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PREFACE

"SOLIDARITY, CREATIVITY, QUALITY, EFFICIENCY FOR ACHIEVEMENTS OF NATURAL RESOURCES AND ENVIRONMENT" are the core value of Hanoi University of Natural Resources and Environment (HUNRE), HUNRE has incessantly attempted to become a key university in the field of resources and environment, that's on a par with advanced universities in the region and reach to cooperation with well-known international universities.

HUNRE has a mission of training high-qualified human resources to serve the management activity and implementation of professional duties, scientific researching, deploying, applying and transferring the advanced technologies in the field of natural resources and environment in Viet Nam to meet the demand of industrialization and modernization in the context of the forth industrial revolution and international integration under the impacts of climate change.

Understanding the crucial role of international cooperation in education, training and scientific research, HUNRE has proactively and initiatively cooperated with many universities, research institutions, enterprises, and scientists around the globe to collaborate and develop international projects, conferences, and colloquiums. And, the newest international conference entitled: "Technology in Natural Disaster Prevention and Risk Reduction", hosted by HUNRE with the purpose of sharing knowledge, exchanging experiences and expertise among scientists in the field of natural resources and environment, such as: Environmental data visualization, Internet of Things (IoT), Unnamed Aerial Vehicle (UAV), Artificial Intelligence (AI), Hydro-Meteorological Disaster Risk Management under climate change, etc... for sustainable development of the major of natural resources and environment in particular, and the socio - economy in general.

Respectively, HUNRE is pleased to introduce a conference proceedings entitled "Technology in Natural Disaster Prevention and Risk Reduction" with our grateful attribute. Hence, we would like to thank managers, domestic and international scientists for their interest and participation. We also want to send our grateful appreciation to the Ministry of Natural Resources and Environment (MONRE) for your unlimited contribution. Furthermore, we want to give a big applause to international institutions and universities, such as the NUFFIC organization, Delft University of Technology, and the University of Twente, the Netherlands. Last but not least, we acknowledge support for open access publishing this document by the OKP project: "Climate Proof Vietnam - Educating together to achieve sustainable change in the Vietnamese deltas".

Compiling a comprehensive conference proceeding costs much time and employment fee, Editorial staff have concentrated their efforts on perfecting this document, however, it is difficult to avoid errors in editing. Therefore, we always want to receive feedback and comments in order to improve our work becoming better.

Thank you for your assistance.

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BUILDING THE QUASIGEOID MODEL IN THE NORTHEAST REGION OF VIETNAM FOR TRANSFERRING FROM ELLIPSOID HEIGHT TO NORMAL HEIGHT

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Abstract

In this study, the Quasigeoid model of the Northeast region was built based on data from GNSS/levelling points and height anomaly data from the global gravity model - EGM2008. A total of 151 GNSS/levelling I, II, and III points were used for the study. When assessing quality of the data series, 8 points were removed. Of the 143 GNSS/leveling points that passed the requirements, 130 points were used to build the model, and 13 points were employed to test the accuracy of the built model. The accuracy of the Quasigeoid model was 6.5 cm. This model was high accuracy, so it can be applied when transferring GNSS height to levelling height and vice versa. This study is meaningful because the terrain in the Northeast is difficult, so levelling surveys are hard. The method of building the Quasigeoid model can be applied to other areas when GNSS/levelling data are available.

Keywords: Height anomaly; Ellipsoid height; Leveling height.

1. Introduction

Surveying and establishing maps are basic jobs for developing socio-economic and ensuring national security and defense. Today, with the advancement of science, modern technologies have been applied to increase labor productivity, improve the accuracy of measurement results, and meet the increasing demands of society.

Global navigation satellite technology is developing rapidly. GNSS receivers are modern, reasonably priced. The processing of GNSS data is convenient and gives quick results with high accuracy. Therefore, GNSS measurement has become very popular, replacing traditional technologies. The height obtained from GNSS technology is called ellipsoid height, which is the height above the ellipsoid surface, denoted by H.

Vietnam's national height system is the normal height system (also known as the levelling height). The levelling height is the distance from the point to the quasi-geoid surface along the normal gravity plumb line, denoted by h.

