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# CORRECTION OF CADASTRAL MAPS USING DIFFERENT ADJUSTMENT METHODS

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## Abstract

Cadastral work in Absheron during the land reform period in 1996. There are several types of cadastral plans created with different production methods, coordinate systems, basic types, and measurement and acquisition methods. The Krassovsky coordinate system (SK-42) is used in land reform by scanning top plans. Later, in the cadastral work, the coordinates of the computer programs used to convert these map coordinates to WGS-84 coordinates were copied. Complex development has occurred in the existing cadastral system. In the WGS-84 coordinate system, errors occur when using coordinates obtained from the GNSS in plans created on the basis of the Krassovsky coordinate system (SK-42). These errors depend on differences in ternary spatial Cartesian coordinate systems, ellipsoidal or tometric heights, planar projections, and planar rectangular coordinate systems. Assigning the necessary geodetic methods to the state national coordinate systems of the existing cadastral maps is a repair. There are many coordinate transformation methods for this purpose. Although the least square (LS) adjustment method is widely used, it has some disadvantages in determining measurement errors. Least value of the error measurement (LAV) and its impact on other measurement results. For the final budget parameters, the generalized least squares (TLS) method is often used. In such transformations, the solution of changing the affine transformation method also depends on the adjustment of the obtained unique and most suitable parameters. The method of coordinate transformation was applied when the inconsistencies were not eliminated during the blocking of cadastral data to the redrawn cadastral maps in the WGS-84 coordinate system.

**Keywords:** affine coordinate transformation; method of regulation; least used method; cadastral work.

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## 1. Introduction

Cadastral changes include legal actions and the correction of changes resulting from changes. A cadastral change is a change in low-level single objects and a topological structural change showing several parcels at a high level. This includes combinations, splits, and rearrangements of parcels. This is called a change in the cadastral structure. It occurs in many cities in the cadastral structure and is the basis for the analysis of changes in the cadastre and updating of data. The investigated cadastral changes are related to spatial changes, which are the first level. Grounds that ensure the validity and fair resolution of cadastral changes in location. Clarification of

the causes of errors in cadastral maps is defined as an important goal for solving these issues.

The cadastral system is a method of obtaining spatial and nonspatial information such as boundaries, geographic locations, and personal rights of land plots. According to cadastre researchers, "cadastre is an important factor in the national economy that creates a strong foundation for human existence." In addition, land and land management systems provide opportunities for sustainable national development (4).

The cadastral works in Absheron have been carried out since 1890, after the invasion of the Caucasus by the Russian Empire under the private company system. This system was mentioned because its special principle was not preserved in the formation of the Soviet system. However, in 1996, for the first time in the old Soviet Union, land reform was carried out in Azerbaijan, and the forms of land state municipality and private individuals were recognized. In precincts, land reform is carried out on the basis of digital maps created by digitizing plans in the Soviet space. Later, those cadastral maps were established as the main cadastral system.

Technological changes in 2001; the International Terrestrial Reference Frame (ITRF) was adopted as the basic reference for Azerbaijan. Therefore, it was necessary to transform the cadastral maps up to this date. Although there are several ways to transform cadastral maps, cadastral maps using the correct transformation method help transform entire WGS-84 coordinates.

Therefore, in the use of these maps, systematic and unsystematic errors arise from production and measurement methods. Additionally, these maps deformed over time during the scanning of cadastral maps, and measurement errors occurred in the obtained point coordinates.

Thus, new cadastral maps were created by carrying out cadastral measurements again, and transferring cadastral data from original maps to new maps became necessary. A three-stage workflow used to improve the spatial accuracy of digital cadastral maps in international practices is presented: global transformation from the old local system to the GPS-based WGS84 system; transformation of the rubber layer to change the boundary corners to adapt to the existing soil characteristics; and LS adjustment with stochastic constraints to include additional cadastral data and geometric terms (2). The transformation of the original land reform maps created in the research area according to international practice was considered to increase the accuracy of information in cadastral verification work.

The cadastral work in the territory of Absheronis was investigated, the cadastral map of the villages of the region was selected, and the best adjustment method was determined via numerical application. The process of correcting the cadastral maps conducted here includes six stages. First, the pages in the cadastral data are analyzed.

Second, cadastral measurements are carried out by means of a global positioning system (GPS) from end to end. Third, transformation parameters are calculated via common points to transform existing data. Fourth, the coordinates of other parcels are transformed via transformation parameters. In the fifth step, adaptation via rubber layer transformation is conducted. The last step is to validate the cadastral data.

## 2. Differences in the coordinate system

Two coordinate systems are used when creating maps. The first coordinate system is a geocentric three-dimensional Cartesian coordinate system whose origin is at the center of the Earth. The geocentric coordinate system defines the shape of the Earth ellipsoid on which the map is drawn. The second coordinate system is a two-dimensional (x, y) plane rectangular coordinate system. The origin of this coordinate system is taken from a point on the Earth's surface—usually the intersection of the equator and the Greenwich meridian. The local rectangular coordinate system is also called the "topocentric" coordinate system (1).

