Determination of Geoid And Transformation Parameters By Using GPS On The Region of Kadınhanı In Konya

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Key words: GPS, Geoid Undulation, Ellipsoidal Height, Transformation Parameters.

SUMMARY

As known, three dimensional position (3D) of a point on the earth can be obtained by GPS. It has emerged that ellipsoidal height of a point positioning by GPS as 3D position, is vertical distance measured along the plumb line between WGS84 ellipsoid and a point on the Earth's surface, when alone vertical position of a point is examined. If orthometric height belonging to this point is known, the geoid undulation may be practically found by height difference between ellipsoidal and orthometric height. In other words, the geoid may be determined by using GPS/Levelling measurements.

It has known that the classical geodetic networks (triangulation or trilateration networks) established by terrestrial methods are insufficient to contemporary requirements. To transform coordinates obtained by GPS to national coordinate system, triangulation or trilateration network's coordinates of national system are used. So high accuracy obtained by GPS get lost a little. These results are dependent on accuracy of national coordinates on region worked. Thus results have different accuracy on the every region.

The geodetic network on the region of Kadınhanı in Konya had been established according to national coordinate system and the points of this network have been used up to now. In this study, the test network will institute on Kadınhanı region. The geodetic points of this test network will be established in the proper distribution for using of the persons concerned. Thus the transformation parameters for various cadastral plans created in different coordinate systems and the local geoid will be determined.

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1. INTRODUCTION

The reference coordinate system is defined for finding of a point on the Earth or map according to accepted beginning system. Datum is named as accepted beginning of the reference coordinate sytem used for defining the points on the Earth's surface. Geodetic datums define the size and shape of the earth and the origin and orientation of the coordinate systems used to map the earth.. A geodetic datum based on an ellipsoid that has its origin at the earth's center of mass. Examples are the World Geodetic System of 1984 (WGS-84), the North American Datum of 1983, and European Datum 1950 (ED50). Geocentric datums are more compatible with satellite positioning systems, such as GPS, than are local datums.

Datum types include horizontal, vertical and complete datums. The horizontal datum is a collection of specific points on the Earth that have been identified according to their precise northerly or southerly location (latitude) and easterly or westerly location (longitude). The vertical datum is a collection of specific points on the Earth with known heights either above or below mean sea level. Near coastal areas, mean sea level is determined with a tide gauge. In areas far away from the shore, mean sea level is determined by the shape of the geoid.

Three dimensional networks can be constituted also with satellite techniques (as GPS). The Cartesian coordinates (X;Y;Z) and the ellipsoidal coordinates (φ, λ, h) of points are obtained in the WGS-84. With satellite techniques to establish and densification three dimensional networks and is more rapid, more accuracy, fewer difficult than terrestrial techniques

National geodetic networks were being formed in order to horizontal and vertical location separately up to now. Constitution of three dimensional national networks has been begun with techniques of satellite geodesy as GPS, GLONASS observations. Thus the problem of transformations to global datum and combining geodetic networks has been appeared.

In this study a test area had been chosen for transformation problem and determination geoid. This test area is in Kadınhanı region. The local geodetic network on the region of Kadınhanı in Konya had been established according to national coordinate system and this network have been used up to now. Then for densification the geodetic points of this test network had been established in the proper distribution for using of the persons concerned. The transformation parameters and geoid undulations had been determined

2. GPS and NATIONAL COORDINATE SYSTEM

General Command of Mapping (GCM) is the national mapping agency of Turkey. GCM is responsible for the basic geodetic control Networks, 1:25.000 and smaller scale map production. The Turkish National Datum 1954 (TND54) had been made up by GCM between 1934-1954 years as a result of intensive geodetic studies throughout the country. The Meşedağ had been accepted as a datum of the Turkish National Geodetic Network and this datum adapted to European Datum 1950 (ED-50). ED-50 is a geodetic datum which was defined after World War II for the international connection of geodetic networks. It was based on the international Ellipsoid of 1909 resp. 1924 ("Hayford"-Ellipsoid) (radius of the Earth's equator 6378,388 km, flattening 1:297) and widely used all over the world up to the 1980s, when GRS80 and WGS84 were established.

