MULTIBAND RASTER DATASETS IN ORDER TO USE GLOBAL GRAVIMETRIC MODELS FOR THE TERRITORY OF THE REPUBLIC OF KOSOVA

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SUMMARY

Due to current situation in Kosova with the national geoid, which is still under development, utilization of global EGM's is more than necessary. In this research, multiband raster datasets with 1km spatial resolution of existing EGM 2008, 1996, and 1984 have been developed. Maximal and minimal differences between the models, range of extreme values of geoid heights in three geoid models, mean heights and other data calculations, are given in this paper.
Calculation have been performed with online geoid calculator GeoidEval, in grid of 10893 points. Based on developed multiband raster model dataset and calculated differences between the models, three maps for the territory of Kosova were compiled. Main purpose of performed research analyses and developed GIS datasets for geoid heights, is free and open for usage by the geo community in Kosova, till the establishing of state gravimetrical network and model.

Key words: EGM, geoid, multiband raster, geoid undulation, earth gravitation, geoid height, Kosova.

INTRODUCTION

A precise local geoid model constitutes one of the most challenging research subjects of geodesy, particularly since 1980s. Geoid modelling deal with the determination of geoid undulations between the geodetic heights obtained from the Global Navigation Satellite Systems (GNSS) techniques and the orthometric heights, or levels, relative to the Mean Sea Level (MSL). Thus, geoid models are crucial for the utilization of GNSS (particularly the Global Positioning System: GPS) in civil engineering projects (Al-Krargy etAll

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2015). Recent advances in GNSS techniques make it possible to measure ellipsoidal heights with an accuracy of a few centimeters. Therefore, if a well-established geoid model is available, orthometric heights can be derived precisely by GNSS positioning, and accordingly a reference height system can be established via the geoid model (Matsuo and Kuroishi 2020).

The basis of the theory of gravity field stands in the definition that a body on the Earth's surface experiences Earth's gravitational force as well as centrifugal force due to the rotation of the Earth, and this is what we call gravity (Bajrami Lubishtani and Idrizi 2020). In geodesy three basic surfaces are encountered: the physical surface of the earth, the geoid and the reference ellipsoid. In relation to these three surfaces another three entities are defined: the orthometric height (h), the ellipsoidal height (H) and the geoidal separation/undulation (N) (Das etAll, 2017). All geodetic measured quantities from the physical surface of the Earth are reduced to the geoid and to the surface of adopted reference ellipsoid through applying corrections on the measured values, as well as into the map projection (Idrizi et All 2018). There are a number of mathematical models to relate the geoidal separation N with corresponding locations in order to define the geoid surface. Such models include simple polynomials, radial basis functions, multilayer perception neural network methods etc (Cakir and Yilmaz, 2014). Though classical geoid determination is restricted to regional computations using the astro-geodetic techniques (Drews and Adam 2019), by grace of the enhancement of space geodesy techniques, are mainly used to determine the figure of the geoid globally and regionally as well in recent decades. The true geoid is not directly observable and estimating it may vary as current knowledge improves. Hence, there may be many models of the geoid surface and, consequently, many geoid height models (Roman et All 2010). The new gravity satellite missions provide new global solutions that allow modeling the long and medium wavelengths of the Earth's gravitational field (Soycan 2014). There are global geoid models such as EGM 84, EGM 96 and EGM 08 which supports the conversion of ellipsoidal heights to orthometric heights with accuracies varying between few centimeters to even a meter.