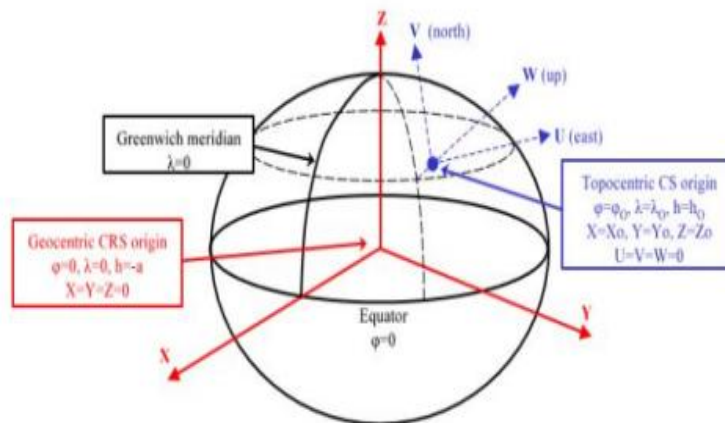


Figure 1. Geocentric and topocentric coordinate systems.

To determine the rectangular topocentric coordinates of raster (electronic) topographic maps in the SK-42 coordinate system, GPS navigators must enter seven transformation parameters into the receiver's memory. These parameters are as follows:

$\Sigma x, \Sigma y, \Sigma z$ - displacement of coordinates;

$\omega x, \omega y, \omega z$  – rotation angles;

$m$  – scaling factor.

The conversion from the SK-42 coordinate system to WGS-84 can be shown as follows:

SK-42 coordinates X, Y, Z WGS-84

here,

$$\Sigma X = X \text{ WGS-84} - X_{SK-42}, \Sigma Y = Y \text{ WGS-84} - Y_{SK-42}, \Sigma Z = Z \text{ WGS-84} - Z_{SK-42}$$

$\varphi$  – geodetic width,  $\varphi \text{ SK-42} = \varphi \text{ WGS-84} - \varphi$

$\lambda$  – geodetic length,  $\lambda \text{ SK-42} = \lambda \text{ WGS-84} - \lambda$

a – semimajor axis of the Earth ellipsoid

b – Semiminor axis of the Earth ellipsoid

f – Flattening of the Earth ellipsoid

H – orthometric height measured above mean sea level.

here,

$$f = (a - b)/a$$

For example, a = 6 378 245 m and b = 6 356 863 m for the Earth ellipsoid of the Krassovsky geodetic system. The image of this ellipsoid is shown in Fig.

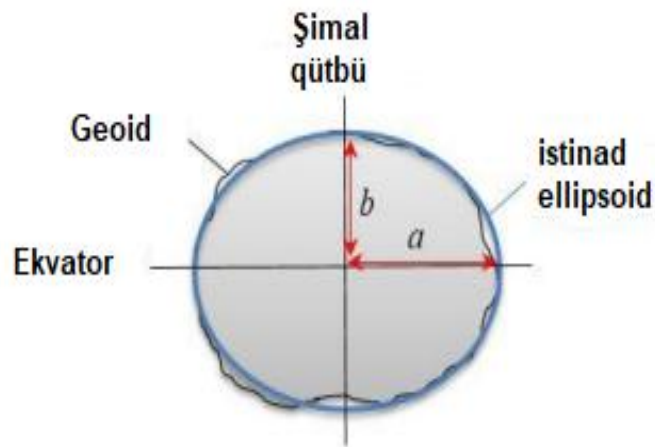


Figure 2. Earth's reference ellipsoid.

$$f = (a - b)/a = (21\,382 \text{ m}) / (6\,378\,245) = 1 : 298.3$$

The values of the transformation parameters between some coordinate systems are shown in Table 1 (3):

Table 1. Transformation parameters between different coordinate systems

Transient parameters	Coordinate systems			
	SK-42 PZ-90*	WGS-72 WGS-84	SK-42 WGS-84	PZ-90 WGS-84
$\Delta X$ (m)	+25	0	+25	0
$\Delta Y$ (m)	-141	0	-141	0
$\Delta Z$ (m)	-80	+4,5	-78,5	+1,5
$m \times 10^{-6}$	0	+0,227	0	0
$\omega_x$ (")	0"	0"	0"	0"
$\omega_y$ (")	-0,35"	0"	-0,35"	0"
$\omega_z$ (")	-0,66"	-0,554"	-0,736"	-0,076"

The PZ-90 (Parameter Zemli 1990, Earth Parameters 1990) geocentric coordinate system was proposed by geodetic scientists of the Russian Federation as a result of GLONASS/GPS measurements (5).

