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# COMPUTATION OF THE HEIGHT REFERENCE SURFACE FOR THE TERRITORY OF THE REPUBLIC OF ALBANIA

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**ABSTRACT:** The purpose of this paper is to determine a high-precision the Republic of Albania geoid model in order to convert the ellipsoidal heights into orthometric heights. The Digital Finite-Element Height Reference Surface method was used to solve this problem. The following models were chosen as the Republic of Albania global geopotential models: EGM96, EGG97 and EGM2008. Calculations of mentioned models were performed for 151 points of the Republic of Albania territory using the Digital Finite-Element Height Reference Surface method to determine the height reference surface. The minimum, maximum, mean values, standard deviation and mean quadratic error of the models in question were identified. The results showed that EGM96 had a standard deviation of 8 cm, EGG97 had a standard deviation of 4.8 cm and EGM2008 had a standard deviation of 4.2 cm as the best model. Thus, it was proved that EGM2008 has topographic distribution and fits well in the extension of the territory of the Republic of Albania.

*Keywords: Geodesy, Geoid model, GNSS, DFHRS method, Levelling.*

## 1. INTRODUCTION

Geoid is a fundamental concept in geodesy. It is an equipotential surface that coincides with the mean sea level and extends beneath continents. Based on the geoid definition, more accurate geopotential models are developed. These mathematical functions approximating the Earth gravitational field in 3D space can be considered as a benchmark for geodesy itself [1]. They provide the ability to calculate orthometric heights and elevation changes in conjunction with Global Navigation Satellite System (GNSS) positioning [2-4].

There are various studies devoted to the definition of the geoid. Işık et al. conducted an experiment on the Colorado geoid to clarify the recurrence of values of the gravitational potential using ground and airborne gravity data [5]. The result was a highly accurate model of the Colorado geoid. Lin and Li applied a tesseroidal modeling method to study this area [6]. Researchers proved that the application of this method has an insignificant influence on increasing the accuracy of the geoid.

Abdulrahman investigated geoid models based on orthometric heights using Global Positioning System (GPS)/leveling [7]. Two gravity models of the Earth of the Duhok region, Iraq, were obtained. Varbla et al. developed a model that can be applied in oceanographic studies [8]. A GNSS model was also used to estimate sea surface heights to bridge the gap between tide gauges and altimetric measurements in the coastal zone.

Sakil et al. used a modification of the Stokes and Hotin formulas by the least-squares method using gravity data with and without gridding over the Auvergne region, France [9]. The results obtained were more accurate than in the traditional method of using gravity data with georeferencing. Abbak et al. used the least squares method for modeling the geoid of a specified area [10]. The developed tool proved to be highly effective in modeling the gravimetric geoid.

Mentioned above publications do not consider the calculation of the Republic of Albania geoid model. Thus, the purpose of this article is to develop a high-precision geoid model of the territory of Albania.

## 2. RESEARCH SIGNIFICANCE

The research described in the paper is significant because it provides a high-precision geoid model for the Republic of Albania. This has practical applications in a range of fields, including construction, surveying, and mapping. The identification of the minimum, maximum, mean values, standard deviation, and mean quadratic errors of the models adds to the reliability and validity of the findings.

## 3. MATERIALS AND METHODS

For the calculation of the Republic of Albania territory geoid model, the method Digital Finite-Element Height Reference Surface (DFHRS) was used (Fig. 1). The method is based on the following principle: observed surface divides into regions and regular point grids. Each region has a datum and is related to the conversion parameters – d. Each regular grid has the HRS parameters – p, that are stored in the DFHRS software database. In this approach, the possibility of continuity is considered, where the NFEM point on the boundary between two regular networks must be dependent on them (C0-continuity) and the entire area (C1-continuity), the slope must be represented at the boundary of regular networks. The boundary variables for the DFHRS method in the Republic of Albania are geographic extent; topographic data (the terrain elevation and slope); geoid model (EGM96, EGG97 and EGM2008); control points; coordinate system (Universal Transverse Mercator (UTM).

