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IMPROVING THE ACCURACY OF THE OPEN ACCESS DIGITAL ELEVATION MODELS USING GNSS: CASE FERGANA VALLEY

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ABSTRACT

The main goal of this study is to improve the accuracy of the DEM generated by SRTM using the combined GNSS and levelling data and the developed regression model.

KEYWORDS: *DEM, SRTM, GNSS, correction surface.*

1. INTRODUCTION

The shape of the Earth's surface is the dominant controlling factor in almost all natural processes occurring on it, as well as in processes occurring in the atmosphere and lithosphere. Precipitation, runoff, soil moisture, incident sunlight and temperature depend on the topography of the area. Therefore, topography mainly determines the local and regional distribution and pattern of vegetation. Topography influences the location and magnitude of surface and groundwater flows. While topography controls many natural processes on and near the Earth's surface, many natural processes in turn control topography. A digital elevation model (DTM or DEM) is a three-dimensional representation of the earth's surface, represented as an array of points with a defined height. DEM is widely used in the geosciences, including climatology, ecology, hydrology, glaciology, and geology [1]. There are various methods for creating DEMs, among which satellite images are increasingly used in practice, given their low cost, availability and ability to cover large areas. Publicly available digital elevation models (DEMs) derived from radar data, such as SRTM, ALOS and ASTER, are used as the main sources of topographic information for many studies, including hydrological analysis, flood modeling and natural hazard mapping, geohazard analysis and a description of the landslide characteristics of the region. The DEM is a model of the elevation surface and, like other models, the data are subject to errors (incomplete density of observations, positional inaccuracy, data entry faults, processing errors, classification, and generalization problems). Analysis of DEM accuracy in the Uzbekistan landscape, especially in mountain areas, is very scarce. To improve the accuracy, many approaches have been used: combining different DEMs, changing the discretization, using polynomial models when integrating various types of initial data [2-5]. The purpose of this study is to improve the accuracy of SRTM for the territory of the Fergana Valley using data from the ground-based measurement network of the global navigation satellite system.

2. DATA AND METHOD

The Ferghana Valley is a valley in the mountains of Central Asia, one of the largest mountain ranges in Central Asia. It is surrounded by the Tien Shan mountains in the north and the Gissar-Alai mountains in the south. It is mainly located on the territory of Uzbekistan, partly on the territory of Kyrgyzstan and Tajikistan. The widest part in the form of a triangle goes to the northern slopes of the Turkestan and Alai ranges, surrounded by the Kuram and Chatkal ranges in the northwest and the Fergana range in the northeast. Altitude 330 m in the west, 1000 m in the east. Its general structure is elliptical. It expands from west to east (Fig. 1). As part of the project to develop the National Geographic Information System in Uzbekistan, the Cadaster Agency carried out high-precision GPS measurements [6].

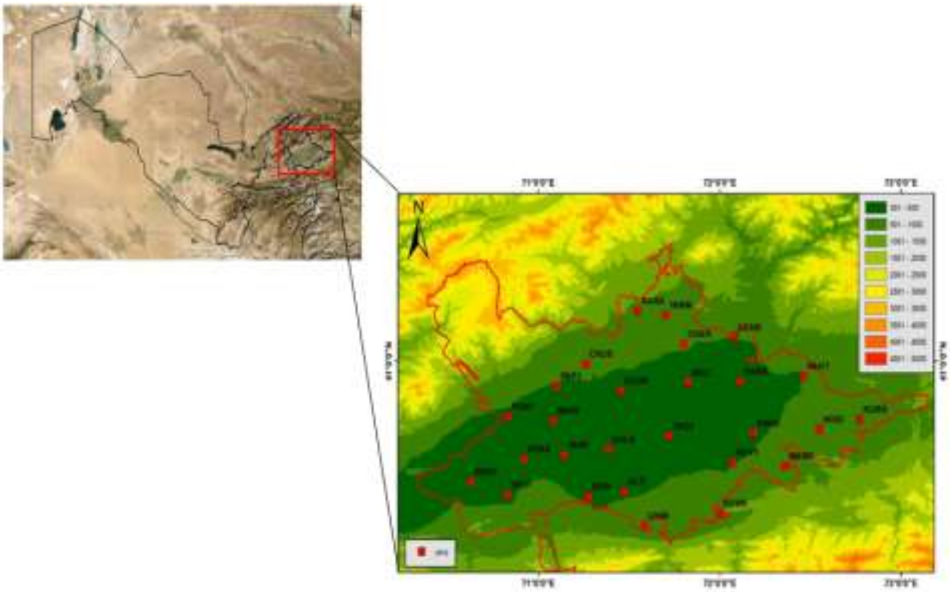


Figure. 1. Study area and GNSS network in the Ferghana Valley

The data used in this study includes:

(1) GNSS network stations distributed over the whole region (Figure 1). In total 27 stations were installed from 2005 to 2015 for the survey applications. GNSS measurements were processed with GAMIT/GLOBK ver. 10.7 software applying standard procedure for positions and velocities calculation [7]. The GNSS data are referenced to the ITRF2014 and provide geometric (ellipsoidal) heights with reference to the WGS84 ellipsoid [8].

