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Correlation Relationship between Different GGMs Data over Egypt

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Abstract

The Ellipsoidal /Geodetic heights (*h*) and the Orthometric heights (*H*), as a vertical positioning value, are measuring by GPS (Global Positioning System) and traditional field survey techniques respectively. Most of civil engineering projects need to convert between the both heights for different territories by knowing (*N*) value (the geoid undulation/geoidal height), which can be calculated by different GGMs (Global Geo-potential Models). Since each GGM will has a different (*N*) value for the same location, so the calculated of (*N*) value will be affect directly in the accuracy of calculated heights. The main objective of this study is to measure the strength of correlation between data of eight GGMs, which were used often over Egypt recently and recommended by different previous studies as a best fit to reality over Egypt. Pearson's correlation coefficient (R) was used to evaluate the correlation relationship between EIGEN-GL04C data (as a reference) and the data of the other seven GGMs individually. The calculated seven values of (R) were used also to re-arrange different GGMs based on the degree of correlated. Due to the distinguished location, the large area (about 1000000 Km^2) and the elevations variety of Egypt territories (mountains, plains, valleys, deserts and flat areas), this are given her additional importance to most field survey studies. So, test points (346 points) were selected and distributed regularly over Egypt. The selected points are confined between two latitudes (ϕ) [22° N, 31° N] and between two longitudes (λ) [26° E, 36° E] and the distance between each two neighbored points about 50 Km. This paper concluded that; the seven calculated correlation coefficient values (R) approached to (+1), which means the correlation relationships between the reference data (EIGEN-GL04C) and each one of other GGMS data are perfectly linear under an increasing relationship. The correlation coefficient (R) values are confined between (R_{Min}) = 0.911315 of EGM96 and ($R_{Max.}$) = 0.997203 of GGM03C. According to the calculated (R) values, the seven GGMs were arranged from largest to smallest value. Finally, this paper recommends five of eight GGMs as a best GGMS data fit to reality over Egypt and consequently the using of these data will affect positively in the calculated orthometric height value (*H*).

Keywords: Ellipsoidal heights, Orthometric heights, Geoid, Undulation, GGM, Correlation Coefficient, Egypt

INTRODUCTION

3D Coordinates for any point are [Latitude (ϕ), Longitude (λ) and Height (h/H)], which were classified to horizontal [ϕ, λ] and vertical components [h/H]. The height component can be gotten based on two known references datum/surface Ellipsoidal datum and Geoid/Equipotential surface (Davis et al., 2011), which are based on a geometric model and the surface of constant gravity potential respectively. Anyway, the height component for each point has two different values [h_i/H_i] Ellipsoidal height/Geodetic height (h_i) which are measured using Global Positioning System (GPS) based on ellipsoidal datum and Orthometric height (H_i) which are measured using Total Station/ Spirit Levelling (as a traditional field survey techniques) based on geoid/equipotential surface. Although the GPS (as one of space-based technology) is used recently as a widespread in the world for many reasons, Orthometric height (H_i) is still needed for many different projects of civil engineering area.

Yilmaz et al. (2017) presented the relation between the Geodetic height (h_i) and Orthometric height (H_i), which were linked mathematically by Geoid Undulation/Geoidal Height (N_i) of any point by equation (1) and graphically in figure (1). So, the orthometric height value (H) at point (i) can be calculated by knowing the ellipsoid height value (h_i) and undulation height value (N_i) in order to combine the advantages between both techniques and converting also.

$$H_i = h_i - N_i \qquad (1)$$

Global Geo-potential Model (GGM) defines the potential of gravitational in the spectral domain by the spherical harmonic coefficient (Tugi et al., 2016). It is used to calculate the undulation height value (N_i). Many GGMs are presented by different authors to calculate the value of undulation height (N), which will be presented in the related work section.

