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ОЦЕНКА ТОЧНОСТИ БЕСПЛАТНЫХ ГЛОБАЛЬНЫХ ЦИФРОВЫХ МОДЕЛЕЙ РЕЛЬЕФА (ЦМР) И ЦИФРОВЫХ МОДЕЛЕЙ РЕЛЬЕФА (ЦМР) НА ОСНОВЕ СОВЕТСКИХ ТОПОГРАФИЧЕСКИХ КАРТ ДЛЯ ПРОЕКТИРОВАНИЯ ДОРОГ В КЫРГЫЗСТАНЕ

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Проводится анализ точности бесплатной глобальной ЦМР по сравнению с ЦМР, созданной по советским топографическим картам. Проведена оценка возможности использования глобальной ЦМР для целей дорожного планирования. Выбраны три отдельные территории с горным, холмистым и равнинным рельефом. Для этих территорий создана ЦМР по советским топографическим картам масштаба 1:25 000. Созданные растры ЦМР затем вычитались из глобальных ЦММ SRTM, ASTER GDEM и ALOS. Результаты вычитания проанализированы с использованием статистических методов и подтверждены наземными данными. Доказана возможность замены построенных по топографическим картам ЦММ глобальными данными для разных территорий. Результаты исследования могут быть полезны дорожным инженерам, которые до сих пор пользуются советскими топографическими картами при планировании дорог. Кроме того, некоторые результаты могут быть интересны специалистам по ГИС, которые часто используют глобальные ЦМР.

Ключевые слова: ЦМР; топографическая карта; анализ; дорожное планирование; топография.

КЫРГЫЗСТАНДА ЖОЛДОРДУ ДОЛБООРЛОО ҮЧҮН СОВЕТТИК ТОПОГРАФИЯЛЫК КАРТАЛАРДЫН НЕГИЗИНДЕ ТҮЗҮЛГӨН ЖЕРДИН САНАРИП МОДЕЛДЕРИНИН (ЖСМ) ЖАНА ЖЕРДИН АКЫСЫЗ ГЛОБАЛДЫК САНАРИП МОДЕЛДЕРИНИН (ЖСМ) ТАКТЫГЫН БААЛОО

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Бул макалада советтик топографиялык карталардан түзүлгөн жердин санарип моделине (ЖСМ) салыштырмалуу акысыз глобалдык ЖСМдин тактыгына талдоо жүргүзүлөт. Бул изилдөөнүн негизги максаты - жолдорду пландаштыруу учурунда глобалдык ЖСМди колдонуу мүмкүнчүлүгүн эсептөө. Бул максатка жетүү үчүн тоо, дөбө жана түз рельеф түзүлүштөгү үч түрдүү аймак тандалып алынган. 1:25 000 масштабындагы советтик топографиялык карталардын жардамы менен ошол аймактар үчүн ЖСМ түзүлгөн. Андан кийин SRTM, ASTER GDEM жана ALOS глобалдык ЖСМдеринен алынып жасалган DEM растрлары түзүлгөн. Салыштыруунун натыйжалары статистикалык ыкмаларды колдонуу менен эсептелип, жер үстүндөгү геодезиялык чекиттердин жардамы менен тастыкталды. Топографиялык карталардан түзүлгөн ЖСМдерди глобалдык ЖСМ маалыматтары менен алмаштыруу мүмкүнчүлүгү ар кайсы аймактарда далилденген. Алынган натыйжалар жолду пландаштыруу максатында советтик топографиялык карталарды колдонуп келе жаткан жол инженерлери үчүн пайдалуу болушу мүмкүн. Ошондой эле, айрым ачылыштар глобалдык ЖСМдерди көп колдонгон ГМС адистери үчүн кызыктуу болушу мүмкүн.

Түйүндүү сөздөр: ЖСМ; топографиялык карта; талдоо; жолдорду пландаштыруу; топография.

ACCURACY ASSESSMENT OF FREE GLOBAL DIGITAL TERRAIN MODELS (DTM) AND DIGITAL TERRAIN MODELS DTM BASED ON SOVIET TOPOGRAPHIC MAPS FOR ROAD PLANNING IN KYRGYZSTAN

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This article analyses the accuracy of free global DTM comparatively to the DEM generated from Soviet topographic maps. The main goal of this research is to estimate the possibility of utilising global DTM for the road planning's purposes. In order to reach this aim, three separate territories with mountain, hill and plain topography were chosen. A DEM was generated for those territories from 1:25 000 scale level of Soviet topographic maps. The generated DEM rasters where then subtracted from SRTM, ASTER GDEM and ALOS global DTMs. Results of the subtraction were analysed using statistical methods and verified with ground data. The Possibility of the replacement of DTMs generated from topographic maps by the global DTM data was proven for the different territories. The results obtained could be useful for the road engineers who still use Soviet topographic maps for the purposes of road planning. Also, some of the findings might be interesting for GIS-professionals who frequently use global DTMs.

