The evaluation of the transformation model of the 3-D information between HTRS07 (Hellenic Terrestrial Reference System 2007) and HGRS87 (Hellenic Geodetic Reference System 1987) at the area of Drama

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We present the assessment of the transformation between the HTRS07 (Hellenic Terrestrial System of 2007) and the HGRS87 (Hellenic Geodetic Reference System of 1987) for horizontal coordinates and orthometric heights in the area of Drama. The evaluation was made by GNSS measurements in a total of eight state's geodetic benchmarks. We used static GNSS measurements (with duration of 3 hours) trying to secure as possible rigorous results. We compared the results from the officially accepted transformation model according to the National Cadastre and mapping Agency and the officially released values from the state agencies. The results reveal a good agreement in the case of the horizontal coordinates and at the same time problematic behaviour for the height information. The RMS for the case of the horizontal differences does not exceed the level of 5 cm, which is better than the national-wide RMS performance (8.3 cm). On the other hand, the height differences reveal a bias of -18.5 cm, which is a clear indication of systematic inconsistencies. In addition, we found that one of the state's benchmark shows the horizontal inconsistency of more than 250 cm which probably corresponds to a blunder of the initial least squares adjustment of the network and it is not controlled so far. The consistency above was conformed from a test to a geodetic network established in a marble quarry in the area of Drama.

Key words: *transformation assessment, ETRS89, datum, GNSS, HTRS07, quarry*

Introduction

The Hellenic Terrestrial Reference System 2007 (Hellenic Terrestrial Reference System 2007- HTRS07, Katsambalos et al., 2010) is a local densification of the European Terrestrial Reference System 1989 (European Terrestrial Reference System 1989- Gubler et al. 1992, ETRS89 Boucher and Altamimi 2011). The HTRS07 was realised for the implementation of the Hellenic Positioning System (Hellenic Positioning System-HEPOS, Gianniou et al., 2010). Basic priority of HEPOS is providing coordinates in real time with the biggest possible accuracy, with the basic target the faster completion of the Greek Cadastre (Katsambalos & Kotsakis, 2008). Because the HGRS87 (Hellenic Geodetic Reference System of 1987, see HEMCO 1995, Veis 1996) is the official geodetic system of the country (and according to the law the Greek Cadastre referred to it), it was deemed appropriate to keep existing as the only acceptable for the geodetic, topographic and cartographic works. So, it was necessary to create a unified transformation of the coordinates of HTRS07 to HGRS87 for the whole country.

The basic methodology for the implementation of the transformation between HTRS07 and HGRS87 was based to 1) an initial Helmert 3-D similarity transformation in about 2200 control points in the whole country (of the network of the Hellenic Military Geographical Service) and 2) in the gridding of the remaining errors of the transformation (e.g. Dewuhrst, 1990; Katsambalos et al., 2010). The assessment of the transformation procedure from HTRS07 to HGRS87 was based on 150 points distributed over the country and showed mean square (RMS) of the fitting error reaching 8.3 cm for the projection coordinates (E, N) national-wide (Katsambalos et al., 2010). We should underline that the initial Helmert Transformation RMS was estimated at the level of 60 cm. At this point, it must be noted that the fitting error goes beyond 15cm in some regions like Epirus and Eastern Macedonia.

In relation to the HGRS87 orthometric height system, the National Cadastre & Mapping Agency S.A. created a "geometric" geoid model based on the ellipsoid heights as to HTRS07 and the orthometric heights of the control points of the Hellenic Military Geographical Service. It must be emphasised here that the orthometric heights system of the National Cadastre & Mapping Agency S.A has not been officially evaluated (www.hepos.gr).

The objective of this paper is to evaluate the quality of the transition from HTRS07 to HGRS87, based on the official model for the projection coordinates and the orthometric heights in the area of Drama, located in Northern part of the country.

