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Global Geopotential Model (GGM) Assessment for Coastal Erosion Study Using Global Navigation Satellite Systems (GNSS) Levelling in Terengganu

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Abstract

GNSS levelling can be used to define the high accuracy geoid based on geodetic, gravimetric, and astrogeodetic approaches. In order accurately measure the gravity anomaly and geoid height in the research region, Terengganu, it is necessary to evaluate the suitable Global Geopotential Model (GGM) because coastal erosion and flood disaster may cause changes in shoreline and beach profiles. The aim of this study is verify the global geopotential model (GGM) with Global Navigation Satellite System (GNSS) levelling data in order to verify the global model with ground truth data in Terengganu. Hence, the Global Geopotential Model (GGM) model are selected based on satellite-only and combined-model in year 2018 through 2022. Next, the root mean square error (RMSE) is computed for each comparison in order to access the accuracy of each model. The study's results using the RMSE calculation showed that ITSG-Grace2018s had the lowest RMSE value, 0.2190m. Hence, the findings found that ITSG-Grace2018s represents the best fit GGM model with ground truth data in Terengganu. Thus, the local geoid height can be determined accurately in Terengganu using the most precise GGM model.

1. Introduction

The development of geoid modelling is based on geodetic, gravimetric, and astrogeodetic approaches. One of the geodetic techniques, Global Navigation Satelite System (GNSS) levelling, can be used to define a high-accuracy geoid. It entails converting the ellipsoidal height (h) obtained from GNSS to the orthometric height (H) [1]. Orthometric heights can be calculated using accurate geoid models rather than levelling. A GNSS boost the precision of time or location measurements and give additional information in urban and hilly regions [2]. GNSS is an effective instrument for time-stamped financial transactions and academic study in geodesy, meteorology, and the troposphere [3].

The coastal region of Terengganu served as study area with latitudes 4° to 6° and longitudes 102° to 104° are used in the study. Global Geopotential Model (GGM) play an important role as a reference surface based on geoid height. Hence, it is necessary to assess the appropriate Global Geopotential Model (GGM) using GNSS Levelling data [4]. It is important to calculate the geoid height and gravity anomaly in the study region, Terengganu, to analyse the accuracy of the Global Geopotential Models (GGMs). This global model is significance to obtain a good accuracy of a regional gravity anomaly and geoid estimation in Terengganu. Hence, the goal of this study is to select the GGM model in year 2018 until 2022 based on satellite-only and combined-model, to validate the GGM with GNSS Levelling data in Terengganu and to calculate the root mean square error (RMSE) of the models with GNSS levelling data.

2. Materials and Methods

The accuracy assessment of the Global Geopotential Model (GGM) is a crucial task as it dictated the best model for a study area in coastal erosion using Global Navigation Satellite System (GNSS) levelling data. The goals in five phases have been accomplished which is, literature review, data acquisition, selection of GGM data from 2018 to 2022, verification of the Global Geopotential Model (GGM) with Global Navigation Satellite System (GNSS) levelling, and RMSE calculation. The usual difference between what a model predicts and what happens has been calculated using Root Mean Square Error (RMSE). This allows to estimate the model's ability to forecast the target value. Then, in Terengganu, GGM are selected based solely on satellite data or a combination of both. The standard deviation and International Centre for Global Earth Models (ICGEM) website, which is an option for identifying the coordinates of this study area, are used to obtain statistics from the performance of the models and validation results [5]. This method has demonstrated how this study achieves its goal.

2.1 Softwares

Figure 1 shows the International Centre for Global Earth Models (ICGEM) server which is http://icgem.gfz-potsdam.de/home. The ICGEM programme was developed to use Surveying and Mapping's airborne-derived gravity anomaly. The orthometric height (H) is calculated in this study using data from the Global Navigation Satellite System (GNSS) obtained from the International Centre for Global Earth Models (ICGEM) server [6].