Keywords: DEM; topographic map; analysis; road planning; topography.

Introduction. Road planning in mountainous region is a complicated problem relating economic and environmental considerations. Designers should evaluate sufficient number of alternative routes to locate a final route with the lowest total cost, while conforming to design specifications and environmental requirements. The current mountain road design systems are not developed to provide a designer with large number of alternative paths. They are generally used to make the mathematical calculations required in manual road design. Besides, they are not capable of minimizing total cost of construction, maintenance, and transportation costs, or aiming for least environmental impacts. One of the best instruments to utilize is a Digital Terrain Model (DTM), these are widely used as a basis for the purposes of road planning. DTM's are a crucial part for finding of the best path for the road itself and locating of all the turns and crossings.

A modern DTM could be obtained by different ground and remote methods. Among them could be the aforementioned traditional topography surveys, GNSS-methods, methods of analog and digital photogrammetry, LIDAR-scanning, hydro location, radiolocation, satellite altimetry and interferometry. However, most of these methods are costly and that's the main reason why they are not very popular in the Post-Soviet states. Instead of these methods road planners and engineers are using Soviet topographic maps of different scale levels. Contours and elevation points are digitized from those maps and became source for the DTM creation.

The usage of Soviet topographic maps as source of the data for the DTM creation have a lot of disadvantages. The most serious of all, is that the Soviet maps were last time updated approximately 30 years ago and therefore are significantly outdated. The digitization of contours is also a very time consuming and tedious job with high probability of errors. Road planners do however in many Post-Soviet states (and especially in Kyrgyz Republic) still prefer to use Soviet topographic maps because their accuracy meets the requirements of regulatory documents which are mandatory for usage by planning engineers.

Global elevation models, like ASTER GDEM, ALOS or SRTM, on the other hand provide elevation data that are actual and convenient for the processing. Although these sources are rarely used by road planers at Post Soviet countries, because they considered as "imprecise" compared to the Soviet topographic maps [1].

Aim of the study. To estimate the accuracy of global altitude data SRTM, ASTER GDEM and ALOS PRISM comparatively to topographic maps of scale 1:25 000 for various types of terrain (plain, hilly and mountain) at the territory of the Issyk-Kul region of Kyrgyz Republic (Fig. 1). Analyze the results of the comparison and estimate possibility of usage of this data for road planning.

The choice of the studied area is due to the characteristic's, uniqueness and peculiar contrast of the topographical structure. Parameters of the selected areas are shown on the Figure 2 and this is territorially limited by trapezes of the corresponding map sheets (maps nomenclature).

Previous research on the subject. The question of the accuracy of SRTM models for the territory of Osh oblast on Kyrgyz Republic was studied in 2007 by A. Djenaliev (Djenaliev A., 2007). He analized an assessment of the quality of SRTM's DEM and notes that despite the relevance of research data for the rest of Kyrgyz Republic, publications on the accuracy of such models is absent [2].

The accuracy of the SRTM matrix was studied by scientists from different countries. A. Karwel and I. Evoic estimate the error of SRTM matrix with the following values: for plain terrain – 2.9 m, hilly – 5.4 m (Karwel A., 2008). In their view, the SRTM matrix meets the requirements for contour creation on topographic maps with a scale of 1:50 000 and smaller, and can also be used to create orthophotomaps based on high resolution satellite imagery.

An ASTER mission took place, and stereoscopic images of a significant surface area between 83° north latitude and 83° south latitude were obtained at the end of 1999. Subsequent generation of DTM's with a resolution of 15 m in one pixel stimulated a new round of research.

The using of methods of DEMs analysis are very helpful in solving road planning problems. The DEM accuracy analysis and modern methods of processing satellite images in this field was studied by A. Bekturov [3].

T. Ha, N. Zhusupov tested SRTM matrices for geographically dispersed objects, one of these was carried out for Central Asia region, and it is possible to assert that the specified data can be applied for updating of topographic bases of territories, for which no other survey data exsits [4].