Thus, the ellipsoid height and the levelling height have different reference surfaces. The difference between two heights is called the height anomaly, denoted by ζ. If the ellipsoid height is known, the levelling height $h = H - \zeta$.

Determining the normal height by surveying levelling routes is a complicated job, which takes a lot of time, and effort, so it is economically costly. Meanwhile, the ellipsoid height determined by GNSS technology is convenient, fast, and highly accurate. Today, in the world, countries and territories tend to build local Quasigeoid models to convert ellipsoid height to normal height for responding to different types of work.

The Northeast region is the territory in the northeast of Vietnam, including the provinces of Phu Tho, Ha Giang, Tuyen Quang, Cao Bang, Bac Kan, Thai Nguyen, Lang Son, Bac Giang and Quang Ninh, which shares a border with China. The northeast region's topography is mainly low hills, with a general inclination descending from the northwest to the southeast. The area has a unique limestone karst topography in many places. Cao Bang, Lang Son, Tuyen Quang are small plains. The highest area in the region is the ancient foundation area upstream of the Chay River. There are many mountains over 2000 m high formed by rugged mountains such as Dong Van and Ha Giang.

With the topographical characteristics of the Northeast as analyzed above, if the Quasigeoid model is established, it will optimize its superiority when transferring the ellipsoid height to the normal height in this area. Levelling heights will be determined quickly without field surveyings. Therefore, the building of the Quasigeoid model in the Northeast region is the task of this study.

The GNSS/levelling data combined with the data of the global gravity model is the method which is widely used to build the Quasigeoid model. GNSS/levelling data has been used to correct the Earth's gravity model to establish local geoid models around the world. It is shown through studies such as the EGM2008 model and GNSS/levelling data to build the local geoid model in Norway [2]; Indonesia [10]; Nigeria [16]; Turkey [17]; China [13]; the US and Iran [14]; model EIGEN6C4, levelling data, and GNSS data to build the local geoid model in Uganda [11]; GNSS/levelling data, EIGEN - 6C4 data, gravity data to establish the geoid model in Qatar [3]; GNSS/levelling data and GOCE data to establish the geoid model in the state of São Paulo [9]; GNSS/levelling data, XGM2019e_2159 data, digital elevation model ACE2 GDEM to build the geoid model in Egypt [1].

In Vietnam, GNSS/levelling data was combined with the data of the global gravity model to build a local Quasigeoid model. Case studies such as the local Quasigeoid model were built on the territory of Vietnam [7], [22], [18]; the Central Highlands [15]; the Northwest region [4], [6]; the coal mine area of Mount Beo - Vinacomin, Quang Ninh [5], Lao Cai province [19]; Cam Pha - Mong Duong area, Quang Ninh [8], [21]; the South Central region [12].

It shows that the study of building a local Quasigeoid model is a matter of interest to many scientists. The method of using GNSS/levelling data in combination with global gravity model data is commonly applied in practice. Therefore, in this study, the above method is used to build a local Quasigeoid model in the Northeast region of Vietnam to convert ellipsoid height to normal height.

2. Meterial and Methods

2.1. Evaluation of the range of measurement values

A set of n observed data values $V_1, V_2, ..., V_n$.

The average of the observed data set (symbol is V_{tb}) also called the value which has the greatest probability of occurrence of that data set calculated by the formula:

$$V_{tb} = \frac{\sum_{i=1}^{n} V_i}{n} \quad (1)$$

The correction number of the observed i value (symbol is v_i) is calculated by the following formula:

$$v_i = V_b - V_i \quad (2)$$

Variance - σ^2

The variance is used to indicate the degree of a random variable (or a statistic) that is scattered around its mean. The following formula is used to calculate the variance:

$$\sigma^2 = \frac{\sum_{i=1}^{n} v_i^2}{n-1} \quad (3)$$

Standard deviation: is the square root of the variance and is denoted by σ;

The standard deviation is used to evaluate the quality of the observed data. The value is often chosen to evaluate the quality of the measured data series to be 2σ, which corresponds to the probability of occurrence of the measured series being about 95 %.

