Transformacija višin med SVS2000/Trst in SVS2010/Koper z državnim transformacijskim višinskim modelom

Height transformation between SVS2000/Trst and SVS2010/Koper with the national height transformation model*

Božo Koler, Tomaž Ambrožič, Dušan Kogoj, Klemen Kregar, Aleš Marjetič, Gašper Štebe, Jernej Tekavec, Tilen Urbančič, Simona Savšek

UDK: UDK: 528.412:519.65:004.4
Klasifikacija prispevka po COBISS.SI: 1.01
Prispelo: 16. 7. 2024
Sprejeto: 20. 2. 2025

DOI: 10.15292/geodetski-vestnik.2025.01.11-42
SCIENTIFIC ARTICLE
Received: 16. 7. 2024
Accepted: 20. 2. 2025

IZVLEČEK

V prispevku predstavljamo vzpostavitev državnega višinskega transformacijskega modela, ki omogoča transformacijo višin med starim (SVS2000/Trst) in novim višinskim sistemom (SVS2010/Koper) in obratno. Višinska transformacijska ploskev SLO-VTP2024 je bila izdelana na podlagi 2116 razlik višin med starim in novim višinskim sistemom na reperjih, ki so enakomerno porazdeljeni po območju Slovenije. Višinska transformacijska ploskev SLO-VTP2024 in ploskev natančnosti SLO-VTP2024 sta določeni z interpolacijsko metodo kriging z dodanim vplivom na variogramu in zapisani v obliki celične mreže. Predstavljen je programski paket ViTra, ki omogoča transformacijo višin na podlagi optimiziranih enačb bilinearne interpolacije. Kakovost SLO-VTP2024 smo ocenili na podlagi razlik med preračunanimi višinami in višinami, določenimi s transformacijo na točkah za določitev višinske transformacijske ploskve – 2116 reperjev, na 8775 oziroma 8695 kontrolnih reperjih, na reperjih posameznih redov nivelmanske mreže, na kontrolnih reperjih, ki so stabilizirani v posameznih zankah nove nivelmanske mreže 1. reda Slovenije in po območjih in na reperjih, ki so stabilizirani v posameznih mestnih nivelmanskih mrežah.

ABSTRACT

In this paper we present the creation of a national height transformation model that allows the transformation of heights between the old (SVS2000/Trieste) and the new height system (SVS2010/Koper) and vice versa. The height transformation surface - SLO-VTP2024 was created on the basis of 2,116 height differences between the old and the new height system on benchmarks evenly distributed across Slovenia. The height transformation surface - SLO-VTP2024 and SLO-VTP2024 accuracy surface is determined by the kriging interpolation method with additional influence of the variogram and written in the form of a cell grid. The ViTra software package is presented, which enables the height transformation on the basis of optimized bilinear interpolation equations. The quality of SLO-VTP2024 was assessed on the basis of the differences between the calculated heights and the heights determined by the transformation at the points for determining the height transformation surface – 2,116 benchmarks, at 8,775 and 8,695 control benchmarks, on control benchmarks belonging to different orders of the levelling network, on control benchmarks stabilized in individual loops of the new 1st order Slovenian levelling network, and by area and benchmarks stabilized in individual city levelling networks.

KLJUČNE BESEDE

višinski transformacijski model, višinska transformacijska ploskev, ploskev natančnosti višinske transformacijske ploskve, celična mreža, programski paket ViTra, analiza kakovosti

KEY WORDS

height transformation model, height transformation surfaces, accuracy of height transformation surface, cell grid, ViTra software package, quality analysis

1 Introduction

In Slovenia, we switched to a new national height system called SVS2010/Koper (EPSG 8690, EPSG codes, 2020) with a height datum of 2010 (Koper) at the end of 2018, replacing the old height system called SVS2000/Trieste (EPSG 5779, EPSG codes, 2020) with a height datum of 2000 (Trieste) (Koler et al., 2019). The legal basis for the transition from the old to the new height system is the Law on the national geodetic reference system (UL, 2014). The Surveying and Mapping Authority of the Republic of Slovenia (SMARS) and numerous other administrations and government agencies manage various spatial data base containing georeferenced data including height determined in the old height system SVS2000/Trieste. With the introduction of the new height system SVS2010/Koper, the old benchmark heights in the area of Slovenia have changed from 1.4 cm to -30.8 cm. Simple height transformation, for height which is determined with an accuracy of a few centimeters by adding or subtracting the mean height difference, which is -13.1 cm, is not possible (Medved et al., 2020). If we supplement existing data bases, which also contain the height data, with new data in which the heights are determined in the new height system (SVS2010/Koper), differences between old and new data arise.

As part of the target research project V2-2294: Development of a national height transformation model between SVS2000/Trieste and SVS2010/Koper, we have developed a unified height transformation model for the territory of Slovenia, which consists of a height transformation surface - SLO-HTS2024, a height transformation program - ViTra and a surface for evaluating the accuracy of the height transformation surface. We hope and believe that the height transformation model will enable various users of spatial data to easily transition from the old to the new height system and vice versa.

2 Input data for determining the height transformation surface

2.1 Review of benchmarks

The SMARS web application (PREG, 2018) collects data on the heights of all benchmarks stabilized in levelling networks and polygons on the territory of Slovenia. The heights of the benchmarks are determined in the old (SVS2000/Trieste) and in the new height system (SVS2010/Koper). Table 1 contains data on the number of benchmarks, which are divided into different orders of leveling polygons.

Table 1: Data on benchmark heights in the SMARS geodetic point database.

Order of levelling polygons	Benchmarks		Benchmarks with height in both height systems	
	n	%	*n*	%
1st	2,871	23.9	2,135	74.4
2 st	662	5.5	568	85.8
3 st	955	7.9	936	98.0
4 st	2,985	24.8	2,973	99.6
City	4,548	37.8	4,477	98.4
Total	12,021	100	11,089	92.2

The database of geodetic points contains 12,021 benchmarks (Table 1). Most of them are benchmarks of city levelling networks (37.8 %), 4th order (24.8 %), 1st order (23.9 %). The database also contains 5.5 % 2nd order benchmarks and 7.9 % 3rd order benchmarks (Koler et al., 2024a). The analysis of the benchmarks whose heights were determined in the old and new height system showed that the largest share is accounted for by the 4th order benchmarks (99.6 %) and the smallest by the 1st order benchmarks (74.4 %). Since the 1st order levelling network was renewed and new benchmarks were stabilized whose heights were not determined in the old height system, the results are expected. Lower order benchmarks were converted from the old to the new height system by adjusting the levelling polygons based on data from old measured height differences. If the difference between the given and measured height difference was too large according to the permited deviations for each order of the levelling network (GURS, 2020), the benchmarks were not included in the database.

2.2 Calculation of the height differences of the benchmarks and assessment of accuracy

To determine the height transformation surface, which is defined by different interpolation methods (chapter 4), we calculate the height difference of the benchmarks using the following equation (Koler et al., 2024a):

$$\Delta H_{SLO-HTS2024} = H_{SVS2010} - H_{SVS2000} \qquad (1)$$

In equation (1):

$\Delta H_{SLO-HTS2024}$ … the difference between the heights of the benchmarks for determining the height transformation surface,

$H_{SVS2010}$ … the benchmark height in the new height system SVS2010/Koper,

$H_{SVS2000}$ … the benchmark height in the old height system SVS2000/Trieste.

Based on the accuracy of the benchmarks heights in the new and old height system, we estimate the accuracy of the height differences between the new and old height system, which are the input data for determining the surface of the quality of the height transformation surface. We calculate the estimated accuracy of the height differences according to the following equation:

$$\sigma_{\Delta H_{SLO-HTS\,2024}} = \sqrt{\sigma^2_{H_{SVS\,2010}} + \sigma^2_{H_{SVS\,2010}}} \qquad (2)$$

In equation (2):

$\Delta H_{SLO-HTS2024}$ … the accuracy of the height difference that represents the input data for determining the accuracy range of the height transformation surface,

$H_{SVS2010}$ … the accuracy of the determination of the benchmark heights in SVS2010/Koper,

$H_{SVS2000}$ … the accuracy of the determination of the benchmark heights in SVS2000/Trieste.

The old and new levelling networks were adjusted using the VimWin program (Ambrožič, 2016). Statistical indicators for the assessment of accuracy after levelling (Koler et al., 2019) are compiled in Table 2.

Table 2: Statistical indicators for assessing the accuracy of the new and old levelling network.

Levelling network of 1st order	$\hat{\sigma}_0[mm/km]$	$\sigma_H[mm]$
Old (SVS2000/Trieste)	0.86	0.12 – 11.46
New (SVS2010/Koper)	0.50	0.06 – 6.08

From Table 2 we can see that the new 1st order levelling network is about 2 times more accurate than the old levelling network, which consists of measurements from the 1950s, 1970s, and 1980s.

2.3 Selection of benchmarks for building the height transformation surface

In the geodetic point database we have 11,089 benchmarks whose height was determined in both height systems (Table 1). Benchmarks for creating the height transformation surface were selected in several steps (Figure 1), which are described in Koler et al. (2024b). Only summaries are presented in this article.

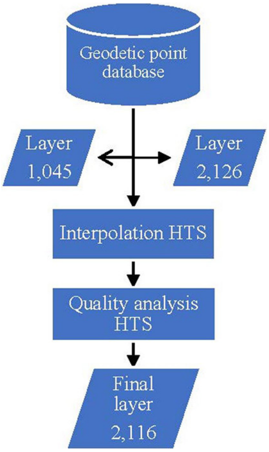


Figure 1: Flowchart of the selection process of benchmarks for the creation of the height transformation surface.

The inpute data for the creation of the height transformation model were determined in the following steps:

a) Data for the transformation surface based on the measured heights of identical 1st order benchmarks in SVS2000/Trieste and SVS2010/Koper – layer of 1,045 data.

In the new survey of the 1st order levelling network in Slovenia, 1,231 old benchmarks were included, which were previously also included in the survey in the old SVS2000/Trieste height system. Since in some cases the difference between the new and the old height system between benchmarks was more than 10 mm (Table 3), we suspect that this could be related to local peculiarities (stabilisation in unsuitable objects; local vertical movements, quality of the old levelling survey, etc.), we have excluded 186 benchmarks. This left 1,045 benchmarks of the new 1st order levelling network, which were also previously included in the SVS2000/Trieste survey and form the basis for determining the height transformation surface (Figure 2).

b) Supplementary data for the calculation of the transformation surface based on the recalculated heights of the lower-order benchmarks in SVS2000/Trieste and SVS2010/Koper – layer of 2,126 data

Since the data used to create the transformation surface are unevenly distributed in certain areas of Slovenia

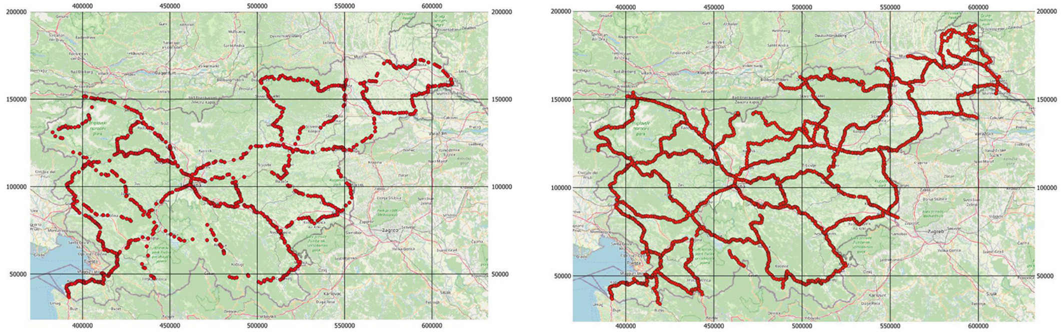
(Figure 2a), we supplemented the base data with additional data that enabled the creation of a more accurate transformation surface (Koler et al., 2024a). In adjusting the old 1st order levelling network, we included additional lower order levelling polygons and new benchmarks, so that we obtained the heights of the new benchmarks also in the old SVS2000/Trieste system and we got the layer of 2,126 data (Figure 2b).

Table 3: Example of the difference between SVS2010/Koper and SVS2000/Trieste for neighboring benchmarks that are more than 10 mm (in red in the text).

Benchmark	Embedded in the object along the Kobarid – Nova Gorica road	$H_{SVS2010}$ $[m]$	$H_{SVS2000}$ $[m]$	$\Delta H_{SLO-VTP2024}$ $[m]$
5352	Administrative building of the Goriška waterworks	106,6234	106,7357	-0,112
5349	Road culvert, Kobarid - Nova Gorica at km 106+593	80,8363	80,9640	-0,109
5351	Road culvert, Kobarid - Nova Gorica at km 109+058	79,5649	79,6735	-0,128
5350a	Wall, Kobarid - Nova Gorica at km 109+290	81,0391	81,1539	-0,115
5349a	Road culvert, Kobarid - Nova Gorica at km 107+580	82,2320	82,3473	-0,115
5349	Road culvert, Kobarid - Nova Gorica at km 106+593	80,8363	80,9640	-0,128
5348a	Road kerb along the main road at km 105+685	82,0822	82,1925	-0,110
O-41	Road culvert, Kobarid - Nova Gorica at km 105+034	89,8892	89,9997	-0,111

c) Final layer – 2,116 benchmarks to determine the height transformation surface

Based on the difference between the calculated and interpolated height difference on 8,775 control benchmarks, we found that larger differences occur in the area of Kočevski Rog, Novo mesto and between Poljčane and Rogaška Slatina (Figure 3, Koler et al., 2024b).



a) Layer of 1,045 1st order benchmarks b) Layer of 2,126 benchmarks of the 1st order and lower orders

Figure 2: Map of the benchmarks for determining the height transformation surface (cartographic basis: Googlemaps).