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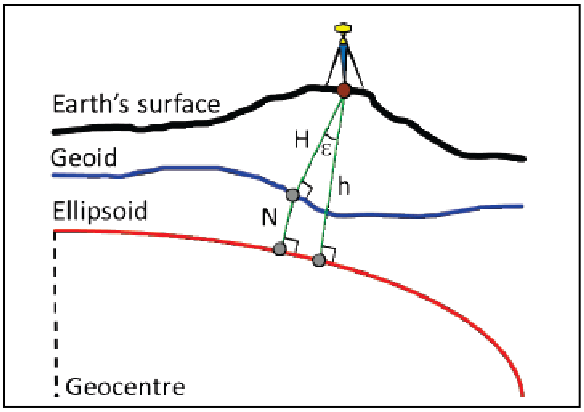

Figure (1): The mathematical relationship between (h_i), (H_i) and (N_i) (Yilmaz et al., 2017).

Egypt's area is one of the largest areas (up to 1 million Km^2) of African countries and GPS data in Egypt are referred usually to the World Geodetic System 1984 (WGS84). Also, due to the distinguished location and the elevations variety of Egypt territories (mountains, plains, valleys, deserts and flat areas), this is given her additional importance to most field survey studies. Therefore, when calculated the undulation height (N) for one point (i) in Egypt using different GGMs, it will be had different values for the same point (i). Certainly, the calculated (N_i) value from each GGMs will affect directly in the calculated orthometric height value (H_i) from Equation (1) (Tarek, 2018). In this paper, a statistical evaluation will be used to study the relationship between the results of different GGMs which were available and the most used over Egypt recently.

RELATED WORK

Four gravity satellite missions collected data over the last two decades to develop different GGMs as following (Tugi et al., 2016; Tarek, 2018; Tarek, 2019-b);

- Gravity Recovery and Climate Experiment (GRACE) which classified as satellite-only models.
- Global Ocean Circulation Experiment (GOCE) which classified as satellite-only models.
- LAser GEOdynamic Satellite (LAGEOS) which classified as a combined model.
- CHAllenging Minisatellite Payload (CHAMP) which classified as satellite-only models.

Tugi et al., (2016) explained the meaning of expressions as following;

- o The satellite-only models: the collected data consists of only artificial satellite-based gravity observation.
- o The combined model: the collected data is combined together with satellite altimetry, topography data, bathymetry data or gravimetry data from terrestrial and/or the airborne.

A lot of efforts were done before to modify the GGMs results to be a best fit to the reality for Egypt territories or even other places on the earth by different researchers such as Mahmoud (2012), quantify the GGM precision in Egypt by Al-Krargy et al. (2015), comparison of geoid undulation values of different GGMs over Egypt by Tarek (2018) and Förste et al. (2009), investigation the accuracy of different GGMs data over Egypt by Tarek (2019-b) and evaluate the performance of different GGMs by Yilmaz et al. (2016). Also, many authors, such as Dawod (1998); Dawod (2008); Abd-Elmotaal (2008); Al-Krargy et al. (2014); Moamen (2019), cared to develop a GGM for Egypt. Tarek (2019-a) tried to derive a new geoid undulation network for Egypt called "DGUNET/2019" by merging different GGMs data.

The selected GGMs for each study of huge numbers (about 160 different GGMs in world) were depending on the authors' standards such as the accurate, availability, the format of dataset, variation in the spherical harmonic coefficient, the most common used in study area recently and the variation in the issue year (Tarek, 2019-b). By applied these standards for these studies and with choosing Egypt as a study area, the huge GGMs numbers in world will less to about 29 different GGMs. Only fourteen GGMs were recommended to use in Egypt by different authors mutually, on the other hand many authors agreed together for choose eight of the recommended fourteen GGMs as a most common used in Egypt recently as following Model(Degree)[Year]; EGM96(360)[1996], EIGEN-CG01C(360)[2004], GGM03C(360)[2009], EIGEN-CG03C(360)[2005], EIGEN-GL04C(360)[2006], EIGEN-05C(360)[2008], EGM2008(360)[2008] and EGM2008 (2190)[2008]. Although many trials were done to get fully trusted results of different GGMs over Egypt by many authors, this target is not gotten until now, therefore more evaluation/investigation is still needed to enhance different GGMs.

