Study of length differences from topography to map projection within the state coordinate systems for some countries on the Balkan Peninsula

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Key words: state coordinate system, state map projection, distortion, length differences, topography, geoid, reference ellipsoid.

SUMMARY

All geodetic measured quantities from the physical surface of the Earth are reduced to the geoid and surface of adopted reference ellipsoid through applying corrections on the measured values, as well projected to the map projection. Before calculating the Cartesian coordinates of points in a formal state geodetic coordinate system, the horizontal lengths between points on the topography surface first should to be reduced from the topography to the mean see level (geoid), then from the geoid to the reference ellipsoid, and after that projected from the ellipsoid into the map projection.

Up to now, within the research analyses have been performed for defining of most appropriate State Plane coordinate system, the choice of most suitable national map projection is based on the requirements of accurate representation of the earth surface on the plane with minimum distortions. This choice is usually based on the research analyses performed for defining of most appropriate State Plane coordinate system. During the literature review, analyses of the length changes between points within successive projections from the earth surface to the chosen state map projection were not found. Recognition of the length differences for whole country areas mapped on the State Plane coordinate system are very important data for many geodetic and cartographic applications.

This research aims to develop and provide national GIS datasets of lengths' differences on a grid with cells 1x1 km covering national territories of seven Balkan countries - Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Kosova, FYRo Macedonia and Montenegro. Assessment and comparison of successive length differences between four surfaces (from the Earth surface, through geoid and ellipsoid, to the map projection) have been realized through calculation of mean linear deformations of 1km lengths, dispersion, maximum and minimum values, as well as their positive, negative or zero values. The differences between the real length on earth surface and on a map projection due to elevation factor were evaluated, that gave an impression on the quality of state geodetic coordinate systems, of the seven analyzed countries.

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1. PREFACE

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. Before calculating the Cartesian coordinates of points in a formal state geodetic coordinate system, the horizontal lengths between points on the topography surface first are reduced from the earth surface to the mean sea level (geoid); second from the geoid to the reference ellipsoid; and then from the ellipsoid into the map projection.
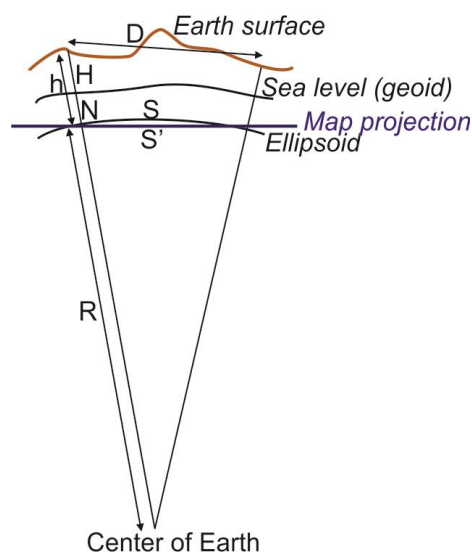
$$S = D(\frac{R}{R + N + H})$$

S - Geodetic distance
S´- Projected distance on map
D - Horizontal distance
H - Mean evaluation
N - Mean geoid heigh
R - Mean radius of Earth

Figure 1. Scheme of length approximations from topography up to map projection through the see level (geoid) and the referent ellipsoid

The scale factor moves us from the ellipsoid to the state plane (aka grid). However, the measurements are not made on the ellipsoid. They are made on the surface of the earth. To move from the surface of the earth down to the ellipsoid, we need to have what's known as an elevation factor. Typically, the elevation factor for a line is the average of the elevation factors at each end of the line (Sickle and Dutton 2017).

Up to now, within the research analyses have been performed for defining of most appropriate State Plane coordinate system, the choice of most suitable national map projection is usually

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based on the requirements of accurate representation of the earth surface with minimum distortions on the map plane. During the literature review for definition of state coordinate systems, we did not find analyses of the length changes between points after successive projection from the earth surface to a state map projection.

The recognition of the length differences for whole country areas mapped on the State Plane coordinate system is very important due to this data are used for many geodetic applications, e.g. high accuracy geodetic measurements, surveying works, combination of GNSS and total station measurements, transformation of local geodetic networks from free oriented in to the state coordinate system, etc.

In this paper we present the analysis of the length differences from topography to map projection within the state coordinate systems for seven countries on the Balkan Peninsula. Comparison with the distortion values of official state map projection, valuation of the methodology for most appropriate state map projection, as well developing GIS database for successive length differences between four surfaces (earth surface, geoid, ellipsoid, and map projection) aimed for practical usage by all professionals-stakeholders as open data are successively presented.

2. RESEARCH OBJECTIVES

The main objective of this research analysis is to calculate the values of differences between the horizontal length on earth surface and on a chosen state map projection, in a grid with cell size of 1 km, in order to get an impression on the quality of state geodetic coordinate systems, by comparing them with distortions in state map projections. Assessment and comparison of the successive length differences after four successive reductions/projections between Earth surface, geoid, ellipsoid, and map projection, have been realized through calculations of following: mean linear deformations of 1km lengths on the grid, range of differences, maximum and minimum difference values, and areas with positive, negative or zero differences.

Results from performed research analyses of the state coordinate systems of seven Balkan countries will directly contribute to valuation of the current methodologies for choosing a most appropriate state map projection, and possible its further improvement. Current methodologies do not take into consideration the elevation factor, i.e. length differences between the topography and the geoid, as well between the geoid and the referent ellipsoid.
Beside scientific outputs, one of the main practical objectives of this research is developing and providing national GIS datasets of lengths' differences on a grid with cells 1x1 km covering national territories of seven Balkan countries: Albania, Bulgaria, Bosnia and Herzegovina, Croatia, Kosova, FYRo Macedonia and Montenegro, to be used by interested stakeholders as open data.