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Methodologies for the evaluation of the transformation between two geodetic reference systems

As we described above, the main tool for the evaluation of the consistency between two reference systems is the well-known Helmert similarity transformation (e.g., Stang and Borre, 1997; Torge, 2001). The Helmert similarity transformation can be applied either in 2-D or 3-D. The use of 2-D similarity transformation is sufficient if the height information is weak or unknown. On the other hand, the 3-D similarity transformation is used in order to assess the full 3-D quality of their consistency (e.g. Cai 2000, Dermanis and Fotiou, 1992). It is also possible to investigate the quality of the reference frame consistency by separating the horizontal and the vertical coordinates. Then the vertical part (e.g., the orthometric heights) could be evaluated using some fitting surfaces. For more details regarding the height transformation procedure, see e.g. Kotsakis and Sideris (1999) and Hofmann-Wellenhof, H. Moritz (2005).

As far the observational methods are concerned, the most appropriate technique is the GNSS measurements. The GNSS measurements offer rigorous 3D estimation and relatively good accuracy. For example, after a few hours of observations, the accuracy for the most of the cases is below 1 cm (e.g. Hofmann-Wellenchoff et al., 2001; Labant et al., 2012). A major problem with the old geodetic datums is the poor knowledge of the geoidal heights. The only vertical information was related to the orthometric heights of the benchmarks (Takos 1989). However, dealing with the 3D information one should obtain reliable geoidal undulation, in order to convert the orthometric to ellipsoidal heights, respectively. This is achieved by using a modern global or local geoid model.

Finally, we should point out that the Helmert transformation can reveal the inherited inconsistencies of the old datum. For instance, the large scale difference between the old datum and a modern geodetic reference frame is an indicator of problematic scale definition of the old one, respectively.

Study area and GNSS data processing

For the evaluation of the transformation, 15 Hellenic Military Geographical Service control points (out of 102) of the sheet "Drama" was initially planned to be measured. Nevertheless, 7 of them were already destroyed or present steep slope. In Table 1, the 15 control points originally set for the evaluation are outlined. Finally, eight control points were measured with GNSS (static method). The measurements took place between 17th and 18th May 2014. Figures 1,2,3 and 4 present the control points during the measurements. We should notice that the orthometric heights at the state's benchmark were measured with trigonometric levelling, with an accuracy of a few cm.

Tab. 1. The Hellenic Military Geographical Service control points to be measured at Drama. The serial number, the projection coordinates (E, N with respect to the HGRS87, referring to the Transverse Mercator projection), the orthometric height (H with respect to the reference point of the Piraeus tide-gauge) and the observation in relation to the measurement capability are given.

code	**E** [m]	**N** [m]	**H** [m]	**observation**
96025	505203.563	4544297.624	60.29	big slope
96032	504823.216	4545677.208	58.88	destroyed
96049	505054.505	4550370.771	69.92	exists
96052	520138.816	4551552.914	148.50	exists
96058	512062.533	4552465.093	103.10	exists
96062	516657.769	4553925.597	162.33	exists
96065	512261.841	4554478.483	118.40	destroyed
96069	515708.965	4555926.669	148.25	destroyed
96070	509148.975	4555750.361	127.14	destroyed
96072	512301.828	4556165.515	162.56	destroyed
96073	514346.339	4556478.900	425.82	destroyed
96075	506191.311	4556440.353	123.53	exists
96080	514679.736	4557729.710	629.35	exists
96081	508469.763	4557719.825	158.94	exists
96086	502344.345	4559060.657	207.77	exists

Fig. 1. Measurement at the Control Point 96058.

Fig. 2. Measurement at the Control Point 96052.

Fig. 3. Measurement at the Control Point 96080.

Fig. 4. Control Point 96069 (destroyed).

The HTRS07 is a local densification of the ETRS89 (European Terrestrial Reference System of 1989) and specifically its realisation the European Terrestrial Reference Frame 2005 (ETRF-2005). The reference realisation epoch is 2007.5 (Katsambalos et al., 2010). The reference frame of the GNSS network for the present study was realised as follows: The basic reference point was the DUTH in Xanthi, belonging to the European Permanent Network of GNSS stations (EPN, www.epncb.oma.be; Bruyininx et al., 2012). Having the DUTH fixed with respect to ETRF 2005 coordinates (2007.5 epoch), the baselines between the station and the control points were solved, using the Topcon Tools Software. Then, least-squares adjustment, fixing DUTH station was applied. The time-span for the GNSS observations was three hours. Every three hours, three baselines were measured, since the available equipment were only two GNSS receivers (Topcon GR-5). In Table 2, the HTRS07 Cartesian coordinates are presented along with their associated accuracies. Figure 5 depicts the eight GNSS-measured control points.