Methodology. First of all, SRTM, ASTER GDEM and ALOS PRISM data was downloaded from the USGS Earth Explorer service. The research territory is covered by the scenes of SRTM, ASTER GDEM and ALOS PRISM data. All datasets were stored in signed 16 bit GeoTIFF raster with WGS-84 coordinate system and EGM96 vertical datum. Using ArcGIS "Extract by Mask" tool and vector footprints of the chosen 1:25 000 scale topographic maps (lists: К-43-48-Б-г, К-43-48-А-г, К-43-57-Б-а) from each elevation raster was extracted part that was covered by the topographic maps. After the extraction obtained nine separate rasters (three rasters for the SRTM three rasters for the ASTER GDEM and three rasters for ALOS PRISM). All

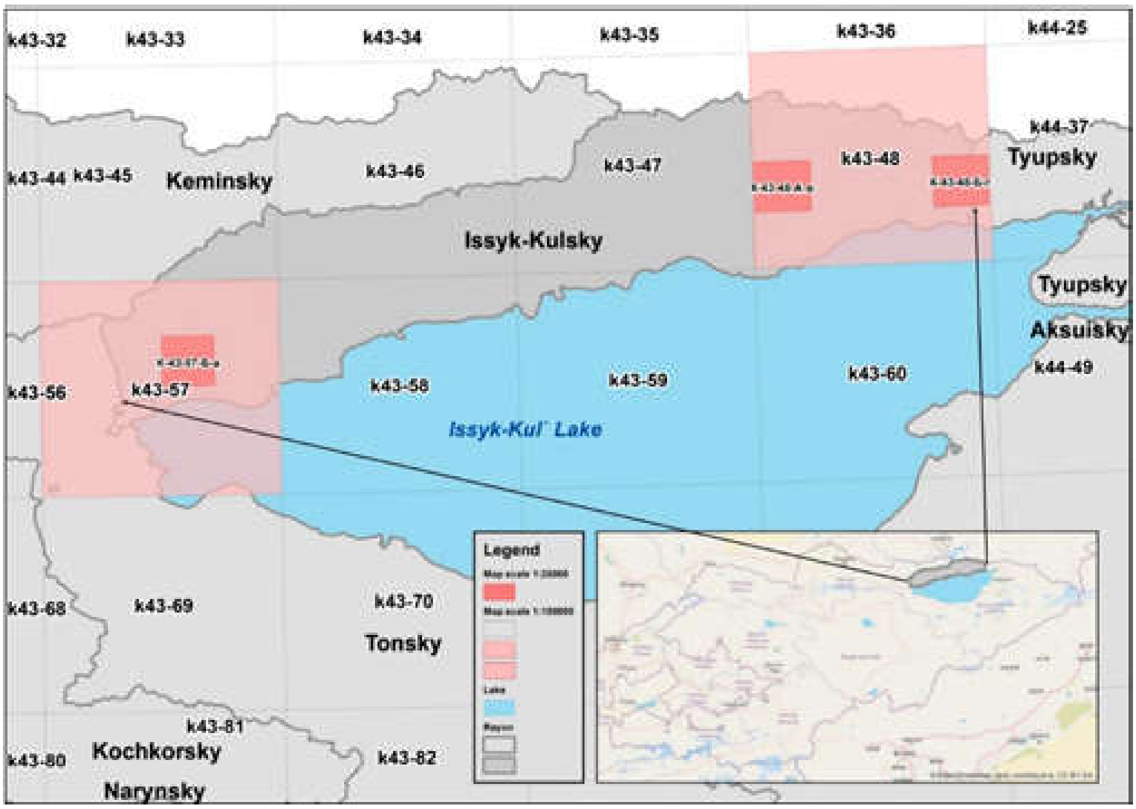

Fig. 1. The scheme of the investigated territory within the nomenclature sheets of topographic maps of different scales