3. DEFINING TEST MODEL

3.1. Defining the main concept of test model

Map projections are an important subject of a comprehensive coordinate reference system management. As it is not possible to map from the Earth surface to a plan without distortions (intrinsic of geometry), a lot of efforts has already been done to analyze the distortion properties. In fact, many projections were constructed by restrictions on the distortions. The methods therefore are given by the surface theory. The mathematical instrument to calculate distortions is based on the Tissot indicatrix, which defines the distortion properties (Voser 2001). Conformal projections are mainly used for displaying topographic data referred to the state coordinate system, because the linear distortions have the same value in all directions (ellipse of distortions is a circle). Main objective of the analyses for most appropriate state map projection should be focused on minimizing the length differences on the Earth surface (topography) and its state map projection. Our research is focused on the analysis of main criteria for choosing the suitable state map projection, i.e. if the linear distortions represent the real length differences compared with those on Earth surface.

Theoretically, the mean linear deformations should approach to zero, the minimum and maximum value of differences within the dispersions should approximately have the same values, and the areas with positive and negative differences should approach the same values (Idrizi 2014). This means that in order to have the appropriateness of official state coordinate system, largest length differences between the topography and its map projection should reach the same values with opposite prefixes, the mean length differences between the topography and the map projection should have values nearby zero, and the dispersion of negative and positive values in lengths' differences between topography and map projection have to be uniform. Based on upper criteria, we decided to analyze:

- mean length' differences in 1km on a grid,
- range of the length' differences,
- maximum and minimum length difference values, and
- areas with positive, negative or zero length differences.

Given the fact that length differences between two or more surfaces for practical issues are expressed in 1km, the test model for each country was developed by defining points in a grid with 1km distance from each other, following the approach given in (Idrizi 2014).

Beside the parameters of state coordinate systems, the geographical coordinates, altitudes and geoid heights for grid points on the model of each country were extracted in order to have the data needed to perform the calculations.

3.2. Data sets for the analyzed territory of seven Balkan countries

The possibilities for utilization of the official data from National Mapping Organizations (NMO) free of charge for scientific research projects are very limited due to current conditions within the geo-market and copyright rules on geospatial data, defined on national

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laws of countries covered by this study. Therefore, the research team decided mainly to use free and open datasets for noncommercial uses, such as Global Map, GADM, ASTER GDEM, SRTM, EUDEM, and EGM08.

Based on the national border lines, with the aim of creating a test model to be used for our research, a point vector grid with 1km distance between points has been developed for seven Balkan countries. According to the national area and the random starting point, the test model respectively contains for Albania 28303points, for Bosnia and Herzegovina 51197 points, for Bulgaria 110947 points, for Croatia 88160 points, for Kosova 10893 points, for FYRo Macedonia 25635 points, and for Montenegro 13331points, which covers entire areas of the seven countries.

By using QGIS software, the Cartesian/geographic coordinates in the state coordinate systems, altitudes from ASTER/SRTM/EUDEM, and geoid heights from EGM08 have been extracted for total 328 466 test model points for seven countries. Calculations are performed in Microsoft Excel by using the formulas from the theory of map projections, geometrical geodesy, physical geodesy, elementary geodesy and surveying.

4. CALCULATION OF LENGTH DIFFERENCES FROM TOPOGRAPHY TO MAP PROJECTION WITHIN THE OFFICIAL STATE COORDINATE SYSTEMS

4.1 General consideration of relations between the Topography, Geoid model, Earth ellipsoid and Map projection

Measurement of the lines must always be done on the topographic surface of the Earth, and not on the ellipsoid. Therefore, the first step in deriving a grid distance must be moving a measured line from the earth to the ellipsoid (Sickle and Dutton 2017). A measured slope distance is typically reduced to horizontal one, using the slope distance and either: 1) the difference in elevations of the end points; or 2) the vertical angle (zenith direction) of the slope distance as measured from either one or both lines' ends. Regardless of how the horizontal distance was obtained, the next step is to reduce the horizontal distance to sea level (Burkholder EF., 2004).

Historical practice has included reducing horizontal distances to sea level, but when working with state plane coordinates, or other geodetic computations, it is more appropriate to reduce the horizontal distance to the ellipsoid (Burkholder 2004).

Horizontal lengths between points on the topography surface, before mapping and calculating the coordinates of edges, should pass at least three projections between three surfaces. During the projection process, the lengths' changes their values due to effect of many factors, such as altitude, geoid height, reference ellipsoid, and map projection parameters. First approximation is a reduction of the horizontal length from topography into the geoid surface (mean sea level) based on the mean altitude value of the line edges. Second approximation is a reduction of the length from the geoid surface into the reference ellipsoid surface, known as geoid undulation, calculated

by using geoid height. Third-final approximation is the length projecting from earth ellipsoid into the plane of map projection. (Idrizi 2014)

Length differences (reduction, geoid undulation and map projecting) are not errors; they are calculated as absolute values, based on the parameters of referent surfaces (topography, geoid, ellipsoid, and map projection), so the accuracy of the calculated values (length differences) depends on the accuracy of used surfaces.

4.2 Calculations within the state coordinate system of seven Balkan countries

Albania: From second half of XIX century, in Albanian territory are made some coordinate reference systems especially to support mapping of Albanian territory. From year 1860 to 1943 the Bon projection based on Bessel 1841 ellipsoid have been used for state coordinate system. After Second World War Albanian coordinate system was defined by the Krasovsky 1945 ellipsoid, and tangential version of Transverse Mercator projection with Central Meridian 21°E (Nikolli and Idrizi 2011), which was in official use till year 2013.

