent to a fuzzy inference system. Now the network needs to be trained. To do this, first all the existing rules are formed in the first layer. For example, if there are 2 inputs in the network, each with 3 membership functions, 9 rules need to be formed.

3- Numerical Results

First, the study area and the observations used are described, and then the statistical analyses performed in the training and testing stages are described. Interpretation of the results and display of spatial changes of the local geoid will be at the end of the section.

-1-3Study area and observations used

Given the availability of a complete set of GPS station observations along with orthometric heights obtained from first-degree leveling in the northwest region of Iran, the study and evaluation of the proposed models of the article have been carried out in this area (Mars; 1996). Observations of 26 GPS stations of the northwest network of Iran have been provided by the National Surveying Organization (https://www.ncc.gov.ir/). Two modes have been considered for training and testing the ANN, ANFIS, SVR and GRNN models. In the first mode, the number of training stations is 22 and the number of test stations is 4. However, in the second mode, by increasing the number of test stations to 7 stations, the error evaluation of the models has been carried out. In other words, in the second scenario, the number of stations used for training is reduced to allow for a more accurate assessment of the error of the machine learning models. It should be noted that the distribution of training and testing stations is completely random (Zaletnyik; 2007). Also, observations from testing stations are discarded during the training phase. Figures (3-1) and (3-2) show the distribution of stations used in this thesis.

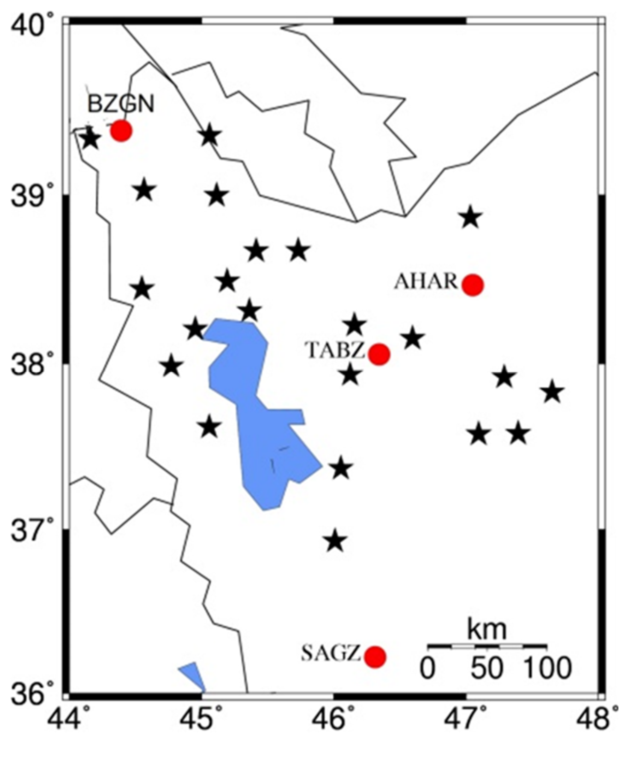


Figure 3-1: How the training stations (black stars) and control stations (red circles) are distributed in the case of 22 training stations and 4 test stations.

Given that the test station information will be used in both scenarios, Table (4-1) presents the geodetic coordinates and orthometric heights of the test stations in the first case.

Table 3-1: Coordinate information of the test stations used in the first case of evaluating machine learning models.

Station Abbreviation	Latitude (deg)	Longitude (deg)	Geodetic Height)m(	Orthometric Height (m)	Geoid Height (m)
TABZ	38/05	46/34	1512/53	1495/597	16/933
BZGN	39/37	44/39	1434/69	1411/695	22/995
SAGZ	36/22	46/31	1538/95	1523/289	15/661
AHAR	38/46	47/04	1360/32	1344/496	15/824