Additional analysis of the input data in areas with larger differences revealed differences in 10 benchmarks that did not match the neighboring height difference values (Table 4). After omitting these 10 benchmarks (marked in red in Table 4), we determined a finite set of height differences (2,116 benchmarks) that represent the final inputs for determining the height transformation surface using the kriging method with added anisotropy in variogram modelling (Figure 4).

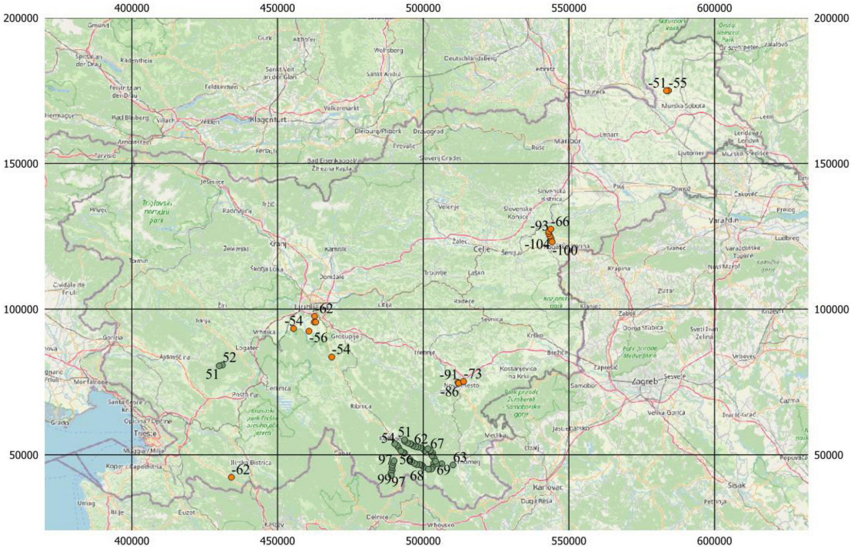


Figure 3: Display of the greater height differences between the calculated and the transformed height in SVS2010 Koper – Layer of 2,126 benchmarks (Cartographic basis: Googlemaps, the unit is mm).

Table 4: The difference between SVS2010/Koper and SVS2000/Trieste for neighbouring benchmarks greater than 10 mm (shown in red in the text).

Leveling polygon N4-P91: Podplat – Tekačevo				Leveling polygon N1-MP406: Petrinja			
Benchmark	$H_{SVS2010}$ [m]	$H_{SVS2000}$ [m]	$\Delta H_{SLO-VTP2024}$ [m]	Benchmark	$H_{SVS2010}$ [m]	$H_{SVS2000}$ [m]	$\Delta H_{SLO-VTP2024}$ [m]
5244d	222,2270	222,3523	-0,125	167	547,4792	547,61600	-0,137
5244b	230,7400	230,7545	-0,014	25	546,3794	546,5715	-0,192
1	237,8567	237,8755	-0,019	203	539,8766	540,0687	-0,192
2	245,0306	245,0465	-0,016	300	536,3200	536,5121	-0,192
3	255,0199	255,0444	-0,024	201	530,4858	530,6779	-0,192
4	266,5728	266,5974	-0,025				
5	245,7315	245,77840	-0,047				

3 Creation of the height transformation surface and the height transformation programme

3.1 Determination of the height transformation surface using various interpolation methods

The height transformation surface is three-dimensional and consists of a continuous field of values over the entire area of the created surface. The interpolation data represents the surface as a grid of equally sized cells. We know interpolations on the basis of deterministic methods and on the basis of geostatistical methods. Deterministic methods determine values based on input data and certain mathematical equations, while geostatistical methods are based on statistical models that include autocorrelation (Ayeni and Samuel, 2014). Data processing was performed in the ArcGIS environment. To determine the height transformation surface, we used four deterministic interpolation methods (inverse distance method, global polynomial interpolation, local polynomial interpolation and radial basis functions) as well as the kriging method (Zhang H., Wang Y., 2010) and kriging with additional anisotropy in variogram modelling, which are geostatistical methods (Koler et al., 2024b).

We assessed the quality of the height transformation surfaces using cross-validation, in which one point is removed from the surface determination in each iteration and then the interpolated surface value is compared with the measured value. A quality analysis, the results of which are presented in Koler et al, 2024b, has shown that the height transformation surface calculated using the kriging method with added anisotropy in variogram modelling is the best (Figure 4).

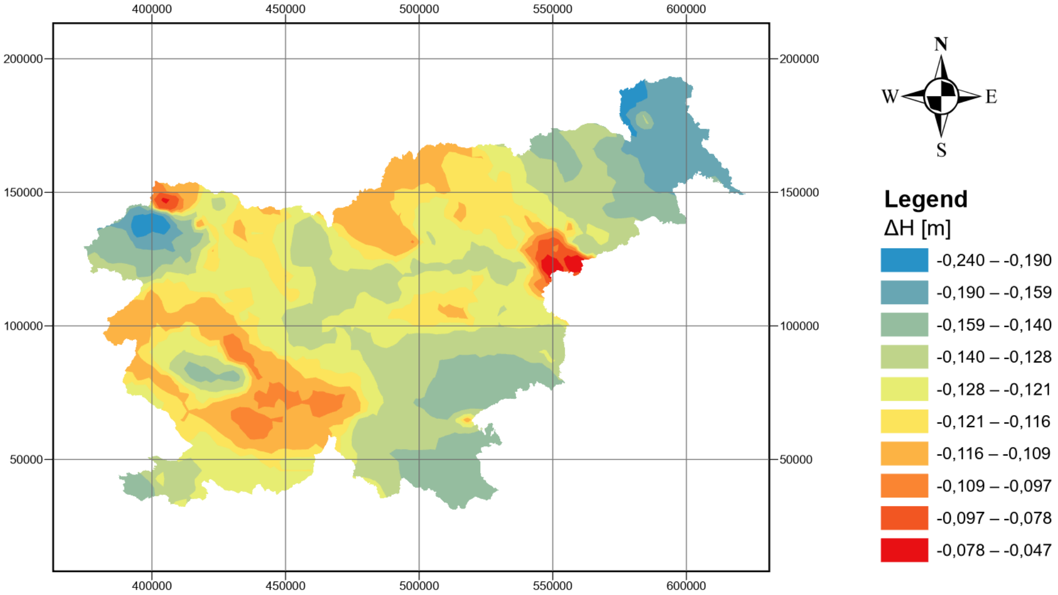


Figure 4: Slovenian height transformation surface – SLO-HTS2024 based on the kriging with added anisotropy in variogram modelling - layer of 2,116 data.

In the next step, we also tested the quality of the height transformation surface, which is determined by the kriging with added anisotropy in variogram modelling, on 8,775 control benchmarks whose height was determined in both height systems. Based on the difference between the calculated (equation 1) and the interpolated height difference on the control benchmarks, we estimated the quality of the height transformation surface. The difference ranged from –102 mm to 109 mm, the RMSE value is 11.7 mm and the average difference is 14 mm.

From the histogram (Figure 5) we can see that 84.2% of the benchmarks have a difference between -10 mm and 10 mm. In 47 control benchmarks (0.5%) the difference is between –50 mm and –102 mm and in 16 control benchmarks (0.2%) between 50 mm and 109 mm. In both cases, the share of control benchmarks with larger differences is negligible.

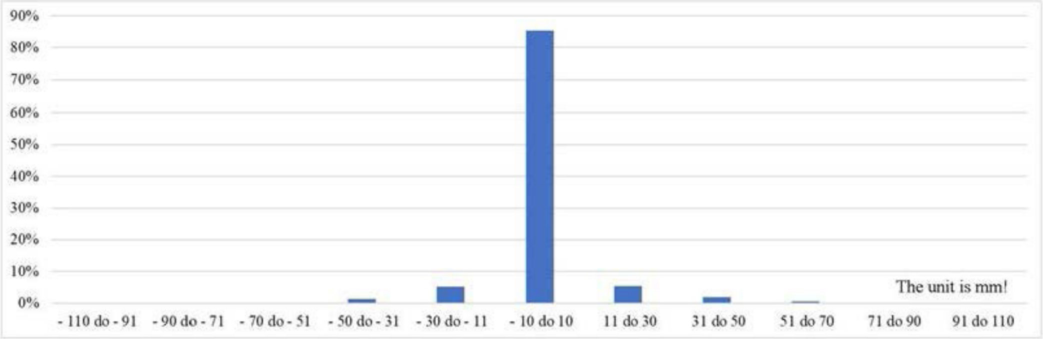


Figure 5: Histogram of the distribution of height differences at the control benchmarks (Koler et al., 2024a).

3.2 Representation of the Slovenian height transformation surface – SLO-HTS2024 as grid

Due to the standardization of the different surfaces managed by SMARS, the height transformation surface is represanted in the same way as the quasigeoid AGM2000 and the Slovenian height reference surface SLO-VRP2016/Koper (Koler et al., 2019):

1. Area: from 45° to 47° north latitude and from 13° to 17° east longitude.
2. Cell grid size: 30" x 45" ($d\phi$, $d\lambda$) approx. 925 m x 925 m (*dn*, *de*).
3. The coordinates of the cell grid are given in decimal degrees with an increment of 0.008333333333°(ϕ) x 0.0125° (λ).
4. The cell grid starts with a point in the lower left corner (southwest point) and specifies all degrees of longitude for a degree of latitude.
5. The number of columns corresponds to the number of longitudes and the number of rows corresponds to the number of latitudes: 321 (columns) and 241 (rows).

The grid is saved in *.grd, *.gri, *.tif, *.tfw, *.xyz and *.txt format. We have named the height transformation surface SLO-HTS2024. The acronym stands for Slovenian Height Transformation Surface from 2024.

3.3 Creating the SLO-HTS2024 accuracy surface

We assessed the quality of the height difference between SVS2010/Koper and SVS2000/Trieste using Equation 2. Table 5 contains statistical indicators for the accuracy of the determination of the height difference between SVS2010/Koper and SVS2000/Trieste for benchmarks selected for the creation of SLO-HTS2024.

Table 5: Statistical indicators for the assessment of the accuracy of SLO-HTS2024.

Benchmark	Levelling polygon/Place	$\sigma_{\Delta H_{SLO-HTS2024}}$ $[mm]$
N1168	N3-51/Sevnica	15.2
C-2	N1-11B/Smolnik pri Rušah	0.1
	Average value	9.2

Figure 6 shows the accuracy surface of the SLO-HTS2024 determination, which is not intended to estimate the accuracy of the height transformation in individual areas. From Figure 6, we can see that the accuracy of the transformation surface is best near the normal benchmark and worst at the edges of the country. This is related to the accuracy of determining the height, which decreases with the distance from the normal benchmark.

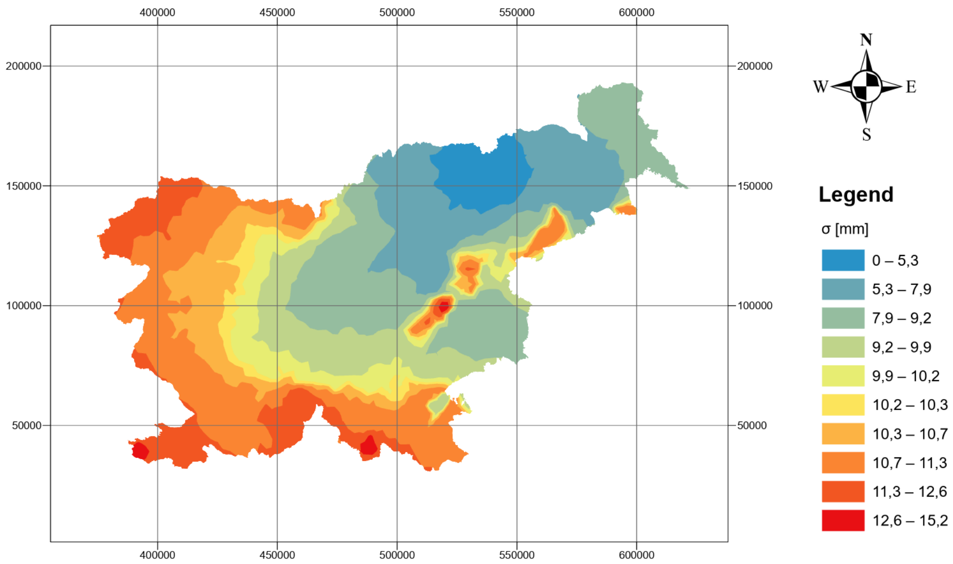


Figure 6: The accuracy surface of the SLO-HTS2024 determination.

3.4 ViTra software package for height transformation

For the transformation of heights from SVS2000/Trieste to SVS2010/Koper and vice versa, we have developed the ViTra program, which is available to users on the SMARS website (https://www.e-prostor.gov.si/dostopi/javni-dostop/storitve/?filter=.pf-javni-dostop). The ViTra program was developed in the MS Visual Studio 2022 environment in the Visual C++ programming language and requires an MS Windows operating system newer than Windows XP. The ViTra program supports the input file formats SHP (ArcView Shapefile Format), CSV (MS DOS), TXT (MS DOS), XYZ files and also ASC files (SMARS, 2024). Optimized equations of bilinear interpolation (Press et al., 1992) are used for the height transformation. The conversion of the coordinates from state planar (D96/TM or D96-17/TM) coordinates (e, n) to curved geodetic coordinates (λ, φ) on the GRS80 ellipsoid is carried out according to the method of Karney (Karney, 2011). By adding the height difference to the height in SVS2000/Trieste, which we obtain with the ViTra program of SLO-HTS2024, we get the transformed height in SVS2010/Koper and vice versa for height transformations from SVS2010/Koper in SVS2000/Trieste.