Many national coordinate systems of Gauss-Krüger are defined by ED50 and oriented by means of Geodetic Astronomy. Up to now it has been used in data bases of gravity field, cadastre, small surveying networks in Europe and America, and by some developing countries with no modern baselines. Turkey has used international Hayford Ellipsoid for national coordinate system since 1946. Universal Transverse Mercator (UTM) projection has been used for 1:25.000 and smaller scale maps, Gauss-Krüger projection is used for big scale maps.

The vertical datum had been made up according to geoid. Antalya meraograph station had been chosen origin point for vertical datum. Then orthometric height of control points had been determined on this datum.

The new geodetic network had been required for local and regional deformation on the national basic geodetic horizontal network which was established by the conventional techniques. So Turkish National Fundamental GPS Network (TUTGA) has been established, to provide reliable and robust geodetic network infrastructure for current and future geo-based data collection technologies (Table 1). TUTGA were established between 1997 and 1999 and it has been realized based on an agreement among General Directorate of Land Registry and Cadastre and General Commander of Mapping. It has been designed as four dimensional (4D). Designing concept is sufficient for all type of small scale, low resolution digital mapping and data collection applications. Datum of TUTGA is International Terrestrial Reference Frame 1996 (ITRF96) at epoch 1998.00. Therefore it is the part of global network. Which means any data collected or map produced based on TUTGA has a global meaning and is globally identified and valid (Çelik et al, 2004).

Table 1. Technical Specifications of TUTGA

Datum	ITRF96
Ellipsoid	GRS80
Number of Control Stations	594
Common with National Geo. Net.	91
Common with Geodynamic Net.	53
Common with Levelling Net.	181
Common with SLR Stations.	5
Range of Control Stations	25-70 km
Density of Control Stations	1315 km2/stn

3. TRANSFORMATION BETWEEN TWO REFERENCE COORDINATE SYSTEM

To fulfill the requirements for transforming data from one reference frame or coordinate system to another is usually resolved by applying coordinate transformation. So transformation parameters can be computed when there are known coordinates of common points at every two system. These transformation parameters define a model relation between two reference coordinate system. There are several transformation models such as Bursa-Wolf Molodensky-Badekas, Veis Model, Thomson-Krakiwsky Model, Helmert Similarity Transformation, Affine transformation. (Hofmann-Wellenhof et al, 1997).

The choice of the most appropriate network transformation model is influenced by such factors as (Rizos, 1999):

- Whether the model is to be applied to a small area, or over a large region.
- Whether one (or both) networks have significant distortions.
- Whether the networks are three-dimensional in nature, 2-D or even 1-D.
- The accuracy required.
- Whether the transformation parameters are available, or must be determined

A transformation in which the scale factor is the same in all directions is called a similarity transformation, and is by far the most widely used of the transformation models. The similarity transformation model may be considered a suitable compromise between elaborate models such as the affine or projection transformations on the one hand, and crude limited parameter models on the other. When used wisely, and with an appreciation of its shortcomings, the similarity transformation is ideal for relating 3-D GPS networks to other GPS or terrestrial networks. In particular, using a similarity transformation on a large network may distort local scale and orientation. Therefore an important consideration is the magnitude of local distortions in scale and orientation. In this regard it should be noted that (Rizos, 1999):

- Similarity transformations will tend to smooth out local distortions.
- It may be more appropriate to divide a region into smaller zones, each with their own set of transformation parameters.
- The results of the transformation may be unreliable outside the area spanned by the common points used to derive the transformation parameters.

3.1. Three-Dimensional Transformation Models

Six parameters are needed to describe the relation between two geodetic reference coordinate system, three translation parameters and three rotations between the coordinate axes. Thus, strictly speaking, no scale distortion should be considered as part of a coordinate transformation, since a scale difference represents a systematic distortion of positions (coordinates) rather than of the reference coordinate system itself (Vanicek and Steeves, 1996).

When coordinate transformations between geodetic reference systems are applied, small values are expected for the rotation and the scale parameters. Thus, assuming rotation parameters of the order of a few seconds of arc, the following form of the 3D similarity transformation is often used (King. et al, 1985).