Correlation Coefficient (R) is one of the statistics tests to find the relationship between two variables. The rank of the R-value is using usually to find the strength degree, direction and describing to which one variable is linearly related to another (Bolboaca and Jäntschi, 2006; Walpole et al., 2012). Three known and famous ways to calculate the correlation coefficient are Pearson's correlation, Kendall's tau correlation and Spearman's correlation. Each way is used for some kind of variables and usually the expression of Correlation Coefficient (R) only is referring to Pearson's correlation. (R) values should be ranging between (+1 and -1). While the strongest correlation value (+1) value will appear if the correlation relationship between the two variables is perfectly linear under an increasing relationship and (-1) value will appear if the correlation relationship between the two variables is perfectly linear under a decreasing relationship, but (Zero) value will appear if both variables haven't any linear relationship between each other. The main objective of this paper is to measure the strength of correlation between data of eight

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GGMs, which were used often over Egypt recently, by statistical evaluation. Pearson's correlation coefficient (R) will be used to evaluate the correlation relationship between data of one GGM, as reference data, and the data of the other seven GGMs individually. Also, the calculated seven values of (R) will be used to rearrange the degree of correlated of GGMs between each other.

STUDY AREA AND DATA OVER EGYPT

Test points (346 points) were selected and distributed regularly over Egypt as shown in figure (2). These 346 points are confined between two latitudes (ϕ) [22° N, 31° N] and between two longitudes (λ) [26° E, 36° E]. In order to cover whole Egypt territories, the intervals between every two lines in both directions (ϕ and λ) is 0.5° and distance between each two neighbored points about 50 Km.

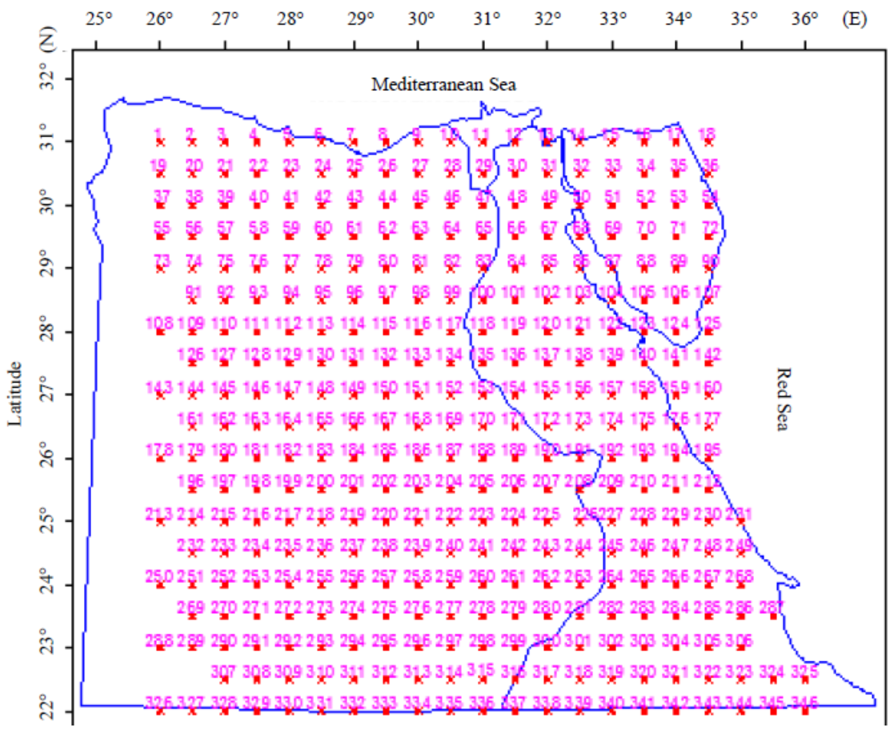

Figure (2): Test points (346 points) were distributed regularly over Egypt (Tarek, 2018).

