# Projecting of Territory of the Republic of Kosova in Several Most Used State Map Projections

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**Key words**: state map projection, Gauss-Krűger projection, stereographic projection, Lambert conform conical projection, UTM.

## SUMMARY

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 negative linear deformation along the central meridian (21□E) and 7500000m false easting. Due to small area of Kosova, all territory projects with negative value in which the largest linear deformation (LD) is -10cm/km, i.e. the mean linear deformation (MLD) is 8.7cm/km.
In efforts for finding of coordinate system with smallest LD, Gauss-Krüger projection with scale factors 0.99996 and 0.999967, as well as without negative LD (tangential case) were researched also. In first variant (0.99996) the maximum LD is 4cm/km in which 2.93cm/km is the MLD, the second option (0.999967) provides the largest LD 4.6cm/km with MLD 2.46cm/km, and Gauss-Krüger projection in tangential variant gives the better MLD (1.3cm/km) in which the largest LD is 7.9cm/km.
Due to configuration of the territory of Kosova, Lambert conic conformal and stereographic projections are probably the suitable as most appropriate state map projections. UTM projection as international has been utilized also.
In a stereographic tangential projection the largest value of LD is 4.18cm/km, in which case the value of MLD is 1.17cm/km. With the target to reduce the deformations in half value, due to the difference distances of extreme points from the central point, -2.1cm/km (0.999979) and -1.9cm/km (0999981) LD in central point were used as extended options of stereographic projection. In first case the maximum LD is -2.1cm/km, in which the MLD is 1.08cm/km, as well in a second effort, the biggest LD is 2.28cm/km with 0.94cm/km MLD.
During projecting of the territory in Lambert conic conformal projection, in tangential case the largest LD is 7.69cm/km, in which MLD of the whole territory is 1.15cm/km. Using of negative LD from -3.8cm/km (0.999962) gives the interval of deformations from -3.8 to 3.89cm/km with 2.85cm/km MLD in whole territory.
Because of the small area of Kosova, utilization of UTM projection provides very large LD, i.e. in interval between -39.21 to -40dm/km. MLD in all territory is 39.87cm/km.
Based on upper results, most appropriate state map projection of the Republic of Kosova for local use is Stereographic projection with scale factor 0.999979, but utilization of UTM projection for international use is irreplaceable.

# Projecting of Territory of the Republic of Kosova in Several Most Used State Map Projections

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## 1. PREFACE

The Republic of Kosova is a newest independent country, located in a central part of the western Balkan, with 10908km$^2$ area and 744km border line. Its central and extreme geographic coordinates (represented in ellipsoid GRS80) are given in next table 1. Dimensions of the trapeze, defined from the extreme points are: 144.1km the length of the northern parallel, 147.5km the length of the southern parallel, as well 186.6km length of the meridian (figure 1). The geometric form of territory of the Republic of Kosova is lengthened along the parallels, as well as along the meridians, and in the same time due to similar distances from the central to extreme points it has approximately a circle form flattered in southeastern, southwestern, northeastern and northwestern parts.

*Table 1. Geographic coordinates of the central and extreme points of Kosova*

| Point | Geographic coordinates | |
|---|---|---|
| | φ | λ |
| **North** | 430 16'07.5'' N | 200 49'01.9'' E |
| **South** | 410 50'50.1'' N | 200 37'36.8'' E |
| **East** | 420 38'48.0'' N | 210 47'42.7'' E |
| **West** | 420 44'10.4'' N | 200 01'10.9'' E |
| **Center** | 420 33'28.8'' N | 200 54'26.8'' E |

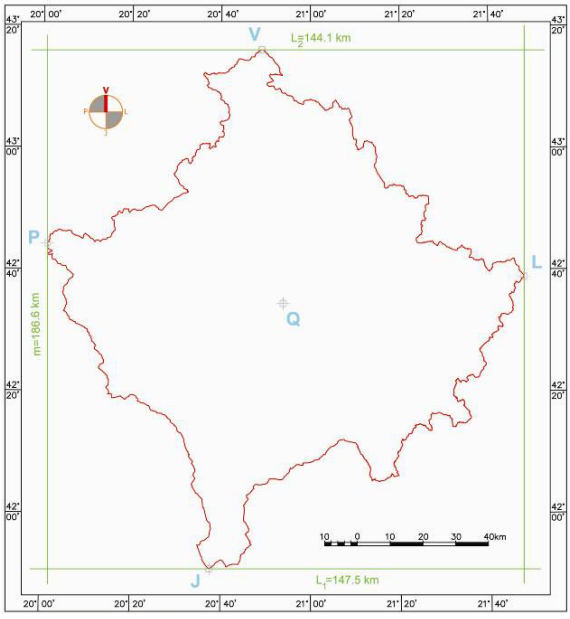


*Figure 1. Length of trapeze and position of the center and extreme points (Lubishtani, 2008)*

All official geodetic, cartographic and cadastral data of Kosova bases in own state coordinate system "KOSOVAREF01" (Meha, 2006), defined on year 2001 by the Kosova Cadastral Agency (KCA). Before that date, the territory of Kosova as a part of former Yugoslavia's federation, was used the coordinate system "FryRef30", which was defined after year 1924. The differences between the new with older coordinate system are in utilized datum and ellipsoid, which can be seen in next table 2. During the process of defining of parameters of new coordinate system, in a period from 1999 to 2001, referent map projection followed by all its parameters has been obtained from old coordinate system, probably without any sustainable scientific analyses.