For the transformation of the geocentric coordinates of a given point on a certain datum to the ones on another datum, Bursa (1962) and Wolf (1963) suggested a simplified form of the three-dimensional Helmert-transformation. As it is a simplification, the Bursa-Wolf method can be used in case of very small (several arc second order) rotations, as follows:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} Tx \\ Ty \\ Tz \end{bmatrix} + (1+k)\underline{R}\begin{bmatrix} U \\ V \\ W \end{bmatrix} \qquad (3.1.)$$

The transformation includes three translation components (the shifting) **Tx**, **T*y***, **Tz** and **R** is a 3×3 orthogonal rotation matrix and a scale component ***k***, which is the deviation of the scale from unity (1+***k***) and is small enough to be expressed in ppm and X, Y, Z are the geocentric coordinates on the target datum. Relationship between 3D coordinate systems is seen Figure 1.

When Bursa-Wolf model invoked for small networks, the rotation parameters highly correlated the translation parameters (Rizos, 1999).

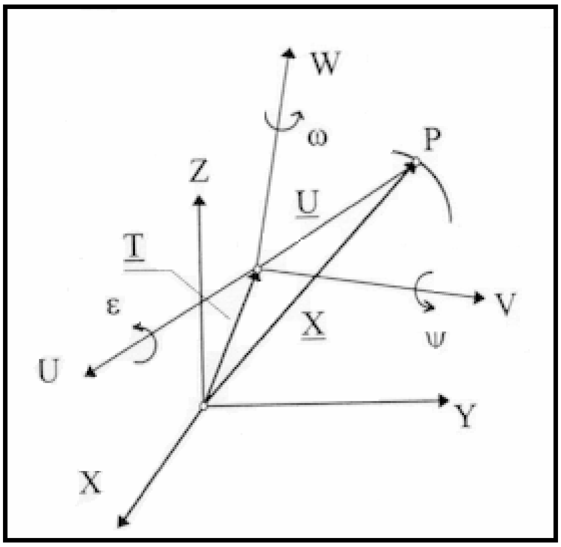

Figure 1. Three dimensional transformation.

3.2. Two-Dimensional Transformation Models

Two-dimensional similarity transformation expresses relationship between two system, two-dimensional coordinate system. The aim of the similarity transformation is to prevent deformation of shape. In this transformation model, the coordinate axes are perpendicular to each other in the own system and it is assumed that scale factor is same on the x axis and y axis in the own system. There is shifting, rotation and scale difference between two coordinate system as (U,V) and (X,Y). Relationship between 2D coordinate systems is seen Figure 1.

In cases of relatively small networks, (less than 100km&100km) two-dimendsional transformation model is often used. The initial 3D Cartesian coordinates are converted to geodetic ones and, finally, to map projection coordinates. Then, the full 2D similarity transformation, with two translation parameters $X_O, Y_O,$ one rotation α and a scale parameter K=(1+k), known as Helmert transformation, is expressed as follows (Hofmann-Wellenhof et al, 1997)

$$\begin{bmatrix} X \\ Y \end{bmatrix} = \begin{bmatrix} X_O \\ Y_O \end{bmatrix} + k \begin{bmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{bmatrix} \begin{bmatrix} U \\ V \end{bmatrix} \tag{3.2}$$

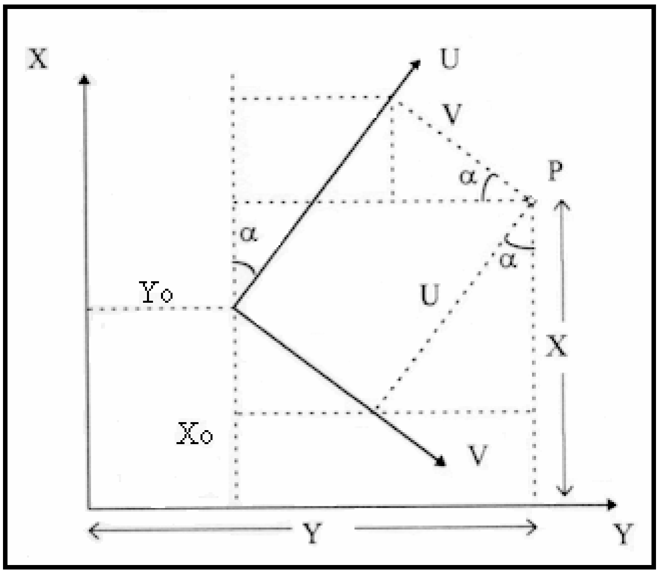

Figure 2. Two dimensional transformation.