Tab. 2. The 3D adjusted Cartesian coordinates of the HTRS07 measured control points along with their accuracies.

code	**X** [m]	**Y** [m]	**Z** [m]
96049	4394644.092±0.004	1962320.759±0.007	4171472.005±0.002
96052	4387828.080±0.006	1975807.985±0.002	4172395.06±0.005
96058	4390550.046±0.002	1968172.579±0.006	4173066.125±0.002
96062	4387835.791±0.005	1971996.482±0.005	4174198.815±0.006
96075	4390568.84±0.005	1961751.384±0.006	4176080.193±0.006
96080	4386676.862±0.004	1969315.602±0.003	4177374.926±0.005
96081	4388894.554±0.005	1963501.226±0.008	4177065.377±0.003
96086	4390617.515±0.003	1957560.340±0.002	4178110.669±0.004

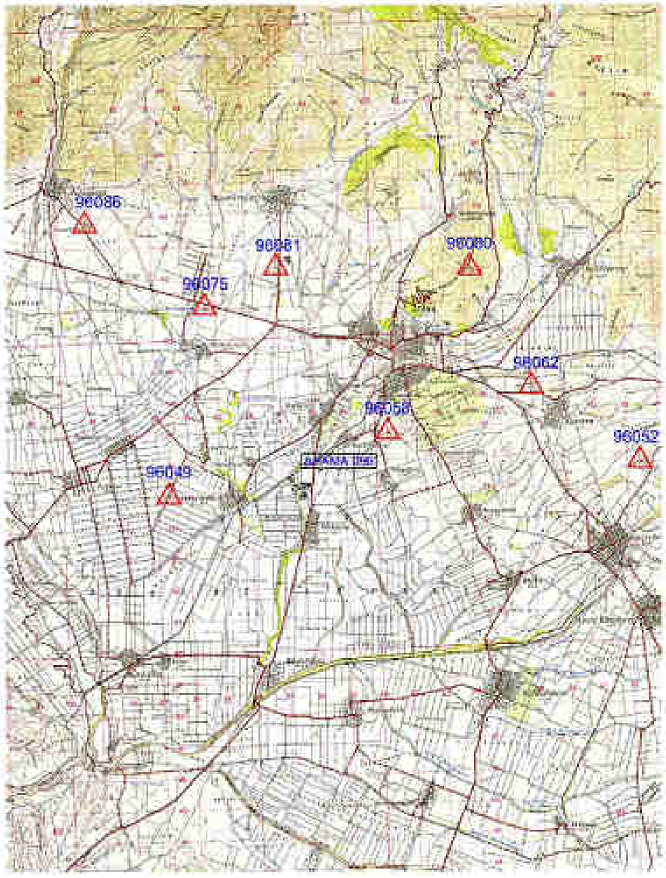

Fig. 5. The distribution of the measured control points.

The assessment of the transformation between HTRS07 and HGRS87

The evaluation of the transformation was accomplished with the use of the free software provided by National Cadastre & Mapping Agency S.A, the HEPOS Transformation Tools. The input data were the HTRS07 3D Cartesian coordinates and the results the HGRS87 projection coordinates and orthometric heights. Table 3 presents the differences between the official Hellenic Military Geographical Service and the measured coordinates (HEPOS Transformation Tools).

Tab. 3. The differences in the projective coordinates (dE, dN) and the orthometric height (dH) between the official values of Hellenic Military Geographical Service in relation to the measured ones (subtraction of the measured from the official values).

code	**dE** [cm]	**dN** [cm]	**dH** [cm]
96049	-3.3	0.3	-19.6
96052	0	-5.6	-13.4
96058	**-263.6**	-0.9	-13.9
96062	-8	-4.1	-18.8
96075	-1	0.5	-19.0
96080	0.1	-3.6	-18.7
96081	-5.7	-1.2	-16.8
96086	-3.9	4.7	-23.0

At first glance, the control point 96058 perfoRMS large discrepancy with respect to its Easting component (more than 2,6m). On the other hand, its Northing presents discrepancy less than a centimetre. The class of the size of the error is due to possible outlier or to an error that wasn't identified in the original adjustment. It is worth noting that the 96058 is located near the village of Nea Sevastia into the limits of the Municipality of Drama and it is possible that it will be (or already has been) a reference point for many surveying studies. This gross error is a consequence of some blunders not found during the initial adjustment procedure, which took part 30 years ago. This is also confirmed by a spatial distance measurement (using a classical total station) between the benchmarks 96058 and 96052: We found an inconsistency (official minus observed) at the level of 230 cm.