After establishment of the Kosovo geodetic datum in 2001, the 1st order network has been exaggerated with additional 450 points covering whole territory of Kosovo with an approximate distance of 10 to 15km between neighbor points (Kohli 2003). Currently, these points are serving as height reference surface, however their deviation in some areas exceed ±50 cm and need to be considered (Ameti, Jaeger 2016). Until now, there is no official state geoid model for the area of the Republic of Kosova developed by the Kosova Cadastral Agency as national responsible institution. A model developed for the Kosova area was calculated by Ameti and Jaeger in year 2016 at the Karlsruhe University in Germany, which unfortunately still is not in official use by the state institutions in Kosova. Aimed to offer three alternative models for the area of the Republic of Kosova, three national models based on three global models (EGM 84, 96 and 08) have been developed within research study performed by this paper authors in collaboration between three institutions: Geo-SEE Institute from Skopje (based on the previous experience for developing three models for North Macedonian territory in year 2013 (Idrizi 2013)), geodesy department of the University of Prishtina (where first and second authors are employed) and geodesy department of the Polytechnic University of Tirana (where the first author is finalizing her PhD thesis on developing of Albanian geoid model). This database in national level has to be developed, and it has to be open and free for usage by geo community (Idrizi 2014). Part of calculations for geoid heights based on EGM for the territory of Kosova have been performed on year 2018 within the research study of length differences from topography to map projection within the state coordinate systems for some countries on the Balkan Peninsula (Idrizi etAll 2018).

EARTH GRAVITATIONAL MODELS (EGM)

The Earth Gravitational Models (EGMs) are geopotential models of the Earth consisting of spherical harmonic coefficients, developed and published by the Office of Geomatics at National Geospatial-Intelligence Agency (NGA) [2], as responsible for collecting, processing, and evaluating gravity data (free-air and Bouguer gravity anomalies) as well as computing gravimetric quantities such as mean gravity anomalies, geoid heights, deflections of the vertical, and gravity disturbances [1]. EGM96 from 1996 is used as the geoid reference of the World Geodetic System [2]. Three versions of EGM are published: EGM84 with n=m=180, EGM96 with n=m=360, and EGM2008 with n=m=2160. “n” and “m” are the degree and orders of harmonic coefficients; the higher they are, the more parameters the models have, and the more precise they are. EGM2008 also contains expansions to n=2190 [1]. Developmental versions of EGMs are referred to as PGMs, Preliminary Gravitational Models (Pavlis etAll 2012).
EGM84 geoid (code 5203) is a vertical datum first defined in 1984, with its geoid origin in WGS 84 ellipsoid. EGM84 geoid is a vertical datum for Geodesy, defined by information from US National Geospatial-Intelligence Agency [4]. Data of EGM84 today have historical importance, without practical utilization (Idrizi 2013). Differences between geoid heights of EGM 84 with two newest models EGM 96 and EGM08 are used in our research just for comparing with two newest models of years 1996 and 2008, and not as a model that can be used at the present time.

EGM96 (code 5773) is a geopotential model of the Earth consisting of spherical harmonic coefficients complete to degree and order 360. It is a composite solution, consisting of a combination solution to degree and order 70, a block diagonal solution from degree 71 to 359, and the quadrature solution at degree 360. It is a result of collaboration between the National Imagery and Mapping Agency (NIMA), the NASA Goddard Space Flight Center (GSFC), and Ohio State University [3]. This gravitational model is complete to spherical harmonic degree and order 2159, and contains additional coefficients extending to degree 2190 and order 2159.

EGM2008 (code 3859) is complete to spherical harmonic degree and order 2159, and contains additional coefficients extending to degree 2190 and order 2159. Computing the geoid undulation values are realized with respect to WGS 84 ellipsoid [1]. Over areas covered with high quality gravity data, the discrepancy between EGM 2008 geoid undulations and independent GPS/levelling data is of the order of ±5 to ±10 cm (Nikolaos et al., 2012). The EGM2008 model gives stable result for the root-mean-square-error (RMSE) of the residuals in terms of relative geoid heights accuracy (Kim, Yun and Choi 2020).

The International Center for Global Earth Models (ICGEM) continuously analyzes the performance of every new released GGM model over several GPS/Levelling check points worldwide. Table 1 presents the statistics of evaluation of the selected seven GGM models in terms of the Root Mean Square error (RMS) of the undulation differences. It can be seen that the overall accuracy of EGM2008 over the entire 12036 check points indicates that it is the most precise GGM (Al-Krargy etAll 2015).