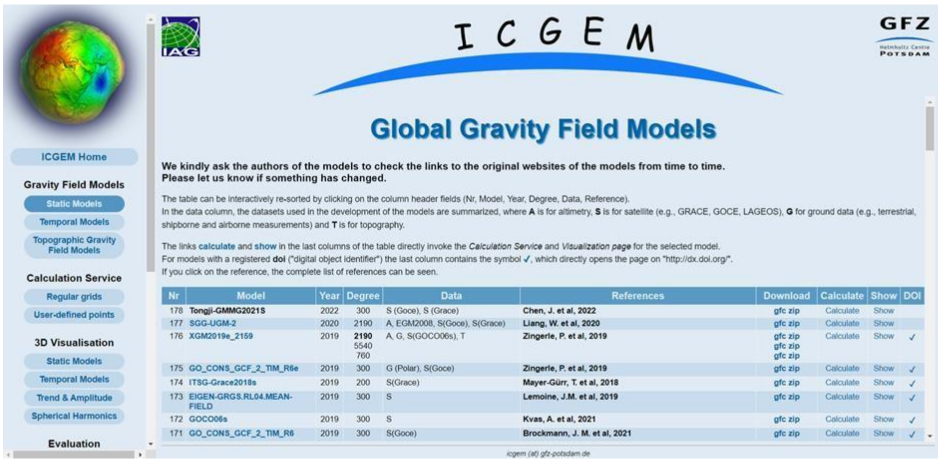

Fig. 1 *International Centre for Global Earth Models (ICGEM) server*

Matrix Laboratory (MATLAB) software used to produce every map for every 14 models. MATLAB is a programming and numeric computing platform used by millions of engineers and scientists to analyze data, develop algorithms, and create models. After running data in MATLAB software, every model with different latitudes and longitude will show different maps.

2.2 Methods

This is one of the techniques for explaining how the study has been carried out. Figure 2 depicts the study's workflow, which includes the fifth phase to achieve the study's goals and objectives. The study's workflow starts with a review of the literature on a paper relevant to this study. Next, the data acquisition was collected, and The Global Geopotential Model (GGM) model based solely on satellite data, or the combined model is then selected from 2018 until 2022 in ICGEM and validated each models using Global Navigation Satellite Systems (GNSS) levelling data. Finally, calculate the model's root mean square error (RMSE) based on GNSS levelling data [7][8].

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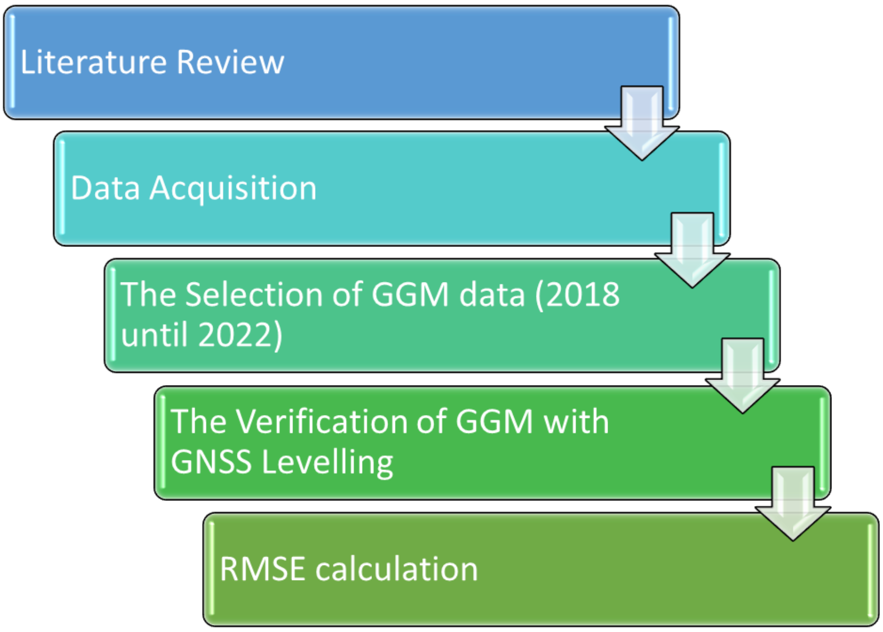

Fig. 2 *The workflow of the study*

2.3 Equations

Eq. 1 represents the RMSE formula which is defined as the residuals' standard deviation that known as prediction error. It determines the typical difference between values that a model predicts and actual values. Through this, it provides an estimation of the model's predictive power for the desired value.