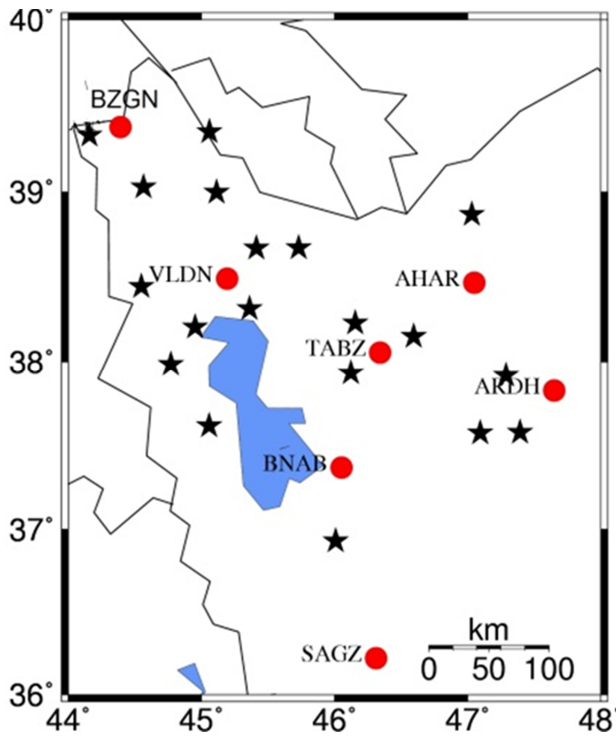


Figure 3-2: How the training stations (black stars) and control stations (red circles) are distributed in the case of 19 training stations and 7 test stations.

Table (3-2) shows the geodetic coordinates and orthometric heights of the test stations in the second case.

Table 3-2: Coordinate information of the test stations used in the second mode of evaluating machine learning models.

Station Abbreviation	Latitude (deg)	Longitude (deg)	Geodetic Height (m)	Orthometric Height (m)	Geoid Height (m)
TABZ	38/05	46/34	1512/53	1495/597	16/933
BZGN	39/37	44/39	1434/69	1411/695	22/995
SAGZ	36/22	46/31	1538/95	1523/289	15/661
AHAR	38/46	47/04	1360/32	1344/496	15/824
VLDN	38/49	45/19	1307/195	1287/209	19/986
ARDH	37/82	47/65	1774/951	1760/90	14/051
BNAB	37/36	46/05	1302/910	1285/799	17/111

The altitude of all the stations used varies from 1280 to 1952 meters. Also, to overcome the multipath error, a choke ring antenna with an elevation angle of 15 degrees has been used in these stations. Figure (3-3) shows the three normal, orthometric and geoid altitudes for all the stations used in this study.

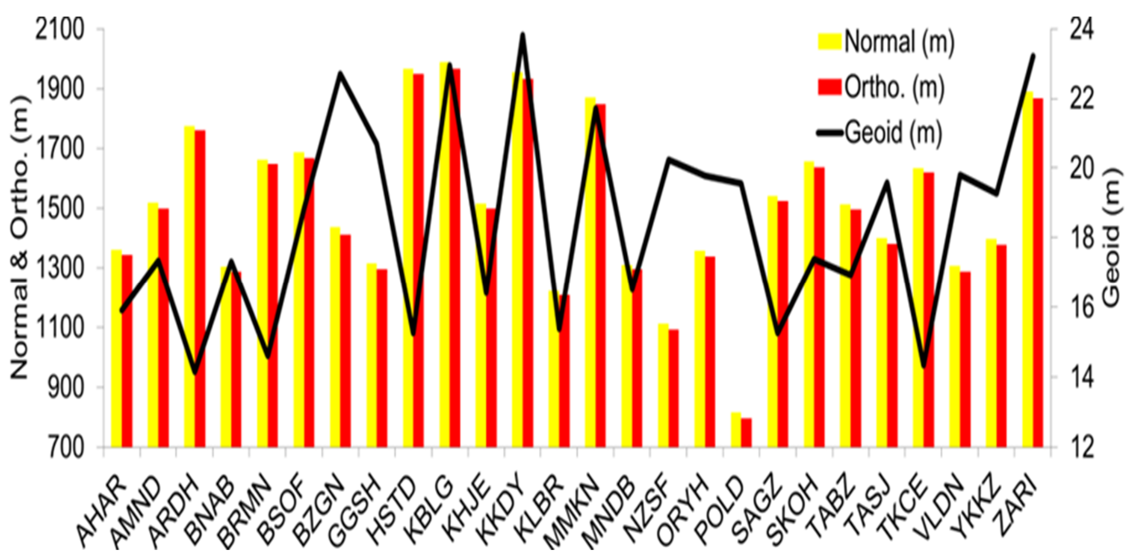


Figure 3-3: How normal height (yellow columns), orthometric height (red columns), and geoid height (black curve) change at all stations used in this study.