*Table 2. Coordinate systems of the Republic of Kosova from year 1924 up to day*

| **Name:** | **FryRef 30** | **KOSOVAREF01** |
|---|---|---|
| **Year of defining:** | 1924 | 2001 |
| **Period of utilization:** | 1924-2001 | 2001-ongoing |
| **Datum:** | Harmannskögel | ETRS89 |
| **Ellipsoid:** | Bessel 1841 | GRS 80 |
| **Map projection** | Gauss–Krüger | Gauss–Krüger |
| **Projecting zone:** | 7th | 7th |
| **Width of the zone:** | 30 | 30 |
| **Prime meridian:** | Greenwich | Greenwich |
| **Central meridian:** | 210 | 210 |
| **Origin of latitude:** | Equator | Equator |
| **False easting:** | 500000m | 7500000m |
| **False northing:** | 0m | 0m |
| **Scale factor:** | 0.9999 | 0.9999 |
| **Length units:** | Meter | Meter |
| **Origin of elevations:** | Mareograph "Molo Sartorio" – Trieste, Italy | Mareograph "Molo Sartorio" – Trieste, Italy |

## 2. DEFINING OF CRITERIAS FOR ESTIMATION OF MAP PROJECTIONS FOR THE TERRITORY OF THE REPUBLIC OF KOSOVA

Analyses for research of most appropriate state map projections have been done in two test models. First test model is a grid of 108 points with 10km distances between them (figure 2), defined with their geographic coordinates in ellipsoid GRS 80. Because the most of geodetic and cadastral works are oriented in cities and around them, as potential economic zones and location oh head offices of the local government, the second test model are "central" points of 30 Kosova's cities defined with their geographic coordinates also. Due to the similar results from both test models, in this paper will be present only the results from 108 points grid test model and extreme points which represents in the same time the whole territory of Kosova.

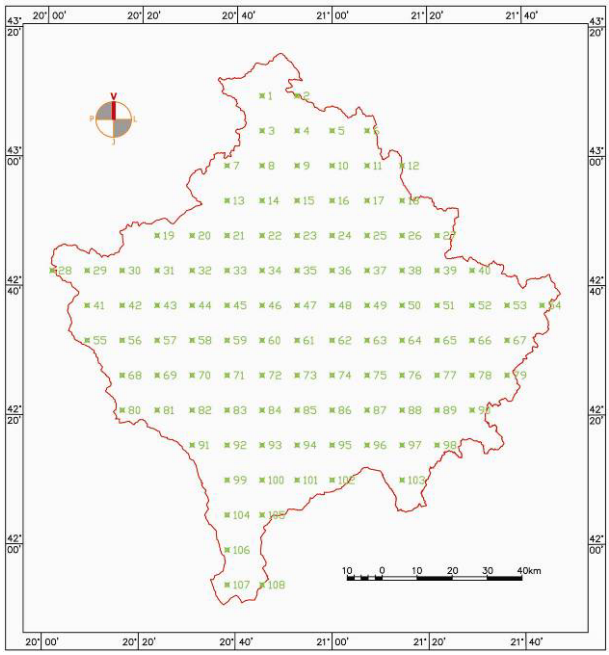


*Figure 2. Test model with 108 points grid (Lubishtani, 2008)*

Basic criteria's for choosing of the most appropriate state map projection according to all standards from the mathematical cartography are (Shehu, 1971):

- the value of the largest linear deformation (main criteria),
- right dispersion of the linear deformations, and
- adopting of the mathematical module for geodetic calculations.

Beside above criteria's, the value of mean linear deformations (calculated by formula 1), sum of squares of linear deformations, mean value of linear deformations in 1km length (calculated by formula 2), and the percent coverage with defined deformation (Shehu, 1982), based on grid test model and Kosova cities have been obtained as extended criteria's for research also.

$$\Theta = \frac{\sum_{1}^{n} |\Delta d|}{n} \quad \text{... (1)} \qquad m = \sqrt{\frac{\sum_{1}^{n} \Delta d \Delta d}{n}} \quad \text{... (2)}$$

In which:

$\Theta$ - mean linear deformation,
$\Delta d$ - linear deformation,
$n$ - number of test model points,
$m$ - mean value of linear deformations in 1km length.