Furthermore, it is worth noting the almost systematic bias which resulted after the comparison with the transformed values; that is approximately 19 cm (mean average). It is a clear indication of the non-reliable orthometric height determination through the National Cadastre & Mapping Agency S.A provided the programme. However, removing the bias term, we get a relative satisfactory accuracy of ~ 3 cm.

We also tried to fit the height error, by the using of the following slope model point-wise, via a Least Squares Adjustment (e.g., Rossikopoulos, 1999):

$$H_i^{official} - H_i^{HEPOS} = a_o + a_1 E_i + a_2 N_i \tag{1}$$

where $H_i^{official}, H_i^{HEPOS}$ are the official and the computed from HEPOS height for the point *i*, respectively, a_o, a_1, a_2 the unknown parameters (bias plus two slope teRMS). The standard deviation of the adjusted residuals was 4.2 cm, approximately 1.2 cm larger than the simple mean average. This practically means, that it underlies a constant bias between the official and the HEPOS-wised solutions in the tested area, respectively. Table 4 that follows shows the statistical characteristics of the total transformation (projection coordinates and orthometric heights), without considering the 96058 point.

Tab. 4. The statistical characteristics of the transformations precision (projection coordinates and orthometric heights) between HTRS07 and HGRS87 in Drama.

***value**	**dE** [cm]	**dN** [cm]	**dH** [cm]
μ	3.1	1.3	-18.5
σ	3.0	3.5	2.9
RMS	4.4	3.7	18.7
min	-0.1	-4.7	-13.4
max	8.0	5.6	-23.0

**(where μ is the mean value, σ is the standard deviation, RMS is the root mean square error, min is the minimum value and max is the maximum value)*

The root mean square error of projection coordinates' discrepancy is 4.4 cm in Easting and 3.7 cm in Northing, which are better than what was estimated national-wide (8.3 cm).

As an additional comment, we should note that the procedure above involves only one fixed station with respect to the HTRS07. This was dictated due to the fact that DUTH was the closest station to this particular area. For more extensive validation, we must include as many good-quality stations as possible.

Numerical application to a geodetic network established for the needs of mapping a marble quarry in Drama

At the year 2005, there was a surveying campaign for the needs of mapping of a marble quarry in the area of Drama. We should notice that the marble market in Drama plays a significant role for the local economy. The geodetic network was realised by traverse (e.g. Gašinec et al., 2012), using two state's triangulation stations and in addition, five new surveying benchmarks were established. The traverse was computed using only a terrestrial device (Leica TPS 800 total stations). In Figure 6 the marble quarry (near the city of Drama) is illustrated (the photo is taken at the year 2006), while Figure 7 depicts a part of the surveying layout with the five new established benchmarks.

Fig. 6. The marble quarry located near the city of Drama.