4 Quality analysis of the height transformation surface

We evaluated the quality of SLO-VTP2024 based on the differences between the heights in SVS2010/Koper maintained by GURS in the PREG geodetic point database and the transformed heigts from SVS2000/Triest to SVS2010/Koper using the ViTra programme (Equation 3).

$$\Delta H_i^{Recal} = H_i^{SVS2010} - H_i^{ViTra} \tag{3}$$

In equation (3) are:

ΔH_i … the height difference between the recalculated height in SVS2010/Koper and the height in SVS2010/Koper transformed with the ViTra program from SVS2000/Trieste at control point i,

H_i^{Recal} … recalculated height of the benchmark i,

H_i^{ViTra} … transformed height of the benchmark i.

We have calculated the quality score of the height transformation with SLO-HTS2024 according to the following equation:

$$\sigma_{ViTra} = \sqrt{\frac{\sum \Delta H_i^2}{n-1}} \qquad (4)$$

4.1 Quality analysis of SLO-HTS2024 at points to determine the height transformation surface

First, we analysed the quality of SLO-HTS2024 on the 2,116 benchmarks that we used to determine the height transformation surface. The minimum difference is –33 mm and the maximum difference is similar (27 mm). The average difference is 0.02 mm and σ_{ViTra} is 3.48 mm.

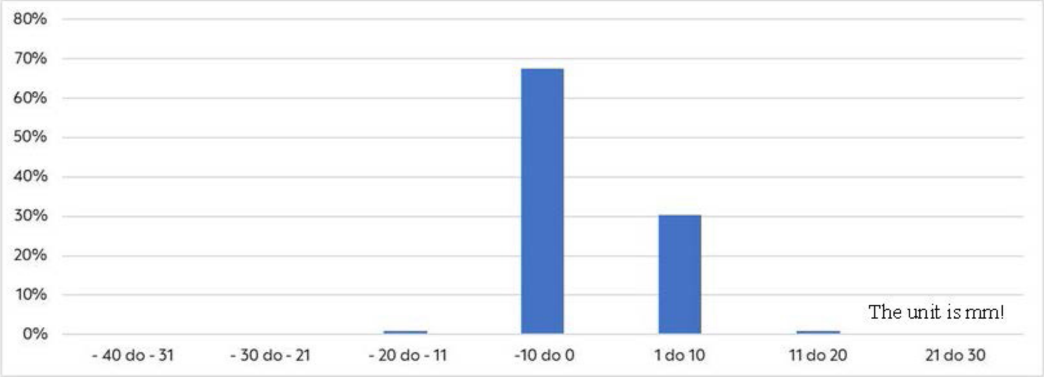


Figure 7: Histogram of the distribution of height differences at 2,116 benchmarks for the determination of SLO-HTS2024.

Figure 7 shows that 97.8% of the height differences at the benchmarks between -10 mm and 10 mm. The results are as expected as this is an internal accuracy assessment (Koler et al., 2024a).

4.2 Quality analysis for control benchmarks

We performed a quality analysis of SLO-HTS2024 on control benchmarks in several steps, which are described below.

4.2.1 Quality analysis at 8,775 and 8,695 control benchmarks

We checked the quality of SLO-HTS2024 on 8,775 control benchmarks whose height was determined in SVS2000/Trieste and SVS2010/Koper. Using the ViTra program, we transformed the heights from SVS2000/Trieste to SVS2010/Koper and compared them with the recalculated heights in SVS2010/

Koper, which are contained in the geodetic point database of the SMARS. Based on the difference between the recalculated and transformed height calculated according to equation (3), we assessed the quality of SLO HTS2024 according to equation (4) (Table 6). Since the SiViS programme (Kozmus Trajkovski, Stopar, 2019), which is intended for the transformation of heights based on GNSS observations, has also been used for height transformation in the past, we also evaluated the quality of the height transformation using the SiViS programme. Table 6 shows that the SiVis program is not suitable for the transformation of heights obtained by levelling or trigonometrical levelling, as the quality of the transformation is about 10 times worse.

Table 6: Statistical indicators to assess the quality of SLO-HTS2024 at 8,775/8,695 control benchmarks.

Statistical indicators	8,775 benchmarks	8,695 benchmarks	
		ViTra	SiVis
Minimum difference [*mm*]	–91	–50	–403
Number of benchmarks with a difference of less than –50 mm	12 (0.14 %)	/	5,084 (58.5 %)
Maximum difference [*mm*]	70	50	155
Number of benchmarks with a difference of more than 50 mm	40 (0.46 %)	/	274 (3.2 %)
Average difference [*mm*]	0.05	–0.06	–67
Share of benchmarks with an abs. difference of less than 10 mm	85.6 %	86.4 %	3.6 %
Share of benchmarks with an abs. difference of less than 20 mm	94.2 %	95.0 %	7.6 %
$\sigma_{ViTra/SiVis}$ [*mm*]	11.1	9.9	92.2

From Table 6 we can see that the minimum difference –91 mm and the maximum difference 70 mm are similar for 8,775 control benchmarks (Figure 8). For 12 control benchmarks (0.14%) the difference is between –50 mm and –91 mm and for 40 control benchmarks (0.46%) between 50 mm and 70 mm.

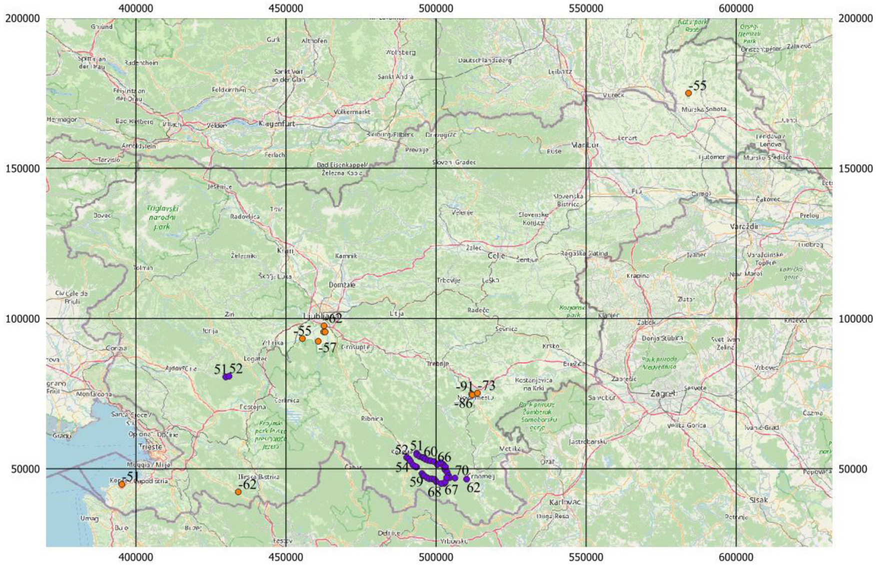


Figure 8: Display of the most important height differences based on the differences between recalculated and transformed heights in SVS2010 Koper – Layer of 2,116 benchmarks (Cartographic basis: Googlemaps, the unit is mm).

From Figure 8 we can see that we have a larger number of "bad" control benchmarks in the area of Kočevski Rog and Ljubljansko barje. The other "bad" control benchmarks are randomly distributed across the entire territory of Slovenia. We found that the larger differences are not the result of lower quality of the height transformation surface in these areas, but may be related to local peculiarities (stabilization in unsuitable objects; vertical movements, such as on Ljubljana marshland; quality of the old levelling survey, etc.). Therefore, we decided to exclude control benchmarks where the difference between the recalculated and the transformed height in SVS2010/Koper is more than ±50 mm from further analysis of the quality of SLO-HTS2024. Table 7 contains information on the number of excluded control benchmarks according to the order to which they belong. After excluding 80 benchmarks (0.91 %, Table 7), 8,695 control benchmarks remained, which we used to control the quality of SLO-HTS2024. It can be expected that the statistical indicators listed in Table 6 are better for the new dataset. Based on the quality assessment, we can conclude that the SLO-HTS2024 we developed provides a sufficiently high-quality transformation of the height databases managed by SMARS.

Table 7: Excluded benchmarks according to the order of the levelling polygon.

Order of the levelling polygon	Number of excluded control benchmarks	Percent
2st	23	28.0 %
4st	20	24.4 %
City	8	9.8 %
City – Ljubljansko barje	31	37.8 %
Total	82	100.0 %

4.2.2 Quality analysis of control benchmarks belonging to different orders of the levelling network

We sorted the control benchmarks according to the order of the levelling polygon to which they belong and investigated whether the order influences the quality of the height transformation. Table 8 summarises the statistical indicators for the control benchmarks of the different orders. As expected, we have the fewest 1st order benchmarks (232 or 2.7%) and the most 4,399 benchmarks from city levelling networks (50.6%). We also see that the average difference is smallest for the 4th order benchmarks (0.04 mm) and largest for the 1st order benchmarks (4.07 mm). The accuracy of the height transformation (σ_{ViTra}) ranges from 9.2 mm for the city levelling network benchmarks to 12.6 mm for the 2nd order benchmarks. The average value of the differences for the benchmarks of all orders is 1.2 mm and the average accuracy (σ_{ViTra}) is 10.4 mm. From the accuracy analysis performed, we can conclude that the height transformation is of comparable accuracy for benchmarks of all orders.

Table 8: Statistical indicators for the control benchmarks of the individual orders.

Benchmark	Number of benchmarks	Percent	Min. diff. [*mm*]	Max. diff. [*mm*]	Average diff. [*mm*]	σ_{ViTra} [*mm*]
1st	232	2.7 %	–7	39	4.07	10.3
2nd	471	5.4 %	–39	49	2.92	12.6
3rd	851	9.8 %	–47	41	–0.41	9.3
4st	2,740	31.5 %	–50	50	0.04	10.4
City	4,399	50.6 %	–49	48	–0.57	9.2

4.2.3 Quality analysis of the control benchmarks stabilised in individual loops of the new 1st order Slovenian levelling network and by area

We have sorted the control benchmarks according to the position of stabilisation by loops of the new 1st order Slovenian levelling network and individual areas according to levelling loops (Figure 9). The division into levelling loops (L.l.) and areas (A) by loops makes sense, as the control benchmarks from SVS2000/Trieste were recalculated in SVS2010/Koper with a connection to the benchmarks of the new Slovenian 1st levelling network. Figure 9 shows three added areas (A1, A8 and A13), which are located near the loops. Due to its size, we have divided loop 10 into L.l.10a, which is located west of the river Sava, and L.l.10b, which is located east of the river Sava.

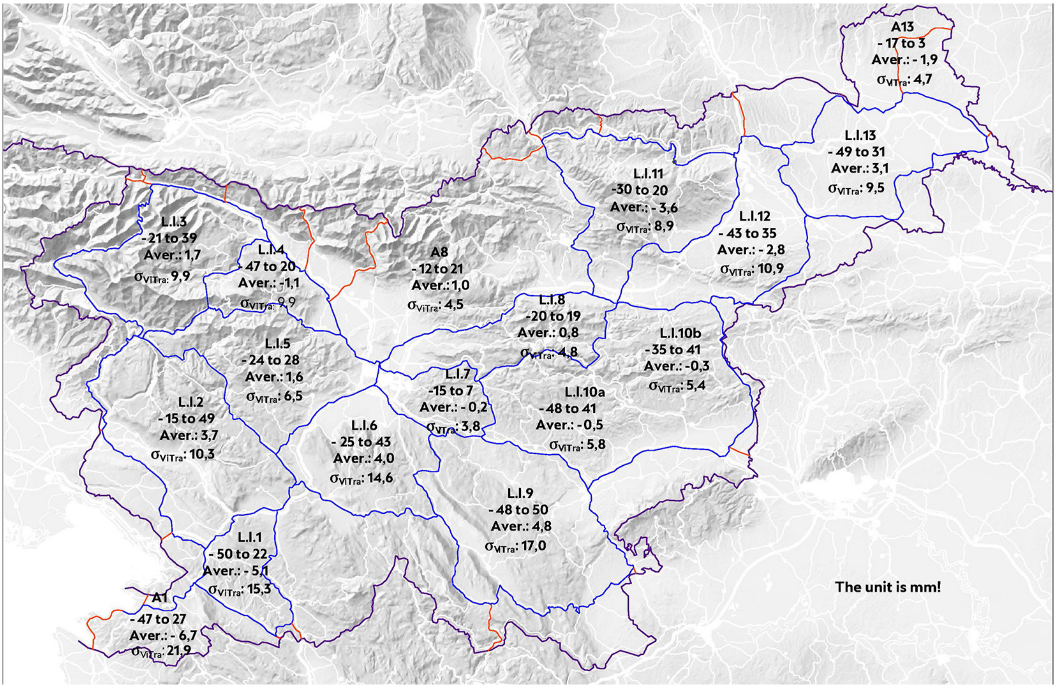


Figure 9: Levelling loops and areas with statistical indicators (Koler et al. 2024a).

Table 9 summarises the statistical indicators for the individual levelling loops (L.l.) and areas (A). Table 9 shows that the benchmarks are not evenly distributed across the loops and areas. The fewest, namely 55 benchmarks, are in area 13 (A13) and the most, namely 874 benchmarks, are in loop 10a (L.l.10a). We also see that the smallest difference ranges from –6.7 mm for area 1 (A1) to 4.8 mm for loop 9 (L.l.9). The accuracy of the height transformation (σ_{ViTra}) ranges from 3.8 mm in loop 7 (L.l.7) to 21.9 mm in area 1 (A1). The average value of the differences in all loops and areas is –0.09 mm and the average accuracy (σ_{ViTra}) is 9.6 mm. As expected, the accuracy of the height transformation is similar to the accuracy of the 8,695 control benchmarks (Table 6).

Table 9: Statistical indicators for individual levelling loops and areas.