2.2. Building the Quasigeiod model

The Quasigeiod model is built on the basis of the approximation theory function, with the input data being the movement velocity of GNSS sites in the study area. The collocation method is presented in this study as an effective data processing tool in the field of geo - statistics.

Assume that there are two sets of random variables:

The set of "measurement values" $\ell_1, \ell_2, ..., \ell_q$ is represented by a q - dimensional vector:

$$\ell = \begin{bmatrix} \ell_1 & \ell_2 & ... & \ell_q \end{bmatrix}^T \tag{4}$$

The set of "signals" that need to be determined is $S_1, S_2, ..., S_m$, represented by the m-dimensional vector:

$$S = \begin{bmatrix} S_1 & S_2 & ... & S_m \end{bmatrix}^T \tag{5}$$

Assume the above random quantities have mathematical expectations equal to zero:

$$E\{\ell\} = 0;\ E\{S\} = 0 \tag{6}$$

The covariance matrix (theoretical) of the measured random vector ℓ is a square matrix of the size q × q.

$$Cov(\ell\ell) = E\left(\ell\ell^T\right) = C_{\ell\ell} \tag{7}$$

The cross-covariance matrix (theoretical) between the measured value vector ℓ and the vector S which has a size m×q:

$$Cov(S\ell) = E\left(S\ell^T\right) = C_{S\ell} \tag{8}$$

The best linear estimator of the vector S is denoted by $\hat{S}$. The calculation formula $\hat{S}$ has the form:

$$\hat{S} = C_{S\ell} C_{\ell\ell}^{-1} \ell \tag{9}$$

The formula (9) is called least squares interpolation or least - squares collocation interpolation. This formula is to determine the theoretical covariance matrices $C_{\ell\ell}$ and $C_{S\ell}$.

To determine the parameters of the theoretical covariance function, firstly must calculate the experimental covariance values. Call ℓ_i is the value of point i.

The experimental covariance follows the distance of k pairs of points P, Q is calculated by the formula:

$$C(s) = Cov(d\ell_i, d\ell_Q) = \frac{1}{k} \sum_{i=1}^{k} d\ell_i^P d\ell_i^Q \tag{10}$$

where:

$$d\ell_i = \ell_i - \ell_{TB} = \ell_i - \frac{1}{n} \sum_{i=1}^{n} \ell_i \tag{11}$$

The experimental covariance will be calculated differently depending on the values of $\left(s-\frac{\Delta s}{2}\right)$ and $\left(s+\frac{\Delta s}{2}\right)$, where Δs is a small quantity which is chosen depending on the data situation.

Corresponding to the value of different s, it will be calculated different experimental covariance.

The larger the number of k-point pairs, the more reliable the calculated covariance value.

When choosing the theoretical covariance function, it is necessary to choose this function in accordance with the law of variation of the experimental covariance values and use the function approximation method to determine the parameters of the theoretical covariance function theory.

In this study, the 3rd order Markov function is used when establishing the absolute movement velocity model in the experimental part. The 3rd order Markov function has the following form:

$$C(s) = C_0 e^{-\frac{s}{L}}\left(1+\frac{s}{L}+\frac{s^2}{2L^2}\right) \quad (12)$$

where:

C_0 is the parameter of the theoretical covariance function.

L is the relation distance.

3. Experimental data

The total number of GNSS/levelling grade I, II, and III points in the Northeast region is 151. Height anomaly data from the EGM2008 model of these points can be found on page http://icgem.gfz-potsdam.de/home.