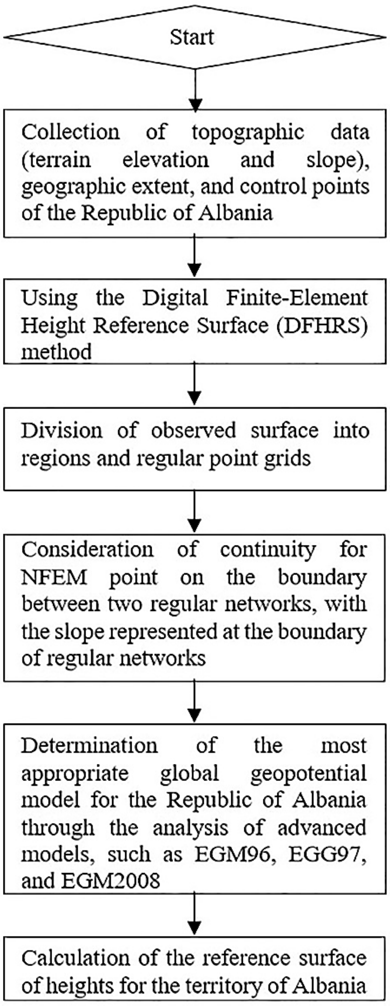


Fig. 1. A research flowchart

Representation of the polynomial NFEM can be written as design matrix f and vector parameters $p$ by Eq. (1) [11]:

$$N_{FEM}(p|\ x, y) = f(x, y)^T p^i \tag{1}$$

The use of geocentric coordinates. NFEM is written as following Eq. (2) [11]:

$$\mathbf{N}_{FEM}(\boldsymbol{\phi}, \boldsymbol{\lambda}|\mathbf{p}) = \mathbf{N}_{FEM}(\mathbf{X}(\boldsymbol{\varphi}, \boldsymbol{\lambda}), \mathbf{Y}(\boldsymbol{\varphi}, \boldsymbol{\lambda})|\mathbf{p}) \tag{2}$$

Regarding bivariate polynomials by Eq. (3) [5]:

$$\mathbf{N}_{FEM}(\boldsymbol{\varphi}, \boldsymbol{\lambda}|\mathbf{p}) = \sum_{i=o'}^{\infty} \sum_{i=o'}^{\infty} \mathbf{ai, j\ xiyj} = \mathbf{f(x, y)T\ .\ p} \tag{3}$$

Geoid altitude from global geopotential models can be expressed as follows at Eq. (4) [11]:

$$N_{GPM}^{i} + \mathbf{v} = \mathbf{f\ (x, y)\ T.\,p} + \mathbf{\partial NG\ (d\ j)} \tag{4}$$

151 points of the territory of the Republic of Albania are included, which have three-dimensional (3D) coordinates obtained by GPS in ETRF2000. Altitude is determined by accurate levelling (Fig. 2).

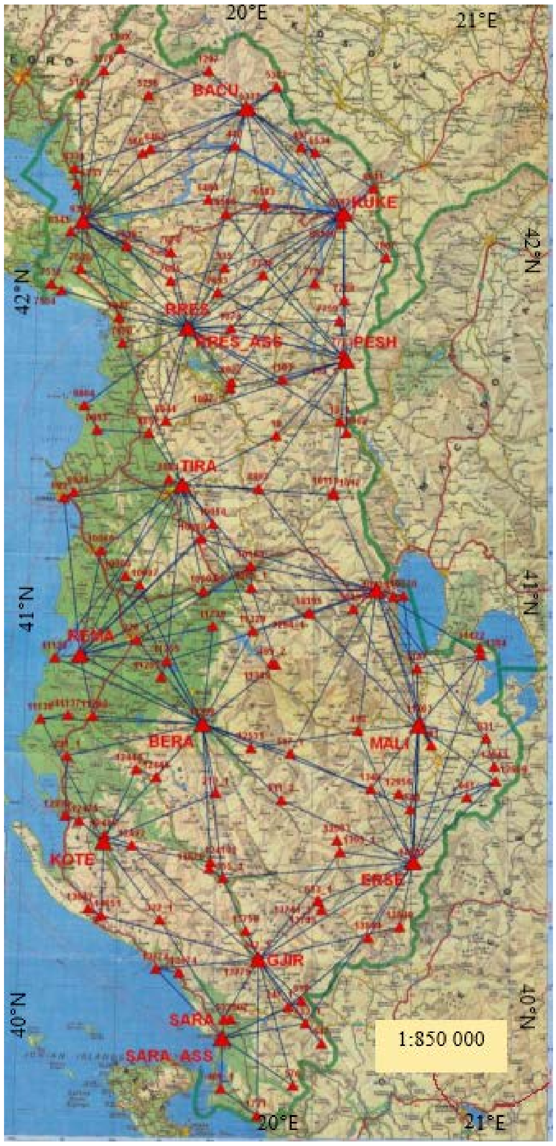


Fig. 2. Static network RGN [12, 13]