It should be noted that the accuracy of orthometric and normal heights is 8.55 and 34.28 mm, respectively. Therefore, considering that the geoid height is the result of the difference between the normal height and the orthometric height, as a result, according to the law of propagation of errors, the geoid height resulting from this difference has an error of about 34.35 mm (3.53 cm) (Najafi; 2007). Normal height is a geometric quantity and is measured relative to the WGS84 datum. Therefore, if the datum does not change and the existing benchmarks in the area do not change in terms of height, this height will be constant over time. The same applies to orthometric height, which is a physical quantity and is measured relative to the physical datum, the geoid. If the datum is fixed and the stations do not move over time, then the orthometric height of a point will also be constant. Assuming that the above two heights are constant over time, the geoid height of all stations in this article is calculated from the difference between these two heights (orthometric and normal). The obtained geoid height is, in fact, the main reference for comparisons at the test stations.

-2-3Results of the training stage of ANN, ANFIS models

The goal of the training stage in machine learning models is to determine the optimal model and network structure so that the model has the minimum error. Table (3-3) shows the values of these two parameters in the training stage.

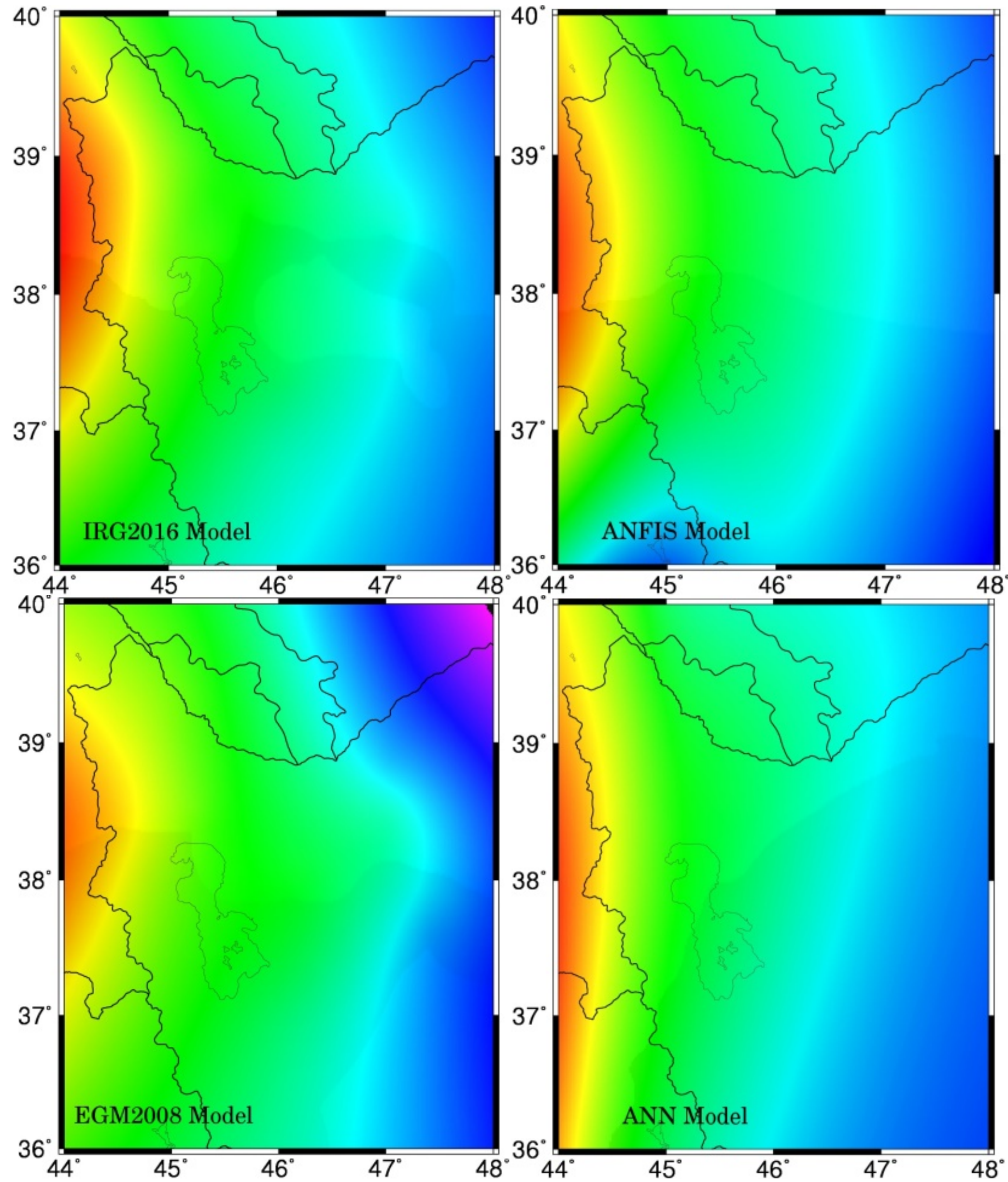
Table 3-3: Comparison of RMSE error values (centimeters) and correlation coefficient of ANN, ANFIS models in the training stage and two different states of the stations.