$$E = \sqrt{\sum_{i=1}^{N} \frac{[z(fi) - z(oi)]^2}{N}} \tag{1}$$

Where,
f = forecasts (predicted values)
o = observed values
N = number of observations

3. Results and Discussion

The maps of 14 Global Geopotential Models (GGM) from year 2018 until 2022 based on satellite-only and combined-model data Each model's data are extracted directly by International Centre for Global Earth Models (ICGEM)website based on the study area. There are 7 satellite only model which are GOSG01S, Tongji-Grace02k, GO_CONS_GCF_2_TIM_R6, GOCO06S, EIGEN-GRGS.RL04. MEANFIELD and ITSG-Grace2018s. Another 7 GGM model are based on satellite combined, SGG-UGM_1, IGGT_R1C, GO_CONS_GCF_2_TIM_R6e, XGM2019e_2159, SGG-UGM-2, Tongji-GMMG2021s and EGM 2008.

Figure 3 shows the maps of the 14 models that produce by MATLAB software through insert the latitudes 4° and 6° and longitude 102° and 104° with the grid step of 0.1. MATLAB is a programming and numeric computing platform used by millions of engineers and scientists to analyze data, develop algorithms, and create models. After obtaining all the maps for each model, the differences between all maps for the model are shown.

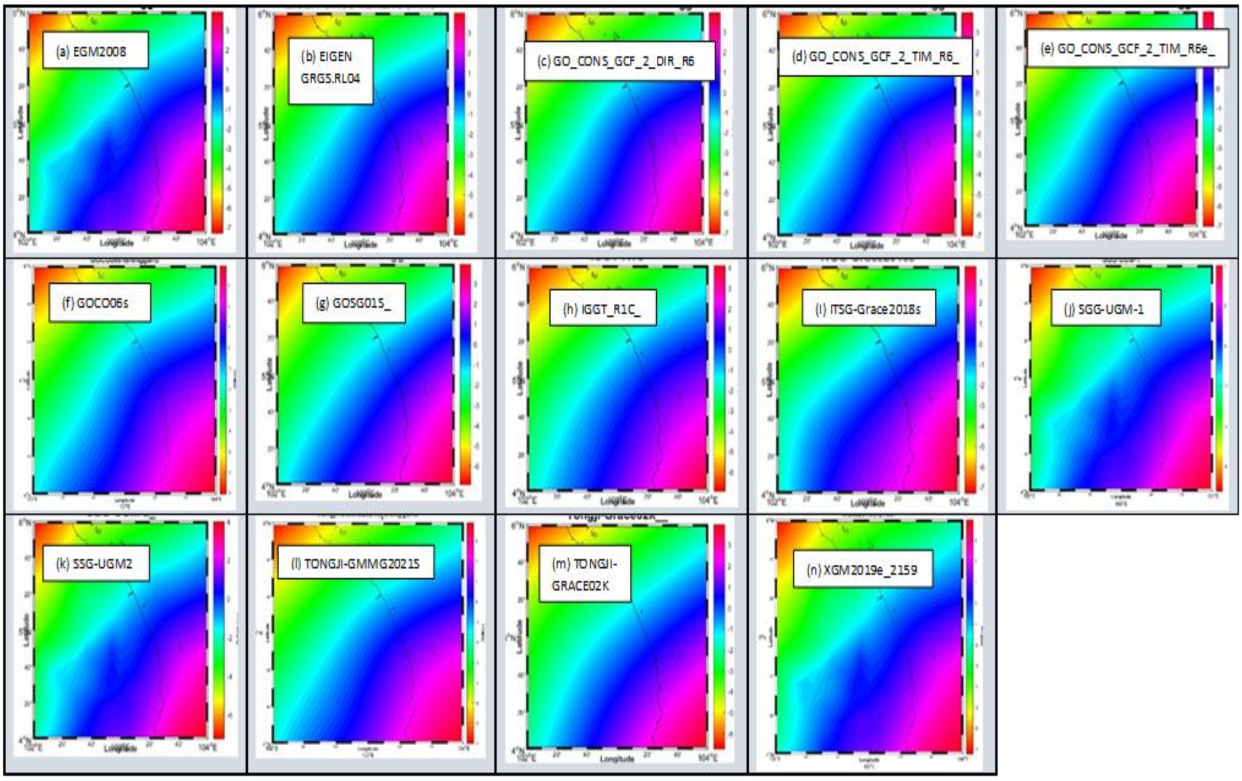

Fig. 3 The workflow of the study

The usual discrepancy between values predicted by a model and actual values was then calculated using the Root Mean Square Error (RMSE) formula. In addition, statistics from model performance and validation results were considered using standard deviation. This study considers the validation result and statistics following the performance of the models by using the standard deviation formulae that calculated by using minimum value, maximum value, and average value. It entails converting ellipsoidal height (h) from the Global Navigation Satellite System (GNSS) to orthometric height (H). The computation is performed using Microsoft Excel to verify the GGM with GNSS levelling data. The color in the figure represents the contour in the study region for each model. The figure shows the best models was ITSG-Grace2018s.

Table 1 *The analysis of GGM verification for all models.*

Type	Model	SD(m)	MIN(m)	MAX(m)	Mean (M)	Correlation(m)
Satellite-only	GOSG01S	0.0910	0.2680	0.4900	0.2990	0.9993
	Tongji-Grace02k	0.1026	0.1330	0.4990	0.2550	0.9993
	GO_CONS_GCF_2_TIM_R6	0.1544	0.3862	0.6062	0.3949	0.9985
	GO_CONS_GCF_DIR_R6	0.1529	-0.6692	0.2143	0.3346	0.9991