## 3. UTILIZATION OF MOST USED STATE MAP PROJECTIONS FOR PROJECTING OF THE TERRITORY OF THE REPUBLIC OF KOSOVA

Based on the theory of map projections (Idrizi, 2006), most used state map projections in relation with the form of territory are: Gauss-Krüger projection for countries lengthened along

the meridians, Lambert conform conic projection for countries lengthened along the parallels, stereographic projection for countries with the form nearness to circle, and the Mercator projection for the countries along the equator. From this criteria's for selection and above data for the form and dimensions of the Republic of Kosova, it is so clear that probably the Gauss-Krüger, Lambert and stereographic projections can give most appropriate projecting of objects with the minimum differences between object dimensions in ellipsoid and projection.

### 3.1 Projecting of territory of the Republic of Kosova in Gauss-Krűger projection

The Gauss-Kruger projection as official for projecting of all objects from ellipsoid to the projection has been in use for the territory of Kosova more than 90 years. During this period, nobody has analyzed the level of adaptability to form and dimensions of Kosova. In a period before year 1999, due to fact that Kosova was a part of former Yugoslavia, it was impossible to make this kind of analyses only for Kosova's territory. After its independence, KCA as a national geodetic and mapping organization, during defining of new state coordinate system, have obtained map projection with all parameters from older one which was in use up to year 1999, without any scientific research for most appropriate state map projection. Based on the theory of map projections, because the form of Kosova is lengthened along the meridian, Gauss-Kruger projection is adaptable to form and dimensions of Kosova.
With target to find most appropriate map projection with minimum values of linear deformations, i.e. nearness length of distances between ellipsoid and projection, firstly the state map projection, as well as the tangential chase has been analyzed.
State map projection of Kosova, as a part of coordinate system KOSOVAREF01, with linear deformations from -1dm/km along the central meridian (21ºE), i.e. 0.9999 scale factor, provides the linear deformations in interval between -1dm/km to –2.1cm/km. In this case, mean linear deformation calculated from grid test model is 8.7cm/km. In figure 3 have been given the isocholes of state map projection of Kosova in interval 1cm/km, where can be shown so clear that all deformations have the negative prefix.
In a second effort with utilization of tangential cylinder, i.e. 1.0000 scale factor, the linear deformations are in interval from 0 to 7.9cm/km. In this case, against to state projection, all linear deformations have the positive prefix, except very small area without deformations. Dispersion of isocholes in this variant can be seen in figure 4. The mean linear deformation calculated from grid test model is 1.3cm/km.
With aim to dimidiate the maximum linear deformation calculated in tangential case, as a third variant have been used the -4cm/km negative linear deformation along the central meridian (21ºE). In this variant, linear deformations were in interval from -4 to 3.9cm/km, in which the mean linear deformation is 2.93cm/km from grid test model. Isocholes of this third variant are shown in figure 5.
Because of the difference between linear deformation at eastern and western extreme points, which is the result of difference distances between central meridian (21ºE) and those points, the average value of deformations on extreme eastern and western points (3.3cm/km) has obtained as fourth researched variant. In this case scale factor on central meridian is 0.999967, in which the interval of deformations is from -3.3 to 4.6cm/km. The mean linear deformation calculated from grid test model is 2.46cm/km. Isocholes of this variant can be seen in next figure 6.