A research for establishing of a new coordinate system by using new map projection with minimal distortions for the Albanian territory has been realized by Skuka and Kuka (1997) and the surveying department of the Polytechnic University of Tirana in 2013. Each research doesn't analyze successive length differences between earth surface and map projection area.
Albanian Geodetic Frame which is currently in use in the Republic of Albania is approved by the Decision of Council of Ministers no. 669, dated on 08/07/2013 and it is called "Korniza Rreferuese Gjeodezike Shqiptare 2010" (KRGJSH-2010). The year "2010" is the index related with the "epoch" used to define geodetic coordinates for all the geodetic points in the Republic of Albania. KRGJSH-2010 was determined on the basis of the European Geodetic Reference System, and is in use for all the applications associated with the use of geodetic coordinates in the country. KRGJSH-2010 includes: Fundamental geodetic parameters determined in Geodetic Reference System (GRS-80), Geodetic coordinate system ETRS89,.Height system of State Leveling Networks involved in the United European Leveling Network (UELN) defined in European Vertical Reference System (EVRS) using gravity data defined in the unified system International Gravity Standardization Network 1971 (IGSN 1971). The system of plain coordinates is Transverse Mercator Projection (TMzn) for mapping at scales larger than 1:500 000 with Central Meridian 20°, Scale factor at the central meridian 1 (tangential projection), False easting 500000m, and False northing: 0m (KRGJSH-2010, 2015).

In this research work the distortions in state map projection were evaluated by 28303 test model pints, by referring to GRS80 Earth ellipsoid. The range of calculated distortions are from 0cm/km along the central meridian up to 9.65cm/km at the largest point of test model from the central meridian (figure 2a), while the mean distortion is 1.22cm/km (Table 1).
By computing successive length differences from the topography surface to the state map projection plain, horizontal lengths of 1km from topography surface are reducing their lengths

with average value of -10.28cm/km, and range from -39.97 to 3.77cm/km (figure 2b). Range and average values of all length differences during the projection procedure between different reference surfaces are given in Table 1.
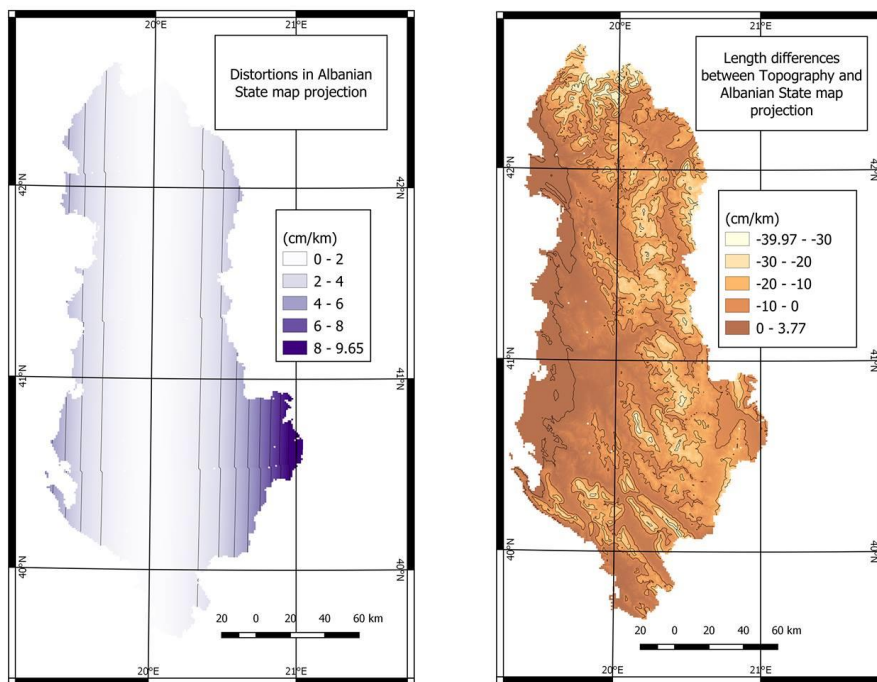

Figure 2. Distortions (a) and length differences of 1km (b) in state coordinate system of Albania

Bosnia and Herzegovina: The reference coordinate system of Bosnia and Herzegovina (B&H) was established in the nineteenth century. This was in fact a geodetic date for the state of the Austro-Hungarian monarchy. As a fundamental point, a trigonometric station Hermannskogel on the hill near Vienna was selected. Coordinates of the fundamental point are determined by astronomical methods and are summarized as follows (Mulić, 2018, p. 129):

- astronomical latitude $\Phi = 48°16'15,''29 \pm 0,''04$;
- astronomical longitude $\Lambda = 33°57'41,''06$ east of the Ferro,
- the network orientation is defined by the azimuth of the trigonometric line „Hermannskogel–Hundsheimer Berg" $\alpha = 107°31'41,''70$.
-

Reference ellipsoid was Bessel 1842, as in the most Central European counties in that period. For the cartographic purposes, Gauss–Krüger cylindrical conformal projection, with the 3 degree meridian zones, was adopted in year 1924, for the whole Kingdom of Yugoslavia. This projection is still in use in Bosnia and Herzegovina. Reference (prime) meridian is Greenwich but central meridians are $15°$, $18°$, $21°$ with linear scale 0.9999 along the central meridian. False easting is 500000m.

Due to the limited accuracy of the state survey of B&H, done by the graphic method from the Austro-Hungarian monarchy period, in 1953 a reconstruction of the trigonometric network was initiated in 1953. The reconstructed network served as the mathematical basis of the state survey, which was made applying aero photogrammetric method. However, over 90% of the territory of the country was surveyed before aggression to the B&H in 1992. Cadaster of Real Estate was established on the basis of the Law on Land Survey and Real Estate Cadaster, adopted in 1984 (Geodetski glasnik, 1986). New Law for the State survey is under preparation based on the GRS80 ellipsoid and ETRS89 coordinate system. Anyhow, since 1998, the state survey in B&H uses European terrestrial reference system and the geospatial data are prepare in accordance to the INSPIRE directive.