Table 1. State GNSS/levelling points in the Northeast region

Nº	Point Name	X (m)	Y (m)	H (m)	h (m)	$\zeta_{EGM2008}$ (m)
1	I(BH - HN)19 - 1	2390906.095	492971.666	-2.5420	26.3956	-29.5836
2	I(BH - HN)20 - 1	2386467.275	497865.565	-2.3853	26.4751	-29.5092
3	I(BH - HN)26	2367594.767	517558.292	1.0380	29.3080	-29.0374
4	I(BH - HN)33	2356527.002	541831.467	-14.6900	13.0419	-28.8206
5	I(BH - LS)11-1	2479163.048	460024.914	67.8223	98.2084	-30.2863
6	I(BH - LS)16A	2479233.996	480266.238	78.1570	108.3074	-30.1981
7	I(BH - LS)21	2492490.503	489065.338	52.7151	83.0872	-30.1146
8	I(BH - LS)31	2390906.095	492971.666	-2.5420	26.3956	-29.5836
9	I(BH - LS)36	2386467.275	497865.565	-2.3853	26.4751	-29.5092
10	I(BH - LS)41	2367594.767	517558.292	1.0380	29.3080	-29.0374
…	…	…	…	…	…	…
142	III(VQ - TQ)4	2502755.615	473497.047	804.0894	833.9359	-29.6993
143	III(VT - MD)4	2453438.467	475232.842	73.5306	103.3761	-30.1249
144	III(YB - AN)3	2468686.545	464753.915	98.9034	129.0514	-30.2578
145	III(YB - AN)5	2463471.584	470236.552	102.6981	132.7153	-30.1822
146	III(YM - ND)10	2546541.024	496940.062	833.8968	863.3975	-29.9721
147	III(YM - ND)3	2561071.298	507229.620	863.6858	892.9846	-29.7881
148	III(YM - NK)12	2568244.267	542384.911	989.9866	1018.2469	-28.3981
149	III(YM - NK)18	2548220.199	543060.546	263.0491	291.9548	-28.9235
150	III(YM - NK)8	2573978.673	532897.160	1095.3858	1123.6558	-28.5304
151	III(YM - YD)11	2531991.996	524995.291	811.0571	840.3560	-28.8127

4. Results and discussion

4.1. Results of data evaluation

From Table 1, the value of the height anomaly ($\Delta\zeta$) of the GNSS/levelling points between the survey and the model is calculated. These values are shown in the form of a diagram in Figure 2. The average value of the height anomaly ($\Delta\zeta_{tb}$) is determined by formula (1), $\Delta\zeta_{tb} = 0.4323\ (m)$.

The standard deviation of the data series:

$$\sigma = \pm\sqrt{\sum_{i=1}^{n} v_i^2 /(n-1)} = \pm 0.3091\ (m)$$

Thus, the probability of occurrence of elevation anomalies of GNSS/levelling points is in the range of values (0.4323 - 2σ) and (0.4323 + 2σ), respectively, from about -0.1859 (m) to +1.0505 (m) is 95 %, indicating that the height anomaly of the GNSS/levelling points outside the above range will be eliminated when processing the data in the next step.

The result shows that points I(BH - LS)26 - 1, I(BH - HN)33, I(BH - LS)21, I(BH - LS)31, I(BH - LS)36, I (BH - LS)41, III(YM - YD)11, III(PT - BN)8 are not in the range of values mentioned above, so they are not used to calculate the next steps.

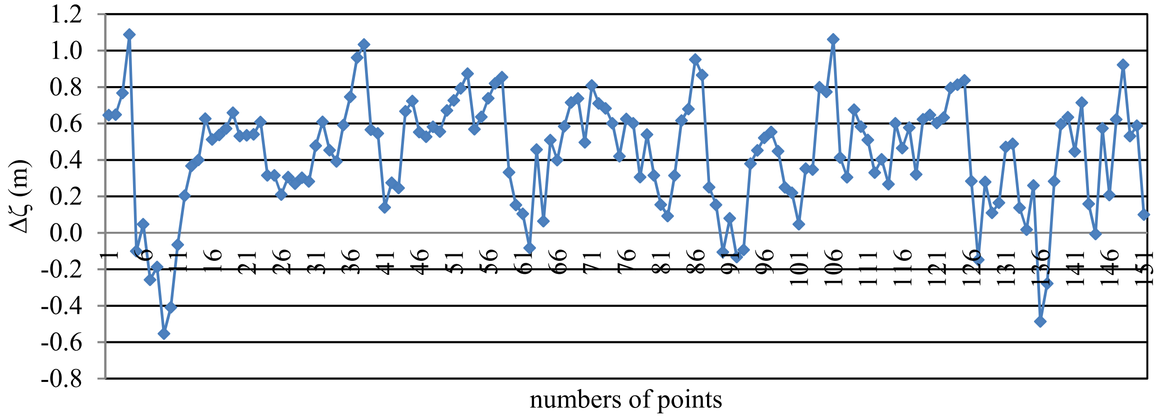

Figure 1: Height anomaly values of GNSS/levelling points between surveying and EGM2008 model

4.2. Building the Quasigeoid model in the Northeast region

The process of building the Quasigeoid model in the Northeast region carries out the following:

- Determining the number of GNSS/levelling points used to build the height anomaly model in the Northeast region, the number of GNSS/levelling points used as test points for the built Quasigeoid model.