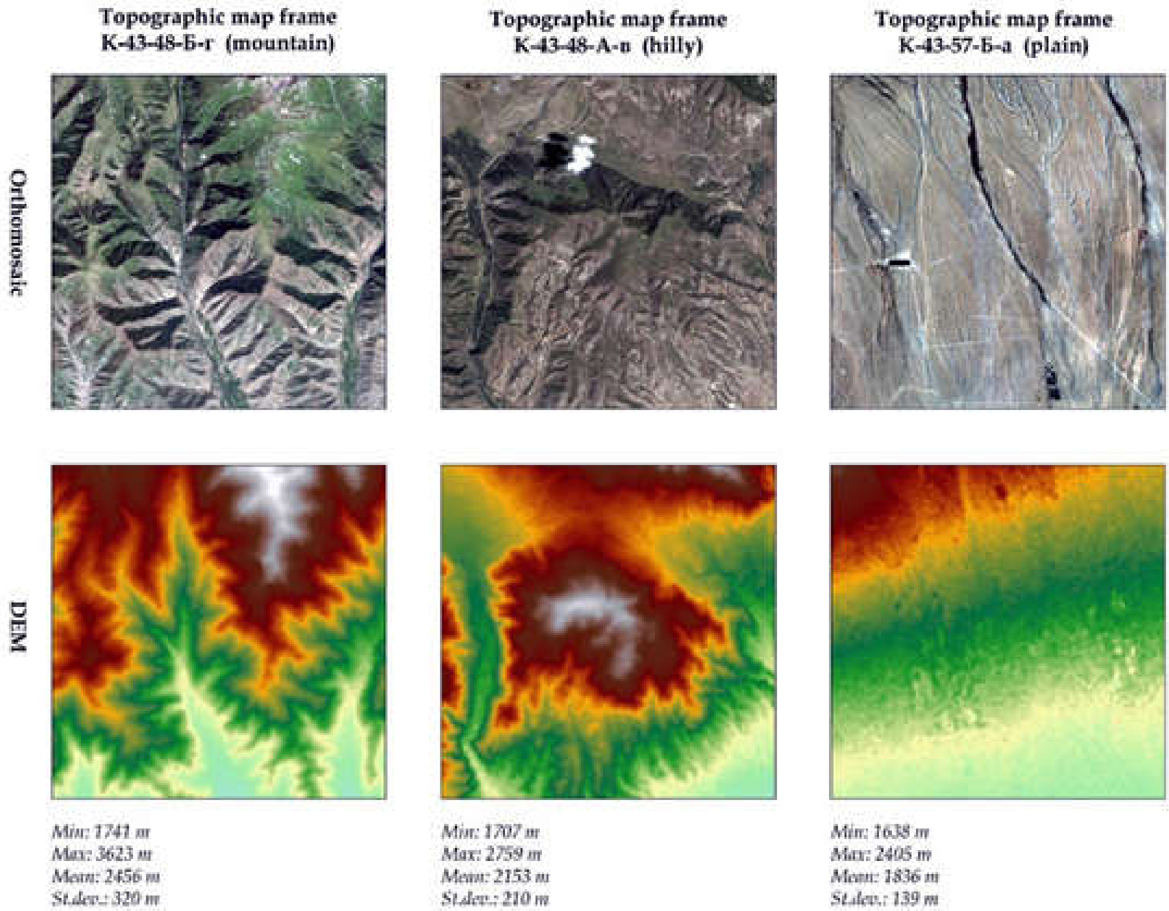

Fig. 2. Elevation characteristics of the researched polygons

these rasters were reprojected to Pulkovo 1942 Gauss Kruger zone 13N coordinate system (EPSG:28473) and resampled to the 30-meter resolution. This was done to ensure that all the raster's have the same extent, resolution and coordinate system and therefore could be compared with each other.

Soviet topographic maps were scanned from the paper sources, stored in the unsigned 8-bit JPEG raster's and georeferenced in Pulkovo 1942 Gauss Kruger zone 13N coordinate system. The overall number of the rasters was three on scale 1:25 000, lists: K-43-48-Б-г for the mountain area, K-43-48-А-в for the hilly area and K-43-57-Б-а for the plain area. Contours and elevation points were digitized for each of the map and stored in the separate shapefiles. Then, with ArcGIS "Topo to Raster" tool nine separate DTMs were generated. The resolution of each DTM was set to 30 meters to match the resolution of the SRTM, ASTER GDEM and ALOS PRISM rasters. All the other parameters of the "Raster to ASCII" tool were set accordingly to the general requirements of DTM generation.