Distortions in state map projection for B&H was evaluated by 51 197 test model pints, 4 596 points for projecting zone 5, 46 471 points for zone 6 and 130 points for zone 7, by referring to Bessel earth ellipsoid, separately in three projecting zones. The range of distortions is from -10cm/km along the central meridian of zone 6 up to 7.99cm/km along the border between projecting zones of the test model (figure 3a), while the mean distortion is -4.97cm/km (Table 1). By computing successive length differences from topography surface up to state map projection flat area, horizontal lengths of 1km from topography surface are reducing their lengths with average value of -16.46cm/km, and range from -56.49 to 4.68cm/km (figure 3b). Range and average values of all length differences during the projection procedure between different reference surfaces are given in Table 1.
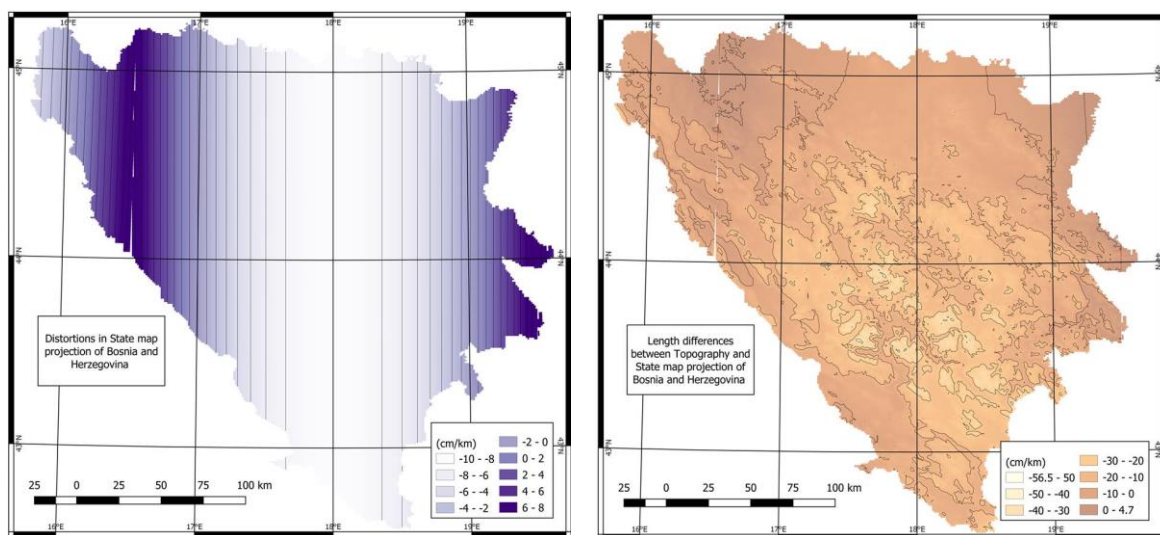

Figure 3. Distortions (a) and length differences of 1km (b) in state coordinate system of Bosnia and Herzegovina

Bulgaria: According to the Decree of the Council of Ministers № 153/29.07.2010 (SG, N61/2010) and Ordinance № 2/30.07.2010 (SG, N62/2010) a new Bulgarian Geodetic System 2005 (BGS 2005) was introduced in Bulgaria. This "new" geodetic system replaced the previously approved Geodetic Reference System 2000 accepted with the Decree N

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140/04.05.2001, which was not realized on practice. There is no difference between two systems in the set of basic geodetic parameters. The BGS'2005 combines three reference systems – (1) Coordinate system 2005 is determined to the epoch 2005.0 from ETRS89 with the fundamental geodetic parameters of GRS80 and realized by the State GPS network and permanent GNSS sites, connected with EPN; (2) Vertical reference system 2005, realized by the First order of the State leveling network and points from the EUNV-DA project, connected with EVRF2007 using old gravimetric data in IGSN71; (3) Gravimetric Reference system IGSN71 with absolute points determined in the UNIGRACE project (2005) and realized by the National gravimetric network.

The main cartographic projection for the Bulgarian territory is chosen to be Universal Transverse Mercator Projection (UTM projection) with two 6^0 zones 34N and 35N with central meridians 21^0 and 27^0 respectively, as the second zone covers the prevailing part of the country, which is regulated by the Instruction № RD-02-20-12/03.08.2012 (SG N63/2012). Deformations of the distances and the area surface mapped in UTM projection outside of the zone boundaries $\pm 3^0$ increased progressively with moving away of the central meridian. Scale factor of the central meridian is m = 0.9996. This Instruction allows the use of geodetic projections other than UTM for cadastral mapping purposes, as well as for other applications related to scales larger than 1: 5000 and their respective digital products. To support high-accuracy applications (e.g., elaboration of cadastral and specialized maps, detailed spatial development and parcel plans, etc.) in Bulgaria was introduced so called "Cadastral coordinate system 2005". This map projection of "Cadastral coordinate system 2005" is Lambert Conformal Conic projection with the following parameters: standard parallels $\varphi_1 = 42^000^0$ and $\varphi_2 = 43^020^0$, $\lambda_0 = 25^030^0$, $y_0 = 5000000$m. The main purpose was to use a most appropriate map projection for the whole territory of Bulgaria with minimum distortions. But, there is no official normative document regulating the adoption of this system in general. The newly adopted map projection system for large-scales mapping is based on new observations and the new GRS2005 of Bulgaria. With the new "Cadastral coordinate system 2005" it is expected the regional distortions in mapped territory to be removed and to made more consistent with the State GPS/GNSS network.

Distortions in state map projection were evaluated with 110947 test model pints, 30184 points for projecting zone UTM 34N, and 80763 points for zone UTM 35N, by referring to GRS80 Earth ellipsoid, separately in 2 projecting zones. The range of calculated distortions is from -40cm/km along the central meridian of zone UTM 35N up to 37cm/km along the border between projecting zones of test model (figure 4a), while the mean distortion is –13.3cm/km (Table 1).