As shown in Table 1, most of the parameters of the SK-42 coordinate system differ from the parameters of the WGS-84 coordinate system. The geographical coordinates of the Krassovsky ellipsoid ( $\varphi$ ,  $\lambda$ ) are converted to the absolute geographical coordinates of the WGS-84 ellipsoid with precise formulas using the seven calculated parameters ( $X$ ,  $Y$ ,  $Z$ ,  $\varphi_x$ ,  $\varphi_y$ ,  $\varphi_z$ ,  $m$ ). This is not enough; the difference between the ellipsoidal and orthometric heights must also be calculated to ensure complete conversion from the SK-42 coordinate system to the WGS-84 coordinate system.

The ellipsoid height ( $h$ ) from the WGS-84 ellipsoid measured by GNSS receivers differs from the orthometric height ( $H$ ) measured above sea level on topographic maps of the SK-42 coordinate system (Fig. 3).

Here,  $N$  is called the geoid height, which is the difference between the ellipsoidal and orthometric heights.

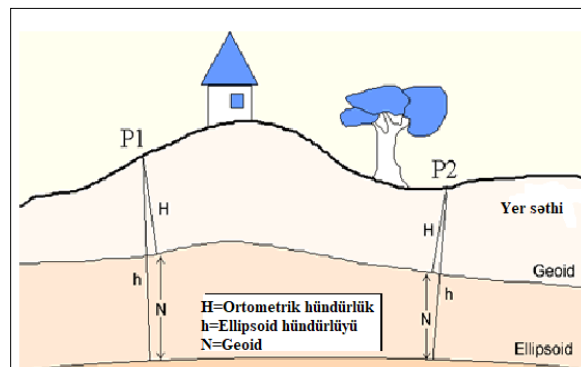


Figure 3. Relationships between ellipsoidal, orthometric and geoid heights (Dave, 2017)

The difference between the ellipsoidal and orthometric heights in Azerbaijan is + 12.6 m, with a value of +10.6 m. The UTM and Gauss–Krüger projections differ from each other in terms of the mathematical requirements of cartography. Owing to the oscillation of the 60-zone projected onto the cylinder in the Gauss–Krüger projection, the scale remains the same everywhere, i.e., 1,000 (4). In the UTM projection, the surface of the 60-zone cylinder is cut along two intersecting lines. In addition, the scale along the central meridian of the zone is 0.9996, and that along the intersection of the ellipsoid is 1.001. These differences are clearly illustrated in Figure 4.

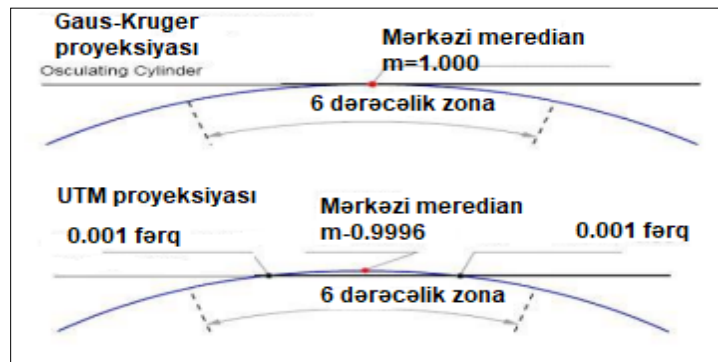


Figure 4. Differences between Gauss–Krüger and UTM projections.

In both projections, the Earth's surface is divided into 60 zones. Each zone is individually projected onto the surface of the cylinder. However, owing to different projections on the surface of the cylinder, the scale changes as it approaches or moves away from the central meridian of the zone. This, accordingly, affects the difference in the coordinates of the maps to which these projections are applied. The difference between the coordinates increases toward the Earth's poles.

The difference in three-dimensional geographic coordinate systems between WGS-84 and SK-42 affects the difference in planar rectangular (topocentric) coordinate systems. The rectangular coordinate system is based on the geographic coordinate system.

All the mentioned errors should be taken into account when we correlate GPS-determined coordinates and ellipsoidal height data in the WGS-84 coordinate system with maps drawn in the SK-42 coordinate system.

When map data are transferred from one coordinate system to another, it is difficult to calculate the projection and orthometric differences in the transformation parameters. For topographic maps of the SK-42 coordinate system, the orthometric height is measured from the mean level of the Baltic Sea, whereas for topographic maps of the WGS-84 coordinate system, the orthometric height is measured from the

mean level of the Atlantic Ocean or the Mediterranean Sea. In addition, the standards of the maps drawn in both coordinate systems are also different.