Based on the fact that global models have been developed to a large extent and are increasingly accurate, they have found wide use in solving and determining the geoid of a country [4]. Advanced models make it possible to determine the geoid height of any point on the Earth's surface, an accuracy varies between 30 cm to several meters [14]. There has also been increased interest in accurately determining the local/regional geoid in order to replace levelling measurements by GPS receivers. Models EGM96, EGG97 and EGM2008 were used in the study to calculate the reference heights. The use of these models is due to several factors:

1. Accuracy: these global geopotential models provide a more accurate representation of the Earth's gravitational field and its variations than previous models.
2. Consistency: by using a global geopotential model, Albania can ensure that its height reference surface is consistent with other countries and regions that use the same model.
3. Accessibility: global geopotential models are widely available and supported by a range of software tools and applications.
4. Future-proofing: the use of modern global geopotential models such as EGM2008 ensures that Albania's geodetic system is up-to-date and future-proofed against changes in technology and scientific understanding.

## 4. RESULTS

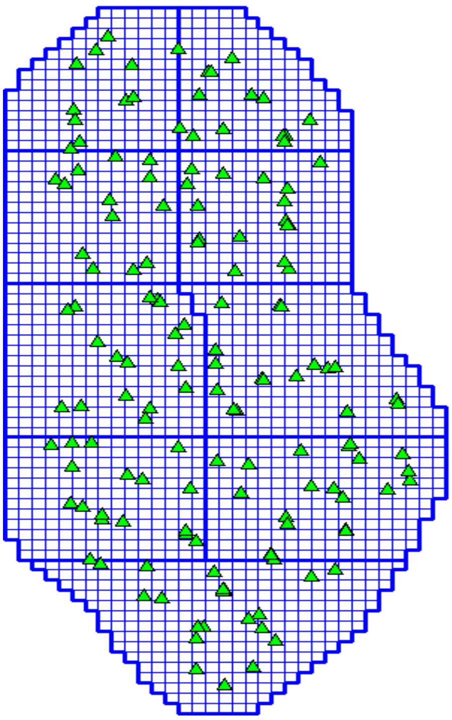

Fig. 3. Presentation of 151 observations divided into regular 5km×5km meshes and creation of 9 groups/patches [4]

The whole of Albania's territory was divided into regular meshes sized 5km×5km as well as for the deviation of possible systematic errors. In continuation, these meshes were grouped in 9 patches, which were used to exclude long and medium wave components in different areas. The 151 GPS meshes observations have been computed for the calculation of the geoid model for Albania and levelling grid as normal height targets. These observations have 3D coordinates determined by GPS in ETRF2000, with the height determined by accurate levelling (Fig. 3).

Region/Groups criteria were set by the geoid model calculation software itself [15]. The first condition, according to the DFHRS method for achieving the accuracy of 1-3 cm of the calculation of the geoid model for a certain territory, is that the mash size should be divided into 5km×5km. The second condition is the placement of 3-5 observations within a region/group. The third condition is the distance between the points to be 20-30 km. After calculating the data with DFHRS software and after processing this data authors computed the standard deviation and the mean quadratic error. A quantity for indicating the deviation degree for a whole group is expressed by standard deviation as Eq. (5) [16]:

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i-\bar{x})^2} \quad (5)$$

The mean quadratic error is calculated as follows at Eq. (6) [16]:

$$\boldsymbol{RMS} = \sqrt{\frac{\sum_i x_i^2}{\boldsymbol{n-1}}} \quad (6)$$

The first model, which was used for calculation in order to determine the Republic of Albania territory geoid model is the global geopotential model EGM96. 151 selected observations were used. These observations have 3D coordinates determined by GPS in ETRF2000, the height is determined by accurate leveling. The standard deviation for the EGM96 model is 0.079 m (Fig. 4). The global geopotential model EGG97 was used to calculate the second geoid model. The standard deviation is 0.048 m (Fig. 5). Through the DFHRS method, the EGM2008 model was used as the third model. A total of 151 selected observations belonged to the GPS network and the leveling network. These observations also have 3D coordinates determined by GPS in ETRF2000; the height is determined by accurate leveling. The standard deviation is 0.042 m (Fig. 6).