Correlation Coefficient		RMSE Error (centimeters)		
ANFIS	ANN	ANFIS	ANN	
0/98	0/97	8/38	30/17	First mode (22 training stations)
0/97	0/97	15/94	23/77	Second mode (19 training stations)

Based on the results of Table (3-3), in both the first and second cases, the error of the ANFIS model in the training stage is less than the error of other models. This model is a combination of two ANN and FIS models and includes the structural features of both. As a result, training in this model is performed with higher accuracy than other models.

3-4 Estimation of geoid height in the study area

After the training and testing stage of the ANN and ANFIS models and the accuracy of all models is determined, the geoid height value can now be estimated within the studied network. In the machine learning models examined in this article, the geoid height is estimated by providing the length and width of any arbitrary geodetic point within the desired network. Figure (3-6) shows the geoid height values estimated within the studied network using the desired models. In this figure, and in order to compare how the geoid height changes, the output of the EGM2008 global geoid model is also displayed. It should be noted that these results were obtained by modeling the first case, i.e., a larger number of training statio


40°
39°
38°
37°
36°
44°
45°
46°
47°
48°
IRG2016 Model
ANFIS Model
EGM2008 Model
ANN Model

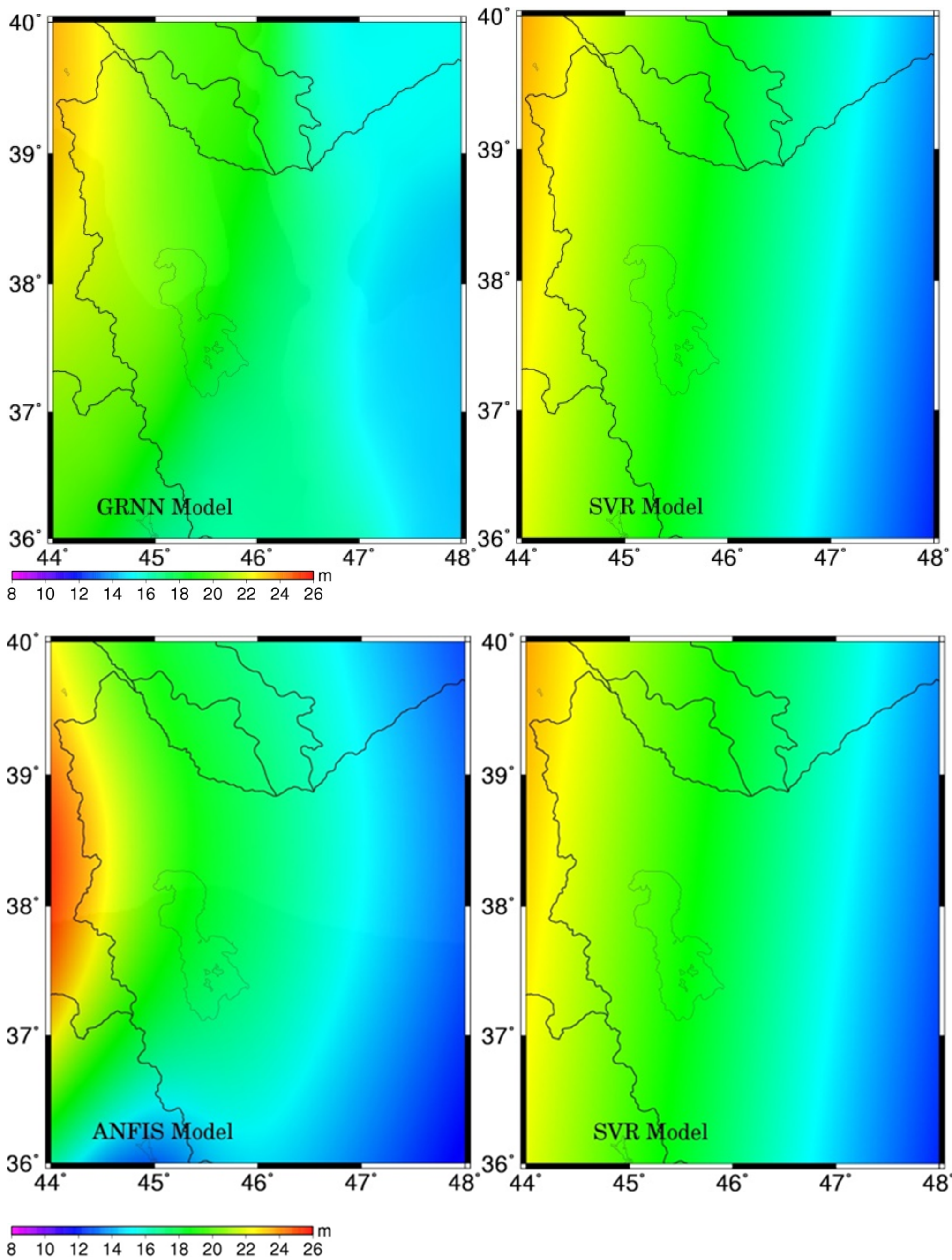


Fig3-6. How the geoid height changes estimated by ANFIS and ANN models in the network area studied in this article.

According to the results of Figure (3-6) and the output of the IRG2016 and EGM2008 models, in the study area, the geoid height changes the most in the latitude of 37 to 40 and longitude of 44 to 45 degrees (Kavzoglu; 2005). As the distance from the mentioned range increases, the geoid height decreases. Comparing the results of the ANFIS and ANN models with the output of the IRG2016 and EGM2008 models shows that these two machine learning models show the geoid height changes with high accuracy in terms of quantity and quality. However, the output of the two SVR and GRNN models is somewhat different from the IRG2016 and EGM2008 models in terms of numerical value. Therefore, the result of Figure (3-6) shows that ANFIS and ANN models have high accuracy in estimating local geoid height and can replace global and local models.