	GOCO06s	0.1838	-0.7187	-0.1511	-0.3085	0.9984
	EIGEN-GRGS.RL04. MEAN FIELD	0.1670	0.3317	0.5510	0.3360	0.9984
	ITSG-Grace2018s	0.1672	-0.1226	0.4115	0.1415	0.9994
Combined	SGG-UGM-1	0.0485	0.1890	0.3770	0.2990	0.9998
	IGGT_R1C	0.1488	6.17-E02	0.5510	0.3350	0.9991
	GO_CONS_GCF_2_TIM_R6e	0.1855	-0.7250	-0.1578	-0.3134	0.9985
	XGM2019e_2159	0.0361	0.2122	0.3602	0.3002	0.9999
	SGG-UGM-2	0.0622	0.1662	0.4322	0.3056	0.9998
	Tongji-GMMG2021S	0.1548	-0.6664	-0.1394	-0.3398	0.9996
	EGM 2008	0.0553	0.1368	0.3622	0.2536	0.9997

Based on the Table 1, ITSG-Grace2018s from the satellite-only model is selected as a best model because its correlation coefficient value is 0.9994 which is closest to ±1. From the combined model, XGM2019e_2159 is selected as second choice model to produce GGMs with the correlation coefficient value is 0.9999 which is closest to ±1.

Table 2 *RMSE value for each model*

Type	Model	RMSE / m
Satellite Only	GOSG01S	0.3123
	Tonji-Grace02k	0.2751
	GO_CONS_GCF_2_TIM_R6	0.4240
	GO_CONS_GCF_2_DIR_R6	0.3678
	GOCO06s	0.3591
	EIGEN-GRGS.RL04. MEANFIELD	0.3753
	ITSG-Grace2018s	0.2190
Satellite Combine	SGG-UGM-1	0.3026
	IGGT_R1C	0.3663
	GO_CONS_GCF_2_TIM_R6e	0.3642
	XGM2019e_2159	0.3024
	SGG-UGM-2	0.3119
	Tongji-GMMG2021S	0.3734
	EGM 2008	0.2596

The RMSE approach was used to choose the best model for the study area among all models. Each model must compute its RMSE using local data establishes, geoid EGM96, and then compare the results to see which one has the lowest RMSE value. The geoid difference for each benchmark which are 27 stations has been applied to calculate the RMSE, minimum and maximum value, standard deviation value, average value, and correlation all models. Table 2 shows the RMSE value for all models. Based on the computation of each models using Negm96 [1], the EGM2008 model had the lowest RMSE value for a combined model. However, this study indicates difference findings, where ITSG-Grace2018's model represents the lowest RMSE value and the highest correlation which closest to±1m, R with 0.2190m and 0.9994m, respectively. Figure 4 shows that the RMSE value, among the satellite only model, ITSG-Grace2018s has the lowest RMSE value, which is 0.2190m and among the combine satellites model, EGM 2008 has the lowest RMSE value which is 0.2596m. It means that ITSG-Grace2018s is the most suitable model for study area at Terengganu based on satellite-only model.