By computing successive length differences from topography surface up to state map projection flat area, horizontal lengths of 1km from topography surface are reducing their lengths with average value of -21.39cm/km, and range from -55.06 to 30.28cm/km (figure 4b). The calculated values of all length differences separately for each projecting zone are given in Table 1.
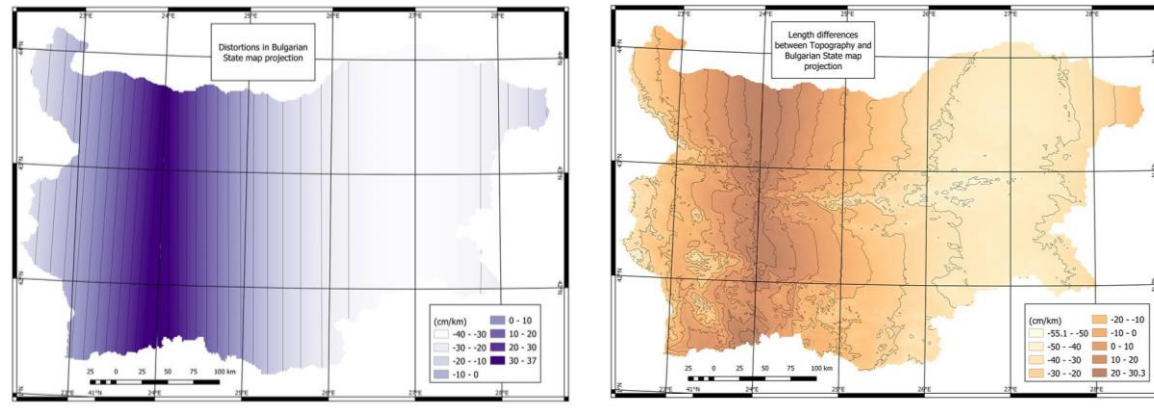
Figure 4. Distortions (a) and length differences of 1km (b) in state coordinate system of Bulgaria

Croatia: Idea to revise official geodetic datums and map projections in Croatia started in mid-1990's. Project by State Geodetic Administration was initiated in 2000 and its results were basis for the Decree on Establishing New Official Geodetic Datums and Planar Map Projections of the Republic of Croatia in 2004 (Narodne novine 2004a and 2004b).

European Terrestrial Reference System 1989 (ETSS89) with GRS80 ellipsoid was selected as a new geodetic datum. Coordinate system of the Transverse Mercator (Gauss- Krüger) projection - abbreviated HTRS96/TM, with central meridian 16°30' and the linear scale factor along the central meridian of 0.9999 was selected as coordinate system of the Republic of Croatia for the cadaster and state topographic cartography. In this decree the height datum, gravimetric datum, realization of ETRS in the epoch 1995.55, map projection for small scale mapping (Lambert conformal conic) and military map projection (UTM) were also defined.
According to the implementation plan, 2010 was defined as the year when all official spatial data should be referenced in the new reference coordinate system. This was finally accomplished with some delays; today all official spatial data produced and maintained by State Geodetic Administration is available in this coordinate reference system.

One of prominent changes was introduction of one planar coordinate reference system which replaced two systems (3-degree Gauss-Krüger zones) used in post-World-War-II period. Maximal linear distortion in these two zones, which was 1:10000 (1dm/km), now increased in one ~6-degree zone to ~1:1500 (~7dm/km). It was no longer possible to neglect map projection linear distortion in surveying and cadastral tasks, at least for areas at distance more than 127 km from central meridian. Technical specifications (Državna geodetska uprava 2009) were published and education of professionals was conducted to accomplish transition to the new reference coordinate system. Curricula at universities were also updated to reflect these changes. New measurement technologies based on GNSS, Croatian Ground Based Augmentation System (CROPOS) and modern surveying instruments facilitated (along with the fact that they also caused geodetic datum change in the first place) the transition of surveyors' everyday work.

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As we can see, the traditional requirement for state reference coordinate systems, that for cadaster and land surveying one should not consider map projection linear distortions, was not followed. It was traded for introduction of only one state planar reference coordinate system instead of two. That removed need to transform coordinates between two zones and introduced necessity for considering linear distortions, which is fairly simple procedure (multiplication or division of distances by scale factor), already supported by modern surveying instruments.

There is no comprehensive analysis of impacts of introduction of the new datum and map projections on surveying or related professions, or quality of official spatial data, that authors are aware of.

Distortions in state map projection were evaluated by 88160 test model pints, by referring to GRS80 earth ellipsoid. The range of distortions is from -10cm/km along the central meridian up to 70.73cm/km at the largest point of test model from the central meridian (figure 5a), while the mean distortion is 4.35cm/km (Table 1).

By computing successive length differences from the topography surface up to state map projection plain, horizontal lengths of 1km from topography surface are reducing their lengths with average value of -0.55cm/km, and range from -38.94 to 70.05cm/km (figure 5b). Range and average values of length differences of state coordinate system are given in Table1.
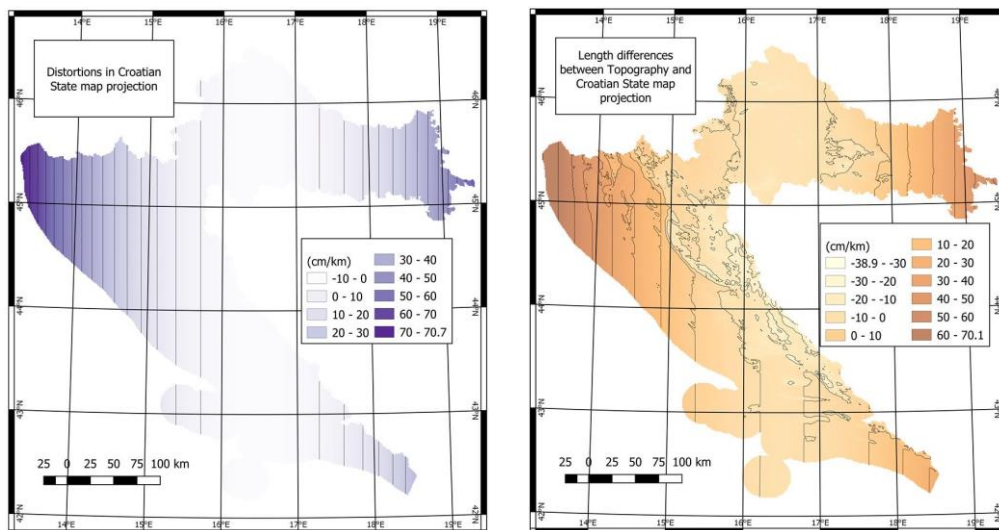

Figure 5. Distortions (a) and length differences of 1km (b) in state coordinate system of Croatia

Kosova: As part of former Yugoslavia, from 30's of last century the coordinate system established based on ellipsoid Bessel1841 and Gauss-Krüger projection with Central Meridian 21°, Scale factor at the central meridian 0.9999 (secant projection), False easting 7500000m, and False northing: 0m, locally known as FRYREF30 and internationally as MGI/Balkan zones 7 (EPSG 31277), was in official use until year 2001.