4. RELATIONSHIP BETWEEN ELLIPSOIDAL AND ORTHOMETRIC HEIGHTS

If it is talked about height of a point on Earth surface, one can understand it describes relationship between point of interest and geoid. This relationship can be interpreted in both geometric and physical ways. Geometric height of a point on Earth surface is a distance described along the plumb line between this point and geoid (Demirel, 1984).

In practice, height of any point is referred to mean sea level, especially for the countries as Turkey where they have no coast to any ocean, an internal sea (i.e. Mediterranean sea) is usually chosen as a reference surface for heights. This surface is also called as "mean sea level surface. Mean sea level surface is sufficient to provide a unified reference system for height measurements in a country. When it is provided such height reference system for entire Earth, then it is said that geoid is formed (Baykal, 1982).

The geoid is that level surface of the Earth's gravity field coincides with the mean ocean surface (Torge, 1980). It is that equipotential surface (surface of fixed potential value) which coincides on average with mean sea level

The geoid is essentially the shape of the earth abstracted from its topographic features. It is an idealized equilibrium surface of sea water, the mean sea level surface in the absence of currents, air pressure variations etc. and continued under the continental masses. The geoid, unlike the ellipsoid, is too complicated to serve as the computational surface on which to solve geometrical problems like point positioning. The geoid surface is more irregular than the ellipsoid of revolution often used to approximate the shape of the physical Earth, but considerably smoother than Earth's physical surface. The geometrical separation between it and the reference ellipsoid (as GRS-80) is called the geoid undulation. The orthometric height is the distance H along a line of force from a given point P at the physical surface of an object to the geoid (Figure 3).

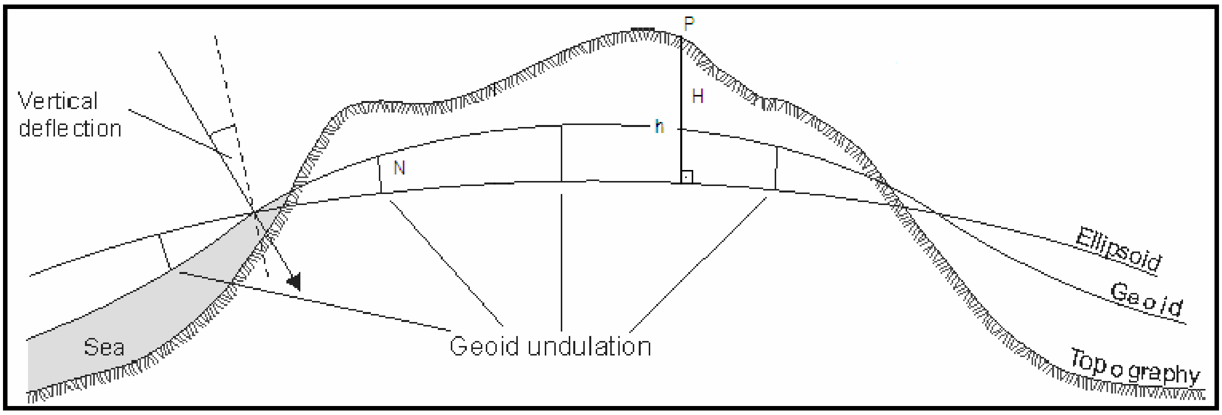

Figure 3. Relationship between ellipsoidal, orthometric height, geoid undulation.

Ellipsoidal height of a point on physical earth as P is equal to the distance between the point P and the point where ellipsoid is touched by the line that passes from the point P and is perpendicular to the ellipsoid.

The heights obtained by GPS are ellipsoidal heights and does not be used in practical geodesy. This ellipsoid is WGS-84 ellipsoid, semi major axis a=6378137m, flattening α=1/298.257223563 (Leick, 1995). If reference coordinate system is defined by ITRF datum, the ellipsoidal height is determined on GRS-80 ellipsoid.

The geometric relationship between the reference ellipsoid -- the datum for ellipsoidal heights -- and the geoid is illustrated in Figure 3 and Figure 4, and defined by the simple equation:

$$\mathbf{N = h - H} \tag{4.1}$$

where **N** is the geoid-ellipsoid separation, or simply the geoid height, or geoid undulation, **h** is the ellipsoidal height and **H** is the orthometric height.

