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APPLICATION OF SATELLITE TECHNOLOGY FOR REFINEMENT OF A HEIGHT SYSTEM IN MONGOLIA

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ABSTRACT: The concept of creating a refined geodetic supply system that can provide accurate geodetic information should deal with the establishing a system which could accurately and promptly determine the Earth's surface point location in a given geographical coordinate and general height system, considering the given requirements. However, this concept should mainly consider an issue of providing specialists, customers and decision-makers with continuous and reliable real-time data. The aim of this research is to identify the rationale for solving the problem associated with the height system using a modern satellite technology. For the problem solving, the GNSS measurements and detailed quantitative spatial model of quasi-geoid are compared with the average value of multi-year observations at the continuously operating origin point.

1. INTRODUCTION

Mongolia has a long tradition with applications of geodesy, mapping and satellite technology (The State Administration of Geodesy and Cartography (SAGAC), 1998). The country created 1:100,000 scale topographic maps covering its entire territory between 1940 and 1949. For the mapping, the definition of elevation was established by the 2nd order of leveling. Re-measurement at 2nd order leveling network was carried out from 1974 to 1990, in order to study the earth's crust and soil vertical movement and to upgrade the elevation grid of the country (The State Administration of Geodesy and Cartography (SAGAC), 2001). The conducted re-measurement calculation of the leveling network was performed twice. The first calculation was conducted in 2000 with accuracy of 3 polygons of 3rd order in the mountainous western part.

In order to improve the accuracy of Mongolian Height Control Network mainly in the agricultural and heavily populated areas, the 1st order height network-were created in 2014-2018 (The Administration of Land Management, Geodesy and Cartography (ALAGAC), 2016). The network had 5 junction benchmarks, 49 ground control points, 48 following benchmarks, 60 check points, 194 benchmarks of soil, 49 benchmarks of stone and of building's wall. Total length of the network was 1161.72 km and its number of sections was 270, and maximum distance between neighboring benchmarks was 8.02 km. In the meantime, the average distance was 4.30 km, a loop error was 25.7 mm (the permissible disclosure is 102.3 mm) and the mean square error was 0.3 mm on the 1 km leveling line (The Administration of Land Management, Geodesy and Cartography (ALAGAC), 2019). Gravity measurements were performed at all height points. In addition, 24 hours and 12 hours of GNSS observations were conducted on the ground control points and benchmarks of soil of 1st order height network (Enkhtuya, 2006, 2008, 2015).

After 1990, in many post-socialist countries, establishment of a proper height system using a modern satellite technology was mainly related to new organizational and financial requirements, occurred in the processes of geodesy, mapping and cartography due to newly developed market economy (Enkhtuya, 2002, 2012). Moreover, it was connected with the changes in geodetic precision and measurement technologies required for development of efficient modern satellite methods. Furthermore, for proper development of the system, appropriate changes should be made to the traditional requirements and principles for creating a geodetic coordinate system and geodetic control network.

In geodetic practice, the method of determining a starting point of height from one control point representing the average surface level of the sea has been applied for many years. This has been a challenging issue in a country like Mongolia for creating a height system, because the country is landlocked and situated at the Central Asian highland in between Russia and China. The geography of Mongolia is characterized by great diversity and is divided into such zones as forest taiga, forest steppe, steppe, dry steppe, Rocky Mountains and Gobi (Amarsaikhan, 2017). The country is mainly mountainous with an average altitude of 1580 m above sea level. The principal mountains are concentrated in the west, while the east part is dominbated by flat steppes.

Within the framework of this research, the rationale for solving the problem associated with the height system has been identified using a modern satellite technology. For this purpose, the GNSS measurements and detailed quantitative spatial model of quasi-geoid were compared with the average value of multi-year observations at the continuously operating origin point. Overall the study indicated that the problems related to the height network and normal height system of Mongolia could be successfully solved by the use of the applied approach.

2. THE RESEARCH METHODOLOGY

In geodesy, classical leveling is considered as the most precise technique for determination of physical heights (orthometric, normal, or normal-orthometric) above the sea level. However, many people assume it as a time consuming and expensive technology (Kenyeres, 2016). Unlike the traditional approach, concept of satellite leveling is based on a set of activities related to the determination of physical heights based on GNSS-positioning technologies (Liebish, 2004).