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The state coordinate system of the Republic of Kosova (KOSOVAREF01) was defined on year 2001, based on ETRS89 datum and Gauss-Krüger projection with -1dm/km distortion (scale factor 0.9999) along the central meridian (21°E), equator as origin of latitude, Greenwich as origin of longitudes, as well 7500000m false easting and 0m false northing. (Idrizi, Bajrami and Lubishtani 2009). This coordinate system is the legal and technical base for all official geodetic, topographic, cartographic and cadastral data in Kosova (www.kca-ks.org).

Analyses for most appropriate state map projection for the Republic of Kosova have been realized on year 2008 by Milot Lubishtani, Fitore Bajrami and Bashkim Idrizi (Idrizi, Bajrami and Lubishtani, 2009), by computing distortions of some potential map projections in order to adopt to national area, however the elevation factor was not take in to consideration!

Distortions in state map projection were evaluated by 10893 test model pints, by referring to GRS80 earth ellipsoid. The range of distortions is from -10cm/km along the central meridian up to -2.19cm/km at the largest point of test model from the central meridian (figure 6a), while the mean distortion is -8.72cm/km (Table 1).

By computing successive length differences from topography surface up to state map projection plain, horizontal lengths of 1km from topography surface are reducing their lengths with average value of -22.13cm/km, and range from -50.25 to 12.86cm/km (figure 6b). All calculated values of length differences of state coordinate system are given in Table1.

Figure 6. Distortions (a) and length differences of 1km (b) in state coordinate system of Kosova

FYRo Macedonia: Based on Law for Real Estate Cadastre of Macedonia and Regulation for basic geodetic works in FYRo Macedonia, the Macedonian state coordinate system is defined with Bessel 1841 earth ellipsoid, and Gauss-Krüger map projection with central meridian 21°E,

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scale factor 0.9999, false easting 500000, and false northing 0m, Greenwich as origin of longitudes and Equator as origin of latitudes (www.katastar.gov.mk). It was established by the Military geographic institute of Belgrade on 30s of last century, internationally known as MGI/Balkans zone 7 – EPSG: 31277.

Agency for Real Estate Cadastre of Macedonia intent to change the coordinate system in order to use ETRS89 with GRS80 as geodetic datum for new coordinate system, by adopting new map projection (www.katastar.gov.mk). For this issue, many researches have been conducted, but all of them are based on distortion of map projection without including of elevation as factor for choosing of state map projection during defining of state coordinate system (Idrizi 2005, Ribarovski et all 1998, Ribarovski 1974, and Srbinoski 2000). At the Strategic plan for the work of the Agency for Real Estate Cadastre of Macedonia for the period 2018–2020, institution is going to prepare a study on choosing the optimal cartographic projection for the Republic of Macedonia which will monitor the ETRS89 coordinate system, after it will have been put in official use in the Republic of Macedonia (www.katastar.gov.mk).

Distortions in state map projection were evaluated by 25635 test model points (Idrizi 2014). The range of distortions is from -10cm/km along the central meridian up to 25.16cm/km at the largest-eastern point of test model from the central meridian (figure 7a), while the mean distortion is -2.27cm/km (Table 1).
By computing successive length differences from topography surface up to state map projection flat area (Idrizi 2014), horizontal lengths of 1km from topography surface are reducing their lengths with average value of -16.01cm/km, and range from -51.56 to 19.48cm/km (figure 7b). All range and average values of length differences of state coordinate system are given in Table 1.
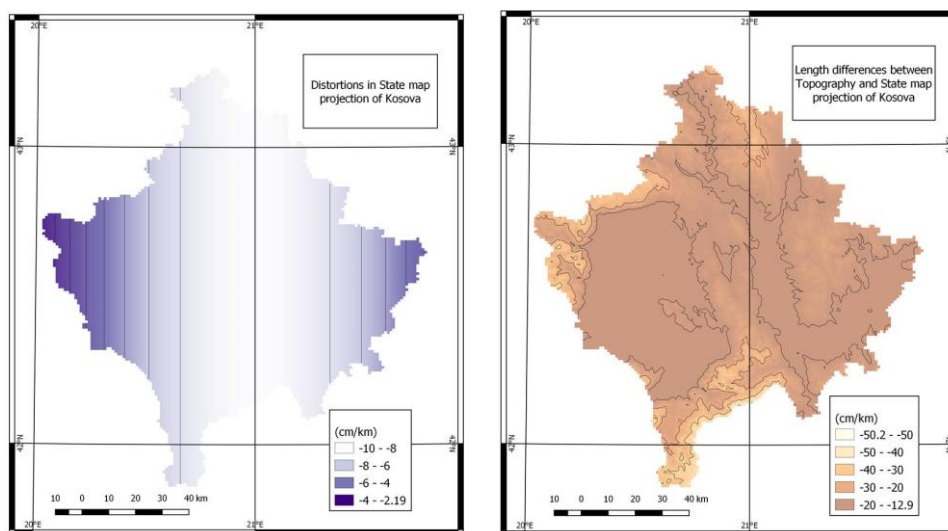

Figure 7.Distortions (a) and length differences of 1km (b) in state coordinate system of Macedonia (Idrizi 2014)

Montenegro: From 30s of last century till year 2007, two projecting zones have been in official use for the territory of Montenegro, inherited from the state coordinate system of

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former Yugoslavia, defined by the Military Geographic Institute in Belgrade. Border between two projecting zones was meridian 19°30', east of which is the 7th zone with central meridian 21°, while on the west it is the 6th zone with central meridian 18° of MGI /Balkan zones.