To obtain orthometric heights from ellipsoidal heights determined by GPS, it is required that geoid undulations (N) are known. In a mission area, if height differences of geoid rather than geoid heights and orthometric height of one point are known, it is possible to calculate orthometric heights of other points. Ellipsoidal heights h_A and h_B of points A and B can also be determined by means of equation 4.2, as below;

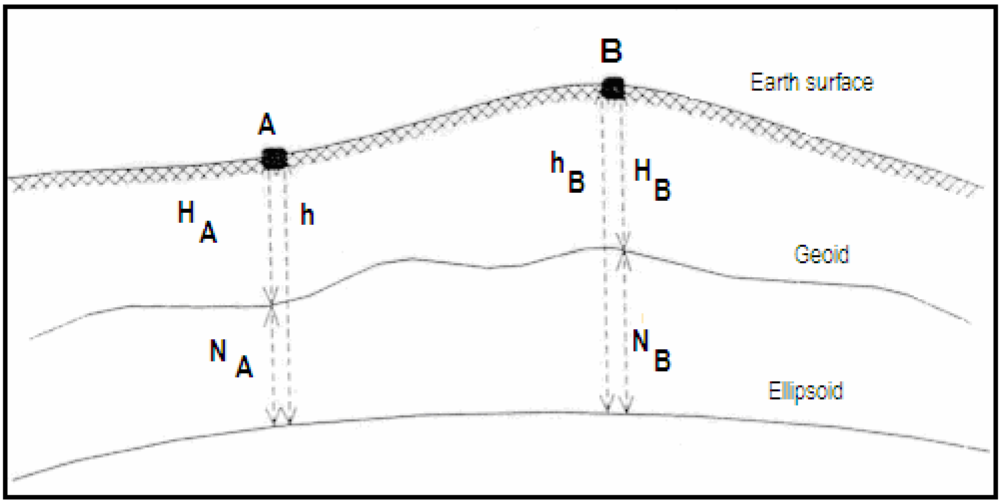

Figure 4. Relative heighting and relationships among height systems.

Using equation 4.2,

$$\Delta h_{BA} = h_A - h_B = (H_A - H_B) + (N_A - N_B) = \Delta H_{BA} + \Delta N_{BA} \quad (4.3)$$

and

$$\Delta H_{BA} = \Delta h_{BA} - \Delta N_{BA} \quad (4.4)$$

can easily be derived (Sideris, 1990). As ellipsoidal height difference is known by GPS, only one problem is computing of dN geoid undulation difference. The basic geoid undulation determination techniques are

1. Astro-geodetic method.
2. Geopotential models
3. Use of surface gravity in techniques such as Stokes' Integral
4. Geometric or interpolation methods: a local representation of the geoid is obtained only at points which have both levelled (orthometric) heights and heights derived using GPS (ellipsoidal). Geoid heights at other points are found by interpolation.

Restructuring and revising efforts of geodetic infrastructure continues in Turkey and also structuring the national geoid model of Turkey is a part of these efforts. So far, regional geoid model of Turkey revised several times. The latest geoid model is “Turkey Geoid 1999A” (TG99A). TG99A geoid model satisfies necessary accuracy for producing large scale maps and routine surveying applications. However, in some parts, this gravimetric based refined geoid model stays weak in accuracy for practical geodetic applications.Local geoid models have a special importance especially for geodetic infrastructure of Turkey. Because, regional geoid model of Turkey hasn’t got homogeneous accuracy in every part of the Turkey. Because of that in some part of the country, it is necessary to be supported with precise local geoid models (Erol and Çelik, 2004).

5. THE APPLICATION

In order to investigate transformation parameters and the variations of geoid undulation, several points at different times were set up and the work was carried out on this study area. The study area is Kadınhanı district within Konya province, total area 150 square km (Figure 5). There is 2 TUTGA points, 4 stations graded by C1, 4 stations graded by C2 appropriately to the Big Scale Map and Map Information Production Regulations (BSH&MIPR) in the study area. There is 54 stations graded by C3 with 4 station graded by C2 in the test area. The fundamental network of Kadınhanı is seen Figure 6. In the test area there is 22 stations which their coordinates are known in TND54.

In the fundamental network, the first section GPS observations had been made on 25-26 July 2003 and the second section GPS observations had been made on 03 December 2003. In the first section, 6 dual frequency Javad receiver and JPSODYSSEY_I antenna integrated into receiver had been used. In the second section, 6 dual frequency Ashtech UZ-12 receiver and Marine L1-L2 antenna had been used. Approximately 2 hours static GPS observation data are recorded with the sampling rate of 10 seconds and with a 15-degree elevation cutoff.