Serious inconsistencies have arisen in the cadastral map materials since appropriate measures for harmonizing the differences indicated in the creation of cadastral maps were not carried out on the basis of a unified approach. The cadastral system has become unusable because of systematic errors in the construction of existing cadastral maps based on the same system, as well as measurement errors after conversion to the WGS-84 coordinate system. Taking this into account, cadastral measurements were searched again, and the spatial locations of the cadastral maps were clarified.

However, it is necessary to coordinate the transformation of those maps to ensure the compatibility of legal documents and divisions by property type in land reform maps.

Several methods are used in such coordinate transformations. However, affine transformation is one of the most commonly used methods in the transformation of cadastral maps.

### 3. Coordinate transformation of land reform maps

The coordinate transformation procedure involves determining the mathematical relationship between two coordinate systems. To achieve this, it is necessary to have common points known in both coordinate systems.

The transformation parameters are calculated using the coordinates of common points, and then other point coordinates in the I coordinate system are transformed into the II coordinate system via the transformation parameters. The methodology of coordinate transformation has been applied in many fields of science. Coordinate transformation can also be applied to cadastral maps on the basis of a different coordinate system (4).

The transformation of the space into a quadruple consisting of the point  $O$  and the bases  $l_1, l_2, l_3$  on the basis of the arbitrary point  $O$  and the arbitrary basis  $l_1, l_2, l_3$  is called a general Cartesian coordinate or affine coordinate transformation in space. This image is denoted by the symbol  $O|l_1l_2l_3$  or  $(O, l_1, l_2, l_3)$ , as shown in -1.

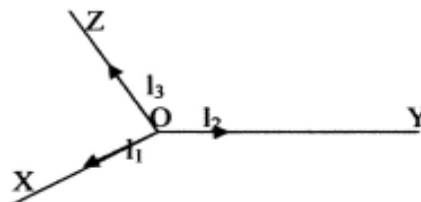


Figure 5. Athenian coordinate system.

In the affine coordinate transformation method, the relationship between two coordinate systems is determined by six parameters, namely, two translations of the coordinate origin, two rotations, and two scale factor coordinate axes, as shown in Figure 1.

Here, the coordinates between the two coordinate systems are as follows:

$$X_i = \lambda_x * x_i * \cos \alpha - \lambda_y * y_i * \sin \beta + X_0 \quad (1)$$

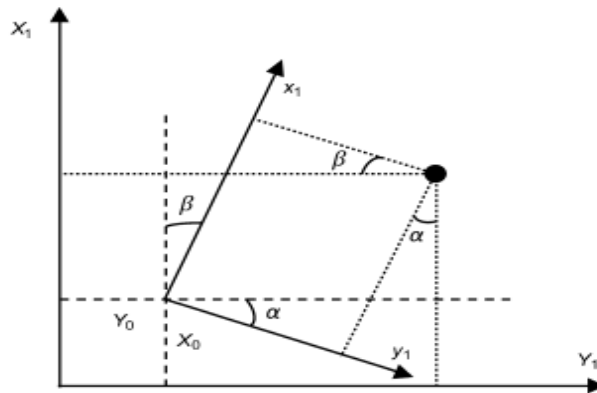


Figure 6. Affine coordinate transformation.

$$Y_i = \lambda_x * x_i * \sin \alpha + \lambda_y * y_i * \cos \beta + Y_0 \quad (2)$$

$$a = \lambda_x * \cos \alpha; b = -\lambda_y * \sin \beta; c = X_0 \quad (3)$$

$$d = \lambda_x * \sin \alpha; e = \lambda_y * \cos \beta; f = Y_0 \quad (4)$$

$$X_i = a * x_i + b * y_i + c \quad (5)$$

$$Y_i = d * x_i + e * y_i + f \quad (6)$$

Here,  $(x_i, y_i)$ ,  $(X_i, Y_i)$ ,  $(\lambda_x; \lambda_y)$ ,  $(\alpha, \beta)$  and  $a, b, c, d, e,$  and  $f$  are point coordinates in the I coordinate system, point coordinates in the II coordinate system, the scale factor of the axes, and the angle of rotation of the coordinate axes, respectively. Although three common points from two different coordinate systems are sufficient to estimate these six parameters, in practice, more common points are used to eliminate measurement errors and achieve more accurate estimates. The transformation parameters of the affine coordinate transformation are estimated via the regularization procedure (5).

#### **4. Results**

LS, LAV and TLS affine transformations of the cadastral parcels selected as a reference were carried out to adapt the country to the national coordinate system. The coordinate system of digital maps created on the basis of scanned maps was considered the I system, and the national coordinate system was considered the II system. The methods were applied to determine the coordinate transformation parameters. The same transformation parameters from the LS and TLS methods and the consistency of the new measurement results were confirmed. Thus, it was decided to continue checking the compatibility of cadastral parcels during further research using the LS and LAV affine transformation methods. Some of the cadastral parcels created on the basis of the scanned maps were transformed into the national coordinate system via this transformation to create a reliable reference.

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