The eight recommended GGMs by many authors as a most common used in Egypt recently are selected as following Model[Data Type]; (EGM96[S, G, A], EIGEN-CG01C[S(CHAMP, GRACE),G, A], GGM03C[S(GRACE), G, A], EIGEN-CG03C[S(CHAMP, GRACE), G, A], EIGEN-GL04C[S(GRACE, LAGEOS), G, A], EIGEN-05C[S(GRACE, LAGEOS), G, A], EGM2008(360)[S(GRACE), G, A] and EGM2008(2190)[S(GRACE), G, A] for this study. Where; S is Satellite Tracking Data, G is Terrestrial Gravity Data, A is Altimetry Data. A geoid undulation value (N_i) for each point (i) of 346 points was calculated by each one of the eight GGMs. Generally, the main mathematical concept of the GGMs methodology is depending equation (2) (Mahmoud, 2012; Tarek, 2018; Tarek, 2019-a; Tarek, 2019-b).

$$N = \left({}^{GM}/_{r\gamma}\right) \sum_{n=2}^{n=max} \left({}^{a}/_{r}\right)^{n} - \sum_{m=0}^{n} [(\bar{C}_{nm} \cos m\lambda) + (\bar{S}_{nm} \sin m\lambda)] \bar{P}_{nm} \sin \phi \qquad (2)$$

Where;

- G is the Newtonian gravitational Constant,
- M is the mass of the earth,
- $\bar{C}_{nm}$, $\bar{S}_{nm}$ are the fully normalized geo-potential coefficients of degree and order n, m,
- $\bar{P}_{nm}$ is the fully normalized associated Legendre function of degree and order n, m,
- a is the semi-major axis,
- n is the degree of the geo-potential model,
- γ is the normal gravity on the reference ellipsoid,
- r is the radial distance from Earth's mass center,
- ϕ, λ are the geocentric latitude and longitude.

In order to avoid the prolongation in this study, the calculated (N_i) results are shown in table (2) for only 17 points of full results on just one Latitude (ϕ = 25.5° N) and the Point ID as original data are shown in figure (2) over Egypt map, but all the results from different eight GGMs are available by the author. where, table (2) is presenting just sample (17 points), but the

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conclusion of this test work will be including, using and analyzing all 346 regularly points in both directions latitude (ϕ) and longitude (λ) as explained before.

Table (2): (*N_i*) results were calculated by eight GGMs for 17 points as an example of 346 points.

			Calculated (N_i) (m)							
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Point (ID)	**Lat. (Deg.)**	**Long. (Deg.)**	**EGM96**	**EIGEN-CG01C**	**GGM03C**	**EIGEN-CG03C**	**EIGEN-GL04C**	**EIGEN-5C**	**EGM2008 (360)**	**EGM2008 (2190)**
196	25.5	26.5	13.559	13.994	14.405	14.557	14.641	14.378	14.776	14.344
197	25.5	27	13.135	13.472	13.846	13.942	13.781	13.885	13.857	13.588
198	25.5	27.5	12.836	12.845	13.339	13.26	12.983	13.287	13.198	12.985
199	25.5	28	12.982	12.565	13.199	13.02	12.862	13.123	13.271	13.134
200	25.5	28.5	13.226	12.544	13.324	13.111	13.172	13.305	13.393	13.136
201	25.5	29	13.219	12.516	13.278	13.184	13.374	13.329	13.219	12.842
202	25.5	29.5	13.494	12.983	13.587	13.656	13.783	13.736	13.457	12.97
203	25.5	30	13.67	13.371	13.752	13.94	13.909	13.878	13.687	13.602
204	25.5	30.5	13.202	13.012	13.283	13.442	13.314	13.226	13.267	12.803
205	25.5	31	13.149	12.862	13.246	13.23	13.147	13.028	13.744	13.343
206	25.5	31.5	13.482	12.939	13.334	13.39	13.422	13.33	14.545	14.171
207	25.5	32	13.49	12.625	13.214	13.27	13.317	13.344	14.371	14.279
208	25.5	32.5	13.051	11.926	12.722	12.766	12.73	12.734	12.841	12.093
209	25.5	33	12.975	11.799	12.611	12.727	12.579	12.51	11.881	11.854
210	25.5	33.5	13.657	12.428	13.287	13.307	13.187	13.15	12.95	12.526
211	25.5	34	14.024	12.705	13.514	13.461	13.543	13.687	13.87	13.445
212	25.5	34.5	13.184	11.82	12.531	12.49	12.797	12.888	12.96	13.127