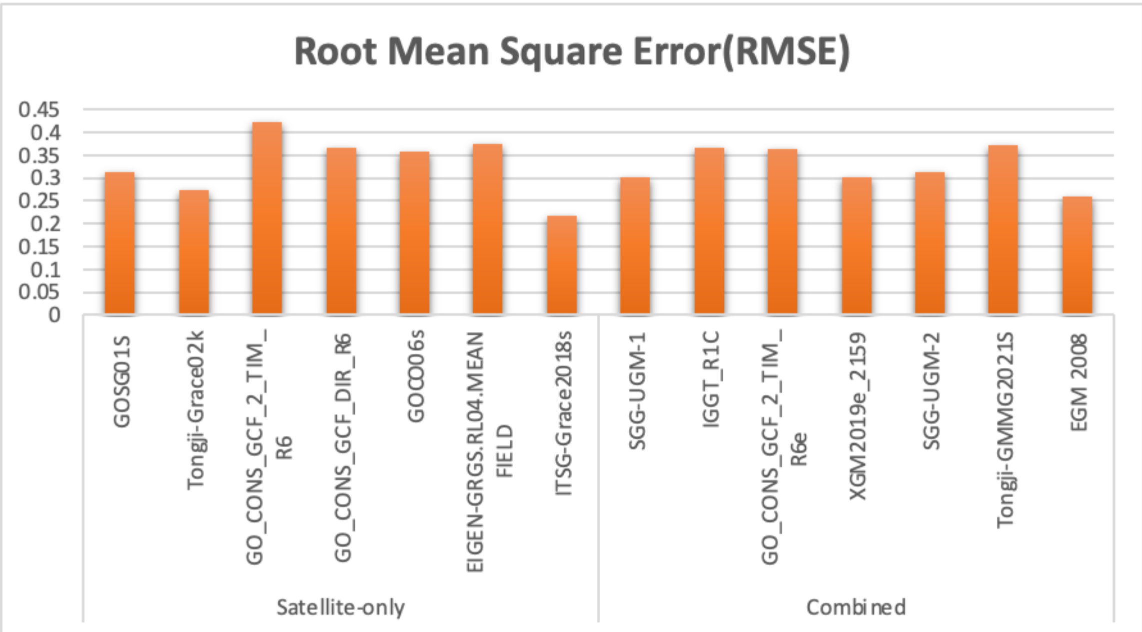

Fig. 4 RMSE value for each model

4. Conclusion

The evaluation of the Global Gravitational Model (GGM) is crucial in determining whether geopotential models are appropriate to assess the accuracy of gravity anomaly and geoid height in the study area, Terengganu. This study has five phases to accomplish the goals which are literature review, data acquisition, the selection of GGM data from 2018 until 2022, the verification of GGM with GNSS levelling and RMSE calculation. GNSS levelling data can help to find the most accurate Global Geopotential model by comparing the data provided. Through this, the most accurate GGM model provide an accurate geoid height in Terengganu. 7 models of combined model data and 7 models of satellite-only model data have been used. Among the models, ITSG-Grace2018s represent the lowest RMSE value and the highest correlation coefficient, R which is 0.2190m and 0.9994m, respectively. The satellite-only model data from ITSG-Grace2018s are therefore shown to be the best fit and appropriate with the ground truth data in Terengganu and it can be applied for the next study related to coastal study, gravity anomaly, geoid height and many more. According to the issues in the research area that might affect the beach profile and coastline, the study's findings prove Terengganu can apply ITSG-Grace2018s.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Lau Tai Wei, Nur Sharmiza;* ***data collection:*** *Aishah Humaira', Lau Tai Wei, Nur Sharmiza;* ***analysis and interpretation of results:*** *Nornajihah, Lau Tai Wei, Nur Sharmiza, Aishah Humara';* ***draft manuscript preparation:*** *Lau Tai Wei, Nur Sharmiza, Aishah Humaira', Nornajihah. All authors reviewed the results and approved the final version of the manuscript.*

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

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