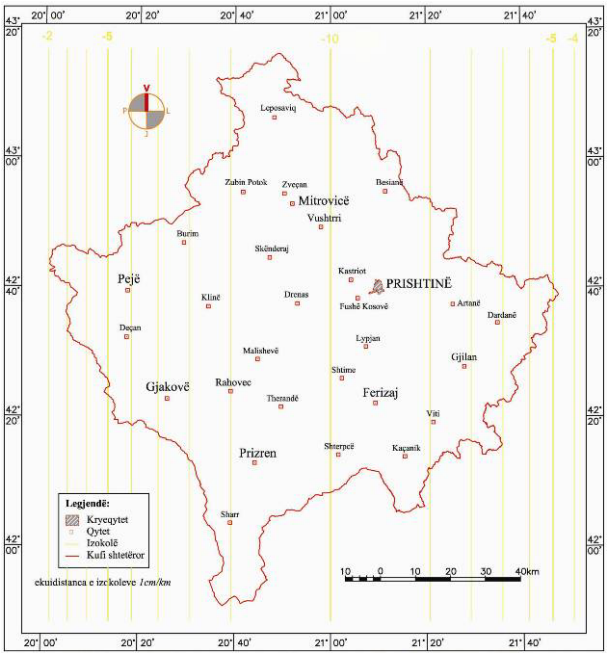


*Figure 3. Isocholes in KOSOVAREF01 (Bajrami, 2008)*

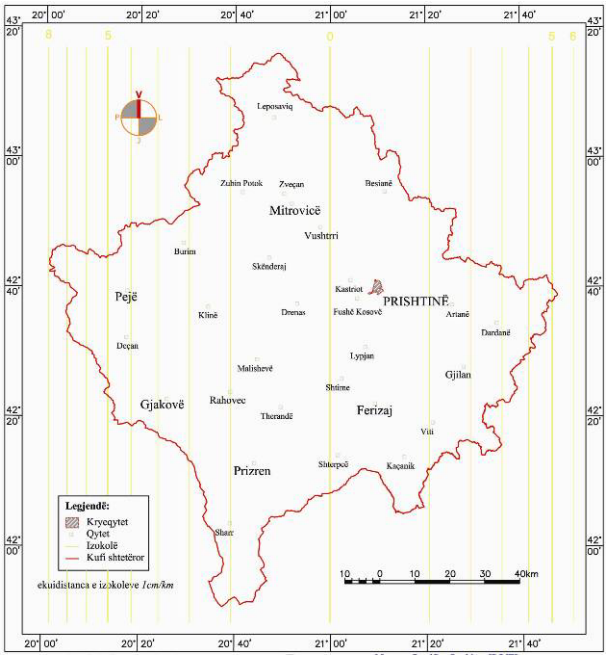


*Figure 4. Isocholes in Gauss-Kruger projection with scale factor 1 (Bajrami, 2008)*

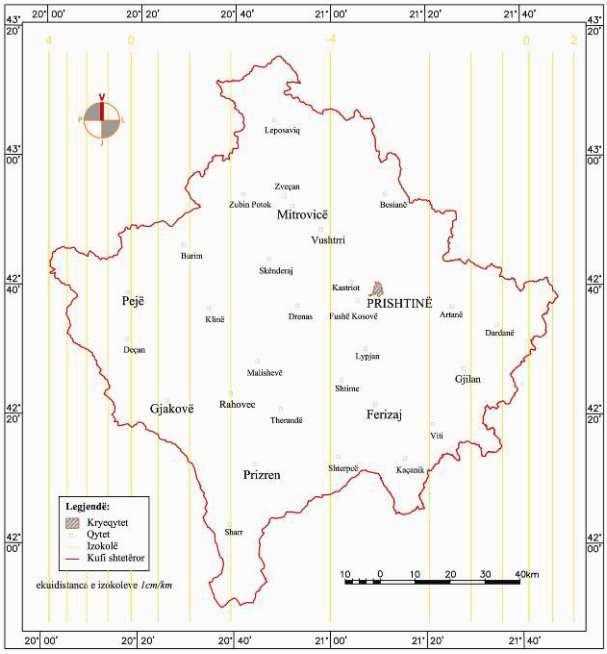


*Figure 5. Isocholes in Gauss-Kruger projection with scale factor 0.99996 (Bajrami, 2008)*

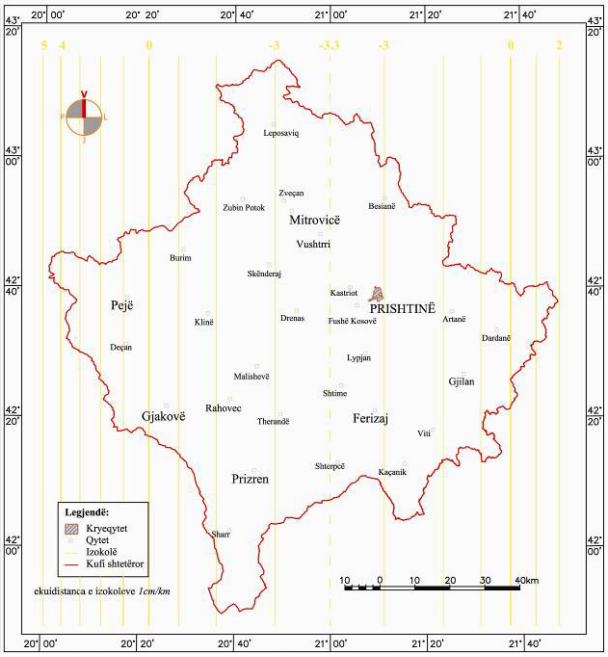


*Figure 6. Isocholes in Gauss-Kruger projection with scale factor 0.999967 (Bajrami, 2008)*

Results from above four researched variants are given in next table 3, where it is so clear that the variant with smaller mean linear deformation is tangential variant, and Gauss-Krűger projection with scale factor 0.99996 gives the smaller value of largest linear deformations.

*Table 3. Results from Gauss-Kruger projection in four variants obtained from grid test model*

| | KOSOVAREF01 ($m_o$=0.9999) | $m_o$=1 | $m_o$=0.99996 | $m_o$=0.999967 |
|---|---|---|---|---|
| Θ | 8.7cm/km | 1.3cm/km | 2.93cm/km | 2.46cm/km |
| **ΣΔdΔd** | 8440.26 (cm/km)$^2$ | 452 (cm/km)$^2$ | 1055 (cm/km)$^2$ | 746 (cm/km)$^2$ |
| $m_0$ | 8.84cm/km | 2.05cm/km | 3.13cm/km | 2.63cm/km |
| $d_{max}$ | -10cm/km | 7.9cm/km | -4cm/km | 4.6cm/km |
| ***Dispersion of deformations*** | -2.1 to -10cm/km | 0 to 7.9cm/km | -4 to 3.9cm/km | -3.3 to 4.6cm/km |
| ***d* positive** | - | 87.30% | 7.04% | 10.85% |
| ***d* negative** | 100% | - | 92.45% | 88.48% |
| ***d* without deformation** | - | 12.70% | 0.51% | 0.67% |

## 3.2 Projecting of territory of the Republic of Kosova in stereographic projection

In a case of using stereographic projection, Kosova's modified center point represents the beginning of coordinate system. With aim to eliminate negative orthogonal coordinates, its false easting and northing values followed by geographic coordinates are given in table 4.