METHODOLOGY AND RESULTS

Tarek (2019-b) re-sorted the eight GGMs based on the coefficient of variation ratio from smallest to largest respectively as following; EIGEN-GL04C, GGM03C, EGM2008(360), EIGEN-5C, EGM96, EIGEN-CG03C, EGM2008(2190) and EIGEN-CG01C. Since EIGEN-GL04C had the smallest coefficient of variation ratio, its accuracy was being higher than the other GGMs. Also when Tarek (2019-a) calculated DGUNET/2019 values (Deriving a Geoid Undulation Network over Egypt by Tarek/2019) as a best fit to reality over Egypt based on merging only the accepted GGMs data by a series of sequential trials, the author suggested five of eight GGMs as following; EIGEN-GL04C, GGM03C, EGM2008(360), EIGEN-5C, and EIGEN-CG03C. Therefore, in this paper the calculated (N_i) values by EIGEN-GL04C will be used as a reference GGM data. In this study, the methodology has been carried based on finding Pearson's correlation coefficient (R) as follows;

a) 346 points have been regularly distributed over Egypt with an interval half a degree in both directions latitudes and longitudes.

b) Each GGM of eight selected GGMs ($k = 1 \rightarrow 8$) were used individually to calculate (N_i) of the 346 points ($i = 1 \rightarrow 346$ and $n = 346$).

c) The calculated (N_i) values by EIGEN-GL04C were used as a reference GGM data $(N_i)_X$.

d) Choose the data of one GGM $(N_i)_k$ to compare with the reference data $(N_i)_X$.

e) The mean value $\overline{N}_k$ and $\overline{N}_X$ for each GGM were calculated $\overline{N} = \frac{\sum (N_i)}{n}$

f) Calculate the parameter $S_{XK} = \sum [(\mathrm{N_i})_X \cdot (\mathrm{N_i})_K] - [n * (\overline{N}_X) * (\overline{N}_k)]$.

g) Calculate the parameter $S_{XX} = \sum [(\mathrm{N_i^2})_X] - [n * (\overline{N}_X)^2]$.

h) Calculate the parameter $S_{KK} = \sum [(\mathrm{N_i^2})_K] - [n * (\overline{N}_K)^2]$.

i) Calculate the correlation coefficient $R_k = \frac{S_{XK}}{\sqrt{S_{XX} * S_{KK}}}$

j) All the previous steps were repeated for each of the other six GGMs individually to compare with the reference data $(N_i)_X$.

k) Table (3) shows the results of different parameters were calculated by each GGMs (*K*) using 346 points.

l) Figure (3) shows the calculated correlation coefficient (R) values by comparing the seven GGMs (*K*) with the reference GGM (EIGEN-GL04C) using 346 points and also re-arrange (R) Values from largest to smallest.

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Table (3): The results of different parameters were calculated by each GGMs (K) using 346 points.

	The results of different parameters for each GGMs (*K*)							
	REF. (*X*)	**1**	**2**	**3**	**4**	**5**	**6**	**7**
parameters	**EIGEN-GL04C**	**EGM96**	**EIGEN-CG01C**	**GGM03C**	**EIGEN-CG03C**	**EIGEN-5C**	**EGM2008 (360)**	**EGM2008 (2190)**
$\sum(N_i)$	4970.409	4869.601	4791.161	4973.540	4970.175	4974.151	4971.712	4856.312
$\overline{N}$	14.36534	14.07399	13.84729	14.37439	14.36467	14.37616	14.36911	14.03558
S_{XX}	2016.30510							
S_{KK}	2016.30510	1967.46990	2244.00942	2023.94953	2055.47345	2037.56913	2026.50743	1991.92323
S_{XK}	2016.30510	1815.09999	2117.93561	2014.47255	2028.36685	2019.00013	2001.41434	1981.48078
R	**1**	**0.911315**	**0.995686**	**0.997203**	**0.996351**	**0.996098**	**0.990113**	**0.988725**
Re-arrange (R) Values (Largest to Smallest)	--------	**7**	**4**	**1**	**2**	**3**	**5**	**6**