Building Quasigeoid model of the experimental area.

+ Calculate the height anomaly of the GNSS/levelling points according to the measurement data (ζ_{do}).

+ Calculate the difference in height anomalies of GNSS/levelling points.

+ Determine the experimental variance function.

+ Determine the theoretical variance function.

+ Determine the precision of the built-up Quasigeoid model.

The results of the above sequence are presented in detail as follows:

To study the building of the Quasigeoid model in the Northeast region, 130 points were used to build the model, 13 points were used as test points for the accuracy of the built model (Figure 2).

In this diagram, red points are grade I points, yellow points are grade II points, blue points are grades III, and squares points are test points.

- Height anomalies of GNSS/levelling points used to build Quasigeoid models from surveying data; calculate its corresponding height anomaly compared with the EGM2008 Earth gravity model.

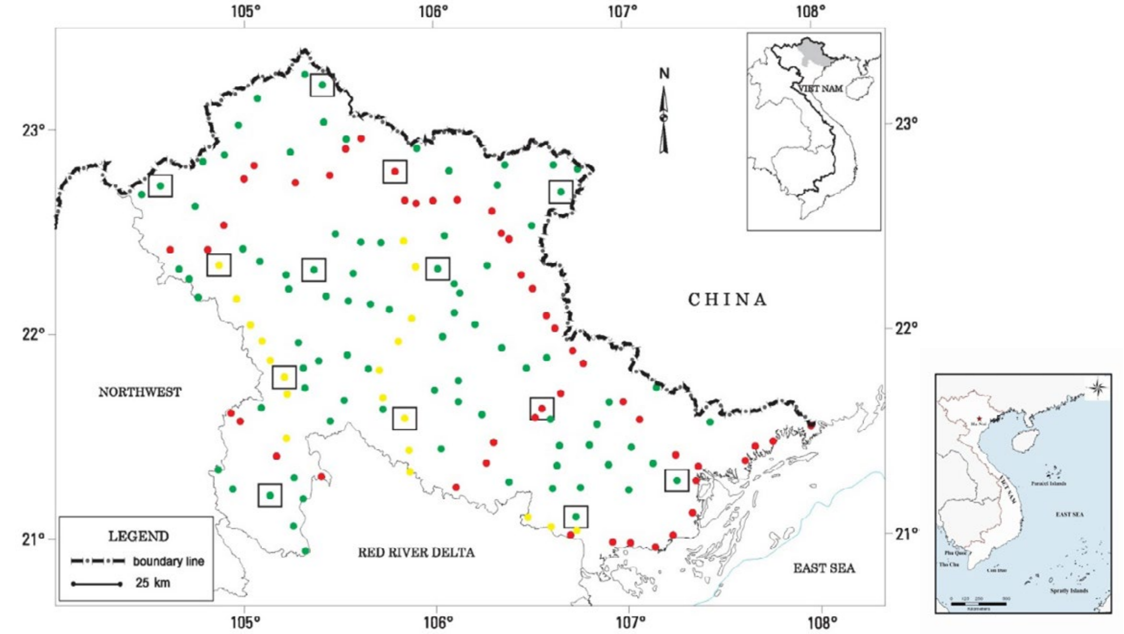

Figure 2: The diagram of GNSS/levelling points in the Northeast region

Table 2. Height anomalies of GNSS/levelling points used to build the Quasigeoid model from surveying data