*Table 4. Geographic and orthogonal coordinates of central point in all variants of Stereographic and Lambert conform conic projections*

| $\varphi_0$ | $\lambda_0$ | *Y (m)* | *X (m)* |
|---|---|---|---|
| 42º 33'30" N | 20º 54'30" E | 7500000 | 4500000 |

Stereographic projection as second utilized map projection for finding of most appropriate state map projection, according to characteristics of this projection and the dimensions and form of Kosova, gives the possibilities for right dispersion of linear dimensions from central to extreme points. Because of the need to define the largest linear deformation, firstly the tangential variant, i.e. without negative linear deformations, has been used. In this variant, the linear deformations are in interval from 0 to 4.18cm/km, in which mean linear deformation calculated from grid test model is 1.17cm/km. Due to tangential touch between ellipsoid and projections flat, all deformations are with positive prefix, except very small area without deformations. In a figure 7 are given the isocholes with 1cm/km interval also.

With the similar methodology of dimidiating of linear deformations with implementing of negative linear deformation with value equal to halve of maximum linear deformation from the tangential case, firstly negative linear deformation of -2.1cm/km, i.e. scale factor 0.999979 have been utilized, in which the linear deformations were in interval from -2.1 to 2.08cm/km, with the mean linear deformation from grid test model 1.08cm/km. Dispersion of isocholes for this variant are given in figure 8.

Due to differences between linear deformations on extreme points of Kosova, the scale factor of the third variant of this kind of projection was calculated as average value from four deformations on extreme points calculated in first (tangential) variant. After calculation, third variant has a scale factor 0.999981, which means that linear deformation in central point is -1.9cm/km. In this case, linear deformations are in interval from -1.9 to 2.28cm/km, in which mean linear deformation from grid test model is 0.94cm/km. Dispersion of isocholes in this variant is given in figure 9.

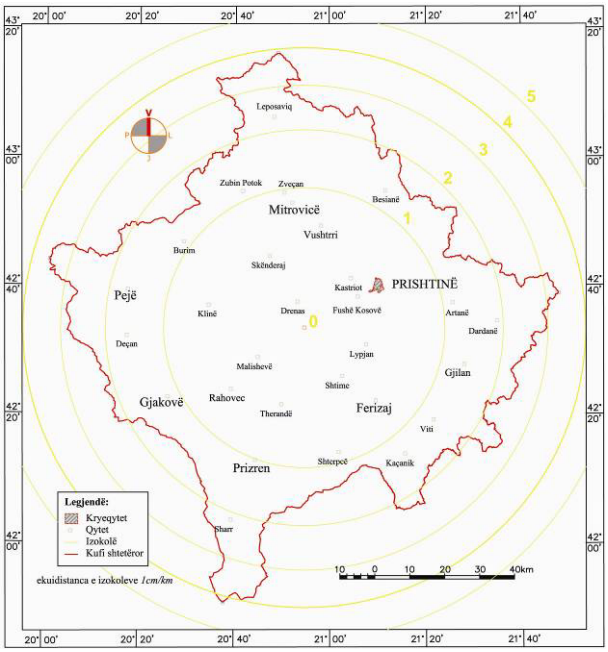


*Figure 7. Isocholes in Stereographic projection with scale factor "1" (Lubishtani, 2008)*

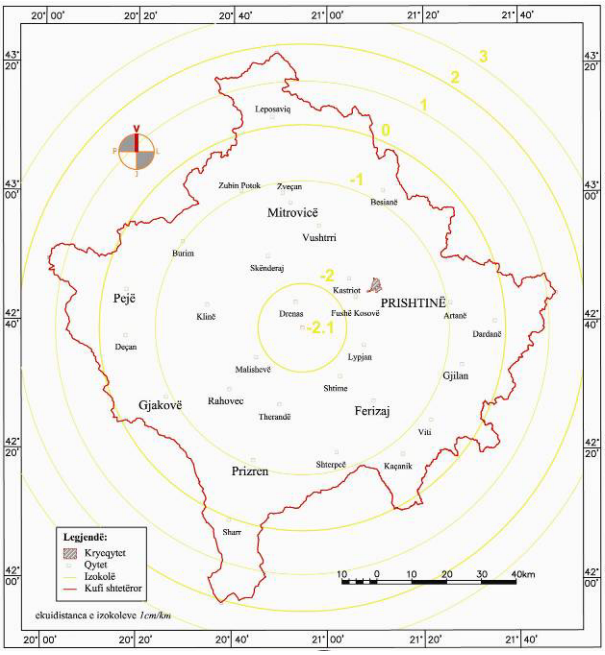


*Figure 8. Isocholes in Stereographic projection with scale factor "0.999979" (Lubishtani, 2008)*