To make a comparative analysis of the DTM generated from the SRTM and other two free global DTMs a map algebra spatial analysis technique was utilized. Using the ArcGIS Raster Calculator tool, each of the rasters generated from SRTM was subtracted with rasters using ASTER GDEM and ALOS PRISM elevations. Also, the ASTER GDEM raster was subtracted from the ALOS PRISM raster. Therefore, the overall number of the rasters generated by this tool is equal to nine and each of them represents elevation difference. For instance, raster SRTM-ASTER.tif represents elevation difference between DEM generated from SRTM and ASTER GDEM raster. On the Figure 3 presented geoprocessing model that was used for the generation

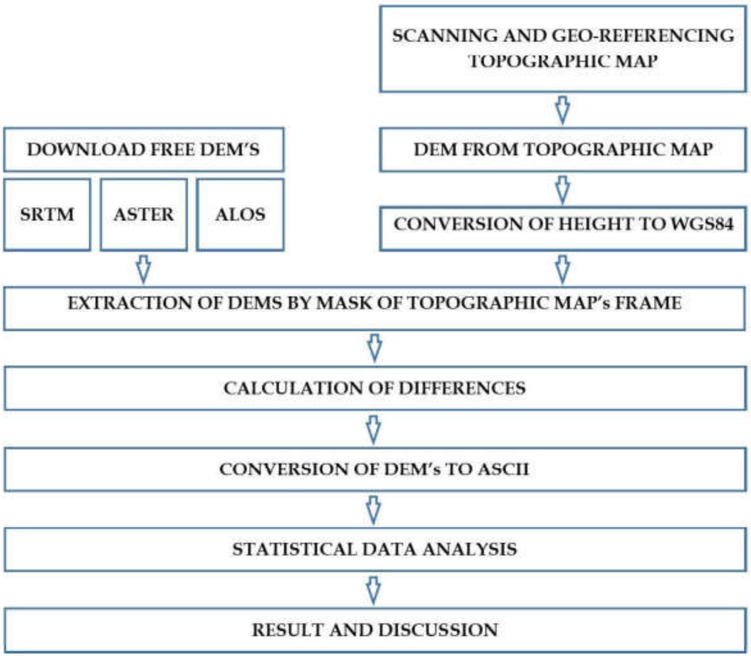

Fig. 3. Methodology of researching

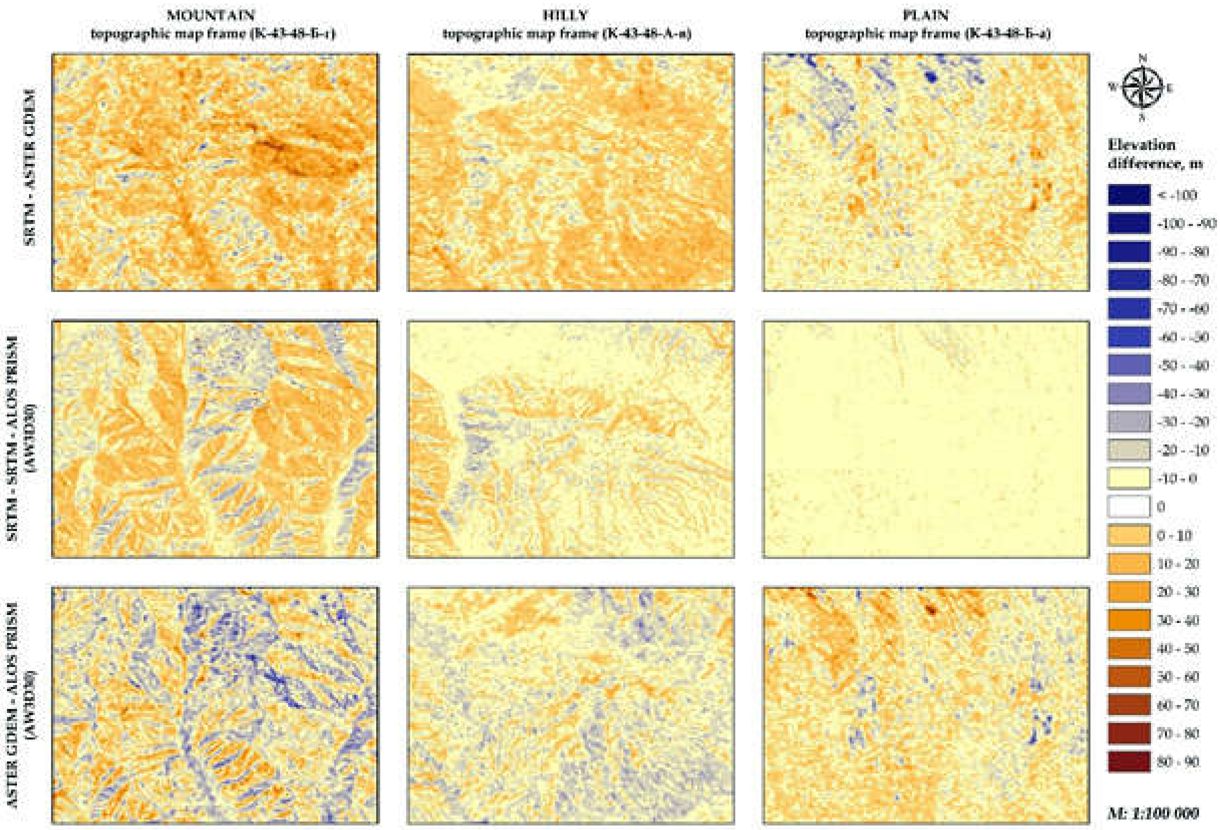

Fig. 4. The rasters of surface's difference according to different sources of DTM data