Levelling loop – area	Number of benchmarks	Min. diff. [*mm*]	Max. diff. [*mm*]	Average diff. [*mm*]	σ_{ViTra} [*mm*]
L.l.1	231	–50	22	–5.10	15.3
A1	115	–47	27	–6.69	21.9
L.l.2	477	–15	49	3.66	10.3
L.l.3	340	–21	39	1.66	9.9
L.l.4	323	–47	20	–1.12	9.8
L.l.5	438	–24	28	1.58	6.5
L.l.6	188	–25	43	4.03	14.6
L.l.7	138	–15	7	–0.22	3.8
L.l.8	542	–20	19	0.79	4.8
A8	266	–12	21	1.00	4.5
L.l.9	546	–48	50	4.82	17.0
L.l.10a	874	–48	41	–0.47	5.8
L.l.10b	571	–35	41	–0.29	5.4
L.l.11	560	–30	20	–3.58	8.9
L.l.12	824	–43	35	–2.81	10.9
L.l.13	686	–49	31	3.14	9.5
A13	55	–17	3	–1.90	4.7
			Average value:	–0.09	9.6

4.2.4 Quality analysis of control benchmarks stabilised in individual city levelling networks

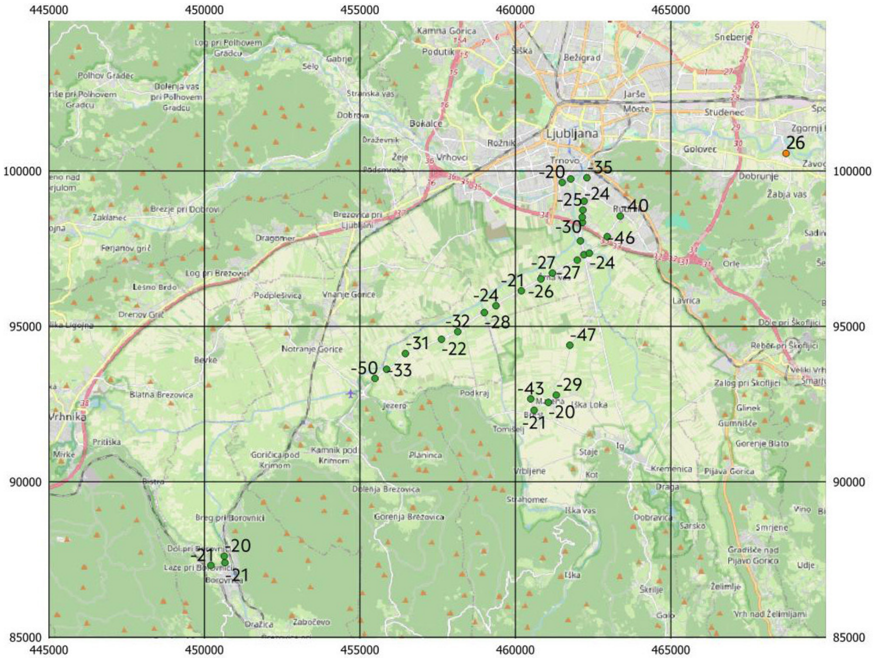


Figure 10: Omitted benchmarks in the area of Ljubljansko barje and Zalog – the unit is mm (cartographic basis: Googlemaps).

We have also conducted a quality analysis for individual larger city levelling networks. Table 10 summarizes the statistical indicators for the individual city levelling networks. Table 10 shows that the benchmarks are not evenly distributed across the city levelling networks. The fewest, namely 45 benchmarks, are stabilized in the city levelling network of Nova Gorica and the most, namely 2,041 benchmarks, in the area of the municipality of Ljubljana and its surroundings. Furthermore, we see that the average difference ranges from –5.0 mm in Ljubljana, or –4.7 mm if we omit the benchmarks in the area of Ljubljana Marshland and Zavoglje (Figure 10), and up to 6.9 mm in Celje. The accuracy of the height transformation (σ_{ViTra}) ranges from 1.5 mm in Domžale to 9.8 mm in Celje and Ptuj. The average value of the differences in all city levelling networks is 1.05 mm and the average accuracy (σ_{ViTra}) is 5.6 mm.

Table 10: Statistical indicators for individual city levelling networks.

City levelling network	Number of benchmarks	Min diff. [*mm*]	Max. diff. [*mm*]	Average diff. [*mm*]	σ_{ViTra} [*mm*]
Celje	253	–12	18	6.87	9.8
Domžale	52	–2	8	0.41	1.5
Grosuplje	52	–6	3	–1.17	2.6
Kranj	119	–6	13	2.07	5.0
Ljubljana – all	2.041	–50	26	–5.01	7.5
Ljubljana	2.009	–19	17	–4.65	6.5
Maribor	892	–30	12	2.39	5.2
Murska Sobota	60	–10	6	0.67	2.2
Nova Gorica	45	–15	12	1.23	4.7
Novo mesto	61	–48	7	–1.65	9.0
Ptuj	69	–11	18.6	3.52	6.9
			Average value:	0.97	5.3

5 Conclusion

The paper presents the method for creating the SLO-VTP2024 height transformation surface, which was carried out in several steps and the accuracy surface of the SLO-HTS2024 determination. By supplementing the data of the base benchmarks (layer of 1,045 data) included in the survey of the old and new levelling network, we obtained a set of data (layer of 2,126 data) evenly distributed over the territory of Slovenia, as the average length between neighbouring benchmarks is about 1 km. We estimate that this is a sufficient density of benchmarks for determining the transformation surface. Based on the quality analysis for determining the height transformation surface performed for both data layers, we concluded that the best height transformation surface for the layer of 2,126 data is determined by the interpolation method of kriging with added anisotropy in variogram modelling.

The quality of the selected height transformation surface was tested on 8,775 control benchmarks whose heights were determined in SVS2000/Trieste and SVS2010/Koper. We compared the height differences of the control benchmarks with the height differences resulting from the height transformation surface. Most of the benchmarks with a negative difference (–60 mm to –102 mm) were located in the Kočevski Rog area and with a positive difference (80 mm to 109 mm) in the area between Poljčane and Rogaška Slatina. In an additional analysis, we excluded 10 benchmarks from the stratum of 2,126 benchmarks that had the greatest influence on the large differences in the above-mentioned areas.

In this way, we obtained the final set of 2,116 benchmarks that we used to determine the height transformation surface – SLO-HTS2024. Due to the standardisation of the different surfaces managed by SMARS, the height transformation surface (SLO-HTS2024) is determined by a cell grid, just like the quasi-geoid AGM2000 and the Slovenian height reference surface SLO HRS2016/Koper.

To transform the heights from SVS2000/Trieste to SVS2010/Koper and vice versa, we have developed the ViTra programme in the MS Visual Studio 2022 environment. The ViTra programme is written in the Visual C++ programming language and requires an MS Windows operating system newer than Windows XP. Optimised equations of bilinear interpolation are used for the height transformation.

The internal accuracy of the height transformation, which was estimated based on the differences between recalculated and transformed heights in 2,116 benchmarks that we used to determine the height transformation surface, is 3.3 mm. The external accuracy, which is 9.9 mm, was estimated using 8,695 control benchmarks. For comparison, we transformed the heights of 8,695 control benchmarks with the SiVis programme, which is designed to transform heights between SVS2000/Trieste and SVS2010/Koper obtained with GPS heighting. We obtained an accuracy of 92.2 mm, which is almost 10 times worse than the transformation with the ViTra programme. We also analysed the quality depending on the order of control benchmarks, distribution on levelling loops and adjacent areas as well as in larger city levelling networks. Based on the performed quality analyses of the control benchmarks, we can conclude that the proposed SLO-HTS2024, which is integrated into the ViTra programme, enables a sufficiently high-quality transformation of height databases managed by the Surveying and Mapping Authority of the Republic of Slovenia and numerous other administrations and government agencies.

Acknowledgements

The research was carried out within the framework of the research program ARIS P2-0227 Geoinformation Infrastructure and Sustainable Spatial Development of Slovenia, the target research project V2-2294: Development of the national height transformation model between SVS2000/Trieste and SVS2010/Koper, which was co-financed by the Public Agency for Research Activity of the Republic of Slovenia and the Surveying and Mapping Authority of the Republic of Slovenia.

Literature and sources:

Ambrožič, T. (2016). Instructions for using the program VimWin ver. 5.1, mar. 16.

Ayeni, B., Samuel, K.J. (2014). An evaluation of digital elevation modeling in GIS and Cartography. Geo-spatial Information Science 17, 2: 139-144. https://www.tandfonline.com/doi/pdf/10.1080/10095020.2013.772808?needAccess=true. Accessed 24 Feburary 2025.

EPSG (2020). EPSG codes for Slovenia. Ljubljana: Surveying and Mapping Authority of the Republic of Slovenia

https://www.e-prostor.gov.si/zbirke-prostorskih-podatkov/drzavni-prostorski-koordinatni-sistem/epsg-kode-za-slovenijo/, Accesed 31 January 2025.

Karney, C.F.F. (2011). Transverse Mercator with an Accuracy of a Few Nanometers. Journal of Geodesy 85, 8: 475-485. https://doi.org/10.1007/s00190-011-0445-3

Koler, B., Stopar, B., Sterle, O., Urbančič, T., Medved, K. (2019). Nov slovenski višinski sistem SVS2010. Geodetski vestnik 63, 1: 27-40. DOI: 10.15292/geodetski-vestnik.2019.01.27-40

Koler, B., Ambrožič, T., Kogoj, D., Kregar, K., Marjetič, A., Savšek, S., Urbančič, T., Tekavec, J., Štebe, G., Goršič, J.. (2024 a). Razvoj državnega višinskega transformacijskega modela med SVS2000/Trst in SVS2010/Koper: ciljni raziskovalni projekt V2-2294 - zaključno poročilo. Ljubljana: Univerza v Ljubljani, Fakulteta za gradbeništvo in geodezijo, 2024. 68 str., ilustr.

Koler, B., Ambrožič, T., Kregar, K., Kogoj, D., Marjetič, A., Savšek, S., Štebe, G., Tekavec, J., Urbančič, T. (2024 b). Transformacija višin med starim in novim višinskim sistemom Slovenije. V: Kuhar, M. (ur.), et al. Raziskave s področja geodezije in geofizike 2023: Zbornik del: 29. srečanje Slovenskega Združenja za geodezijo in geofiziko, Ljubljana, 1. februar 2024. Ljubljana: Slovensko združenjeza geodezijo in geofiziko, str. 123-137, ilustr. ISBN 978-961-95299-4-2. https://fgg-web.fgg.uni-lj.si/SUGG/referati/2024/SZGG_2024_Koler_in_dr.pdf http://www.dlib.si/details/URN:NBN:SI:doc-387N5KJT Accessed 31 January 2025.

Kozmus Trajkovski, K., Stopar, B. (2019). Navodila za uporabo programa za pretvorbo višin med višinskimi sistemi RS – SiVis-v2.0, maj 2019. http://sitranet.si/sivis.html Accessed 24 February 2025.

Medved, K., Kozmus Trajkovski, K., Berk, S., Stopar, B., Koler, B. (2020). Uvedba novega slovenskega višinskega sistema (SVS2010). Geodetski vestnik 64, 1: 33-42. DOI:10.15292/geodetski-vestnik.2020.01.33-42

Myers, D. (1993). Cross-validation and variogram estimation. Theory of Probability and Applications, 37, 345–347. DOI: http://dx.doi.org/10.1137/1137074

PREG (2018). http://prostor3.gov.si/preg/. Accessed 24 Februar 2025.

Press, W.H., Teukolsky, S.A., Vetterling, W.T., Flannery, B.P. (1992). Numerical Recipes in C: the Art of Scientific Computing. Second Edition. Cambridge University Press, New York, str. 123–124. https://freecomputerbooks.com/Numerical-Recipes-in-C-Second-Edition.html. Accessed 31 January 2025.

SMARS (2024). ViTra - Transformacija višin med starim (SVS2000/Trieste) in novim višinskim sistemom Slovenije (SVS2010/Koper), Uporabniški priročnik, Različica 1.0, februar 2024, 18 str. https://www.e-prostor.gov.si/podrocja/drzavni-koordinatni-sistem/drugo/razno/transformacija-v-novi-visinski-sistem/, Accessed 31 January 2025.

Sterle, O., Koler, B. (2019). Določitev novega višinskega datuma Slovenije. Geodetski vestnik 63, 1: 13-26. DOI: 10.15292/geodetski-vestnik.2019.01.13-26

Uredba o določitvi parametrov višinskega dela vertikalne sestavine državnega prostorskega koordinatnega sistema. (2018). Uradni list Republike Slovenije, štev. 80/2018. https://www.uradni-list.si/glasilo-uradni-list-rs/vsebina/2018-01-3854?sop=2018-01-3854 Accessed 31 January 2025.

Zhang H. and Wang Y. (2010). Kriging and cross-validation for massive spatial data. Environmetrics, 21, 290–304. DOI: https://doi.org/10.1002/env.1023

** The English translation was made with the help of ChatGPT and verified by Instatext.*

Transformacija višin med SVS2000/Trst in SVS2010/Koper z državnim transformacijskim višinskim modelom

OSNOVNE INFORMACIJE O ČLANKU

GLEJ STRAN 11

1 Uvod

V Sloveniji smo konec leta 2018 z Uredbo o določitvi parametrov višinskega dela vertikalne sestavine državnega prostorskega koordinatnega sistema (UL, 2018) prešli na nov državni višinski sistem z oznako SVS2010 (EPSG 8690, EPSG-kode, 2020) z višinskim datumom 2010, Koper (SVS2010/Koper, Sterle, Koler, 2019), ki nadomešča stari višinski sistem z oznako SVS2000 (EPSG 5779, EPSG-kode, 2020) z višinskim datumom 2000, Trst (SVS2000/Trst, Koler in sod., 2019). Zakonsko podlago za prehod iz starega v novi višinski sistem daje Zakon o državnem geodetskem referenčnem sistemu (UL, 2014).