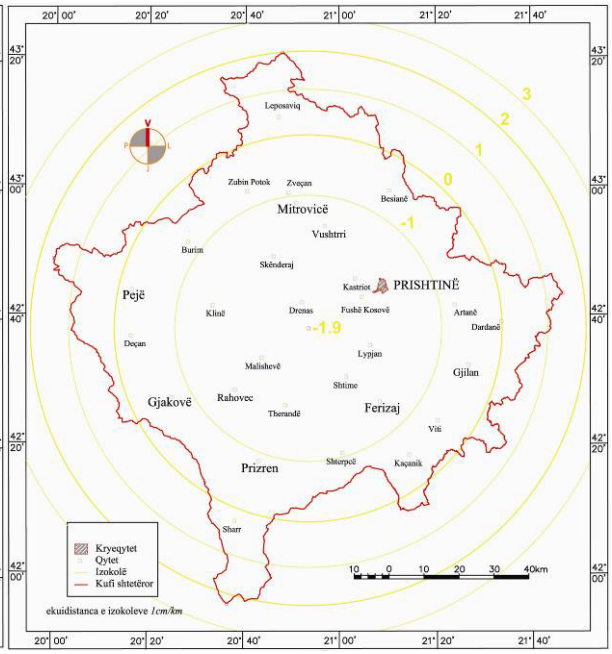


*Figure 9. Isocholes in Stereographic projection with scale factor "0.999981" (Lubishtani, 2008)*

Results from above three researched variants of stereographic projection are given in next table 5, where it is so clear that the variant with smaller mean linear deformation is variant with scale factor 0.999981, and stereographic projection with scale factor 0.999979 gives the smaller value of linear deformations.

*Table 5. Results from stereographic projection in three variants obtained from grid test model*

| | $m_o$=1 | $m_o$=0.999979 | $m_o$=0.999981 |
|---|---|---|---|
| Θ | 1.17cm/km | 1.08cm/km | 0.94cm/km |
| ΣΔdΔd | 219 (cm/km)$^2$ | 164 (cm/km)$^2$ | 128 (cm/km)$^2$ |
| $M_0$ | 1.42cm/km | 1.23cm/km | 1.09cm/km |
| $d_{max}$ | 4.18cm/km | -2.1cm/km | 2.28cm/km |
| *Dispersion of deformations* | 0 to 4.18 cm/km | -2.1 to 2.08cm/km | -1.9 to 2.28cm/km |
| *d* positive | 97.67% | 12.04% | 16.46% |
| *d* negative | - | 85.89% | 80.91% |
| *d* without deformation | 2.33% | 2.07% | 2.63% |

## 3.3 Projecting of territory of the Republic of Kosova in Lambert conform conic projection

The same way of research has been used in a case of utilization of Lambert conform conic projection as Kosovas map projection also. Lengthened of the territory of Kosova along the parallel was the main criterion for its usage. Beginning of coordinate system in this case was defined at cross point between the parallel with the value of latitude 42º 33'30"N and meridian with longitude 20º 54'30"E, which defines the "central" point of Kosova. Values of false easting and northing are the same as in a previous used projection, i.e. table 4.
With aim to calculate the largest linear deformation in a case of Lambert projection, tangential variant with central parallel (42º 33'30"N) was utilized. The interval of linear deformations in tangential variant is from 0 to 7.69cm/km, which mean that all deformations have positive prefix, i.e. they are longer in projections flat in comparing with them before projecting from ellipsoid, except very small area without deformations. Mean linear deformation obtained from grid test model is 1.14cm/km. In figure 10 have been given the isocholes of this variant.
In a same way as in both previous map projections, with target to dimidiate linear deformations by implementing of negative linear deformation along the central parallel with value equal to halve of maximum linear deformation from the tangential case, as well as to have the right dispersion of deformations in all territory of Kosova, negative linear deformation of -3.8cm/km (scale factor 0.999962) along the central parallel have been utilized, in which the linear deformations were in interval from -3.8 to 3.79cm/km, in which the mean linear deformation from grid test model is 2.85cm/km. Dispersion of isocholes for this variant is given in figure 11.
Results from above two researched variants of Lambert conform conic projection are given in next table 6, where can be seen so clear that the variant with smaller mean linear deformation is tangential variant with scale factor 1, and the Lambert projection with scale factor 0.999962 gives the smaller value of linear deformations.