In the satellite leveling, it is necessary to consider that the sum of the orthometric height and geoid height at a given control point is not equal to the geodetic height determined by the satellite measurements. This is related with the two different factors (firstly-the size of the global ellipsoid and counting ellipsoid in a WGS-84 coordinate system are different; second-there are the error's effects of three important parameters as H_0^{γ}, H_0^{G} , ζ_i and ζ_0).

Therefore, in order to determine ζ_i , beside the nature of the change in geoidal height, also the related errors should be taken into account. In a traditional leveling method, it is necessary to fasten the rapport every 5 km, which is the longest leveling route and the distance that can be measured per day. When transmitting the orthometric elevation of the satellite leveling method over long distances, there are special requirements for geoid accuracy, especially when it corresponds to high precision leveling data at 1st and 2nd order leveling network's points (Enkhbayar and Saandar, 2006).

3. RESULTS AND DISCUSSION

Within the framework of the present study, the 2006 and 2014 geoid height models of Mongolia and the EGM96 and EGM08 models of the World Geopotential were compared and the accuracy was evaluated at 85 points of the main and sub-network of the national GPS network (Table 1).

Table 1. Evaluation of the accuracy of Global Geopotential Model /EGM96, EGM08/, Mongolia's "Geoid Height Mode l/MGL06, MGL14/" on 85 points of GPS main and sub-network.

№	Name of dimension	Marking	ζ_{EGM96}-ζ_{EGM08}	ζ_{MGL06}-ζ_{MGL14}
1	The average value of the difference	[d]/n м	0.38	-0.06
2	The maximum value of the difference	d_{Max}, м	3.965	4.271
3	Minimum value of difference	d_{Min}, м	-1.043	-1.321
4	Standard deviation (SD)	m_{SD}, м	1.01	0.61
5	Mean squared error (RMSE)	m_d, м	0.50	0.30

The mean square error of the difference between the 2014 model and the EGM96 geoid height in Mongolia is 53 cm, standard the deviation is 91 cm, the mean square error of the difference between EGM2008 is 22 cm, and the standard deviation is 96 cm, respectively. According to this, it is possible to believe that the accuracy of the Global Geopotential Model EGM2008 has been improved by about 30-40 cm compared to the previous model EGM96, and the Geoid Height of Mongolia 2014 model was improved by 40-50 cm compared to 2006. The results of this comparative study are shown graphically in Figure 1.

As seen, the geoid height at the points of High-precision geodetic network determined by gravimetric data can be accurately converted to a Baltic Height System using the formula (1) at each point for the geodetic heights obtained at satellite measurements.

$$\zeta_i = \zeta_{gr} + \Delta\zeta_e \quad (1)$$

Where:
ζ_i —value of the height of the geoid at the points of the Astronomy-geodetic control network and the high-precision geodetic network, obtained from the data of the satellite and geometric leveling.
ζ_{gr} —geoid height calculated by the use of gravimetric data.
$\Delta\zeta_e$ —correction for gravimetrical geoid.