Geodetska uprava Republike Slovenije (GURS) in številni drugi upravljavci ter državni organi vodijo različne zbirke prostorskih podatkov, ki vsebujejo georeferencirane podatke, vključno z višino, ki je določena v starem višinskem sistemu SVS2000/Trst. Z uvedbo novega višinskega sistema SVS2010/Koper so se spremenile stare višine reperjev na območju Slovenije od 1,4 cm do – 30,8 cm. Preprosta transformacija višin, ki so določene z nekajcentimetrsko natančnostjo, s prištevanjem oziroma odštevanjem srednje višinske razlike, ki znaša – 13,1 cm, ni mogoča (Medved in sod., 2020). Ko obstoječe podatkovne zbirke, ki vsebujejo tudi podatek o nadmorski višini, dopolnjujemo z novimi podatki, kjer so višine določene v novem višinskem sistemu (SVS2010/Koper), nastanejo razlike med višinami v starem in novem višinskem sistemu.

V okviru ciljnega raziskovalnega projekta *V2-2294: Razvoj državnega višinskega transformacijskega modela med SVS2000/Trst in SVS2010/Koper* smo razvili enotni višinski transformacijski model za območje Slovenije, ki ga sestavljajo višinska transformacijska ploskev – SLO-VTP2024, program za transformacijo višin – ViTra in ploskev ocene natančnosti višinske transformacijske ploskve. Upamo in verjamemo, da bo višinski transformacijski model različnim upravljavcem prostorskih podatkov omogočal enostaven prehod iz starega v novi višinski sistem in obratno.

2 Vhodni podatki za določitev višinske transformacijske ploskve

2.1 Pregled obstoječih podatkov o višinah reperjev v bazi geodetskih točk GURS

V spletni aplikaciji GURS (PREG, 2018) so zbrani podatki o višinah vseh reperjev, ki so stabilizirani v nivelmanskih mrežah in poligonih na območju Slovenije. Višine reperjev so določene v starem (SVS2000/Trst) in novem višinskem sistemu (SVS2010/Koper). V preglednici 1 so zbrani podatki o številu reperjev, ki so razdeljeni v različne redove nivelmanskih poligonov.

Preglednica 1: Podatki o višinah reperjev v bazi geodetskih točk GURS.

Red nivelmanskega poligona	Reperji		Reperji z višino v obeh višinskih sistemih	
	n	%	*n*	%
1	2.871	23,9	2.135	74,4
2	662	5,5	568	85,8
3	955	7,9	936	98,0
4	2.985	24,8	2.973	99,6
Mestni	4.548	37,8	4.477	98,4
Skupaj	12.021	100	11.089	92,2

V bazi geodetskih točk je vodenih 12.021 reperjev (preglednica 1). Največ je reperjev mestnih nivelmanskih mrež (37,8 %), 4. reda (24,8 %) in 1. reda (23,9 %). V bazi je zajetih tudi 5,5 % reperjev 2. reda in 7,9 % reperjev 3. reda (Koler in sod., 2024a). Analiza reperjev, ki imajo višine določene v starem in novem višinskem sistemu, je pokazala, da je največji delež takšnih reperjev 4. reda (99,6 %) in najmanjši delež takšnih reperjev 1. reda (74,4 %). Ker je bila nivelmanska mreža 1. reda sanirana in so bili stabilizirani novi reperji, ki višine nimajo določene v starem višinskem sistemu, so rezultati pričakovani. Reperji nižjih redov so bili z izravnavo nivelmanskih poligonov preračunani iz starega v novi višinski sistem na podlagi podatkov o starih merjenih višinskih razlikah. Če je bila razlika med dano in merjeno višinsko razliko prevelika, glede na dovoljena odstopanja za kateri koli red nivelmanske mreže (GURS, 2020), reperji niso bili preračunani in niso vključeni v bazo.

2.2 Izračun razlik nadmorskih višin reperjev

Za določitev višinske transformacijske ploskve, ki je določena z različnimi interpolacijskimi metodami (poglavje 4), izračunamo razliko nadmorskih višin reperjev po naslednji enačbi (Koler in sod., 2024a):

$$\Delta H_{SLO-VTP2024} = H_{SVS2010} - H_{SVS2000} \tag{1}$$

V enačbi (1) so:

$\Delta H_{SLO-VTP2024}$ … razlika nadmorskih višin reperjev za določitev višinske transformacijske ploskve,

$H_{SVS2010}$ … nadmorska višina reperja v novem višinskem sistemu SVS2010/Koper,

$H_{SVS2000}$ … nadmorska višina reperja v starem višinskem sistemu SVS2000/Trst.

Na podlagi natančnosti določitve višin reperjev v novem in starem višinskem sistemu ocenimo natančnost razlik nadmorskih višin med novim in starim višinskim sistemom, ki predstavljajo vhodni podatek za določitev ploskve ocene natančnosti višinske transformacijske ploskve. Oceno natančnosti razlik višin reperjev izračunamo po enačbi:

$$\sigma_{\Delta H_{SLO-VTP\,2024}} = \sqrt{\sigma^2_{H_{SVS\,2010}} + \sigma^2_{H_{SVS\,2010}}} \tag{2}$$

V enačbi (2) so:

$\sigma_{\Delta H_{SLO-VTP2024}}$ … natančnost razlike višin, ki je vhodni podatek za določitev ploskve ocene natančnosti višinske transformacijske ploskve,

$\sigma_{H_{SVS2010}}$ … natančnost določitve nadmorske višine reperjev v SVS2010/Koper,

$\sigma_{H_{SVS2000}}$ … natančnost določitve nadmorske višine reperjev v SVS2000/Trst.

Stara in nova nivelmanska mreža sta bili izravnani s programom VimWin (Ambrožič, 2016). Statistične cenilke ocene natančnosti po izravnavi (Koler in sod., 2019) so zbrane v preglednici 2.

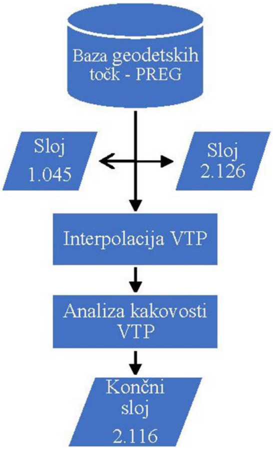
Preglednica 2: Statistične cenilke za oceno natančnosti nove in stare nivelmanske mreže.

Nivelmanska mreža 1. reda	$\hat{\sigma}_0[mm/km]$	$\sigma_H[mm]$
Stara (SVS2000/Trst)	0,86	0,12–11,46
Nova (SVS2010/Koper)	0,50	0,06–6,08

Iz preglednice 2 vidimo, da je nova nivelmanska mreža 1. reda približno dvakrat kakovostnejša od stare nivelmanske mreže, sestavljene iz meritev, ki so bile izvedene v 50., 70. in 80. letih prejšnjega stoletja.

2.3 Izbira reperjev za izdelavo višinske transformacijske ploskve

V bazi geodetskih točk imamo 11.089 reperjev, ki imajo višino določeno v obeh višinskih sistemih (preglednica 1). Izbor reperjev za izdelavo višinske transformacijske ploskve (VTP) je potekal v več korakih (slika 1), ki so opisani v Koler in sod. (2024b). V tem prispevku so predstavljeni le povzetki.



Slika 1: Diagram poteka izbire reperjev za izdelavo višinske transformacijske ploskve.

Reperje za izdelavo višinske transformacijske ploskve smo izbrali v naslednjih korakih:

a) Podatki za transformacijsko ploskev na podlagi merjenih višin identičnih reperjev 1. reda v SVS2000/Trst in SVS2010/Koper – sloj 1.045 reperjev

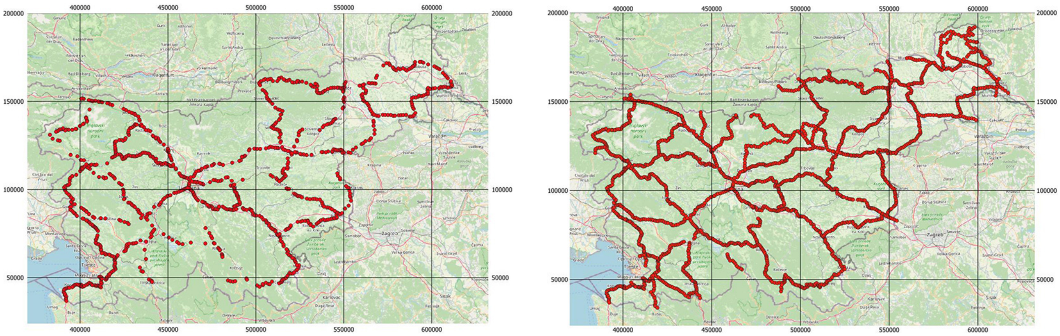
V novo izmero nivelmanske mreže 1. reda Slovenije je bilo vključenih 1231 starih reperjev, ki so bili predhodno vključeni tudi v izmero v starem višinskem sistemu SVS2000/Trst. Ker je v določenih primerih razlika med novim in starim višinskim sistemom med sosednjimi reperji presegala 10 mm (preglednica 3) in ker ocenjujemo, da jih lahko povezujemo z lokalnimi posebnostmi (stabilizacija v neprimerne objekte, lokalni vertikalni premiki, kakovost stare nivelmanske izmere ipd.), smo izločili 186 reperjev. Tako je ostalo 1045 reperjev nove nivelmanske mreže 1. reda, ki so bili predhodno vključeni tudi v izmero SVS2000/Trst in so podlaga za določitev višinske transformacijske ploskve (slika 2).

b) Dopolnjeni podatki za izračun transformacijske ploskve na podlagi preračunanih višin reperjev nižjih redov v SVS2000/Trst in SVS2010/Koper – sloj 2126 reperjev

Ker so na posameznih območjih Slovenije podatki za izdelavo transformacijske ploskve neenakomerno porazdeljeni (slika 2a), smo osnovne podatke dopolnili z dodatnimi podatki, ki so omogočili izdelavo bolj kakovostne transformacijske ploskve (Koler in sod., 2024a). V izravnavo stare nivelmanske mreže 1. reda smo vključili dodatne nivelmanske poligone nižjih redov in nove reperje, ki so bili zajeti v izmero nove nivelmanske mreže 1. reda Slovenije, ter tako dobili višine novih reperjev tudi v starem sistemu SVS2000/Trst in sloj 2126 reperjev (slika 2b).

Preglednica 3: Primera razlike med SVS2010/Koper in SVS2000/Trst med sosednjimi reperji, ki presega 10 mm (rdeče v besedilu).

Reper	Vgrajen v objekt ob cesti Kobarid–Nova Gorica	$H_{SVS2010}$ $[m]$	$H_{SVS2000}$ $[m]$	$\Delta H_{SLO-VTP2024}$ $[m]$
5352	Upravna zgradba Goriških vodovodov	106,6234	106,7357	-0,112
5349	Propust, Kobarid –Nova Gorica pri km 106+593	80,8363	80,9640	-0,109
5351	Propust, Kobarid–Nova Gorica pri km 109+058	79,5649	79,6735	-0,128
5350a	Stena, Kobarid–Nova Gorica pri km 109+290	81,0391	81,1539	-0,115
5349a	Propust, Kobarid–Nova Gorica pri km 107+580	82,2320	82,3473	-0,115
5349	Propust, Kobarid–Nova Gorica pri km 106+593	80,8363	80,9640	-0,128
5348a	Močnejši robnik ob glavni cesti pri km 105+685	82,0822	82,1925	-0,110
O-41	Propust, Kobarid–Nova Gorica pri km 105+034	89,8892	89,9997	-0,111



a) Sloj 1045 reperjev 1. reda

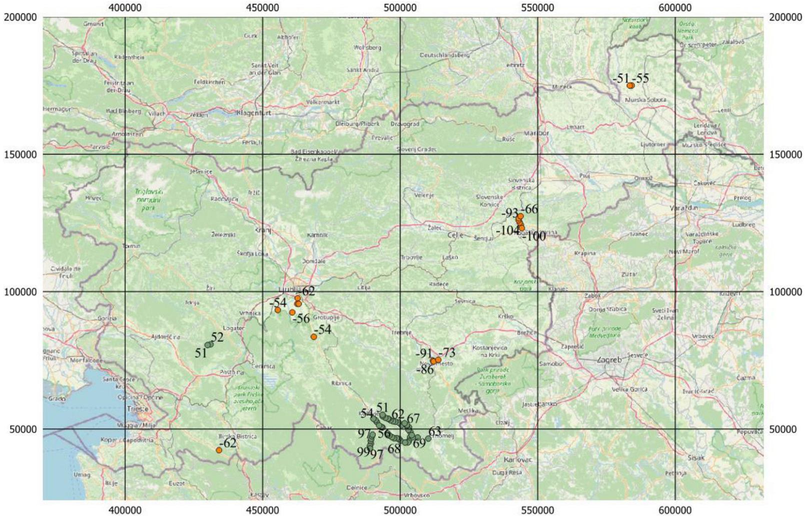
b) Sloj 2126 reperjev 1. reda in nižjih redov

Slika 2: Skica reperjev za določitev višinske transformacijske ploskve (Kartografska podlaga: Googlemaps).

c) Končni sloj – 2116 reperjev za določitev višinske transformacijske ploskve

Na podlagi razlike med izračunano in interpolirano razliko višin na 8775 kontrolnih reperjih smo ugotovili, da so se večje razlike pojavile na območju Kočevskega roga, Novega mesta ter med Poljčanami in Rogaško Slatino (Slika 3, Koler in sod., 2024b).