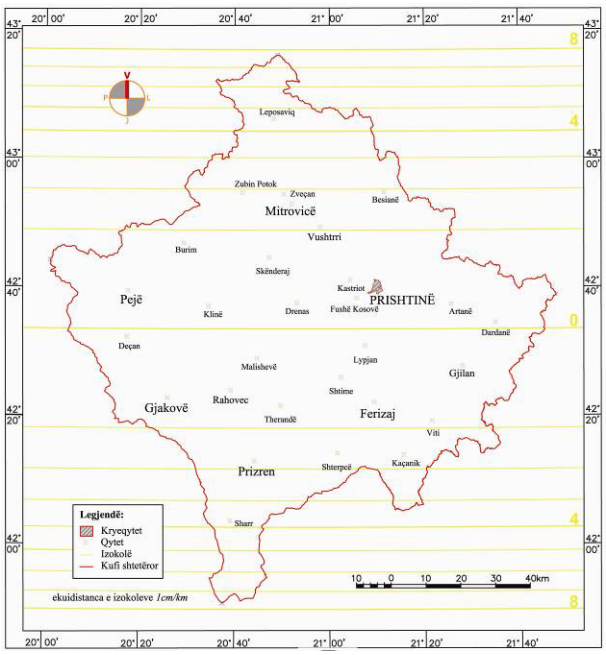


*Figure 10. Isocholes in Lambert projection with scale factor "1" (Lubishtani, 2008)*

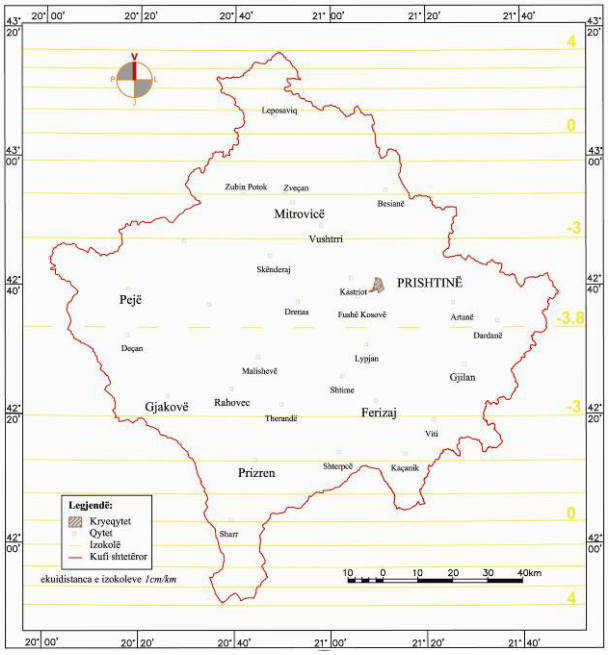


*Figure 11. Isocholes in Lambert projection with scale factor "0.999962" (Lubishtani, 2008)*

*Table 6. Results from Lambert projection in two variants obtained from grid test model*

| | $m_0$=1 | $m_0$=0.999962 |
|---|---|---|
| **Θ** | 1.14cm/km | 2.85cm/km |
| **ΣΔdΔd** | 374 (cm/km)$^2$ | 993 (cm/km)$^2$ |
| $M_0$ | 1.86cm/km | 3.03cm/km |
| $d_{max}$ | 7.69cm/km | -3.8cm/km |
| ***Dispersion of deformations*** | 0 to 7.69 cm/km | -3.8 to 3.79cm/km |
| ***d* positive** | 84.34% | 92.51% |
| ***d* negative** | - | 7.11% |
| ***d* without deformation** | 15.66% | 0.38% |

## 3.4 Projecting of territory of the Republic of Kosova in UTM projection

At the end of research, an analysis of the level of utilization of UTM projection is inalienable. It descends from the international importance of UTM projection. According to tile reference, all territory of the Republic of Kosova belongs to 34th zone of UTM projection, with central meridian 21ºE.

Six degrees width of projecting zones, directly have an impact to largest deformations in comparison with previous options, with target to project all elements with linear deformation smaller or equal to 4dm/km, with negative or positive prefix, in which the largest deformations are in central (-4dm/km) and border (+4dm/km) meridians of UTM zones. Because of the big difference between width of UTM projection zone (6º longitude) and width of the territory of Kosova (1º46'31.8" longitude), utilization of UTM projection provides so large linear deformations, which are in limits from -4dm/km along the central meridian to -

39.21cm/km in a western point, which mean that all linear deformations have the negative prefix. In this case the mean linear deformation for Kosova based on grid test model is 38.7cm/km. Dispersion of isocholes is given in next figure 12.
In this case there aren't possibilities to use other values of scale factor, because the UTM projection has forward defined parameters, which can't be modified.
Results from research of UTM projection are given in next table 7, where can be seen so clear that the value of linear deformations are so large in comparison with previous variants.