of every elevation difference raster and on Figure 4 is a nine-elevation difference raster for the 1:25 000 scale. These were used as a basis for the further statistical analysis.

For the calculation of statistical indicators in the above-mentioned study, the following equations have been used:
average:

$$\left(\bar{d}\right) = \frac{\sum d}{N}, \quad (1)$$

where d – height difference of two matrices in a cell and N – number of cells

$$d = H_1 - H_2 \quad (2)$$

standard deviation:

$$\sigma = \sqrt{\frac{\sum\left(d-\bar{d}\right)^2}{N-1}} \quad (3)$$

value that with probability will not exceed 90 %

$$\left(LE90\right) = 1.645 \times \sigma \quad (4)$$

$\left(LE95\right) = 1.96 \times \sigma$ value that with probability will not exceed 95 %

$$\left(LE95\right) = 1.96 \times \sigma. \quad (5)$$

Statistical processing of high-altitude matrices was performed in the environment of the Microsoft Office Excel 2013 table processor, this is shown in the Table 1.

From the results obtained, it can be seen that the accuracy of SRTM data is pretty high. On the area enclosed by the map sheet K-43-48-Б-а (plain territory), the proximity of the mean value and the mean-square deviation is observed, indicating a systematic error. If we consider the situation in the indicated area (see Fig. 2), then it can be noted that a large part is covered with stones, which greatly distorts the results in height. Analyzing the mean square deviation in Table 1, the tendency of its direct dependence on the type of relief of the territory is revealed.

As in the previous case, a separate comparison of the ASTER GDEM, ALOS PRISM and SRTM matrices among themselves (see Table 2), similarly revealed a systematic error in the plain area of the study, due to the presence of territories covered with stones and vegetation.

The SRTM, ALOS PRISM and ASTER GDEM elevation matrices can be analyzed more precisely by grouping the differences that, with a given probability of 90%, these do not exceed the deviations of the characteristic point height estimate from its true height (see Table 3).

The standard deviation calculation for study areas based on the reference data are mentioned in Table 1. Standard deviation table shows that the least amount of standard deviation for mountain, hilly and plain areas. The bar diagram of the table is showed in Figure 5.

Since, in ASTER with SRTM data comparison case (Fig. 5), such groups did not exceed the range from –15 to +15 m, it was decided to take them for a clear comparison for the construction of the three corresponding histograms.

ALOS PRISM data compared with SRTM showed good results, which range from --19 to +19 m;

ASTER GDEM data compared with SRTM showed slightly weaker results (Fig. 6). In the case of the mountain areas, for a scale of 1:25 000 it took an interval of –24 to +24 m.

Table 1 – The statistical parameters of map's height difference DTM by topographical maps and matrix data SRTM, ASTER GDEM and ALOS PRISM

Scale	1:25000								
Relief type	Plain			Hilly			Mountain		
Height matrix	SRTM - ASTER GDEM	SRTM - ALOS PRISM (AW3D30)	ASTER GDEM - ALOS PRISM (AW3D30)	SRTM - ASTER GDEM	SRTM - ALOS PRISM (AW3D30)	ASTER GDEM - ALOS PRISM (AW3D30)	SRTM - ASTER GDEM	SRTM - ALOS PRISM (AW3D30)	ASTER GDEM - ALOS PRISM (AW3D30)
Average	2.63	2.80	0.17	3.66	2.38	6.04	6.51	0.31	6.82
Standart deviation	9.32	2.41	9.37	8.55	6.87	8.93	12.51	11.49	14.86
LE90, m	15.33	3.97	15.42	14.07	11.30	14.69	20.59	18.89	24.45
LE95, m	18.27	4.73	18.37	16.76	13.46	17.50	24.53	22.51	29.13