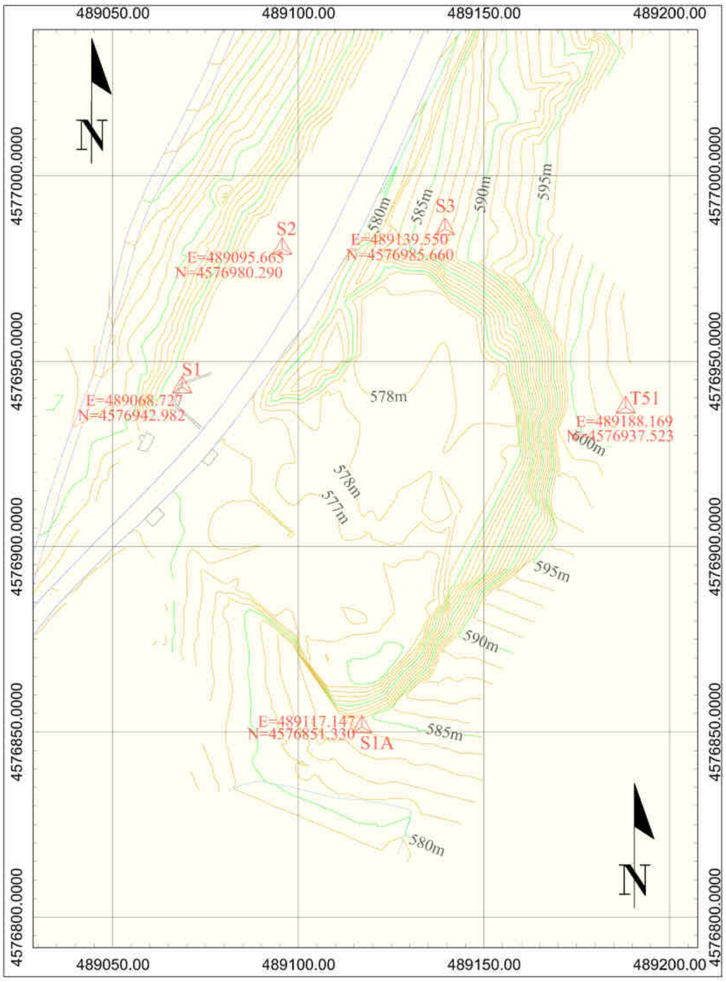

Fig. 7. Part of the surveying layout realised for the needs of the marble quarry activities.

In order to test the results using the GNSS measurements, we remeasured in October of 2016 the five benchmarks (established in 2005, Fig. 7), following the same observation and realisation concept discussed in the previous chapter (ibid.). Table 5 presents the coordinate differences between the classical geodetic network (using terrestrial measurements) and the HTRS07 derived coordinates, respectively.

Tab. 5. The statistical characteristics of the transformations precision (projection coordinates and orthometric heights) between the HTRS07 and HGRS87 in the geodetic network of the marble quarry located near the city of Drama.

***value**	**dE** [cm]	**dN** [cm]	**dH** [cm]
μ	2.8	1.9	-17.6
σ	3.2	3.5	3.2
RMS	4.3	4.0	17.9
min	-0.6	-5.0	-14.4
max	7.4	6.2	-22.0

**(where μ is the mean value, σ is the standard deviation, RMS is the root mean square error, min is the minimum value and max is the maximum value)*

The results verify the findings of our first application to the official state's benchmarks. The RMS of the horizontal components do not exceed the value of 4.5 cm. However, the vertical component related RMS is almost 18 cm. We can imply that the GNSS derived HGRS1987 projection coordinates show a consistency better than 5 cm, which allows its usage to classical surveying studies. On the other hand, the heights should be significantly improved in order to be used for precise surveying applications.

Conclusions and suggestions

The evaluation of the transformation model between the HTRS07 and the HGRS87 reference systems in the area of Drama was presented in this paper. The results showed that one point presents huge error in the Easting while the estimated orthometric heights present an almost systematic error of -18.5cm. After the removal of the outlier, the horizontal accuracy is significantly improved. It is important to mention that a significant number of benchmarks of the Hellenic Military Geographical Service in the area it is either ruined or presents big slope and is impossible to be properly measured. The height transformation cannot be thought as reliable, by no means. This bias consists of many possible systematic errors. In particular: observational biases of the benchmarks, adjustment errors, and deformation. The (practically) same results derived from a numerical application tested in a surveying network, established for the needs of a marble quarry mapping in the area of Drama.

We believe that the procedure above is possible to be applied in the whole state from public authorities (e.g., Regions, Municipalities, Hellenic Military Geographical Service, National Cadastre & Mapping Agency S.A., Universities, etc.) as well as from Freelancers Rural and Surveying Engineers. For cost reduction, it may be used the technique of the point determination in real time (Real Time Kinematics-RTK) with a few minute measurements at the trigonometric benchmarks. Finally, it is clear that the orthometric height based on the transformation model does not provide the necessary accuracy for geodetic and surveying applications. However, for some geophysical aspects (e.g., gravity surveys) the accuracy above is adequate. It is necessary to reform the orthometric heights network in Greece. In advance, Greece should improve its gravity geoidal heights estimation, in order to provide reliable information for the orthometric heights derivation.

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HEPOS : www.hepos.gr

EPN: www.epncb.oma.be