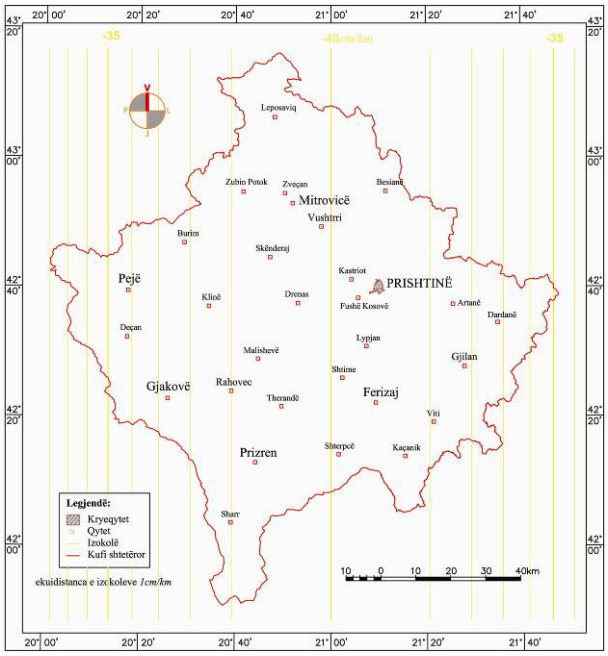


*Figure 12. Isocholes in UTM projection – zone 34 (Idrizi B., at al, 2009)*

*Table 7. Results from UTM projection obtained from grid test model*

| | $m_0=1$ |
|---|---|
| Θ | 38.7cm/km |
| **ΣΔdΔd** | 161988 (cm/km)$^2$ |
| $M_0$ | 38.73cm/km |
| $d_{max}$ | -40cm/km |
| ***Dispersion of deformations*** | -32.11 to -40 cm/km |
| ***d* positive** | - |
| ***d* negative** | 100% |
| ***d* without deformation** | - |

## 4. CONCLUSIONS

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 negative linear deformation along the central meridian. Due to the small area of Kosova, all territory projects with negative value i.e. mean linear deformation is 8.7cm/km.

In efforts for finding of coordinate system with smallest linear deformations, Gauss-Krüger projection with scale factors 0.99996 and 0.999967 were researched, as well as without negative linear deformations (tangential case) also. In first variant (0.99996) the maximum linear deformations is 4cm/km, in which 2.93cm/km is the mean linear deformation for the whole territory. The second option (0.999967) provides the biggest linear deformations 4.6cm/km, with mean linear deformation from 2.46cm/km. Gauss-Krüger projection in tangential variant gives the better mean value (1.3cm/km), but the largest linear deformations is 7.9cm/km.

Due to the configuration of the territory of Kosova, Lambert conic conformal and stereographic projections are probably the suitable as most appropriate state map projection. UTM projection as international has been utilized also.

In a stereographic tangential projection the linear deformations are all with positive prefix with the largest value 4.18cm/km, in which case the mean value of linear deformation for whole territory is 1.17cm/km. With the target to reduce the deformations in half value, due to the difference distances of extreme points from the central point, -2.1cm/km (0.999979) and -1.9cm/km (0999981) linear deformations in central point were used as extended options of stereographic projection. In first case deformations the maximum linear deformation is -2.1cm/km, in which the mean value of deformations is 1.08cm/km, as well in a second effort, the biggest deformation is 2.28cm/km with 0.94cm/km mean linear deformation.

During projecting of the territory in Lambert conic conformal projection, in tangential case the largest linear deformation is 7.69cm/km, in which mean linear deformation of the whole territory is 1.15cm/km. Using of negative linear deformation from -3.8cm/km (0.999962) gives the interval of deformations from -3.8 to 3.89cm/km with 2.85cm/km mean linear deformations in whole territory.

Because of the small area of Kosova, utilization of UTM projection provides very large linear deformations, i.e. in interval between -39.21 to -40dm/km. Mean deformation in all territory is 39.87cm/km.

During the analyses, values of area and length of the border line in all researched variants have been calculated also. Those results are given in next table 8.

*Table 8. Area and length of border line of the Republic of Kosova projected in several map projections*

| **Map projection** | **Area** | **Border line** |
|---|---|---|
| KOSOVAREF 01 (Gauss-Krüger, $m_o$=0.9999) | 10906.05 km$^2$ | 744.042 km |
| Gauss-Krüger ($m_o$=1) | 10908.23 km$^2$ | 744.117 km |
| Gauss-Krüger ($m_o$=0.99996) | 10907.36 km$^2$ | 744.087 km |
| Gauss-Krüger ($m_o$=0.999967) | 10907.51 km$^2$ | 744.092 km |
| Stereographic ($m_o$=1) | 10908.23 km$^2$ | 744.118 km |
| Stereographic ($m_o$=0.999979) | 10907.77 km$^2$ | 744.103 km |
| Stereographic ($m_o$=0.999981) | 10907.81 km$^2$ | 744.104 km |
| Lambert conform conic ($m_o$=1) | 10908.20 km$^2$ | 744.118 km |
| Lambert conform conic ($m_o$=0.999962) | 10907.38 km$^2$ | 744.090 km |
| UTM | 10899.50 km$^2$ | 743.819 km |

Based on upper results, most appropriate state map projection of the Republic of Kosova for local use is Stereographic projection with scale factor 0.999979, but utilization of UTM projection for international use is irreplaceable.

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