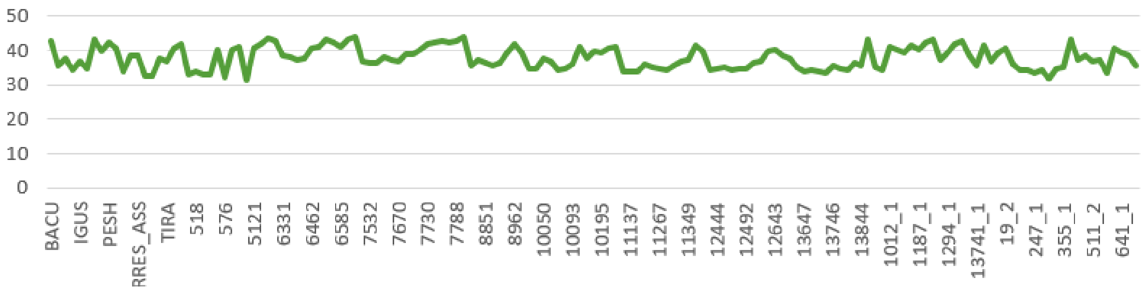


Fig. 4. Represent calculation of N-EGM96 geoid heights.

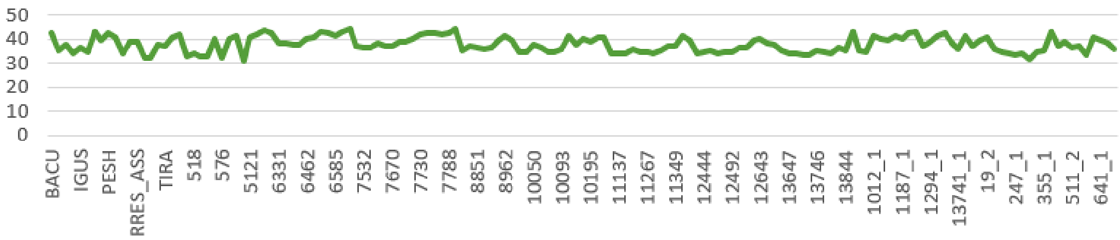


Fig. 5. Represent calculation of N-EGG97 geoid heights.

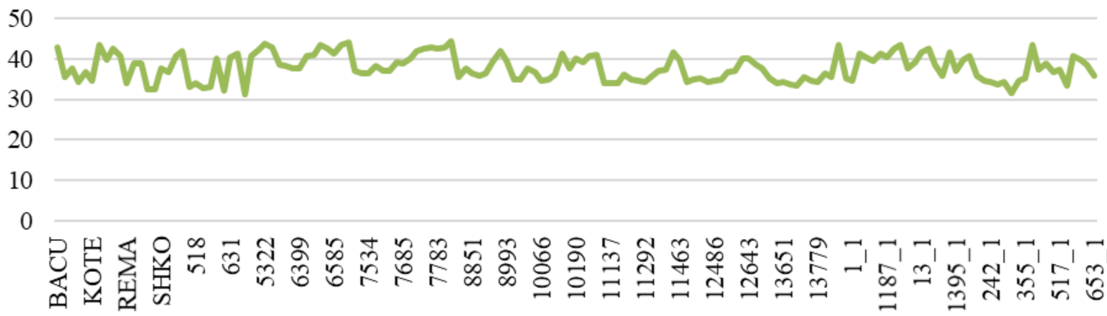


Fig. 6. Represent calculation of N-EGM2008 geoid heights.

The map for the EGM96, EGG97 and EGM2008 models were compiled and shown in the Figs. 7-9. The reference surface of the Albania heights-geoid model was determined by using the DFHRS method. Starting from the GPM EGM96 [17], calculated from 151 observations, max. degree is 360 and the standard deviation is 8cm, then for the GPM EGG97 [18] max. degree is 10×15 with a standard deviation of 4.8 cm, to continue with the GPM EGM2008 [19], which max. degree is 2190 and is calculated with standard deviation 4.2 cm. The authors decided to compare the differentiations of the EGG97 and EGM2008 models, since the standard deviation of the EGM96 exceeds the expected accuracy (Fig. 10, Tables 1, 2).