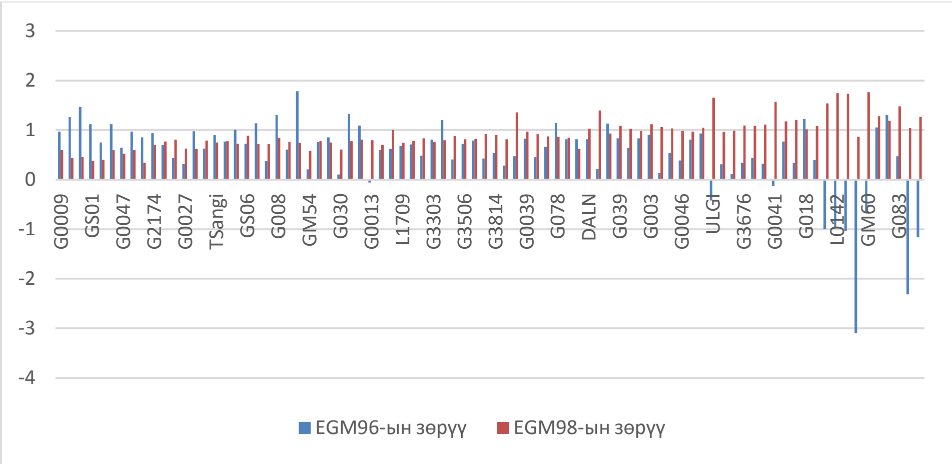

Figure 1. Graph of the difference between the geoid height obtained from the geoid height model of Mongolia/MGL14/ and the geoid height obtained from the Earth Geopotential model /EGM96, EGM08/ on 85 points of the GPS main and sub-network.

In order to obtain this correction for the territory of Mongolia, the geoid height obtained from the geoid height model of Mongolia and the geodetic height determined by GPS measurements at a total of 92 points (54 nodes of the Elevation Class II network, 38 points of the Gravitational Class 1 and 2 network), calculated the difference value by comparing the difference between the orthometric height determined by geometric leveling and the geoid height, and the statistical results of the accuracy evaluation are shown in Table 2, and the picture of the difference is shown in Figure 2, respectively.

Table 2. Evaluation of the accuracy of the geoid height difference ($\Delta\zeta_e$) calculated from the "Geoid height model" of Mongolia and the orthometric height determined by geometric leveling

№	**Name of dimension**	**Marking**	□MGL14-□geo.lev
1	The average value of the difference	[d]/n см	-1.76
2	Maximum value of the difference	d_{Max}, см	+217,19
3	Minimum value of difference	d_{Min}, см	-262,17
4	Standard deviation (SD)	m_{SD}, см	48.263
5	Mean squared error (RMSE)	m_d, см	9.854

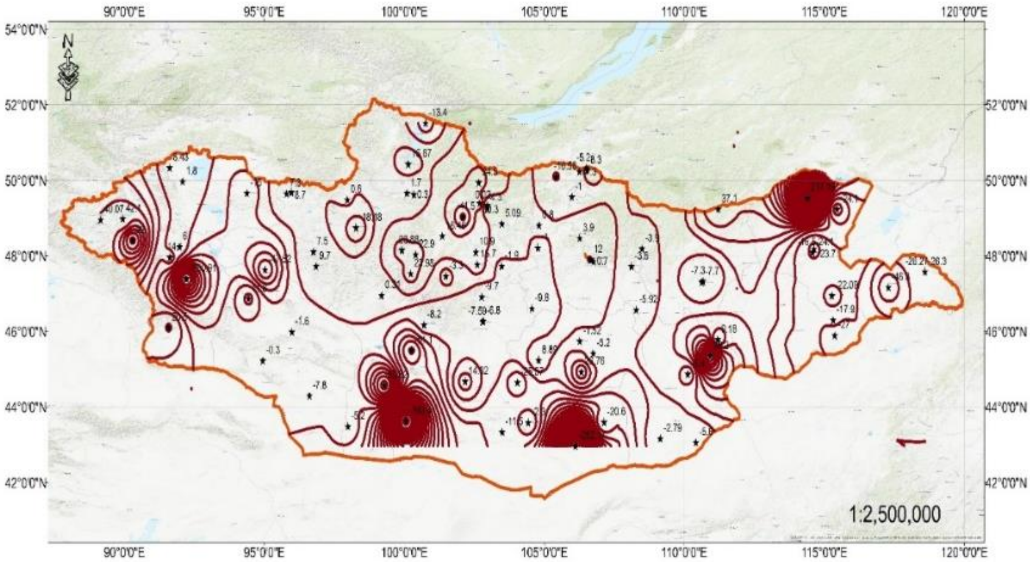

Figure 2. Map of difference ($\Delta\zeta_e$) on the territory of Mongolia (Height of generation 10 cm).

A technological scheme of applying a satellite technology for the development of a normal height system is shown in Figure 3.