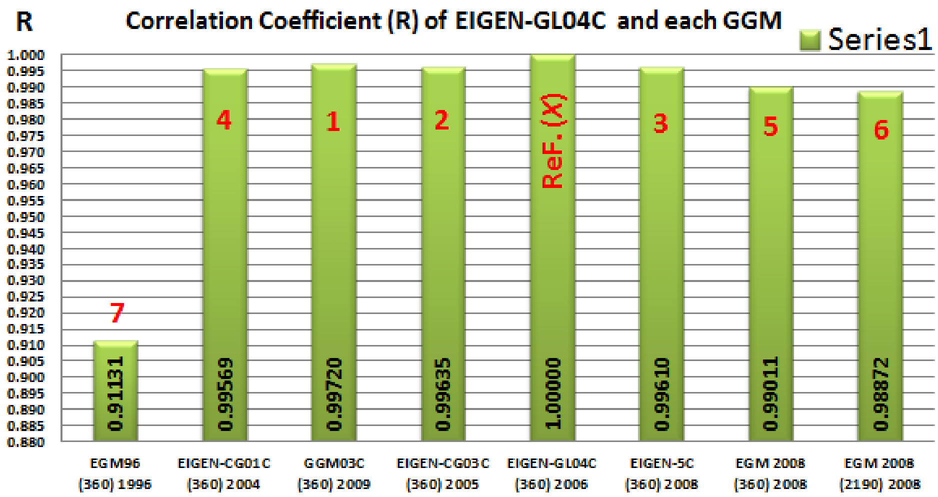

Figure (3): The calculated correlation coefficient values (R) by comparing each GGMs with the reference GGM (EIGEN-GL04C) using 346 points.

According to table (3) and figure (3), all calculated correlation coefficient values (R) were approaching to (+1), which means the correlation relationship between each two variables is perfectly linear under an increasing relationship. The correlation coefficient (R) values are confined between (R_{Min}) = 0.911315 of EGM96 and ($R_{Max.}$) = 0.997203 of GGM03C. finally Correlation coefficient (R) values which calculated by comparing the reference GGM (EIGEN-GL04C) with the other seven GGMs (*K*) using 346 points were rearranged (R) from largest to smallest value respectively as following; GGM03C, EIGEN-CG03C, EIGEN-5C, EIGEN-CG01C, EGM2008 (360), EGM2008 (2190) and EGM96. Therefore, it is recommending to use the data were calculated by EIGEN-GL04C, GGM03C, EIGEN-CG03C, EIGEN-5C and EIGEN-CG01C as a best GGMS data fit to reality over Egypt and so the using of these data will affect positively in the calculated orthometric height value (H_i).

CONCLUSIONS

The main objective of this study is to measure the strength of correlation between data of eight GGMs, which were used often over Egypt recently and recommended by different previous studies as the best fit to reality over Egypt. Pearson's correlation coefficient (R) was used to evaluate the correlation relationship between EIGEN-GL04C data (as a reference) and the data of the other seven GGMs individually. The calculated seven values of (R) were used also to re-arrange different GGMs based on the degree of correlated as shown in table (3) and figure (3). Test points (346 points) were selected and distributed regularly over Egypt and the distance between each two neighbored points about 50 Km.

this paper concluded that; the seven calculated correlation coefficient values (R) approached to (+1), which means the correlation relationships between the reference data (EIGEN-GL04C) and each one of other GGMS data are perfectly linear under an increasing relationship. The correlation coefficient (R) values are confined between (R_{Min}) = 0.911315 of EGM96 and ($R_{Max.}$) = 0.997203 of GGM03C. According to re-arrange the calculated (R) values from largest to smallest value, the seven GGMs were

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arranged respectively; GGM03C, EIGEN-CG03C, EIGEN-5C, EIGEN-CG01C, EGM2008 (360), EGM2008 (2190) and EGM96.

Finally, this paper recommends using the data were calculated by each of EIGEN-GL04C, GGM03C, EIGEN-CG03C, EIGEN-5C and EIGEN-CG01C as a best GGMS data fit to reality over Egypt and so the using of these data will affect positively in the calculated orthometric height value (H_i).

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