N°	Point Name	X (m)	Y (m)	ζ_{do} (m)	$\Delta\zeta$ (m)
1	I(BH - HN)19 - 1	2390906.014	492972.405	-28.9376	0.6460
2	I(BH - HN)20 - 1	2386467.208	497866.302	-28.8604	0.6488
3	I(BH - HN)26	2367594.687	517559.040	-28.2700	0.7674
4	I(BH - LS)11 - 1	2479162.983	460025.610	-30.3861	-0.0998
5	I(BH - LS)16A	2479233.929	480266.940	-30.1504	0.0477
6	I(BH - LS)44 - 1	2533733.538	554975.933	-28.6661	-0.0647
7	I(BH - LS)48	2539380.448	563324.019	-28.4677	0.2040
8	I(BH - LS)62	2505947.578	586946.656	-27.5323	0.3679
9	I(BH - LS)65	2504272.291	593037.939	-27.5597	0.3997
10	I(BH - LS)68	2505724.465	602152.440	-27.4806	0.6265
…					
121	III(TY - CL)8	2386132.303	752156.872	-22.9820	0.2844
122	III(VQ - TQ)4	2502755.547	473497.760	-29.8465	-0.1472
123	III(VT - MD)4	2453438.386	475233.561	-29.8455	0.2794
124	III(YB - AN)3	2468686.465	464754.649	-30.1480	0.1098
125	III(YB - AN)5	2463471.515	470237.249	-30.0172	0.1650
126	III(YM - ND)10	2546540.957	496940.756	-29.5007	0.4714

Nº	Point Name	X (m)	Y (m)	ζ_{do} (m)	Δζ (m)
127	III(YM - ND)3	2561071.226	507230.314	-29.2988	0.4893
128	III(YM - NK)18	2548220.117	543061.278	-28.9057	0.0178
129	III(YM - NK)22	2538998.684	555255.258	-28.6462	0.0999
130	III(YM - NK)8	2573978.630	532897.839	-28.2700	0.2604

- Calculating height anomalies of GNSS/levelling points are test points of the built Quasigeoid model.

Table 3. Height anomalies of GNSS/levelling points as test points

Nº	Point Name	X (m)	Y (m)	ζ^{kt}_{do} (m)
1	I(BH - LS)57	2521495.165	581616.609	-27.4892
2	I(LS - HN)10	2393378.653	661161.678	-25.4527
3	II(NB - HN)40	2388050.022	586929.965	-27.6646
4	II(NK - PT)19 - 1	2410320.461	521894.407	-28.9539
5	II(NK - PT)2 - 1	2470899.840	486476.067	-30.0661
6	III(BT - DH)16	2468344.263	537853.114	-29.1481
7	III(DC - QT)8	2334819.968	679612.944	-24.4740
8	III(KD - HT)10	2354501.711	734290.060	-23.5256
9	III(PD - NR)5	2468944.623	604816.354	-27.3614
10	III(PL - HG)17	2513718.511	454740.558	-29.8301
11	III(PT - LB)8	2346431.748	514065.024	-27.8813
12	III(TK - HQ)11	2510497.233	671461.008	-26.3486
13	III(YM - NK)12	2568244.213	542385.603	-28.2603

- Determine the experimental covariance function:

Table 4. Parameter values of the experimental covariance function by distance

Nº	S_i (km)	Number of point pairs	Value C^0_R (cm²)
1	0	130	669.8687
2	10	41	565.1564
3	20	89	529.5021
4	30	151	369.1946
5	40	192	286.3788
6	50	212	215.1868

- Parameters in the loop calculation:

Table 5. Parameter values during loop calculation.

Loop	C	L	dC	dL
1	0 573.80280	20.19964	-96.0658	10.1996
2	1 625.46746	31.87466	51.6647	11.675
3	2 645.73048	33.42365	20.263	1.549
4	3 645.67099	33.44609	-0.0595	0.0224
5	4 645.66825	33.44649	-0.0027	0.0004
6	5 645.66820	33.4465	0	0

where: dC, dL are the corresponding corrections of the parameters of the covariance function C and the relationship distance L.

- The theoretical covariance function is determined with the parameters shown in the Table 6.