Dodatna analiza vhodnih podatkov na območjih z večjimi razlikami je pokazala razlike na 10 reperjih, ki se niso ujemale s sosednjimi vrednostmi razlik višin (preglednica 4). Ko smo izpustili teh 10 reperjev (označeni z rdečo v preglednici 5), smo določili končni niz razlik višin (2116 reperjev), ki predstavljajo končne vhodne podatke za določitev višinske transformacijske ploskve z metodo kriging z dodanim vplivom na variogramu (slika 4).



Slika 3: Prikaz večjih razlik višin med preračunano in transformirano višino v SVS2010/Koper – sloj 2126 reperjev (Kartografska podlaga: Googlemaps, enota je mm).

Preglednica 4: Odstopanja med sosednjimi reperji na območjih, kjer dobimo večje razlike višin po transformaciji višin iz SVS2000/Trst v SVS2010/Koper.

Nivelmanski poligon N4-P91: Podplat – Tekačevo				Nivelmanski poligon N1-MP406: Petrinja			
Reper	$H_{SVS2010}$ $[m]$	$H_{SVS2000}$ $[m]$	$\Delta H_{SLO-VTP2024}$ $[m]$	Reper	$H_{SVS2010}$ $[m]$	$H_{SVS2000}$ $[m]$	$\Delta H_{SLO-VTP2024}$ $[m]$
5244d	222,2270	222,3523	-0,125	167	547,4792	547,6160	-0,137
5244b	230,7400	230,7545	-0,014	25	546,3794	546,5715	-0,192
1	237,8567	237,8755	-0,019	203	539,8766	540,0687	-0,192
2	245,0306	245,0465	-0,016	300	536,3200	536,5121	-0,192
3	255,0199	255,0444	-0,024	201	530,4858	530,6779	-0,192
4	266,5728	266,5974	-0,025				
5	245,7315	245,77840	-0,047				

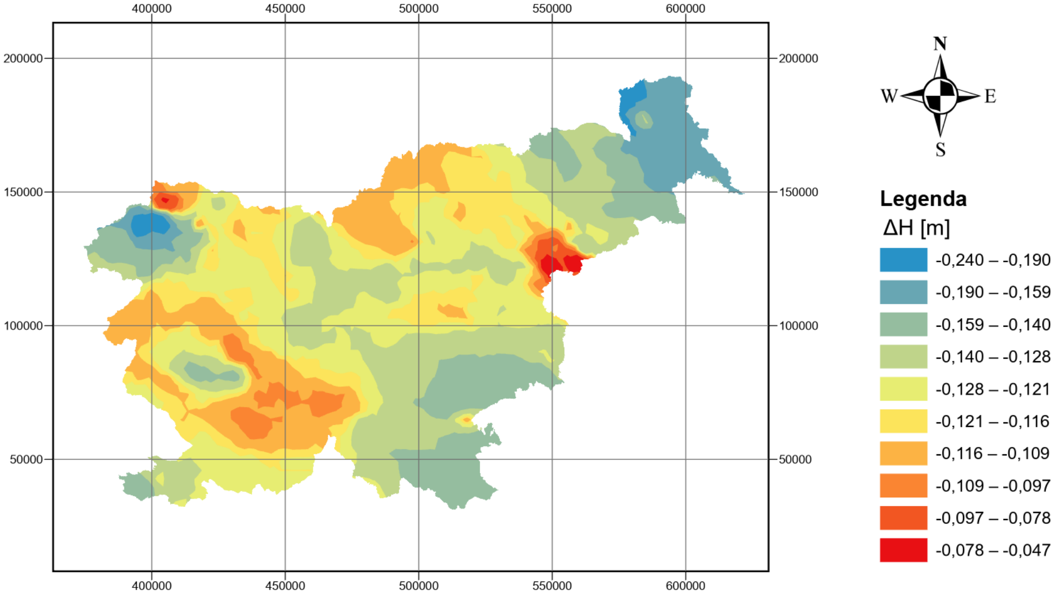
3 Izdelava višinske transformacijske ploskve in programa za transformacijo višin

3.1 Določitev višinske transformacijske ploskve z različnimi interpolacijskimi metodami

Višinska transformacijska ploskev je tridimenzionalna in jo sestavlja zvezno polje vrednosti po celotnem območju izdelane ploskve. Podatki interpolacije predstavljajo površino ploskve kot mrežo celic enakih velikosti. Poznamo interpolacije na podlagi determinističnih metod ter na podlagi geostatističnih metod. Deterministične metode določajo vrednosti na podlagi vhodnih podatkov in določenih matematičnih enačb, medtem ko geostatistične metode temeljijo na statističnih modelih, ki vključujejo avtokorelacijo (Ayeni in Samuel, 2014).

Obdelavo podatkov smo naredili v okolju ArcGIS. Za izdelavo višinskih transformacijskih ploskev smo uporabili štiri deterministične metode interpolacije (metodo inverzne razdalje, globalno polinomsko interpolacijo, lokalno polinomsko interpolacijo in radialne bazne funkcije) ter metodo kriging (Zhang H., Wang Y., 2010) in kriging z dodanim vplivom smeri na variogramu, ki sta geostatistični metodi (Koler in sod., 2024b).

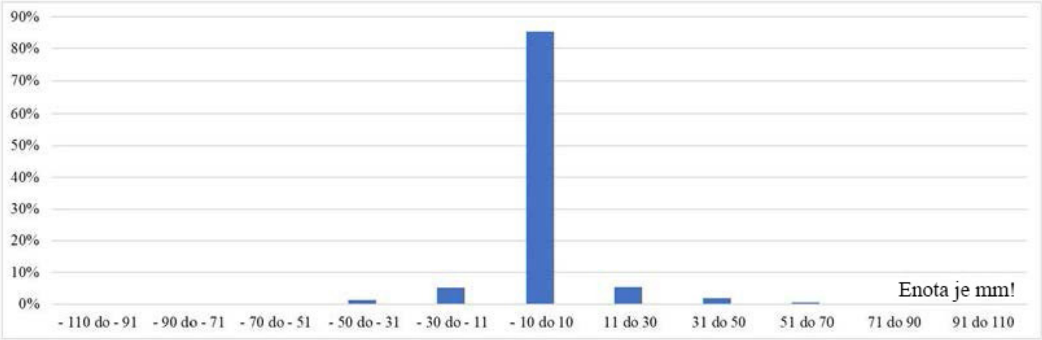
Kakovost višinskih transformacijskih ploskev smo ocenili z navzkrižnim preverjanjem (Myers, D., 1993), ki v vsaki iteraciji odstrani eno točko iz določitve ploskve in nato primerja interpolirano vrednost ploskve z merjeno vrednostjo. Analiza kakovosti, katere rezultati so predstavljeni v Koler in sod., 2024b, je pokazala, da je višinska transformacijska ploskev, ki je izračunana z metodo kriging z dodanim vplivom smeri na variogramu, najboljša (slika 4).



Slika 4: Slovenska višinska transformacijska ploskev – SLO-VTP2024 na podlagi interpolacijske metode kriging z dodanim vplivom smeri na variogramu – sloj 2116 reperjev.

V naslednjem koraku smo kakovost višinske transformacijske ploskve, ki je določena z metodo kriging z dodanim vplivom na variogramu, testirali tudi na 8775 kontrolnih reperjih, ki imajo višino določeno v obeh višinskih sistemih. Na podlagi razlike med izračunano in interpolirano razliko višin na kontrolnih reperjih smo ocenili kakovost višinske transformacijske ploskve. Razlika je znašala od – 109 mm do 102 mm, vrednost RMSE znaša 11,71 mm, srednja razlika pa -0,51 mm.

Iz histograma (slika 5) vidimo, da na 85,2 % reperjih razlika znaša od – 10 mm do 10 mm. Na 18 kontrolnih reperjih (0,2 %) razlika znaša od – 50 mm do – 109 mm in na 47 kontrolnih reperjih (0,5 %) od 50 mm do 102 mm. V obeh primerih je delež kontrolnih reperjev z večjimi razlikami zanemarljiv.



Slika 5: Histogram porazdelitve razlik višin na kontrolnih reperjih.

3.2 Zapis Slovenske višinske transformacijske ploskve – SLO-VTP2024 s celično mrežo

Zaradi poenotenja različnih ploskev, ki jih vodi GURS, je višinska transformacijska ploskev določena enako kot kvazigeoid AGM2000 in slovenska višinska referenčna ploskev SLO-VRP2016/Koper (Koler in sod., 2019):

1. Območje: od 45° do 47° severne geografske širine ter od 13° do 17° vzhodne geografske dolžine.
2. Velikost celične mreže: 30“ x 45“ ($d\varphi$, $d\lambda$) cca 925 m x 925 m (dn, de).
3. Koordinate celične mreže so podane v decimalnih stopinjah s korakom 0,008333333333° (φ) x 0,0125° (λ).
4. Celična mreža se začne s točko v skrajnem levem kotu spodaj (jugozahodna točka).
5. Število stolpcev je število geografskih dolžin in število vrstic je število geografskih širin: 321 (stolpcev) in 241 (vrstic).

Celična mreža je zapisana v *.grd, *.gri, *.tif, *.tfw, *.xyz in *.txt formatih. Višinsko transformacijsko ploskev smo poimenovali SLO-VTP2024. Akronim pomeni SLOvenska Višinska Transformacijska Ploskev iz leta 2024.

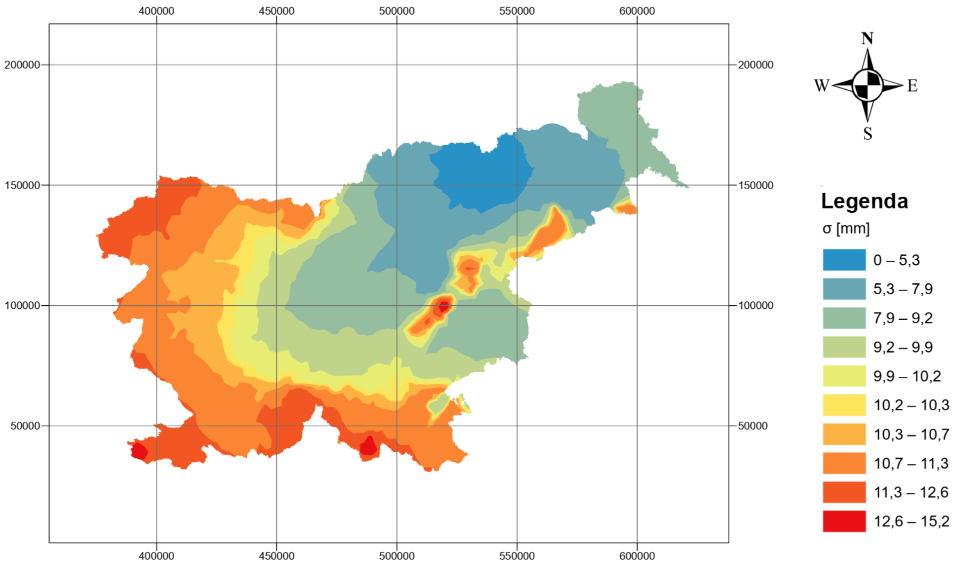
3.3 Izdelava ploskve natančnosti SLO-VTP2024

Kakovost razlike višin med SVS2010/Koper in SVS2000/Trst smo ocenili po enačbi 2. V preglednici 5 sta zbrana statistična kazalca za oceno natančnosti določitve razlik višin med SVS2010/Koper in SVS2000/ Trst na reperjih, ki so bili izbrani za izdelavo SLO-VTP2024.

Preglednica 5: Statistična kazalca za oceno natančnosti SLO-VTP2024.

Reper	Nivelmanski poligon/Kraj	$\sigma_{\Delta H_{SLO-VTP2024}}$ $[mm]$
N1168	N3-51/Sevnica	15,2
C-2	N1-11B/Smolnik pri Rušah	0,1
	Srednja vrednost:	9,2

Na sliki 6 je prikazana ploskev natančnosti določitve SLO-VTP2024, ki ni namenjena oceni natančnosti transformacije višin na posameznih območjih. S slike 6 vidimo, da je natančnost transformacijske ploskve najboljša v bližini normalnega reperja in najslabša na robovih Slovenije. To je povezano z natančnostjo določitve nadmorske višine reperja, ki pada z oddaljenostjo od izhodiščnega reperja.



Slika 6: Ploskev natančnosti določitve SLO-VTP2024.

3.4 Programski paket ViTra za transformacijo višin

Za transformacijo višin iz SVS2000/Trst v SVS2010/Koper in obratno smo razvili program ViTra, ki je za uporabnike dostopen na spletni strani GURS (https://www.e-prostor.gov.si/dostopi/javni-dostop/storitve/?filter=.pf-javni-dostop). Akronim pomeni Višinska Transformacija. Program ViTra je razvit v okolju MS Visual Studio 2022 v programskem jeziku Visual C++ in zahteva operacijski sistem MS Windows, ki je novejši od Windows XP. Program ViTra podpira oblike vhodnih datotek SHP (ArcView Shapefile Format), CSV (MS DOS), TXT (MS DOS), datoteke XYZ in tudi datoteke ASC (GURS, 2024).

Za transformacijo višin so uporabljene optimizirane enačbe bilinearne interpolacije (Press in sod., 1992). Pretvorba koordinat iz državnih ravninskih koordinat (n, e) (D96/TM oziroma D96-17/ TM) v krivočrtne geodetske koordinate (φ, λ) na elipsoidu GRS80 je izvedena s Karneyjevo metodo (Karney, 2011).

S prištevanjem višinske razlike višini v SVS2000/Trst, ki jo dobimo s programom ViTra iz SLO-VTP2024, dobimo transformirano višino v SVS2010/Koper in obratno za transformacije višine iz SVS2010/Koper v SVS2000/Trst.