The EGM2008 model has a relatively low mean quadratic error and standard deviation compared to the other two models, suggesting that it provides a more accurate and consistent representation of the Earth's gravitational field and its variations. The main way to assess the accuracy of the geoid model in this study was to compare its geoid waviness with GPS and leveling data. The final selection of the reference relief surface–geoid model is then required, on the basis of the models' minimum and maximum values, to select the most appropriate model for the surface/area under study.

The minimum and maximum of the EGM2008 model: -1.2 cm and 1.3 cm, respectively. The below Fig. 11 are presented the comparison between the two models based on the DFHRS method. The following results were obtained: the minimum value is: -1.3cm, and the maximum is 1.3cm.

## 5. DISCUSSION

Taking into consideration that technology has recently advanced a lot and some of the traditional methods are no longer used due to the time required for measurements and data processing [4]. Today, satellite gravity models are regularly used for providing long-wavelength gravity field information for regional geoid modeling, as well as airborne and ground-based gravity data contribute to the gravity field medium-wavelength and short-wavelength. The principal task of geoid modeling is the properly combined satellite gravity model, that includes ground gravity data and airborne gravity data.

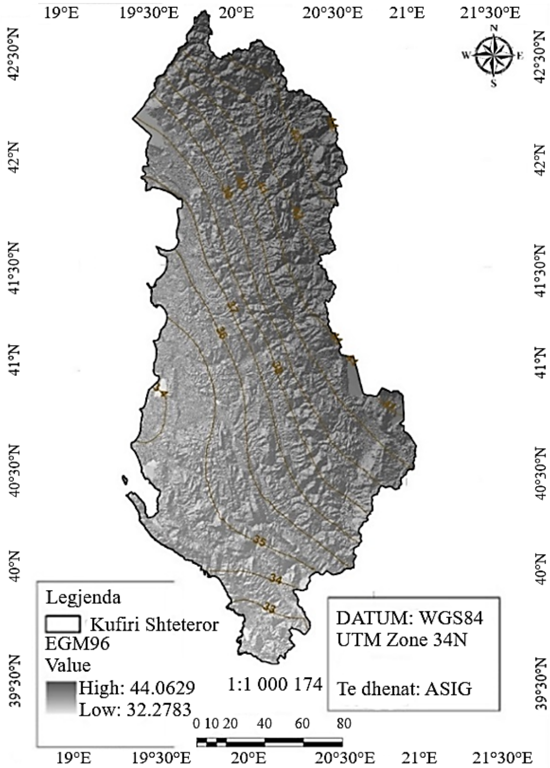


Fig. 7. Construction of the map with data from the calculation of global geopotential model EGM96

The Republic of Albania ground gravimetric measurements were performed in 2015 and 3 such points were measured in Tirana, Saranda and Shkodër. This amount of data is insufficient for the determination of the geoid model [4]. Considering the lack of terrestrial and aerial gravimetric data or insufficient data, as the only alternative was to use the global geopotential models to calculate the Albania elevation reference surface using GPS/leveling data. Between GNSS measurements and global geopotential models, it is possible to determine a fairly accurate geoid model for a given territory. But also taking into account the trends and developments that occur both in the region and beyond, there is a constant demand to follow in their footsteps [20]. Following the recent developments in the region and Europe that have progressed in the development of the geoid model using global geopotential models as a good possibility of determining the reference surface of heights in order to convert ellipsoid heights determined by GPS in orthometric heights, which refer to the elevation reference surface and that with acceptable accuracy [4].

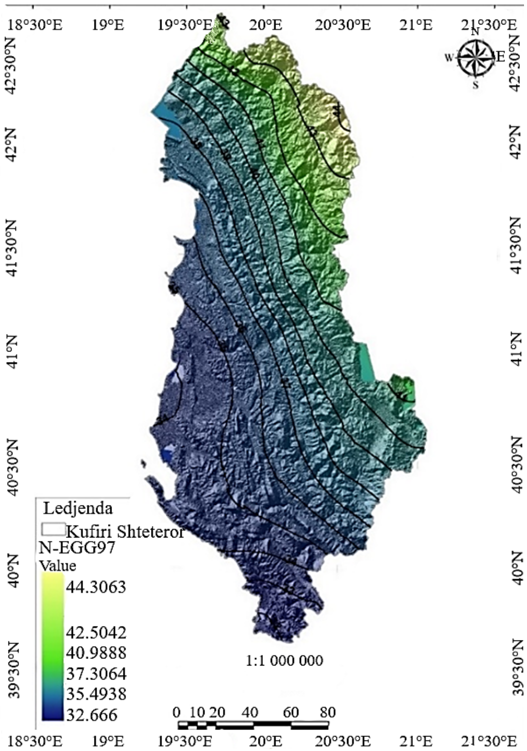


Fig. 8. Construction of the map with data from the calculation of global geopotential model EGG97

