A Comparison of Orthometric Heights Calculated from (GPS/Leveling) and (EGM08) Methods Based –GIS

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Abstract. Interest in the study of global gravitational models has increased recently all over the world because it is necessary for height datum transformations. Today the International Center for Global Earth Models (ICGEM) provides the largest collection in the world produced through gravitational data from the gravitational satellite’s missions CHAMP, GRACE, and GOCE ... Etc. To allow easy access through the internet with its more intelligent technologies, it is one of the International Gravity Organization's services. While the Global Positioning System (GPS) has become one of the most preferred technologies in engineering surveying, a major dilemma in GPS survey lies in oval-based elevations. At the same time, orthometric heights are commonly used in the engineering field. Therefore, it is necessary to convert the measured heights by satellites assigned to the elliptical surface into orthometric heights and supported to the geoid surface (mean sea level) through an accurate geodetic model. The differences between orthometric measurement heights from DGPS/leveling data (obtained from 57 points in the study area) are increasingly used by professionals geographical information systems(GIS). However, the local determination of Geoid is necessary for better accuracy of the orthometric height from DGPS. This paper aims to introduce a modern technique for determining elevation, avoiding cumbersome and time-consuming spirit leveling operations. Fast vertical positioning can be obtained using DGPS with geoid models. The Root Mean Square Error (RMSE) is ± 0.19 m with high precision of DGPS derived with EGM08; thus, the more it describes the Earth's gravitational field in more detail.

Keywords: GIS, leveling, orthometric height, EGM08, Heights, Root Mean Square Error.

1. Introduction

The determination of the Earth's surface and its external gravitational field, and the normal Earth ellipsoid is the biggest issue currently confronting geodesists worldwide. The Earth's surface is uneven and, as a result, impossible to be described by a mathematical surface. Instead, Geoid, the gravitational field's equipotential surface will strongly approximate the mean sea level (M.S.L.). The Geoid is important for every country to achieve accurate vertical positioning. All geodetic measurements are directly related to gravity's real field when taken on Earth's physical surface. This anomaly area is the fundamental parameter for the transition of geodetic measurements from the physical space of observation (Geoid) to the computation's geometric space, ellipsoid [1].

To convert ellipsoid height into a more useful orthometric height, we need to know the relation between Geoid which representing the actual equipotential figure of the Earth's surface. The
ellipsoidal height represents Earth's mathematical figure. The Geoid is one of the most important parts of a geodetic infrastructure. It is well known that globally, mean sea level best fits in the least square sense, Geoid, representing the equipotential surface of the Earth's gravity field and used as a reference for physical height system like orthometric heights. This means that by combining ellipsoidal heights from GPS and geoid heights, the orthometric height can be determined [2].

2. Study Area
The chosen study area is the campus of the University of Baghdad in the heart of the capital, Baghdad, located between Latitude (33º 16' 55.6") to (33º 16' 4.5") N, Longitude (44º 22' 11.8") to (44º 23' 20.4") E., which covers an area of (2.9km$^2$). It is shown in figure (1).

![Figure 1. The study area of the campus of the University of Baghdad.](image)

3. The Theoretical Background

3.1. The Orthometric and Ellipsoid Heights
The (H) refers to an isotope reference surface. The orthometric height of a distance from the point on the surface of the Earth to the distance that points to the Geoid (the equipotential surface that coincides with the mean sea level) is measured along the normal vertical line to the Geoid, which is measured by using the level [3]. The ellipsoidal height measured using DGPS represents the height from the surface of any reference ellipsoid to the point on the ground. The separation between the ellipsoid and the Geoid surface is called Geoid height or Geoid Undulation (N), as shown in figure (2). The determination of the Geoid Undulation at each point can be calculated using a well-known formula[4]:

$$N = h - H$$  \hspace{1cm} (1)

h is ellipsoidal height, H is orthometric height, and N is geoid undulation.
3.2. Leveling

Leveling is the general term applied to any of the various processes by which height is determined. It is a vital process in producing the data needed for mapping, engineering design, and construction. Leveling results are used for designing highways, railways, canals, sewage, water supply systems, and other facilities with a grade line that best aligns with the current terrain [6]. The type of level device used in this paper is Topcon (ABN 26).