Table 1. RMS of Differences of GGM-Based Geoid Undulations over GPS/Levelling Check Points (m)

Test area	**USA**	**Canada**	**Europe**	**Australia**	**Japan**	**Brazil**	**All**
No. of check points	6169	2691	1047	201	816	1112	12036
EGM08	0.248	0.128	0.125	0.217	0.083	0.460	0.240
EGM96	0.379	0.353	0.493	0.298	0.364	0.730	0.427

Source: http://icgem.gfz-potsdam.de/ICGEM/ICGEM.html

Three global gravitational models are open for download and utilization through the official web page of NGA [1], as well as from many other web pages. One of the WEB GIS based free product via internet is the geoportal of surveying.org web page, where can be found very wide range of special spatial data, such as weather, NGS (national geodetic survey), USGS maps, geoid heights, magnetic declination, state plan systems, UTM zones etc (Idrizi 2013).

SOURCE DATA AND BASIC TEST MODEL

Since the possibility for usage of official data by responsible institution for geospatial information is very limited, as source data have been used test model developed for analyses of length differences between topography and geoid as well as between geoid and referent ellipsoid, with 10893 points with Cartesian/geographic coordinates in the state coordinate system in ground resolution of 1km shown in figure 1 (Idrizi etAll 2018), while for elevation dataset the ASTER global DEM [6] with 30m spatial resolution have been used.

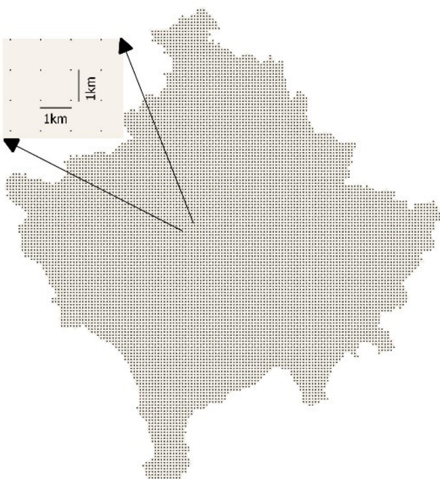


Figure 1. Dataset for test model with 10893 points

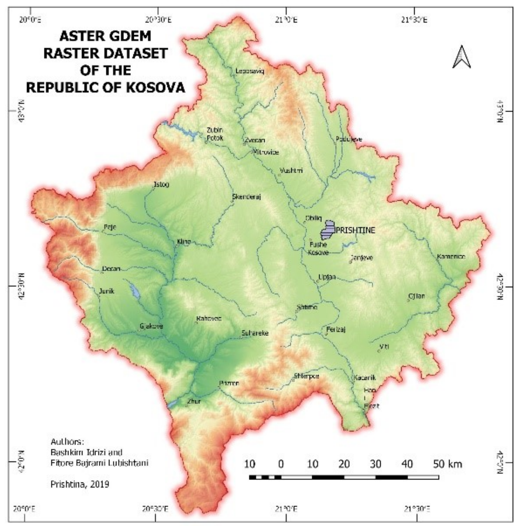


Figure 2. Relief of Kosova based on ASTER GDEM

Aimed to calculate empirical values for three geoid models and differences between them (steps 9, figure 3), as output for each of 10893 points should be calculated:

- Maximal values,
- Minimal values,
- Differences between maximal and minimal values,
- Mean values, and
- Standard deviations.

DEVELOPING EGM MODELS 2008, 1996 AND 1984 FOR THE KOSOVA's TERRITORY

Three EGM models (2008, 1996 and 1984) for the national area of the Republic of Kosova are developed as separate point vector datasets with 1km ground resolution (Idrizi etAll 2018), while later converted to raster datasets, and finally merged into multiband raster dataset based on obtained elevation values, obtained geoid heights for three models, and calculated values between geoid heights and with elevations. Schema for whole process is given in next figure 3.