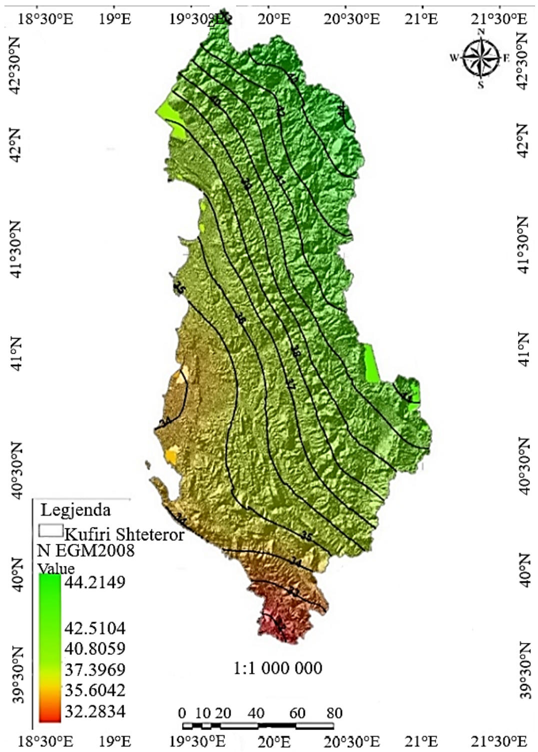


Fig. 9. Construction of the map with data from the calculation of global geopotential model EGM2008.

Table 2 Minimum and maximum values, mean, standard deviation and mean quadratic error for the 3 global geopotential models of the Republic of Albania territory for 151 points

| GGModels | Min (m) | Max (m) | Mean quadratic error (m) | Mean (m) | STD (m) |
|---|---|---|---|---|---|
| EGM96 | -0.202 | 0.160 | 0.080 | 0.000 | 0.080 |
| EGG97 | -0.133 | 0.132 | 0.048 | 0.000 | 0.048 |
| EGM2008 | -0.118 | 0.136 | 0.042 | 0.000 | 0.042 |

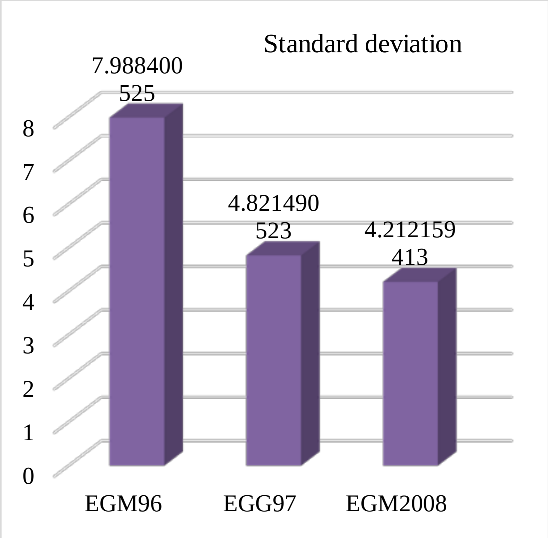


Fig. 10. Shows the differences in the calculation of geoid heights for 3 global geopotential models, EGM96, EGG97, and EGM2008