In the test area, GPS observations had been made on 27-29 June 2006. For GPS observations 2 dual frequency Leica GX1230 receiver and AX1201 antenna, 2 dual frequency Leica SR9500 receiver ve AT302 antenna, 2 single frequency Ashtech Promark receiver and ASH110454 antenna had been used in the fundamental network. Approximately 30 minutes rapid-static GPS observation data are recorded with the sampling rate of 5 seconds and with a 15-degree elevation cutoff.

The GPS observations were processed and adjusted in Leica Geoffice 1.0 commercial GPS software. The adjustment had been made appropriately to BSH&MIPR by using the Cartesian coordinates of two TUTGA stations which were fixed at 2003.7068 epoch in ITRF datum. After adjustment, yearly velocity vectors of points, which were graded by C1 and C2, had been estimated by interpolation method (epoch 1998.00). Then the test network which consisted of graded by C3 stations had been adjusted at reference epoch 1998.00.

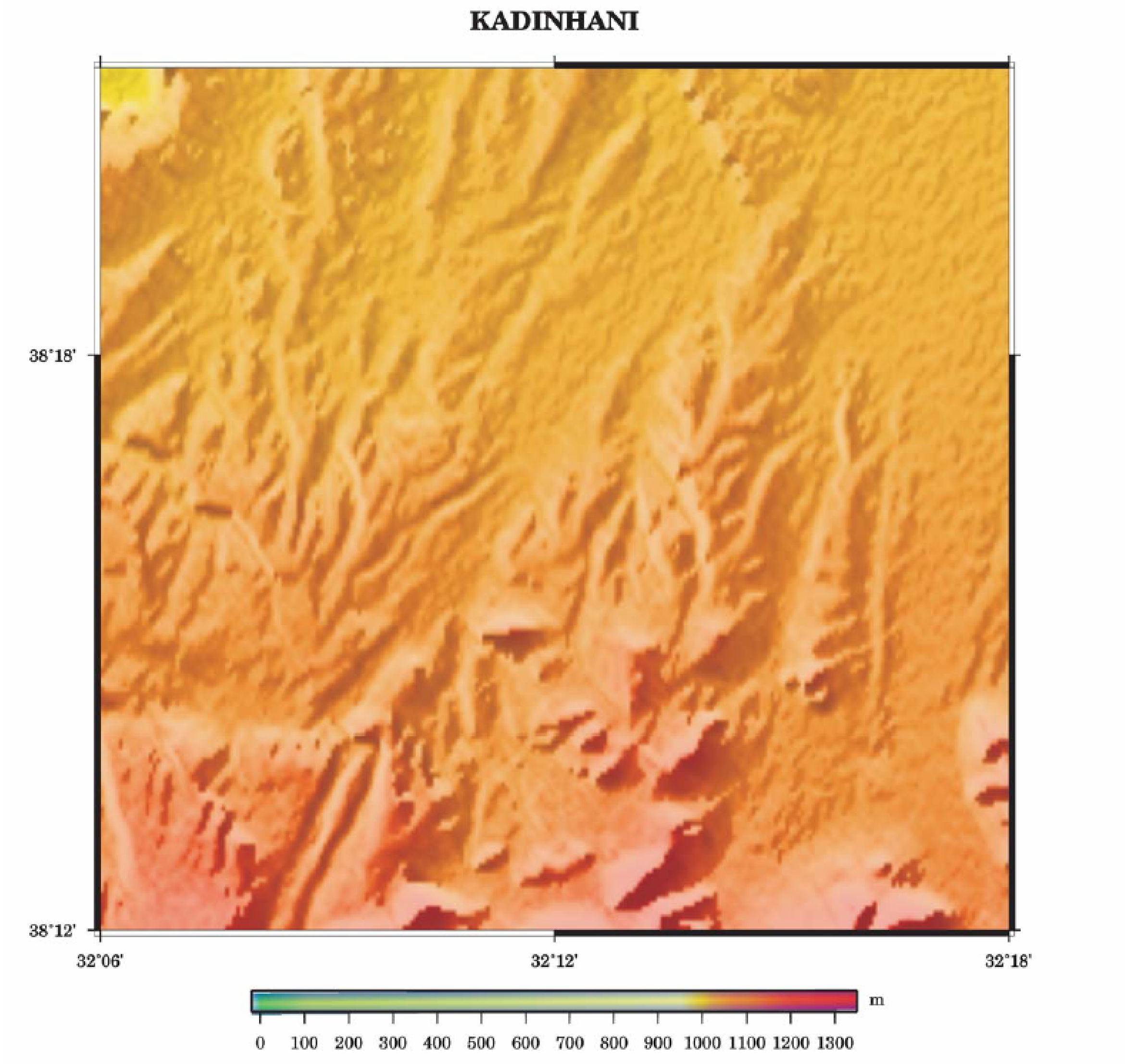

Figure 6. Topograhy of Kadınhanı region, created by GMT (Wessel and Smith, 1998).

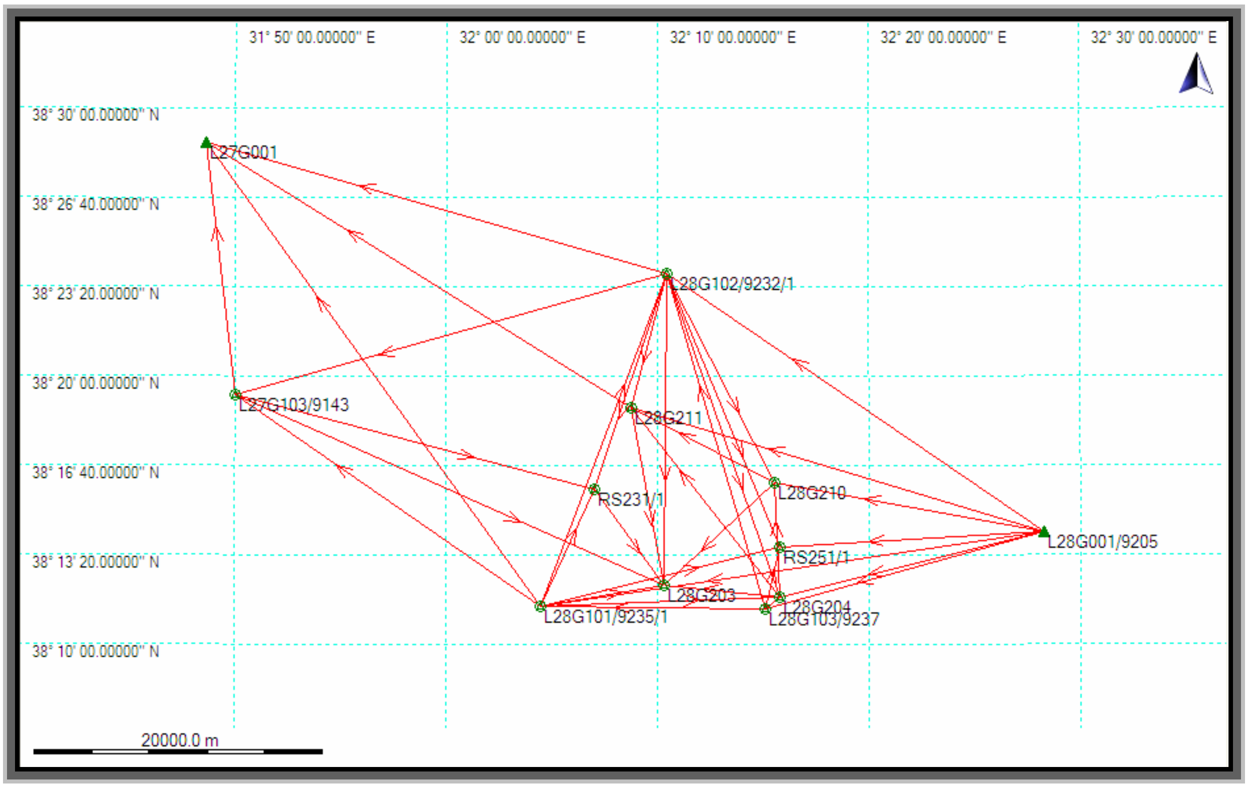

Figure 5. Kadınhanı fundamental geodetic network

The horizontal transformation from ITRF to TND54 had been made by using 2D Helmert similarity transformation model. 22 stations were used in transformation. Root means square of transformation is ±4.3cm. Transformation parameters between ITRF and TND54 are given in Table 1.