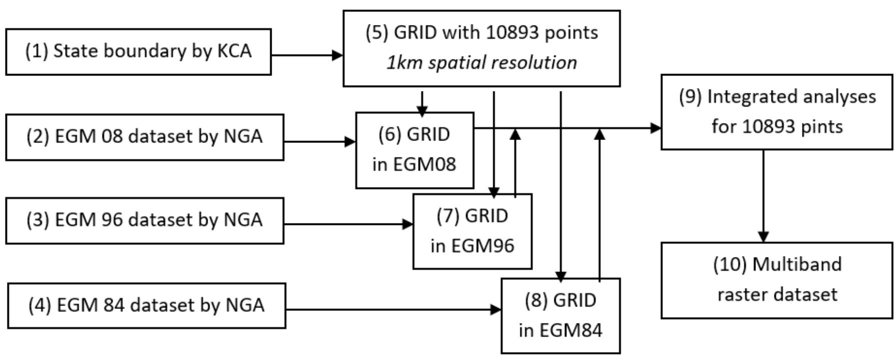


Figure 3. Scheme of developing multiband raster dataset of EGM 08, 96 and 84 for the Republic of Kosova

Test model used from previous research of Idrizi etAll 2018 (steps 1 and 5) contain cartesian/geographical coordinates and ASTER elevation [6] data for each of 10893 points. Data for steps from (2) to (4) were extracted directly from official web page of NGA [1], which then have been used for calculation of geoid heights [5] for all test model points (steps 6 to 8).

Three grids of 10893 points (6, 7 and 8) with values for coordinates, elevations, and geoid heights for three EGM models, at final step of calculation, before developing multiband raster dataset, have been used for calculation of differences between geoid heights of three models and ellipsoidal heights based on difference between the elevations and geoid heights of three models (step 9). With this, input grid of 10893 points with coordinates and elevations (5) is extended with nine new columns for geoid heights of three EGMs, difference between them and ellipsoidal heights based on each EGMs (9).

Final output database of test points with three obtained values for coordinates and elevations (step 5), as well nine calculated values (steps 6 to 9), as final product has been converted to single multiband raster dataset with ten bands and 10893 cells of 1km spatial resolution. Meaning of bands are given in bellow table with description:

Table 2. Description of bands in developed multiband raster dataset

BAND	DATA	BAND	DATA
1	ASTER elevation	6	Difference between geoid heights of EGM 08-96
2	Geoid height (EGM 84)	7	Difference between geoid heights of EGM 08-96
3	Geoid height (EGM 96)	8	Ellipsoidal heights based on EGM 84 and ASTER
4	Geoid height (EGM 2008)	9	Ellipsoidal heights based on EGM 96 and ASTER
5	Difference between geoid heights of EGM 08-96	10	Ellipsoidal heights based on EGM 2008 and ASTER

EGM 2008 FOR THE NATIONAL AREA OF KOSOVA

In step 6 of above given schema, the geoid heights for all points have been calculated for the entire area of Kosova. Calculation of geoid heights have been realized with precision of 4 decimals after meter (0.1mm), and 1mm RMS of interpolation of geoid heights in points of test model. From the calculated results, maximum value of geoid heights within EGM08 is 46.433m, while the minimum is 43.9215m. The difference between extreme values within the territory of Kosova of EGM08 geoid heights is 2.5115m, while the mean geoid height is 45.5391m, shown in table 3. In figure 4 [9], compiled map of geoid heights based on EGM2008 for the national area of Kosova is given.

EGM 1996 FOR THE NATIONAL AREA OF KOSOVA

The identical procedure as in a case of using EGM 08 for the territory of Kosova, have been implemented for EGM96 also (step 7), by calculation of geoid heights with precision of 4 decimals after meter (0.1mm), and 1mm RMS of interpolated geoid heights of points of test model. The largest value of geoid heights within EGM96 is 45.8281m, the lowest one is 43.1571m, mean height is 43.9581m, and the difference between extreme values is 2.671m, given in table 3. With the same methodology as in a previous case of EGM2008, the GIS raster dataset with 1km spatial resolution of EGM96 for Kosova is compiled, which is shown in bellow figure 5 [10].

EGM 1984 FOR THE NATIONAL AREA OF KOSOVA

Procedure and methodology for calculation of EGM84 geoid heights for the territory of Kosova (step 8) and their representing in a compiled map (figure 6) [11], were same as in a cases for EGM08 and EGM96. Greatest value of geoid heights within EGM84 is 47.198m, the smallest one is 43.9867m, the mean height is 45.5669m, while the difference between extreme values within the EGM84 geoid heights is 3.2113m, given in table 3.