3.3. Differential Global Positioning System (DGPS)

The GPS heavenly body was initially planned as 24 satellites put in three orbital planes. Each slanted at 63 degrees as the equator chose height was (~20 ~200 km, offering to ascend to an orbital time of 12 sidereal hours. This is 50% of the Earth's turn time frame, offering to ascend to rehashing ground tracks' operational advantage. These satellites were disseminated consistently in the orbital planes, with each plane having eight satellites [7].

3.4. Earth Gravitational Model of 2008 (EGM2008)

The EGM2008 is a gravitational model of the Earth created by a least-squares mix of the ITG-GRACE03S gravitational model (with its related blunder covariance lattice) and a 5'x5' matrix of free-air gravity irregularities. EGM2008 is created to degree/request 2159 with some extra terms up to degree/request 2190 [8].

EGM2008 depends on the GRACE (Gravity Recovery and Climate Experiment) just gravity field model ITG-GRACE03S which gives a profoundly exact depiction of the long-and medium-frequency gravity field range up to degree and the order 180. The ITG-GRACE03S model joins right around six years of GRACE gravity field perceptions and different wellsprings of gravity information, especially point gravity estimations. Consequently, the EGM2008 circular consonant coefficients should be extended to degree 2190 instead of 2159 or 2160 when utilized in pragmatic applications [9].

3.5. Data Sets

The orthometric heights for the 57 points were obtained from the leveling for these heights in the middle of Iraq (FAW). The datum was called MSL FAW, and this data is shown in Table 2. The differential global position system (DGPS) type Topcon Hiper-II GNSS has used a static method to observed 57 points, each point is observed 3 hours. The data points were then submitted to the AUSPOS online GPS Processing Service (HTTP: www.ga.gov.au). To calculate Geoid undulation using EGM2008, a zip file can be downloaded that contains an ESRI GRID raster data set of 2.5-minute. The American Surveying Authority worked on making Raster networks that cover all parts of the world. Each network is about 45×45 of Latitude and longitude that gives the values of N within the ready-made Raster network, and that can be called to the ARC GIS program. The network files cover lines from the length is 2 to 90, and the width from 5 to 60 covers approximately the eastern Arab world, including the Iraqi lands. The Raster can be downloaded from the link below: https://earth-info.nga.mil/GandG/wgs84/gravitymod/egm2008/egm08_gis.html.
As shown in table (3) and Fig. (3), by cutting the province of Baghdad and noting that the value of T
the Geoid Heights N varies from the highest [0.690 m] to the lowest [-2.910 m].

Figure 3. The Geoid Heights EGM08 raster within the capital Baghdad.

3.6. Calculate the root mean square error (RMSE)
Modeling heights of the calendar using a geometric method of calculating model accuracy with a
root mean square error indicator (RMSE) to calculate model accuracy requires orthometric point
heights from the model (\(H_{\text{GGMs}}\)), i.e., orthometric heights of points obtained from the differences
between typical geodetic heights and elliptical point heights with the corresponding altitudes in
addition to the orthometric heights (\(H_{\text{obs}}\)) to obtain (orthometric residuals remains). The orthometric
residuals and the total number of points specified for the RMSE are used along with the model
accuracy. The RMSE index is provided in the formula to calculate model accuracy [8].

\[
\text{RMSE} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (\delta H_{\text{Residual}})^2}
\]

\[
\delta H_{\text{Residual}} = H_{\text{obs}} - H_{\text{GGMs}}
\]

\(H_{\text{obs}}\): Known Orthometric Height
\(H_{\text{GGMs}}\): Model Orthometric Height
\(n\): the number of points.