4 Analiza kakovosti višinske transformacijske ploskve

Kakovost SLO-VTP2024 smo ocenili na podlagi razlik med nadmorskimi višinami v SVS2010/Koper, ki jih vodi GURS v bazi geodetskih točk PREG, in transformiranimi višinami iz SVS2000/Trst v SVS2010/ Koper s programom ViTra (enačba 3).

$$\Delta H_i^{Tran} = H_i^{SVS2010} - H_i^{ViTra} \tag{3}$$

V enačbi (3) so:

ΔH_i^{Tran} … razlika višin med višino v SVS2010/Koper in transformirano višino s programom ViTra iz SVS2000/Trst v SVS2010/Koper na kontrolnem reperju *i*,

$H_i^{SVS2010}$ … višina reperja *i* iz baze geodetskih točk PREG,

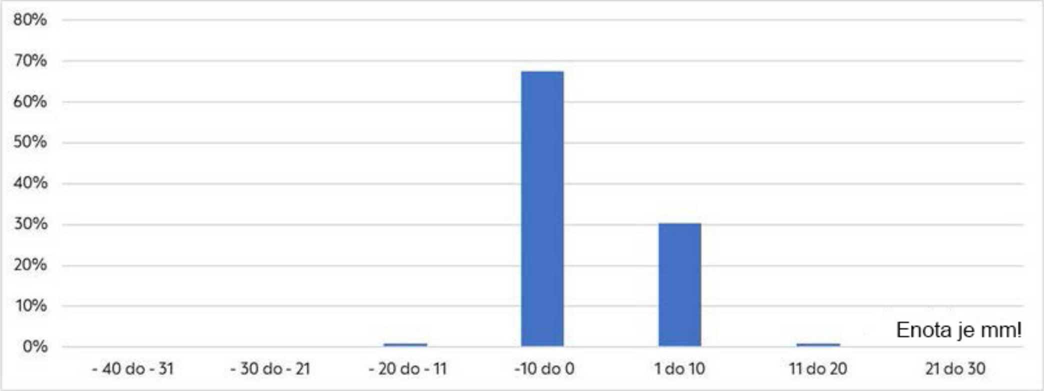
H_i^{ViTra} … transformirana višina reperja *i*.

Oceno kakovosti transformacije višin s SLO-VTP2024 smo izračunali po enačbi:

$$\sigma_{ViTra} = \sqrt{\frac{\sum \Delta H_i^{Tran^2} \Delta H_i^2}{n-1}} \tag{4}$$

4.1 Analiza kakovosti SLO-VTP2024 na točkah za določitev višinske transformacijske ploskve – sloj 2116 reperjev

Najprej smo analizirali kakovost SLO-VTP2024 na 2116 reperjih, ki smo jih uporabili za določitev višinske transformacijske ploskve. Minimalna razlika znaša – 33 mm, podobne velikosti je tudi maksimalna razlika (27 mm). Srednja razlika znaša 0,02 mm in σ_{ViTra} je 3,48 mm.



Slika 7: Histogram porazdelitve razlik višin na 2116 reperjih za določitev SLO-VTP2024 (Koler in sod., 2024).

S slike 7 vidimo, da je 97,8 % razlik višin na reperjih med – 10 mm in 10 mm. Rezultati so pričakovani, saj gre za tako imenovano notranjo oceno natančnosti (Koler in sod., 2024a).

4.2 Analiza kakovosti SLO-VTP2024 na kontrolnih reperjih

Analizo kakovosti SLO-VTP2024 smo izvedli na kontrolnih reperjih v več korakih, ki so opisani spodaj.

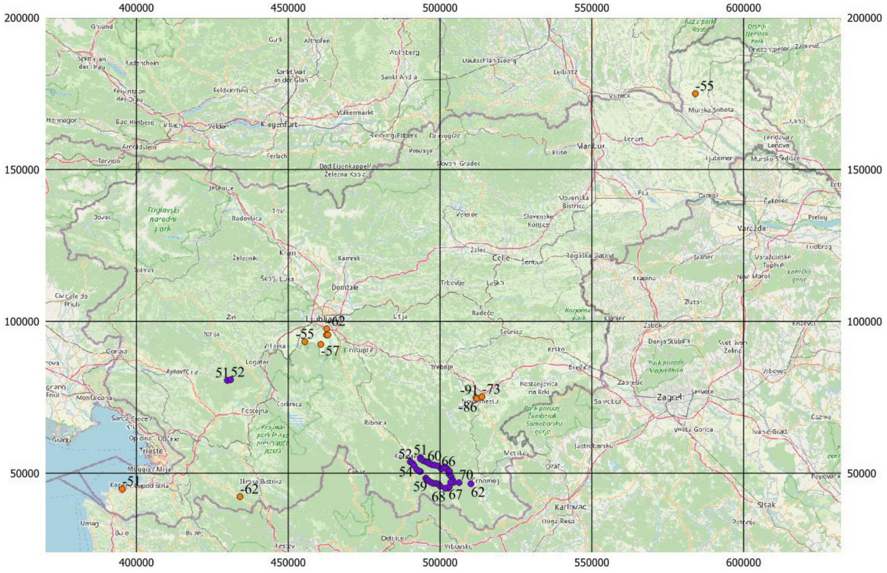
4.2.1 Analiza kakovosti na 8775 oziroma 8695 kontrolnih reperjih

Kakovost SLO-VTP2024 smo kontrolirali na 8775 kontrolnih reperjih, ki imajo višino določeno v SVS2000/Trst in SVS2010/Koper. S programom ViTra smo transformirali višine iz SVS2000/Trst v SVS2010/Koper in jih primerjali z višinami v SVS2010/Koper, ki so zajete v bazi geodetskih točk GURS. Na podlagi razlike med višinami iz baze geodetskih točk GURS in transformirano višino, ki je izračunana po enačbi (3), smo ocenili kakovost SLO-VTP2024 po enačbi (4) (preglednica 6). Ker se je v preteklosti za transformacijo višin uporabljal tudi program SiVis (Kozmus Trajkovski, Stopar, 2019), ki je namenjen transformaciji nadmorskih višin, ki jih dobimo z višinomerstvom GNSS, smo ocenili tudi kakovost transformacije višin s programom SiVis. Iz preglednice 6 vidimo, da program SiVis ni primeren za transformacijo višin, ki jih dobimo z niveliranjem ali trigonometričnim višinomerstvom, saj je kakovost transformacije približno 10-krat slabša.

Iz preglednice 6 vidimo, da znaša minimalna razlika – 91 mm, podobne velikosti je tudi maksimalna razlika (70 mm) za 8775 kontrolnih reperjev (slika 8). Na 12 kontrolnih reperjih (0,14 %) je razlika med – 50 mm do – 91 mm in na 40 kontrolnih reperjih (0,46 %) od 50 mm do 70 mm.

Preglednica 6: Statistične cenilke za oceno kakovosti SLO-VTP2024 na 8775/8695 kontrolnih reperjih.

Statistične cenilke	8775 reperjev	8695 reperjev	
		ViTra	SiVis
Minimalna razlika [*mm*]	– 91	– 50	– 403
Število reperjev z razliko manjšo od –50 mm	12 (0,14 %)	/	5084 (58,5 %)
Maksimalna razlika [*mm*]	70	50	155
Število reperjev z razliko večjo od 50 mm	40 (0,46 %)	/	274 (3,2 %)
Srednja razlika [*mm*]	0,05	– 0,06	– 67
Delež reperjev z abs. razliko manjšo od 10 mm	85,6 %	86,4 %	3,6 %
Delež reperjev z abs. razliko manjšo od 20 mm	94,2 %	95,0 %	7,6 %
$\sigma_{ViTra/SiVis}$ [*mm*]	11,1	9,9	92,2



Slika 8: Prikaz večjih razlik višin na podlagi razlik preračunanih in transformiranih višin v SVS2010/Koper – sloj 2116 reperjev, enota je mm (Kartografska podlaga: Googlemaps, enota je mm).

S slike 8 vidimo, da imamo večji niz »slabih« kontrolnih reperjev na območju Kočevskega roga in Ljubljanskega barja. Ostali »slabi« kontrolni reperji so slučajno porazdeljeni na območju Slovenije. Ocenili smo, da večje razlike niso posledica manjše kakovosti višinske transformacijske ploskve na teh območjih, temveč jih lahko povezujemo z lokalnimi posebnostmi (stabilizacija v neprimerne objekte; vertikalni premiki, na primer na Ljubljanskem barju; kakovost stare nivelmanske izmere ipd.). Zato smo se odločili, da kontrolne reperje, kjer razlika med preračunano in transformirano višino v SVS2010/Koper presega ± 50 mm, izpustimo iz nadaljnje analize kakovosti SLO-VTP2024. V preglednici 7 so zbrani podatki o številu izpuščenih kontrolnih reperjev glede na red, ki mu pripadajo. Po izločitvi 80 reperjev (0,91 %, preglednica 7) je ostalo 8695 kontrolnih reperjev, ki smo jih uporabili za kontrolo kakovosti SLO-VTP2024. Pričakovano je, da so statistične cenilke, navedene v preglednici 6 za novi niz podatkov, boljše. Na podlagi ocene kakovosti lahko ugotovimo, da bo SLO-VTP2024, ki smo jo razvili, omogočala dovolj kakovostno transformacijo višin podatkovnih zbirk, ki jih vodijo na Geodetski upravi Republike Slovenije.

Preglednica 7: Izločeni reperji glede na red nivelmanskega poligona.

Nivelmanski poligon	Število izločenih kontrolnih reperjev	Delež
2. red	22	27,4 %
4. red	19	23,8 %
Mestni	7	8,8 %
Mestna občina Ljubljana in Ljubljansko barje	32	40,0 %
Skupaj	80	100,0 %

4.2.2 Analiza kakovosti na reperjih posameznih redov nivelmanske mreže

Kontrolne reperje smo razporedili glede na red nivelmanskega poligona, ki mu pripadajo, in ocenili, ali red vpliva na kakovost transformacije višin. V preglednici 8 so zbrane statistične cenilke za kontrolne reperje različnih redov. Pričakovano imamo najmanj reperjev 1. reda (232 oz. 2,7 %) in največ 4399 reperjev mestnih nivelmanskih mrež (50,6 %). Poleg tega vidimo, da je srednja razlika najmanjša na reperjih 4. reda (0,04 mm) in največja na reperjih 1. rada (4,07 mm). Natančnost transformacije višin (σ_{ViTra}) znaša od 9,2 mm na reperjih mestne nivelmanske mreže do 12,6 mm na reperjih 2. reda. Srednja vrednost razlik na reperjih vseh redov je 1,2 mm in srednja natančnost (σ_{ViTra}) 10,4 mm. Na podlagi opravljene analize natančnosti lahko ugotovimo, da je transformacija višin na reperjih vseh redov primerljive natančnosti.

Preglednica 8: Statistične cenilke za kontrolne reperje posameznih redov.

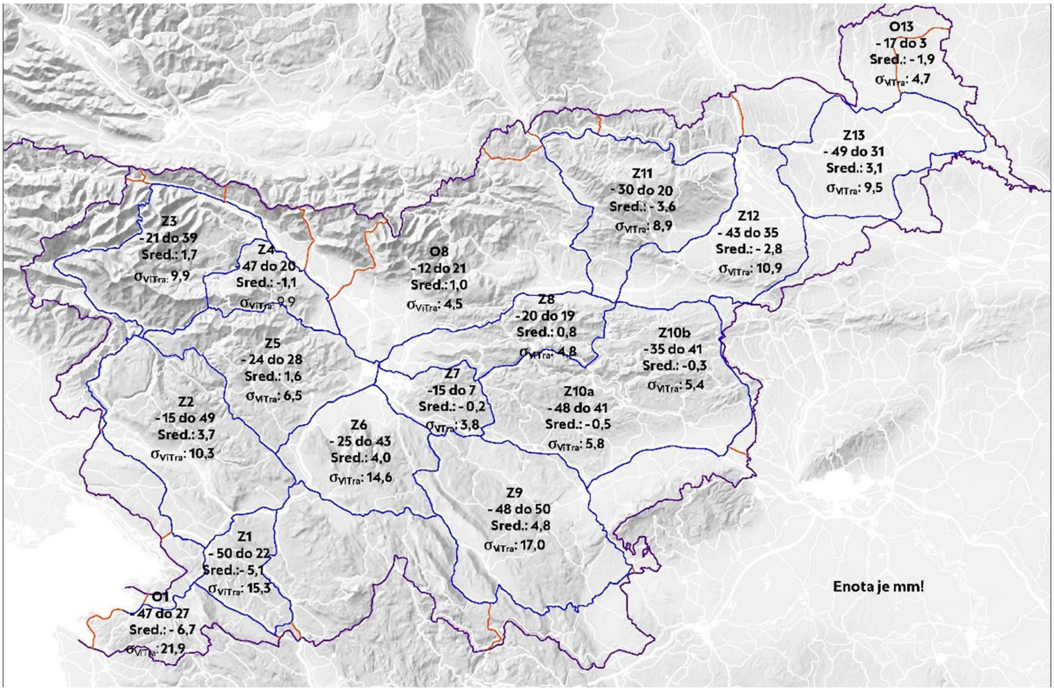
Reper	Število reperjev	Delež	Min. razl. [*mm*]	Maks. razl. [*mm*]	Sred. vred. razl. [*mm*]	σ_{ViTra} [*mm*]
1. red	232	2,7 %	– 7	39	4,07	10,3
2. red	471	5,4 %	– 39	49	2,92	12,6
3. red	851	9,8 %	– 47	41	– 0,41	9,3
4. red	2.740	31,5 %	– 50	50	0,04	10,4
Mestna	4.399	50,6 %	– 49	48	– 0,57	9,2

4.2.3 Analiza kakovosti na kontrolnih reperjih, ki so stabilizirani v posameznih zankah nove nivelmanske mreže 1. reda Slovenije, in po območjih

Kontrolne reperje smo glede na položaj stabilizacije razporedili po zankah nove nivelmanske mreže 1.

reda Slovenije in po posameznih območjih ob nivelmanskih zankah (slika 9). Razdelitev na nivelmanske zanke in območja ob zankah je smiselna, saj so bili kontrolni reperji iz SVS2000/Trst preračunani v SVS2010/Koper z navezavo na reperje nove nivelmanske mreže 1. reda Slovenije. Slika 9 prikazuje tri dodana območja (O1, O8 in O13), ki se nahajajo ob zankah. Zaradi velikosti smo zanko 10 razdelili na Z10a, ki leži zahodno od reke Save, in Z10b, ki leži vzhodno od reke Save.