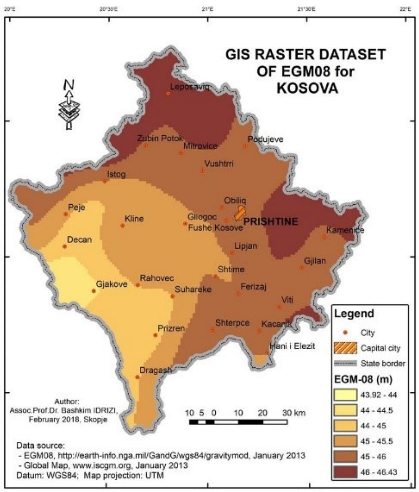


Figure 4. GIS raster dataset with 1km spatial resolution of EGM2008for Kosova

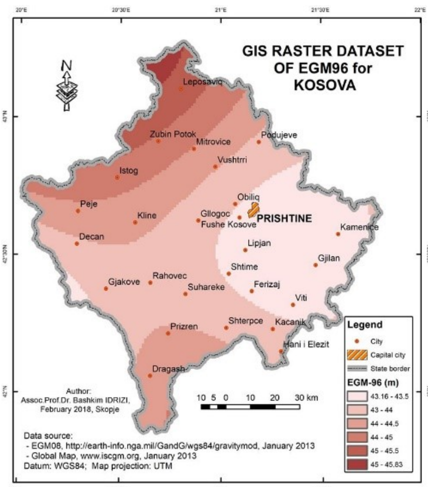


Figure 5. GIS raster dataset with 1km spatial resolution of EGM96 for Kosova

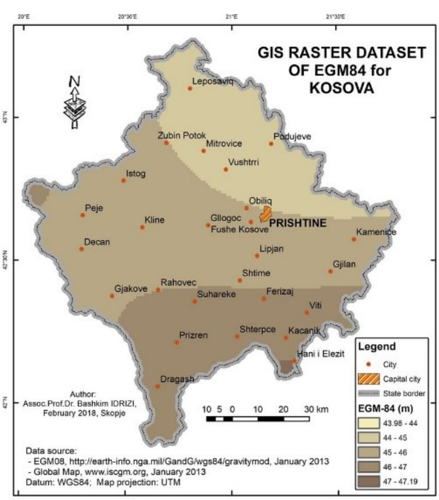


Fig. 6. Gis raster dataset with 1 km spatial resolution of EGM84 for Kosova

Table 3. Geoid heights and differences between EGM 08, 96 & 84 in the territory of Kosova

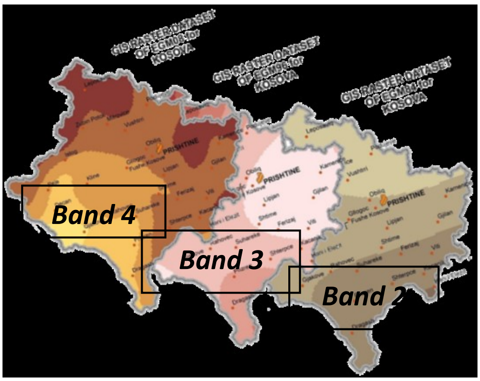
	Geoid heights (m)			Difference between two geoid heights (m)		
	EGM84	EGM96	EGM2008	EGM 08-96	EGM 96-84	EGM 08-84
Max value (m)	47.198	45.8281	46.433	2.9344	1.1018	2.1423
Min value (m)	43.9867	43.1571	43.9215	0.2611	-3.259	-2.0307
Diffe Max-Min (m)	3.2113	2.671	2.5115	2.6733	4.3608	4.173
Mean value (m)	45.56692	43.95809	45.53911	1.581024	-1.608835	-0.027811
Stand.Dev. (m)	0.690377	0.572147	0.493465	0.6974836	1.003411	1.04026

MULTIBAND RASTER DATASET FOR GEOID HEIGHTS FOR THE NATIONAL AREA OF KOSOVA

In the last step 10 (figure 3), according to ASTER elevation data and calculated values for all 10.893 points, as are presented in table 2, in GIS software multiband raster dataset with 10 bands was established. Each cell of raster image contains 10 values, per one in each band, which means that multiband raster image with 10.893 cells contain 108.930 values/calculations. Developing multiband raster image instead developing separate raster images for each calculated value, i.e. one instead ten raster images, is intended for multipurpose usage and creating suitable environment for further analyzes in this subject for the area of the Republic of Kosova. In bellow figure 7, three bands (EGM 08, 96 and 84 geoid heights) out of ten are shown as example/extract from developed multiband raster dataset, followed by the short description of each band.