GGMs are the smallest RMSE values. Since then, the better it represents the Earth’s gravitational field
in more detail, and vice versa. The greater the value of it, the greater the representation of gravity with
less detail.

4. Results and Discussion
Accuracy assessment of GPS observations processed by (EGM2008 RASTER)
The level is the most accurate way to calculate orthometric heights for scanning points above the
giode. But this method has become obsolete no longer to keep pace with the rapid development in the
modern world. So, it is no longer feasible for several reasons, including it takes a long time and great
effort and high cost, thus, an easier, faster, and less expensive is required.

Unfortunately, GPS delivered only height relative to the Earth’s mathematical ellipse, known as
ellipsoidal height, rather than the orthometric height related to the MSL with its physical meaning,
thus, parallel to the development of GPS and methodology.

To convert the Ellipsoid heights obtained from DGPS for the observed points into orthometric heights
calculated by applying equation (1) converting the heights inside the program is required.
Table 1. The Comparison of leveling data with GPS processed data.

| METHOD                        | Maximum (m) | Minimum (m) | Mean (m) | Standard deviation (m) |
|-------------------------------|-------------|-------------|----------|------------------------|
| Leveling measurement height H(m) | 38.264      | 35.930      | 36.653   | 0.586                  |
| GPS processed data            | 38.128      | 35.762      | 36.541   | 0.625                  |
| Difference                    | 0.399       | -0.401      | 0.111    | 0.152                  |

The difference in leveling data with GPS processed data (HEGM08) is clearly shown that the accuracy of the results of GPS data is within the Standard deviation ±0.152m as illustrated in the table (1). The RMSE The EGM2008 model equal to [± 0.187973m] as shown in figure (4), applied the equal (3). The height data performed herein offers useful insight for a range of applications relating to height. The production and updating of large-scale topographical maps in various engineering and construction applications, particularly for water resource management. The topographic map of the Study Area is shown in figure (5).

Table 2. Ellipsoidal and Orthometric heights(2020).

Figure 4. The Accuracy of DGPS data after processing.

Figure 5. Representing the topographic map of the Study Area.
| Point No. | Northing(m) | Easting(m) | Ellipsoidal height h (m) | Orthometric height Hobs (M.S.L) (m) |
|-----------|-------------|------------|--------------------------|-----------------------------------|
| BU01      | 3681622.477 | 442158.483 | 34.5552                  | 36.271                            |
| BU02      | 3681641.119 | 441821.245 | 35.1578                  | 36.906                            |
| BU03      | 3681646.752 | 442271.423 | 34.5022                  | 36.369                            |
| BU04      | 3681717.383 | 441480.99  | 36.3873                  | 38.242                            |
| BU05      | 3681756.014 | 441869.274 | 35.7915                  | 37.345                            |
| BU06      | 3681848.047 | 442032.804 | 34.1972                  | 35.934                            |
| BU07      | 3681828.833 | 442052.868 | 35.4727                  | 37.025                            |
| BU08      | 3681905.955 | 441876.638 | 35.2064                  | 37.173                            |
| BU09      | 3681912.62  | 441946.785 | 34.2758                  | 36.153                            |
| BU10      | 3681911.887 | 442069.661 | 35.3165                  | 36.867                            |
| BU11      | 3681949.221 | 442265.198 | 35.1257                  | 37.07                             |
| BU12      | 3682018.665 | 442240.00  | 35.3347                  | 36.95                             |
| BU13      | 3681583.049 | 442107.802 | 34.548                   | 36.319                            |
| BU14      | 3681594.571 | 441776.986 | 34.4333                  | 36.075                            |
| BU15      | 3681625.908 | 441584.439 | 36.2443                  | 37.621                            |
| BU16      | 3681625.188 | 441755.697 | 35.5055                  | 37.17                             |
| BU17      | 3681645.93  | 441789.195 | 35.3775                  | 36.937                            |
| BU18      | 3681655.103 | 441697.41  | 36.2296                  | 37.427                            |
| BU19      | 3681659.146 | 441896.635 | 34.5345                  | 36.278                            |
| BU20      | 3681668.477 | 441829.946 | 35.5159                  | 37.191                            |
| BU21      | 3681695.023 | 442026.201 | 34.4483                  | 36.251                            |
| BU22      | 3681695.209 | 442201.861 | 34.5521                  | 36.261                            |
| BU23      | 3681712.222 | 442293.025 | 34.1764                  | 35.93                             |
| BU24      | 3681734.101 | 442394.825 | 34.4988                  | 36.361                            |
| BU25      | 3681742.759 | 441923.005 | 35.5912                  | 37.19                             |
| BU26      | 3681764.947 | 441920.809 | 34.4304                  | 36.085                            |
| BU27      | 3681763.181 | 442217.27  | 35.3766                  | 37.033                            |
| BU28      | 3681774.058 | 441942.077 | 34.1916                  | 36.051                            |
| BU29      | 3681790.089 | 441784.883 | 35.2071                  | 37.18                             |
| BU30      | 3681794.279 | 442322.228 | 35.0626                  | 36.55                             |
Table 3. Geoid heights at points using (h-H) method and undulation height by EGM08 raster (2020).