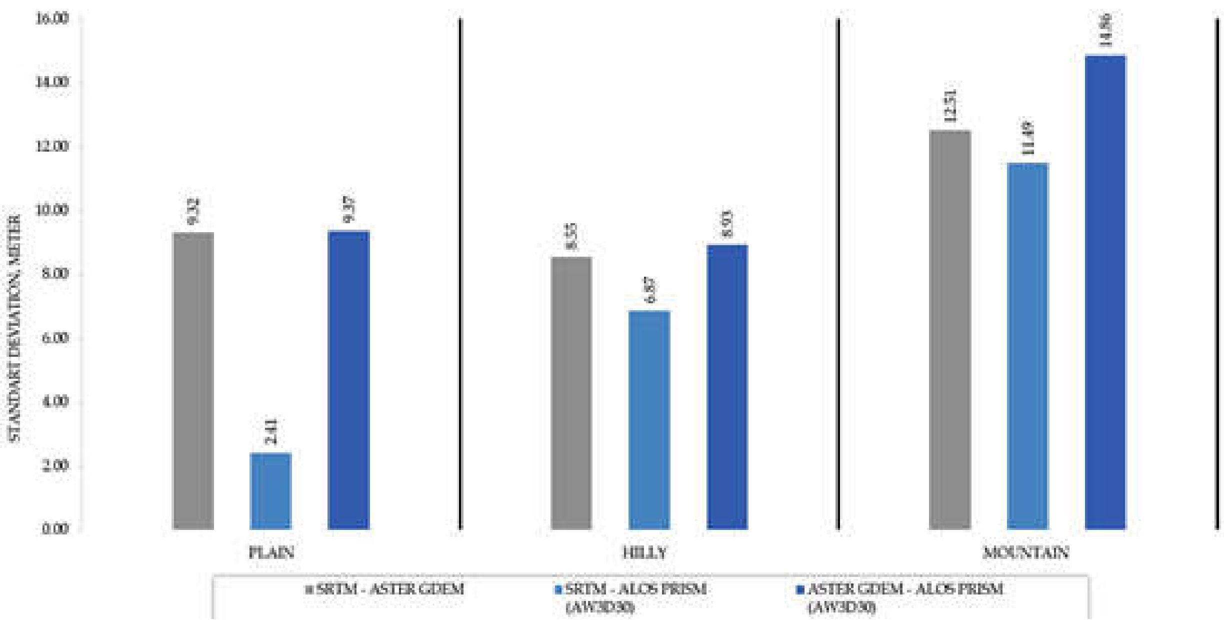

Fig. 5. Standard deviation comparison of free DEM's

Table 2 – Ranges of deviations of high-grade DTM markings satisfying the condition LE90
for different scale and conditions of relief

Scale	1:25000		
Height matrix / Relief type	SRTM - ASTER GDEM	SRTM - ALOS PRISM (AW3D30)	ASTER GDEM - ALOS PRISM (AW3D30)
Plain	[-15 +15]	[-4 +4]	[-15 +15]
Hilly	[-14 +14]	[-11 +11]	[-15 +15]
Mountain	[-21 +21]	[-19 +19]	[-24 +24]