It is open for further improvement by adding additional bands with geoid heights data developed by other researchers. A new band with official geoid model of the Republic of Kosova after its development by the responsible national mapping institution (Kosova Cadastral Agency), will be added by our side, in order to put into one place many geoid models for multipurpose usage, for everyday professional up to research purposes. If the national digital elevation model will be available free of charge by the KCA, it will be added to this multiband raster dataset, and some data as ellipsoidal heights (bands 8, 9 and 10) will be recalculated and updated.

Main objective of developed multiband raster is to fill current gap in this field in the Republic of Kosova, as well as to establish platform that will be used for performing multipurpose research analyses in a period post developing of official national geoid model.



Band 1	ASTER elevation
Band 2	Geoid height (EGM 84)
Band 3	Geoid height (EGM 96)
Band 4	Geoid height (EGM 2008)
Band 5	Difference between geoid heights of EGM 08-96
Band 6	Difference between geoid heights of EGM 08-96
Band 7	Difference between geoid heights of EGM 08-96
Band 8	Ellipsoidal heights based on EGM 84 and ASTER
Band 9	Ellipsoidal heights based on EGM 96 and ASTER
Band 10	Ellipsoidal heights based on EGM 2008 and ASTER

Figure 7. Multiband raster dataset for EGM 08, 96 and 84 geoid heights for Kosova

CONCLUSIONS

Model for utilization of existing global Earth Gravitational Models (EGM) for entire area of the Republic of Kosova through developing GIS dataset is given in this paper. Due to current situation in Kosova with the national geoid, which is still under development process by the Kosova Cadastral Agency [7], usage of global EGM's for issues related to geoinformation is more than necessary. Three existing global models EGM 2008, EGM 96 and EGM 84 [1] have been used for performing this research study. Comparing of the results between three models, were calculated based on joint GRID model with 10893 points which covers all national area with 1km ground resolution. Maximal and minimal differences between the models, maximal and minimal geoid heights (height of geoid above/bellow the WGS84 ellipsoid) in three geoid models, mean differences, standard deviation, ellipsoidal heights and other data-calculations, followed by developing of multiband raster dataset, are main outputs of performed research in this study.
Based on three developed models and differences between the models, nine maps for the territory of the Republic of Kosova were compiled. For map background, such as data for cities and boundaries, open and free Kosova Global Map data has been utilized, as official data developed by the national mapping authority of Kosova [7], while for the elevation data the ASTER global Digital Elevation Model (DEM) with 30m spatial resolution [6] has

been used. Within the paper, only three maps EG models with geoid heights as layouts of three bands are shown.
Calculation with online geoid calculator GeoidEval [5], gave us feedback and insure for calculated geoid heights for three models. Control points were selected by criteria to cover entire national area of Kosova. Based on the calculated values, the differences between calculated geoid heights with online geoid calculators and those exported from models in GIS platform have been evaluated, which resulted with very low differences.
Main purpose of analyses and developed GIS dataset for geoid heights and other data, is their open usage by geo community in Kosova, mainly for direct obtaining of elevations during field measurements and further research projects, till the establishing and formalization of national gravimetrical network and national geoid model.
Multiband raster image with ten bands in 1km spatial resolution, which contain 108.930 values stored in 10.893 cells, is the main output of this research study. It is open and extendable raster dataset, that is intended for multipurpose usage and update its content, as well inclusion of new band with the official national geoid model of the Republic of Kosova as soon as it is developed by the Kosova Cadastral Agency. Until the official national geoid, this model will fill the current gap in geo sector in the Republic of Kosova as contribute of academic community for professional and research usage of global geoid models for national purposes.

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