By having local geoid height using machine learning models and also normal height obtained from satellite timing systems, orthometric height can be obtained in the study area without performing leveling operations. Of course, it should be noted that this method can be used for low-precision works and in precise civil engineering and surveying works, the best method for determining orthometric height is still using leveling.

4- Conclusion

The statistical evaluations showed that in the case of 22 training stations and 4 testing stations, the RMSE of the ANN and ANFIS models in the testing phase are 37.32, 19.83, 34.49, 53.82, 23.57 and 29.65 cm, respectively. However, in the case of 19 training stations and 7 testing stations, the error values of the models are 36.63, 31.58, 39.64, 29.41, 12.56 and 24.68 cm, respectively. In other words, as the number of training stations decreases, the error of the machine learning models increases. The results of this thesis showed that, with a sufficient number of training stations, ANFIS and ANN models have high accuracy in estimating the local geoid and can replace global models such as EGM2008. These models can also be used in civil engineering and surveying.

Reference

[1] Ardalan, A.A., Hatam, C.Y., Sharifi, M.A., Safari, A., Gazavi, K., Motagh M., (2002). Determination of Precise geoid for Iran based on Potential approach. Technical report, National Cartographic Center of Iran (NCC), Tehran, Iran.

[2] Kiamehr, R., (2006). Precise Gravimetric Geoid Model for Iran Based on GRACE and SRTM Data and the Least-Squares Modification of Stokes' Formula: with Some Geodynamic Interpretations. PhD Thesis. Royal Institute of Technology, Stockholm, Sweden.

[3] Kavzoglu, T., Saka, M. (2005). Modeling local GPS/leveling geoid undulations using artificial neural networks. J Geodesy **78**, 520–527, doi.org/10.1007/s00190-004-0420-3.

[4] Mars, P., J.R. Chen, R. Nambiar (1996). Learning Algorithms: Theory and Applications in Signal Processing, Control and Communications, CRC Press, Boca Raton, Florida.

[5] Najafi M., (2004). Determination of Precise Geoid for Iran Based on Stokes-Helmert Scheme. Report 2003. TOTAK Project, National Cartographic Center of Iran (NCC), Tehran, Iran.

[6] Zaletnyik, P., Völgyesi, L., Paláncz, B., (2007). Modeling local GPS/leveling geoid undulations using Support Vector Machines. Civil Engineering 52/1 (2008) 39–43, doi: 10.3311/pp.ci.2008-1.06.