V preglednici 9 so zbrane statistične cenilke za posamezne nivelmanske zanke in območja. Iz preglednice 9 vidimo, da reperji niso enakomerno porazdeljeni po zankah in območjih. Najmanj, 55 reperjev, jih je v območju 13 (O13) in največ, 874 reperjev, v zanki 10a (Z10a). Poleg tega vidimo, da znaša najmanjša razlika od – 6,7 mm za območje 1 (O1) do 4,8 mm za zanko 9 (Z9). Natančnost transformacije višin (σ_{ViTra}) znaša od 3,8 mm v zanki 7 (Z7) do 21,9 mm na območju 1 (O1). Srednja vrednost razlik v vseh zankah in območjih znaša – 0,09 mm in povprečna natančnost (σ_{ViTra}) 9,6 mm. Pričakovano je natančnost transformacije višin podobna, kot je natančnost na 8695 kontrolnih reperjih (preglednica 6).



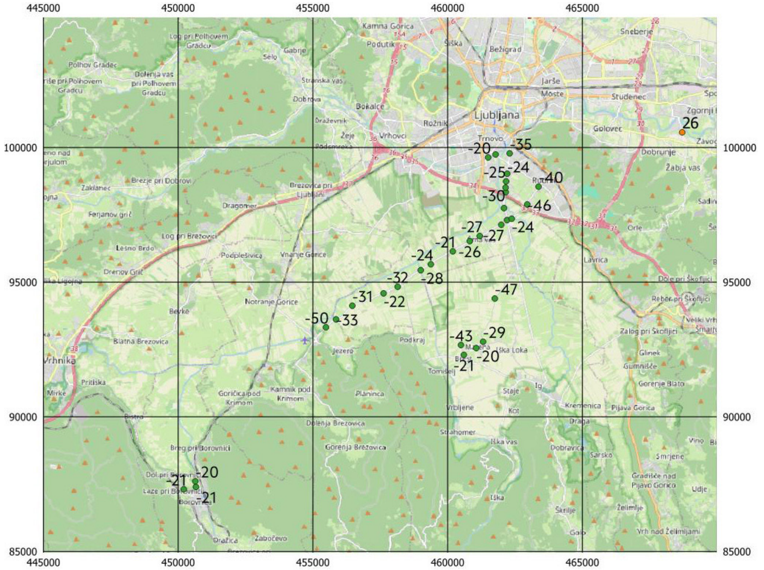
Slika 9: Nivelmanske zanke in območja s statističnimi cenilkami (Koler in sod., 2024a).

Preglednica 9: Statistične cenilke za posamezne nivelmanske zanke in območja.

Niv. zanka – območje	Število reperjev	Min. razl. [*mm*]	Maks. razl. [*mm*]	Sred. vred. razl. [*mm*]	σ_{ViTra} [*mm*]
Z1	231	– 50	22	– 5,10	15,3
O1	115	– 47	27	– 6,69	21,9
Z2	477	– 15	49	3,66	10,3
Z3	340	– 21	39	1,66	9,9
Z4	323	– 47	20	– 1,12	9,8

Niv. zanka – območje	Število reperjev	Min. razl. $[mm]$	Maks. razl. $[mm]$	Sred. vred. razl. $[mm]$	$\sigma_{ViTra}\,[mm]$
Z5	438	– 24	28	1,58	6,5
Z6	188	– 25	43	4,03	14,6
Z7	138	– 15	7	– 0,22	3,8
Z8	542	– 20	19	0,79	4,8
O8	266	– 12	21	1,00	4,5
Z9	546	– 48	50	4,82	17,0
Z10a	874	– 48	41	– 0,47	5,8
Z10b	571	– 35	41	– 0,29	5,4
Z11	560	– 30	20	– 3,58	8,9
Z12	824	– 43	35	– 2,81	10,9
Z13	686	– 49	31	3,14	9,5
O13	55	– 17	3	– 1,90	4,7
			Srednja vrednost:	– 0,09	9,6

4.2.4 Analiza kakovosti na kontrolnih reperjih, ki so stabilizirani v posameznih mestnih nivelmanskih mrežah



Slika 10: Izpuščeni reperji na območju Ljubljanskega barja in Zaloga, enota je mm (Kartografska podlaga: Googlemaps).

Analizo kakovosti smo naredili tudi za posamezne večje mestne nivelmanske mreže. V preglednici 10 so zbrane statistične cenilke po mestnih nivelmanskih mrežah. Iz preglednice 10 vidimo, da reperji pričakovano niso enakomerno porazdeljeni po mestnih nivelmanskih mrežah. Najmanj, 45 reperjev, jih je stabiliziranih v mestni nivelmanski mreži Nove Gorice in največ, 2041 reperjev, na območju Mestne občine Ljubljana in okolici. Poleg tega vidimo, da znaša srednja razlika od – 5,0 mm v Ljubljani oziroma – 4,7 mm, če izpustimo reperje na območju Ljubljanskega barja in Zaloga (slika 10) in do 6,9 mm v Celju. Natančnost transformacije višin (σ_{ViTra}) znaša od 1,5 mm v Domžalah do 9,8 mm v Celju in Ptuju. Srednja vrednost razlik v vseh mestnih nivelmanskih mrežah znaša 1,05 mm in povprečna natančnost (σ_{ViTra}) 5,6 mm.

Preglednica 10: Statistične cenilke za posamezne mestne nivelmanske mreže.

Mestna nivelmanska mreža	Število reperjev	Min. razl. [mm]	Maks. razl. [mm]	Sred. vred. razl. [mm]	σ_{ViTra} [mm]
Celje	253	– 12	18	6,87	9,8
Domžale	52	– 2	8	0,41	1,5
Grosuplje	52	– 6	3	– 1,17	2,6
Kranj	119	– 6	13	2,07	5,0
Ljubljana – vsi	2041	– 50	26	– 5,01	7,5
Ljubljana	2009	– 19	17	– 4,65	6,5
Maribor	892	– 30	12	2,39	5,2
Murska Sobota	60	– 10	6	0,67	2,2
Nova Gorica	45	– 15	12	1,23	4,7
Novo mesto	61	– 48	7	– 1,65	9,0
Ptuj	69	– 11	18,6	3,52	6,9
			Srednja vrednost:	0,97	5,3

5 Zaključek

V prispevku je prikazan način izdelave višinske transformacijske ploskve SLO-VTP2024 in ploskve natančnosti SLO-VTP2024, ki je bil izveden v več korakih. Z dopolnjevanjem podatkov osnovnih reperjev (sloj 1045 reperjev), ki so bili vključeni v izmero stare in nove nivelmanske mreže, smo dobili niz podatkov (sloj 2126 reperjev), ki so enakomerno porazdeljeni na območju Slovenije, saj povprečna dolžina med sosednjimi reperji znaša okoli 1 km. Ocenjujemo, da je to zadostna gostota reperjev za določitev transformacijske ploskve. Na podlagi analize kakovosti določitve višinske transformacijske ploskve, ki je bila izvedena na obeh slojih podatkov, smo prišli do ugotovitve, da je najboljša višinska transformacijska ploskev za sloj 2126 reperjev, ki je določena z interpolacijsko metodo kriging z dodanim vplivom smeri na variogramu.

Kakovost izbrane višinske transformacijske ploskve smo testirali na 8775 kontrolnih reperjih, ki imajo višine določene v SVS2000/Trst in SVS2010/Koper. Primerjali smo razlike višin na kontrolnih reperjih z razlikami višin, ki jih dobimo iz višinske transformacijske ploskve. Največ reperjev z negativno razliko (– 60 mm do – 102 mm) dobimo na območju Kočevskega roga in s pozitivno razliko (80 mm do 109 mm) na območju med Poljčanami in Rogaško Slatino. Z dodatno analizo smo iz sloja 2126 reperjev izločili 10 reperjev, ki so najbolj vplivali na velike razlike na navedenih območjih. Tako smo dobili končni niz 2116 reperjev, ki smo jih uporabili za določitev višinske transformacijske ploskve – SLO -V TP2024. Zaradi poenotenja različnih ploskev, ki jih vodi GURS, je tudi višinska transformacijska ploskev (SLO -VTP2024) določena s celično mrežo enako kot kvazigeoid AGM2000 in slovenska višinska referenčna ploskev SLO VRP2016/Koper.

Za transformacijo višin iz SVS2000/Trst v SVS2010/Koper in obratno smo v okolju MS Visual Studio 2022 razvili program ViTra. Program ViTra je napisan v programskem jeziku Visual C++ in zahteva operacijski sistem MS Windows, ki je novejši od Windows XP. Za transformacijo višin so uporabljene optimizirane enačbe bilinearne interpolacije.

Notranja natančnost transformacije višin, ki je bila ocenjena na podlagi razlik med preračunanimi in transformiranimi višinami na 2116 reperjih, ki smo jih uporabili za določitev višinske transformacijske ploskve, znaša 3,3 mm. Zunanjo natančnost, ki znaša 9,9 mm, smo ocenili na 8695 kontrolnih reperjih. Za primerjavo smo višine 8695 kontrolnih reperjev transformirali s programom SiVis, ki je namenjen transformaciji višin med SVS2000/Trst in SVS2010/Koper, ki jih dobimo z višinomerstvom GNSS. S programom SiVis smo dobili natančnost 92,2 mm, kar je skoraj 10-krat slabše, kot nam omogoča transformacija s programom ViTra. Analizirali smo tudi kakovost glede na red kontrolnih reperjev, porazdelitev po nivelmanskih zankah in sosednjih območjih ter v večjih mestnih nivelmanskih mrežah. Na podlagi opravljenih analiz kakovosti na kontrolnih reperjih lahko ugotovimo, da predlagana SLO-VTP2024, ki je vgrajena v program ViTra, omogoča dovolj kakovostno transformacijo višin v zbirkah prostorskih podatkov, ki jih vodijo Geodetska uprava Republike Slovenije in številni drugi upravljavci ter državni organi.

Zahvala

Raziskava je nastala v okviru raziskovalnega programa ARIS P2-0227 *Geoinformacijska infrastruktura in trajnostni prostorski razvoj Slovenije*, ciljnega raziskovalnega projekta V2-2294: *Razvoj državnega višinskega transformacijskega modela med SVS2000/Trst in SVS2010/Koper*, ki sta ga sofinancirali Javna agencija za raziskovalno dejavnost Republike Slovenije in Geodetska uprava Republike Slovenije.

Koler B., Ambrožič T., Kogoj D., Kregar K., Marjetič A., Štebe G., Tekavec J., Urbančič T., Savšek S. (2025). Transformacija višin med SVS2000/Trst in SVS2010/Koper z državnim transformacijskim višinskim modelom. Geodetski vestnik, 69 (1), 11-42.
DOI: https://doi.org/geodetski-vestnik.2025.01.11-42

Doc. dr. Božo Koler,
Univerza v Ljubljani, Fakulteta za gradbeništvo in geodezijo,
Jamova cesta 2, 1000 Ljubljana.
e-mail: Bozo.Koler@fgg.uni-lj.si

Izr. prof. dr. Tomaž Ambrožič,
Univerza v Ljubljani, Fakulteta za gradbeništvo in geodezijo,
Jamova cesta 2, 1000 Ljubljana.
e-mail: Tomaz.Ambrozic@fgg.uni-lj.si

Izr. prof. dr. Dušan Kogoj,
Univerza v Ljubljani, Fakulteta za gradbeništvo in geodezijo,
Jamova cesta 2, 1000 Ljubljana.
e-mail: Dusan.Kogoj@fgg.uni-lj.si

Doc. dr. Klemen Kregar,
Univerza v Ljubljani, Fakulteta za gradbeništvo in geodezijo,
Jamova cesta 2, 1000 Ljubljana.
e-mail: Klemen.Kregar@fgg.uni-lj.si

Doc. dr. Aleš Marjetič,
Univerza v Ljubljani, Fakulteta za gradbeništvo in geodezijo,
Jamova cesta 2, 1000 Ljubljana.
e-mail: Ales.Marjetic@fgg.uni-lj.si

Asist. dr. Gašper Štebe,
Univerza v Ljubljani, Fakulteta za gradbeništvo in geodezijo,
Jamova cesta 2, 1000 Ljubljana.
e-mail: Gasper.Stebe@fgg.uni-lj.si

Doc. dr. Jernej Tekavec,
Univerza v Ljubljani, Fakulteta za gradbeništvo in geodezijo,
Jamova cesta 2, 1000 Ljubljana.
e-mail: Jernej.Tekavec@fgg.uni-lj.si

Doc. dr. Tilen Urbančič,
Geotočka d.o.o., Tehnološki park 24, 1000 Ljubljana in Univerza v Ljubljani, Fakulteta za gradbeništvo in geodezijo, Jamova cesta 2, 1000 Ljubljana.
e-mail: Tilen.Utbancic@geotocka.si in Tilen.Utbancic@fgg.uni-lj.si

Doc. dr. Simona Savšek,
Univerza v Ljubljani, Fakulteta za gradbeništvo in geodezijo,
Jamova cesta 2, 1000 Ljubljana.
e-mail: Simona.Savsek@fgg.uni-lj.si