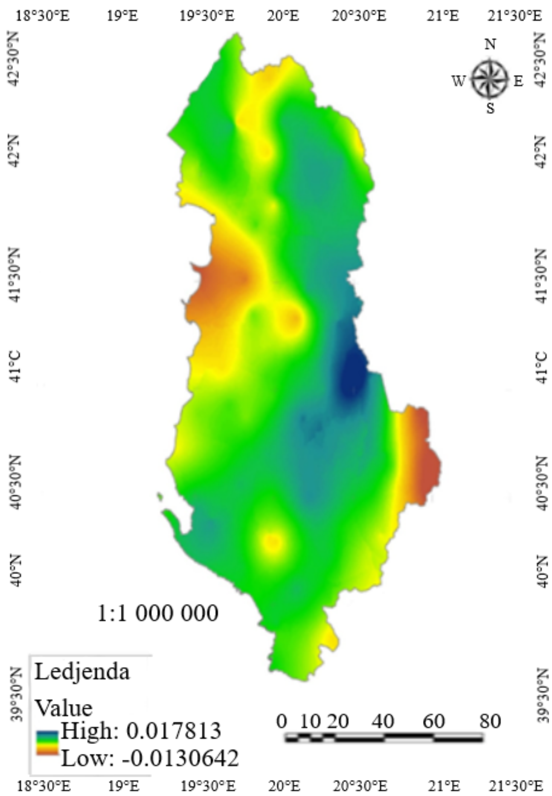


Fig. 11. Differences between EGG97 and EGM2008 models

There are various studies on GNSS measurements. Soycan et al. evaluated geoid models for altitude conversion at different geographic locations in Turkey based on GNSS/leveling data [21]. The differences between observed and computed values were investigated. The TG03 and EGM2008 models were found to be about 2 times less accurate than the precise local geoid models. Alcaras et al. created a geoid model of the island of Corsica, France, which includes 81 rows and 40 columns, has a grid spacing of 1.5 in latitude and 2 in longitude, covering an area of about 24,767 km$^2$ [22]. It was found that ordinary kriging gives more accurate results than universal kriging, but the discrepancies between two models are minimal when there is high number of points.

The application of GPS/Levelling data and machine learning for modelling the exact geoid of Kuwait is discussed in Kaloop et al. [23]. Minimax Probability Machine Regression, Gaussian Process Regression and Multivariate Adaptive Regression Splines MLs have been developed to carry out calculations. The results show that the use of machine learning techniques significantly improves the accuracy of the geoid model compared to standard methods. The model predicted the accurate height of the geoid with a maximum deviation of ±0.02 m. The geoid models EGM96 and EGM2008 were also used in Hamza et al. [24].

The geoid of the Greater Tunisia region was computed by computing the correction applied to the two global models by least squares and kriging methods. It was found that the use of the improved EGM2008 global geoid model and kriging correction improves the accuracy of the results. The mean square deviation was 12 cm.

To determine the hybrid geoid model, Malaysia et al. used two approaches [25]. The first approach is based on the use of GNSS-levelling data and a conventional method for fitting the gravimetric geoid to the geometric waviness. The second approach directly fits the gravimetric geoid to the mean sea level reference; tide gauge data were obtained from the Port Klang tide gauge station. Three gravity data sources were used: terrestrial, airborne, and satellite altimetry-derived gravity anomaly [26]. The developed model PMGG2020 is based on a modification of the Stokes formula by an additive-corrected least-squares method. An accuracy of ±4.6 cm was achieved, which confirms the effectiveness of the development.

One potential difference between this study and previous ones is the use of the digital finite element reference surface (DFHRS) method. After all, this study was focused precisely on the use of DFHRS to determine the most suitable geoid model for the Republic of Albania. Another potential difference is the specific global geopotential models EGM96, EGG97 and EGM2008 to determine the most appropriate geoid model for the Republic of Albania.

## 6. CONCLUSION

The main tasks of geodesy are to define the geoid model so that users can get complete, accurate, and updated data in real-time. Many different methods for determining the geoid model have been proposed over the years; each method uses its own technique and content. The common goal of all proposed methods is to determine a geoid model with high accuracy. The computation was performed by applying the DFHRS method, which was developed by the Faculty of Geomatics, University of Applied Sciences of Karlsruhe to determine the most suitable geoid model for the territory of the Republic of Albania. The data that were used to perform the research analysis were provided by institutions such as the State Authority for Geospatial Information and the Faculty of Civil Engineering within this study. In this research, the geoid model was calculated by using the DFHRS method with the aim of converting the ellipsoid heights determined by GPS into orthometric heights.

The reference surface of the heights for Albania was calculated with a standard deviation of 4.2 cm using the EGM2008 model in the framework of the DFHRS method, which gave the best accuracy compared to the other two models used. It has been proven that the EGM2008 geoid model has the best accuracy at every stage of the calculation, and at the same time, it fits well with the topographic extent of the Republic of Albania territory. This model is more modern and accurate since its Mean quadratic error is 2-4 cm. Based on the findings of this research, it is recommended that further studies should be conducted to determine the geoid model for other regions or countries using the DFHRS method. The study can be expanded to include more geodetic data points to improve the accuracy of the calculations.

## 7. ACKNOWLEDGMENTS

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