Table 6. Values of the parameters of the theoretical covariance function according to the distance and its difference with the value of the experimental covariance function

Nº	S_i (km)	Pair of points	Approximate function	v_i (cm^2)
1	0	130	645.6683	-24.2004
2	10	41	600.5643	35.4079
3	20	89	503.9108	-25.5913
4	30	151	393.5666	24.372
5	40	192	289.1457	2.7669
6	50	212	199.467	-15.7198

- Accuracy of factors:

+ The mean square error determines the parameters:

$$\mu = \pm\sqrt{\frac{\sum v_i v_i}{t-2}} = \pm 28.910 \ \ (cm^2)$$

+ Calculate the mean square error of the correction for the parameter of the covariance function C, denoted by m_{dC}:

$$m_{dC} = \mu\sqrt{Q_{11}} = \pm 20.500 \ \ (cm^2)$$

+ Calculate the square error of the correction for the contact distance L, denoted by m_{dL}

$$m_{dL} = \mu\sqrt{Q_{22}} = \pm 1.757 \ \ (km)$$

- The formula for expressing the theoretical covariance function has the following form:

$$C(S_i) = 645.6683 \ \ e^{\frac{-S_i}{33.4465}}(1 + \frac{S_i}{33.4465} + \frac{S_i^2}{2237.3367})$$

Thus, the experimental area Quasigeoid model has been built, expressed through the theoretical covariance function.

- The leveling height of the test point calculated according to the built Quasigeoid model has the following values:

Table 7. Height anomalous values from test GNSS/leveling points

Nº	Point Name	$\zeta^{kt}_{tinh\_tu\_mo\_hinh}$ (m)	$d\zeta^{kt}$ (cm)
1	I(BH - LS)57	-27.5509	-6.2
2	I(LS - HN)10	-25.4912	-3.9
3	II(NB - HN)40	-27.6653	-0.1
4	II(NK - PT)19 - 1	-28.8918	6.2
5	II(NK - PT)2 - 1	-30.127	-6.1
6	III(BT - DH)16	-29.2087	-6.1
7	III(DC - QT)8	-24.5325	-5.9
8	III(KD - HT)10	-23.5025	2.3
9	III(PD - NR)5	-27.3576	0.4
10	III(PL - HG)17	-29.7649	6.5
11	III(PT - LB)8	-27.8303	5.1
12	III(TK - HQ)11	-26.3122	3.6
13	III(YM - NK)12	-28.2208	4.0

where: $d\zeta^{kt} = \zeta^{kt}_{tinh\_tu\_mo\_hinh} - \zeta^{kt}_{do}$

It can be seen that the biggest deviation between the height anomaly determined from the model built and the height anomaly surveyed of test GNSS/levelling points is 6.5 cm, and the smallest is 0.1 cm. Thus, the Quasigeoid model built in the Northeast region has an accuracy of 6.5 cm.

Compare the results of this study with published studies such as: Quasigeoid models on Vietnamese territory in the literature [22] (accuracy is 8.2 cm), [20] (accuracy is 9.7 cm); the Northwest Quasigeoid model [4] (accuracy is 9.4 cm); the Quasigeoid model in the Central Highlands [15] (accuracy about 7.5 cm); and the Quasigeoid model in the South Central region [12] (accuracy about 8 cm). This shows that the Quasigeoid model in the Northeast region has higher accuracy.

5. Conclusion

Some conclusions are drawn as follows:

- The height anomaly model in the Northeast region is built based on the data of 130 GNSS/levelling points in strict and precise steps. This modelling process is completely applicable to other experimental areas where GNSS/levelling points are available.

- A total of 13 GNSS/levelling points are used as the building model's accuracy checkpoints. The research results show that the Quasigeoid model has an accuracy of 6.5 cm.

- The Quasigeoid model of the Northeast region has been expressed as a mathematical function. This function allows to directly determine the height anomaly values of points in the experimental area. Therefore, the height anomaly values of those points have high accuracy and reliability. Those are not affected by the interpolation error from the mesh points of the Quasigeoid model.

- The Quasigeoid model built in the Northeast region has high accuracy. The Northeast is difficult terrain for measurement, so the Quasigeoid model is very useful when transferring height when measured by global satellite navigation technology to the national height.

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