Table 1. Transformation parameters between ITRF and TND54

Rotation origin	Y0:	430294.057 m.	
	X0:	4236263.581 m.	
Parameter	**Value**	**R.m.s.**	**Dim.**
Shift dy	28.141	0.0092	m
Shift dx	182.899	0.0092	m
Rotation about Z	0.892	0.3361	["]
Scale	12.095	1.6296	[ppm]
Max. North Errror	11.40 cm		
Max. East Error	9.17 cm		
Min. North Errror	0.09 cm		
Min. East Error	0.49 cm		

The orthometric heights of 13 stations are known. Spirit leveling has been carried out to determine orthometric heights of unknown heights of stations. During the spirit leveling, Sokkisha automatic level, staffs with level tube and staff shoes were used. Heights of the 25 points in study area were determined with respect to the point of L28G210 and L28G521. the geoid undulations were determined by using multiquadratic surface fitting. The geoid undulation equation computed surface fitting is given in (5.1). Root means square of surface fitting is ± 2.9 cm. Information about multiquadratic surface fitting is given Table 2.

$$N=A1+A2Y+A3X+A4Y^2+A5XY^2+A6XY+A7X^2+A8X^2Y+A9X^2Y^2 \qquad (5.1)$$

Table 2. Information about multiquadratic surface fitting.

MULTIQUADRATIC SURFACE COFFICIENTS AND HEIGHT ERROS			
A 1 =	36.4679 m	**STATION ID**	**V(cm)**
A 2 =	-0.0000352149	L280517	-0.8
A 3 =	0.0000001517	L280518	0.6
A 4 =	-0.0000000018	L280519	1.4
A 5 =	0.0000000000	L280520	-3.4
A 6 =	0.0000000023	L280521	3.2
A 7 =	0.0000000023	L28G203	-0.6
A 8 =	0.0000000000	L28G204	0.3
A 9 =	0.0000000000	L28G210	-0.1
		L28G211	-0.2
		L28G553	0.0
		L742	-2.5
		L784	1.7
		RS231/1	0.3

Then the stepwise method from SKI 2.3 GPS processing software were used by using height transformation to determine orthometric heights. The regional geoid undulation N=36.787m was obtained from this method (Table 3). The counture lines in Kadınahanı region map are seen Figure 6.

Table 3. Information about height transformation computed by stepwise method.

Height Transformation:				
Number of common points:	13			
Height parameters:	-0.00001023	0.00001105	-36.787m	
Inclination of height reference plane in X-direction:			-0.00059 degree	
Inclination of height reference plane in Y-direction:			0.00063 degree	
Point Id	**GPS [m]**	**orig. [m]**	**transf. [m]**	**res.[m]**
L280517	1181.237	1144.843	1144.782	0.061

L280518	1187.240	1150.826	1150.771	0.055
L280519	1288.083	1251.633	1251.607	0.026
L280520	1233.960	1197.433	1197.477	-0.044
L280521	1164.386	1127.908	1127.878	0.030
L28G203	1323.402	1286.867	1286.878	-0.011
L28G204	1401.703	1365.198	1365.270	-0.072
L28G210	1115.231	1078.650	1078.703	-0.053
L28G211	1074.961	1038.310	1038.279	0.031
L28G553	1070.529	1033.915	1033.926	-0.011
L742	1119.398	1082.810	1082.804	0.006
L784	1111.124	1074.584	1074.511	0.073
RS231/1	1104.941	1068.187	1068.277	-0.090
Mean transformation accuracy for 13 points:	**dHm:**		±0.05m	

5. CONCLUSIONS

In this study. because study area is small, two dimensional transformation parameters for horizontal coordinates (easthing and northing) between ITRF-96 to TND54 was obtained. The maximum error is 11.4 cm and 9.2 cm resptectively northerly and easterly. So these parameters appropriate for the Big Scale Map and Map Information Production Regulations . These transformation parameters can be used for various cadastral plans and points, which are known coordinates in ITRF or TND54.

The root mean square of differences between stepwise method and levelling is ±4.6 cm and between surface fitting and levelling is ± 7.4 cm. According to results the stepwise method may be widely used. If a surface fitting method is used to obtain orthometric heights from ellipsoidal heights, it is necessary to have some known points in the both height systems in an almost certain density. It is also required to know the variations of geoid undulation to reach the best point distribution in the surface fitting.

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BIOGRAPHICAL NOTES

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