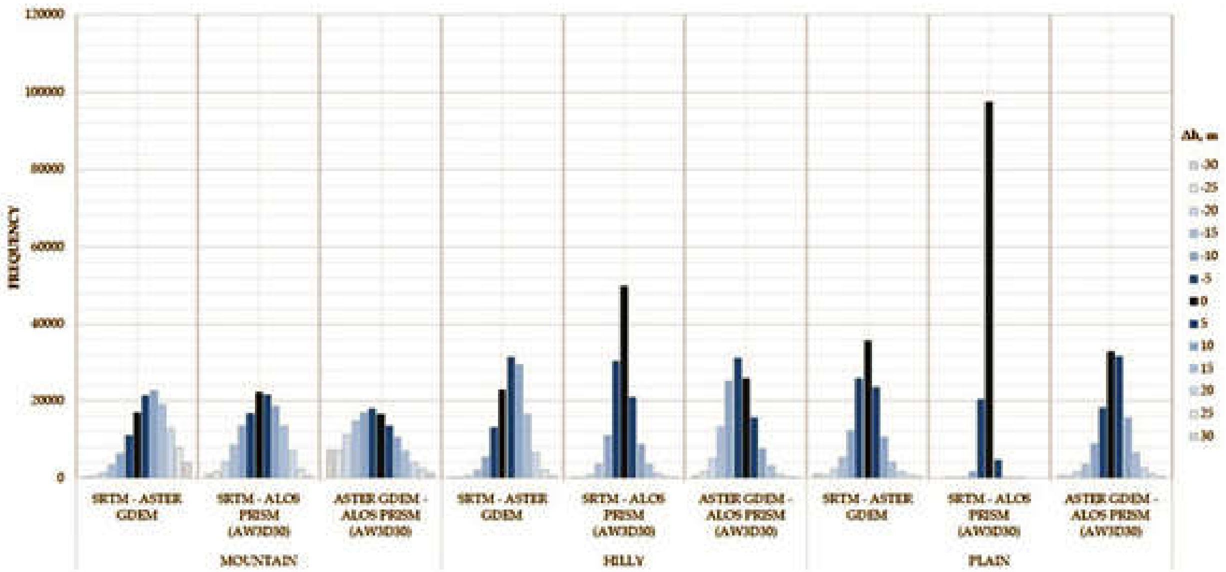

Fig. 6. DEM Elevation Error Distribution Histogram for different scales and terrain conditions

Given vertical scale at Figure 5 is characterized by a smaller difference and being in close proximity to the reference values. However, in case there is a clear tendency: on a plain type of terrain, a greater number of values are characterized by smaller standard deviations in relation to reference heights, and vice versa, with the transition to a more complex topography, the trend is reversed.

The quality of DTM can be estimated by comparing the results obtained with the normative values of the mean square deviation of the definition of the height position of the point. According to basic guidelines for the creation of the topographic maps, at each maps sheet of the 1:25 000 scale must be at least three points of the horizontal and vertical geodetic basis, including the points of the state geodetic network, geodetic networks of congestion and points of sampling networks fixed on the ground by the centers.

Control points were selected exclusively on the open, mountainous, hilly and plain territories (Table 3). The obtained results showed significantly less error in the SRTM matrix compared to the ASTER GDEM and ALOS PRISM matrix in almost all the cases. The emergence of maximum differences has quite objective reasons. Thus, we can assume that a slight linear displacement in any of the directions would give a completely different result. In this case, everything is limited to raster resolution capabilities.

Results. The use of statistical estimation methods is justified, but with greater probability it is possible to establish the accuracy of the created model of the study area relief. Instead, comparing the results of a model to individual points can lead to a probable fall in the point of anomalies, which exceeds the value LE90.

Of all the constructed difference maps, without correlation and coefficient of variation is specific for the DTM SRTM of plain (6.00 m), hilly (25.40 m) and mountain (21.90 m), which indicates that these DTMs are

Table 3 – Difference of high values of global surfaces with respect to separate markings of topographic maps

Relief type	The name of the point State Geodetic Network or altitude mark	Height on topographic map, m	Height on matrix SRTM, m	d, m	Height on matrix ASTER GDEM, m	d, m	Height on ALOS PRISM (AW3D30)	d, m
Plain	Chon Taldy-Bulak river	1785.20	1783.00	2.20	1780.00	5.20	1785.00	0.20
	Orto Taldy-Bulak river	1826.00	1825.00	1.00	1827.00	-1.00	1825.00	1.00
	pumping station	1725.00	1719.00	6.00	1716.00	9.00	1721.00	4.00
Hilly	Kok-Dobo mountain	2629.50	2608.00	21.50	2621.00	8.50	2624.00	5.50
	Uch-Kungey pass	2198.00	2199.00	-1.00	2196.00	2.00	2203.00	-5.00
	geodetic point «2513.4»	2513.40	2488.00	25.40	2491.00	22.40	2501.00	12.40
Mountain	At-Zhailoo river	2591.10	2610.00	-18.90	2620.00	-28.90	2623.00	-31.90
	Bakhtiyar spring	2560.40	2567.00	-6.60	2553.00	7.40	2545.00	15.40
	geodetic point «2824.9»	2824.90	2803.00	21.90	2791.00	33.90	2795.00	29.90

as close as possible than other DEMs to topographic maps of scale 1:25 000. This is indicated by the histogram of the distribution of heights of the DTM (Fig. 4).

The results for ASTER GDEM shows following numbers: for plain (9.00 m), hilly (22.40 m) and mountain (33.90 m)

The results for ALOS PRISM for the same area and scale had map difference larger (for the flat – 4.00 m, the hilly – 5.50 m and mountains – 31.90 m).

Conclusions

Obtained results allow the following conclusions to be drawn.

1. SRTM data, with proper correction and analysis, fall within the acceptable accuracy range for the purposes of road planning.

2. The use of open radar interfacing data allows achieving a tangible economic effect. DTMs built on their basis can be used in surveys at the stage of feasibility study, for tracing the passage of linear structures, etc.

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