(2) The classic leveling data in Baltic Height System (BHS77) downloaded from free available database of the International Gravimetric Bureau in Toulouse [9].

(3) SRTM parameters used for the analysis are presented in Table 1. Resolution of the publicly available DEM based on remotely sensed observations, such as SRTM (Shuttle Radar Topography Mission), improved considerably and offer nearly global coverage in areas with insufficient observational data and difficult to access for observation. The range of supported applications is still a function of the geographic extent of the coverage area. SRTM coverage now includes Africa, Europe, North America, South America and newly processed areas Asia, Australia. The data are provided in the WGS 84 orthometric height with respect to the EGM96.

Table 1. SRTM parameters

DEM	Time of releasing	Grid spacing (m)	RMS, m	Linear error at 95% confidence, m	Reference
SRTM Version 3.0 (SRTMGL1)	2021	30	9.7	19.07	Mizuta, Sasagawa, Koido, Urabe, & Tanaka, 2007

In practice, normal heights can be determined by classical geometric leveling. The use of these methods is limited by distances due to the limitation of the observation range from the level, which varies only within 50-100 m. Satellite leveling is used to measure distances between points from tens to hundreds of kilometers. The current level of development of GNSS technologies in Uzbekistan makes it possible to consider the possibility of replacing classical methods with high-precision satellite GNSS leveling and measurements over short periods of time. But the ellipsoidal height determined by GNSS receivers can be converted to normal only if an accurate model of the geoid of the area is taken into account. And, despite the centimeter-level accuracy supported by GNSS receivers, in the absence of an accurate geoid model, the results of the height network adjustment will be much underestimated.

The DEM uses the EGM96 geoid model. The global geoid height model EGM96, obtained from gravity measurements, is publicly available on the website of the Computational Service of the International Center for Global Earth Models (ICGEM) [10]. But the assessment of its accuracy was not carried out for the territory of Uzbekistan and, therefore, may be insufficient for the tasks of users. The lack of gravimetric knowledge of the area further exacerbates the problem of using global models without preliminary processing and evaluation. To improve the efficiency of the global model, earlier studies used the methods of the polynomial model [11], GNSS/leveling [12]. The method proposed in this paper uses a network of points with known GNSS/leveling heights and EGM96 data. Improvement of EGM96 with GNSS data was performed by modeling and further interpolation for the entire range of differences between GNSS and EGM96 heights at “common” points [13]:

$$\Delta N_i = N_i^{GNSS-leveling} - N_i^{EGM96}$$

namely, the construction of the so-called corrective surface (CSF):

$$f(\varphi, \lambda) = \Delta N = N_i^{GNSS-lev} - N_i^{EGM96} = a_0 + a_1\varphi_1 + a_2\lambda_i \ldots = a_i^T x + v_i$$

$T_i = a_0 + a_1\varphi_1 + a_2\lambda_i + \ldots -$ trend surface.

The trend values were calculated for each point, then the dN values were calculated by subtracting the difference in geoid heights:

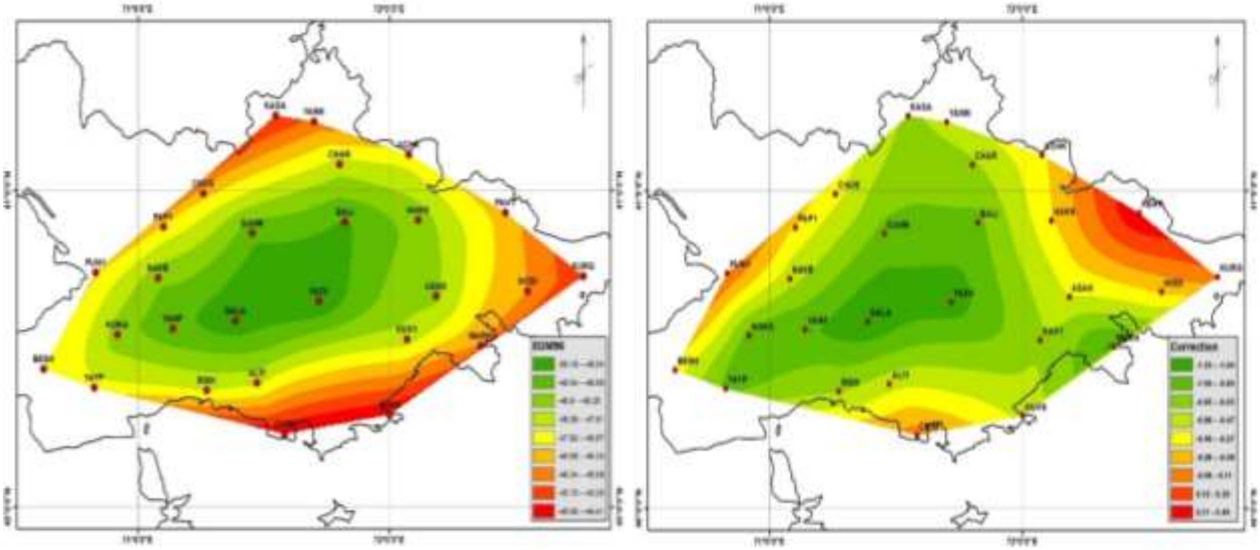
$$dN_i = \Delta N_i - T_i$$

As a result, the improved value of the geoid heights is:

$$N_i^{improv} = N_i^{EGM96} + dN_i$$

3. RESULTS

EGM96 geoid height anomalies (Fig. 2a) and constructed correction surfaces (Fig. 2b) for the study area with 1'×1' grid spacing are presented on Fig 2. A uniform surface was created using Natural Neighbor interpolation, one of the most suitable methods for providing an accurate approximation of geoid heights in mountainous regions [13]



a) *b)*

Figure 2. EGM96 geoid height (a) and geoid correction surface (b)

The range of corrections to the geoid height is from -1.23 m to 0.50 m, with an average value for the region of 0.55 m. Significant correction values are concentrated in the northeastern part of the territory. Next step, the DEM surface was built using the refined geoid model (Fig. 3). DEM statistics before and after the correction is given in the table 2.

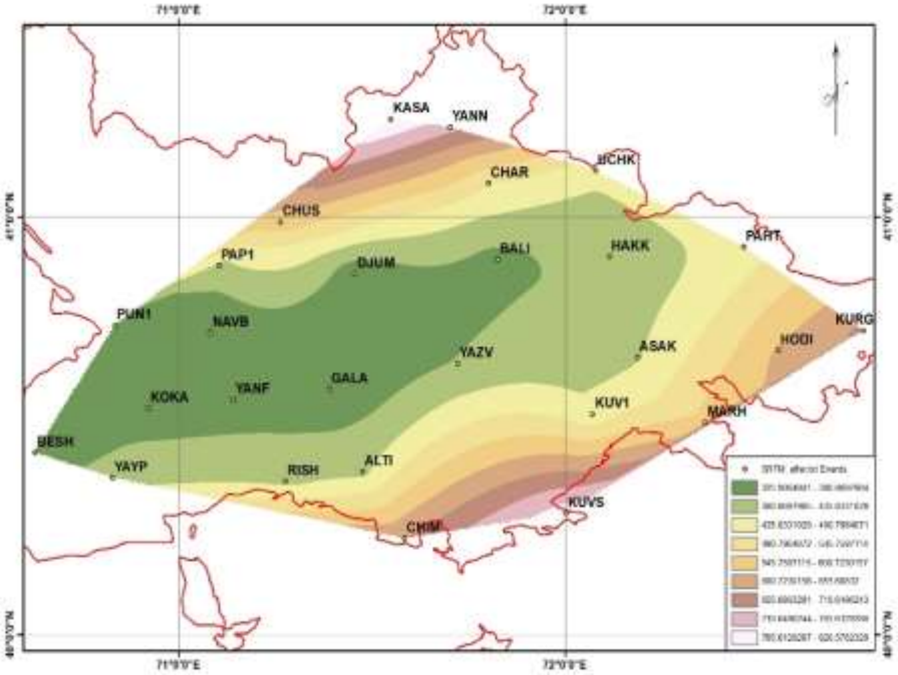


Figure 3. The refined geoid model for study area

Table 2. Statistic parameters of DEM before and after applying correction

Parameter	SRTM (before)	SRTM (after)
Min, m	373.621	325.442
Max, m	868.898	824.646
Mean, m	524.563	477.660
RMS, m	10.90	10.95

4. CONCLUSIONS

The present study was carried out to improve the vertical accuracy of the DEM (SRTMGL1) for the Ferghana Valley in Uzbekistan. The GNSS network of the Ferghana Valley was used as reference data. The initial improvement in accuracy was based on the determination between the point-converted DEM and the GNSS reference data. The EGM96 geoid was refined using GNSS/levelling points of the state geodetic network. DEM height values were converted from normal height to ellipsoidal height based on corrected EGM96 geoid heights. The resulting DEM can be used in the future to solve such practical problems as studying the drainage system, building a system of heights of the region.

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