Based on the Law on State Survey and Real Estate Cadastre, Article 24 ("Official Gazette of the Republic of Montenegro" No. 29/07), the Universal Transversal Mercator (UTM) projection was adopted as new state map projection. Whole country area belongs to UTM zone 34N, with central meridian 21°E.

The reason for defining new state coordinate system is that the GRS80 ellipsoid more coincides with the Earth dimensions, and most of the European countries have adopted the ETRS89 reference coordinate system, defined as a straight, rectilinear, geocentric system, which is firmly bound to the European lithosphere surface. This will facilitate the exchange of geospatial data between Montenegro and other European countries in the future.

Distortions in state map projection were evaluated by 13331 test model pints, by referring to WGS84 earth ellipsoid. From computed values, range of distortions is from -36.06cm/km at the eastern point up to 13.01cm/km at the largest point of test model (western point) from the central meridian (figure 8a), while the mean distortion is -13.07cm/km (Table 1).

By computing successive length differences from topography surface up to state map projection flat area, horizontal lengths of 1km from topography surface are reducing their lengths with average value of -29.81cm/km, and range from -70.46 to 11.21cm/km (figure 8b). All calculated values of length differences of state coordinate system are given in Table1.
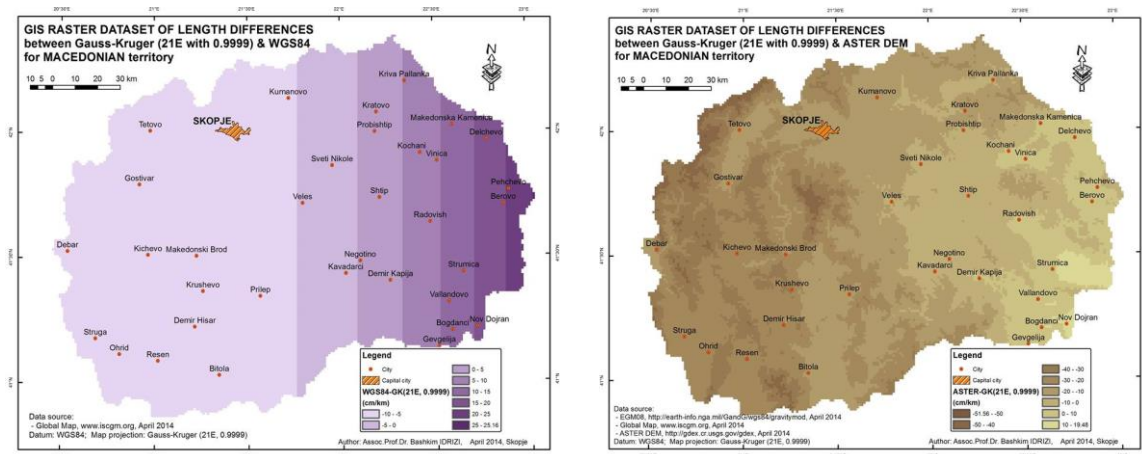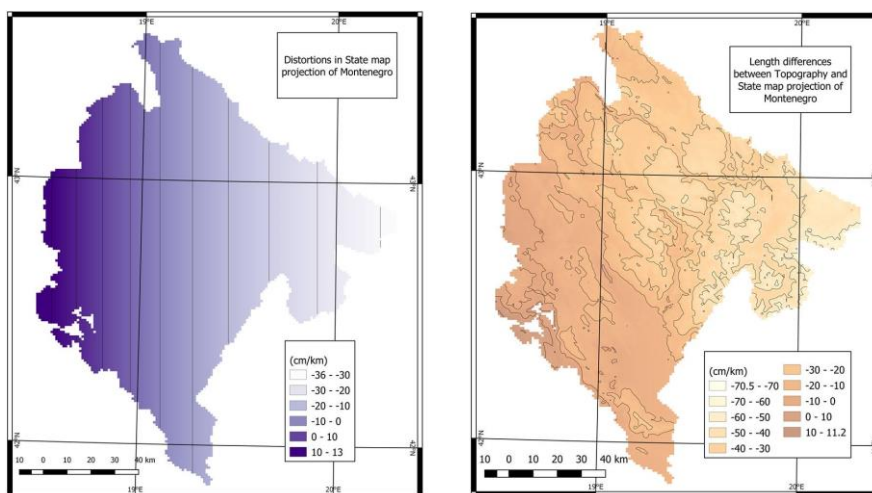

Figure 8. Distortions (a) and length differences of 1km (b) in state coordinate system of Montenegro

5. RESULTS AND FINDINGS FROM TEST MODEL ANALYSES

Assessment and comparison of the length differences in a grid 1x1 km after successive projection between four referent surfaces (earth surface, geoid, ellipsoid, and map projection)

have been realized. Seven values are evaluated: average linear deformations of 1km horizontal lengths, range of differences, maximum and minimum difference values, and areas with positive, negative, and without length differences.

The values for separate differences between four referent surfaces and successive differences between earth surface and referent ellipsoid, and between earth surface and state map projection for each point of test model are calculated. Thus for each point of test model, per seven values have been calculated:

1. Length difference of 1km between topography and see level (geoid);
2. Length difference of 1km between see level (geoid) and referent ellipsoid;
3. Length difference of 1km between referent ellipsoid and state map projection;
4. Length difference of 1km between topography and referent ellipsoid; and
5. Length difference of 1km between topography and state map projection.
6.