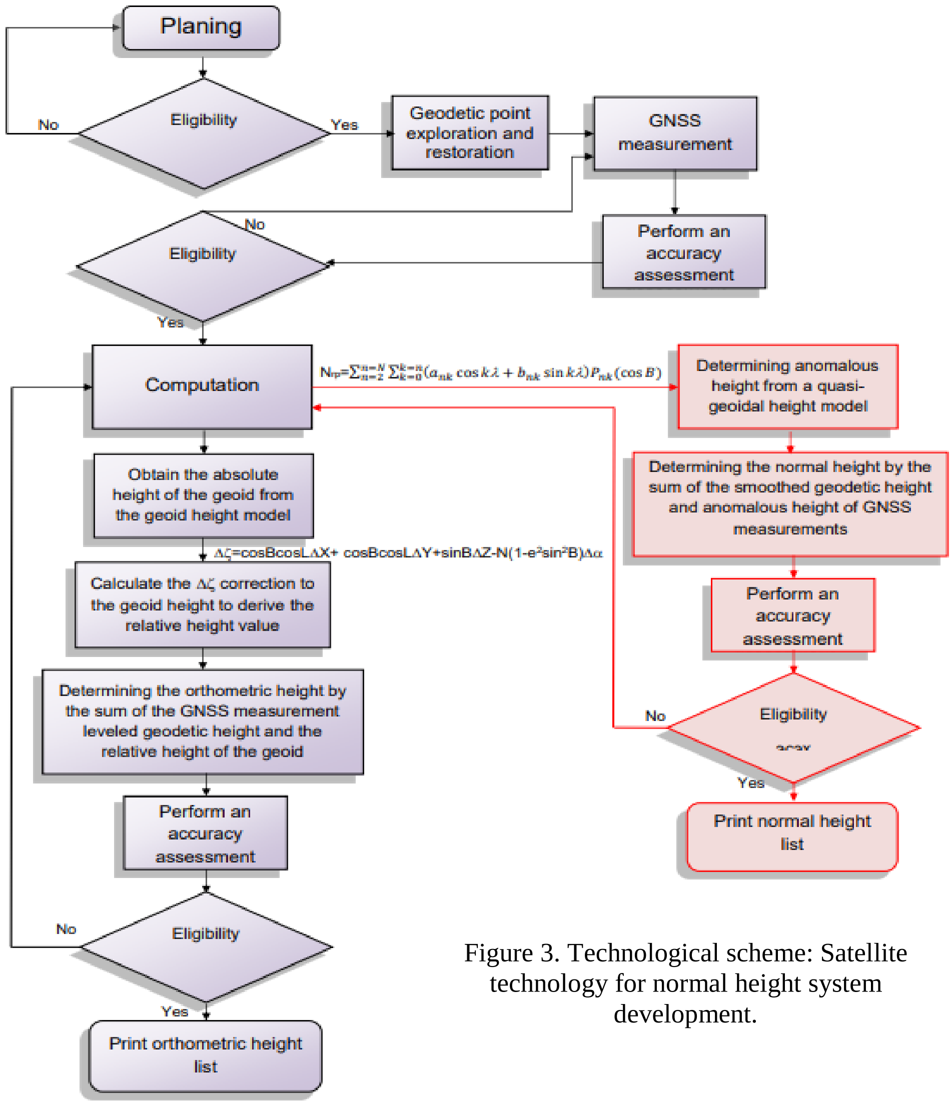

Figure 3. Technological scheme: Satellite technology for normal height system development.

4. CONCLUSION

Elaboration of a new system, providing the customers, specialists and decision-makers with accurate basic geodetic data obtained by modern satellite measurements became a major challenge for the National Geodetic Services around the world. In this study, we solved the problem related to the Mongolian height system by the use of a modern satellite technology. For the analysis, the GNSS measurements and detailed quantitative spatial model of quasi-geoid were compared with the average value of multi-year observations at the continuously operating origin point. As seen, it is not necessary to take any sea surface level as a starting point by using basic parameters of geodesy for developing a height system. However, the basic parameters must meet the high accuracy requirements. For further development of the normal height system of Mongolia, it should be taken such measures as the evaluation of the country's geoid model and its accuracy, and accuracy improvement of the geoid height model based on a high-grade gravimetric grid. Consequently, for determination of the normal height, satellite measurements could be applied instead of a geometric method. The modern development of the height system could contribute to the regional and global geodynamic studies and further improvement of the global geopotential model.

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