Since the test model consists of 328 466 points, the total number of calculated values for length differences in the seven countries reached up **11 496 310**.

Differences between calculated values of above mentioned points 3 and 5 above are the values of special interest for ours research; therefore these results are presented in the Table 1 for each country separately.

Table 1. Average and range of distortions and length differences in 1km in state coordinate systems of Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Kosova, Macedonia and Montenegro

Country	Coordinate zones	Points of test model	Distortions between ellipsoid and map projection		Length differences between topography and map projection	
			Average	Range	Average	Range
Albania	1 zone	28303	1.22cm/km	0 to 9.65cm/km	-10.28cm/km	-39.97 to 3.77cm/km
Bosnia and Herzegovina	Zone 5	4596	1.47cm/km	-5.845 to 7.75cm/km	-8.65 cm/km	-27.29 to 4.68cm/km
	Zone 6	46471	-5.64cm/km	-10 to 7.99cm/km	-17.28cm/km	-56.49 to 4.43cm/km
	Zone 7	130	6.88cm/km	4.86 to 7.99cm/km	-2.27cm/km	-9.86 to 3.67cm/km
	Whole country	51197	-4.97cm/km	-10 to 7.99cm/km	-16.46cm/km	-56.49 to 4.68cm/km
Bulgaria	UTM 34N	30184	4.88cm/km	-25.07 to 37cm/km	-7.62cm/km	-55.06 to 29.9cm/km
	UTM 35N	80763	-20.09cm/km	-40 to 36.62cm/km	-26.53cm/km	-55.02 to 30.28cm/km
	Whole country	110947	-13.3cm/km	-40 to 37cm/km	-21.39cm/km	-55.06 to 30.28cm/km
Croatia	1 zone	88160	4.35cm/km	-10 to 70.73cm/km	0.55cm/km	-38.94 to 70.05cm/km
Kosova	1 zone	10893	-8.72cm/km	-10 to -2.19cm/km	-22.13cm/km	-50.25 to -12.86cm/km

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				-10 to 25.16cm/km		-51.56 to 19.48cm/km
Macedonia	1 zone	25635	-2.27cm/km	-10 to 25.16cm/km	-16.01cm/km	-51.56 to 19.48cm/km
Montenegro	1 zone	13331	-13.07cm/km	-36.06 to 13.01cm/km	-29.81cm/km	-70.46 to 11.21cm/km

From all calculated values, raster datasets with 1km spatial resolution have been developed separately, for each country and/or projection zones. Since the analyses of points of test model were conducted as five analyses between referent surfaces (upper points from 1 to 5), per five raster datasets for ten projecting zones have been developed (in total 50 rasters):

- per five raster datasets with 1km spatial resolution for the countries with 1 projecting zone (Albania, Croatia, Kosova, FYRo Macedonia and Montenegro),
- 10 raster datasets with 1km spatial resolution for 2 projection zones of Bulgaria, and
- 15 raster datasets with 1km spatial resolution for 3 projection zones of Bosnia and Herzegovina.
-

Layouts for 14 of 50 raster datasets, per two for each of the seven countries are presented in upper six figures.

Raster datasets have been developed to be used for practical issues by the general public and industry, as open data. By this contribution, every professional user of state coordinate systems will be able to obtain the values of reductions, undulations, distortions, as well length differences between earth surface and state coordinate system in every point of the country area.

The differences between the real lengths on earth surface (topography) and on a state map projection (plain area with orthogonal coordinates) presented in Table 1 give an idea of the quality of state geodetic coordinate systems. Results show clearly big differences in all analyzed chases of the distortions of map projection and the length reduces from the Earth surface to the state map projection. By comparing of calculated values we came to the next general findings:

- differences between the distortion in state map projections and length differences between the topography and the map projection are too large,
- largest length differences between the topography and the map projection doesn't reach same values with opposite prefixes,
- mean length differences between the topography and the map projection in all cases do not have values nearby zero, and
- the range of length differences didn't reach the criteria of uniform dispersion, which was resulted with too large differences between areas with negative and positive linear deformations.

Thus, we can summarize that during establishing of the state coordinate systems were not taken into account all length reductions - differences beginning from the topography to the relevant map projection.

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6. CONCLUSIONS

In this paper, the analysis for length differences between the topography and map projections with chase study of FYRo Macedonia (Idrizi 2014) has been extended by including other six countries from the Balkan Peninsula. Obtained results for the territory of seven countries covering about 330000km2, shows the same problems related to the too large differences between distortions and length differences between the topography and the map projection, as it was previously confirmed for the case of FYRo Macedonia.

It was a challenging task to process 328.466 points by defining their altitude and geoid heights, as well as to calculate 11 496 310 values of length reductions between four surfaces. Today, the powerful software and computers give an opportunity to accelerate and automate such complex analyses using relevant mathematical model and large amount of data.

Developing and providing national datasets of lengths' differences on a grid with cells 1x1 km covering the territories of seven Balkan countries can be successfully used by professional users of the state coordinate systems in their countries. The obtained results are useful as the corrections on the measured values-distances for many geodetic applications, such as the high accuracy geodetic measurements, surveying, combination of GNSS and total station measurements, special/local geodetic networks, transformation of the local geodetic networks from free oriented into the state coordinate system, etc.

The performed analyses show that successive length differences between four surfaces, must take into account during selecting of a most appropriate state map projection. Especially, the study of the length reductions beginning from the topography up to the map projection is indicative for big differences instead of the distortion values, which are usually calculated between reference ellipsoid and map projection. This conclusion was verified by computed linear deformation values (Table 1), which in all cases have largely avoided from the expected values.

Based on the calculated values from the performed analyzes, we can conclude that similar problems have an absolute number of the formal state coordinate systems, all over the world.

This research aims to contribute to further studies of defining a new approach for choosing the most appropriate national map projection, in order to minimize the length differences between topography and map projection, as well as to fulfill the criteria/standards of linear differences between referent surfaces in state coordinate systems.

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