| Point Nu. | Northing(m) | Easting(m) | Nr(EGM08)(m) | Hr(EGM08)(m) |
|-----------|-------------|------------|--------------|---------------|
| BU01      | 3681622.477 | 442158.483 | -1.6129      | 36.1681       |
| BU02      | 3681641.119 | 441821.245 | -1.6025      | 36.7603       |
|   |   |   |   |   |
|---|---|---|---|---|
| BU03 | 3681646.752 | 442271.423 | -1.6158 | 36.118 |
| BU04 | 3681717.383 | 441480.99 | -1.5907 | 37.978 |
| BU05 | 3681756.014 | 441869.274 | -1.6015 | 37.393 |
| BU06 | 3681848.047 | 442032.804 | -1.6067 | 35.8039 |
| BU07 | 3681828.833 | 442052.868 | -1.6055 | 37.0782 |
| BU08 | 3681905.955 | 441876.638 | -1.5987 | 36.8051 |
| BU09 | 3681912.62 | 441946.785 | -1.6006 | 35.8764 |
| BU10 | 3681911.887 | 442069.661 | -1.6043 | 36.9208 |
| BU11 | 3681949.221 | 442265.198 | -1.6093 | 36.735 |
| BU12 | 3682018.665 | 442240.00 | -1.6072 | 36.9419 |
| BU13 | 3681583.049 | 442107.802 | -1.6122 | 36.1602 |
| BU14 | 3681594.571 | 441776.986 | -1.6021 | 36.0354 |
| BU15 | 3681625.908 | 441584.439 | -1.5957 | 37.8400 |
| BU16 | 3681625.188 | 441755.697 | -1.6008 | 37.1063 |
| BU17 | 3681645.93 | 441789.195 | -1.6014 | 36.9789 |
| BU18 | 3681655.103 | 441697.41 | -1.5985 | 37.8281 |
| BU19 | 3681659.146 | 441896.635 | -1.6043 | 36.1388 |
| BU20 | 3681668.477 | 441829.946 | -1.6022 | 37.1181 |
| BU21 | 3681695.023 | 442026.201 | -1.6075 | 36.0558 |
| BU22 | 3681695.209 | 442201.861 | -1.6127 | 36.1648 |
| BU23 | 3681712.222 | 442293.025 | -1.615 | 35.7914 |
| BU24 | 3681734.101 | 442394.825 | -1.6176 | 36.1164 |
| BU25 | 3681742.759 | 441923.005 | -1.6034 | 37.1946 |
| BU26 | 3681764.947 | 441920.809 | -1.6029 | 36.0333 |
| BU27 | 3681763.181 | 442217.27 | -1.6117 | 36.9883 |
| BU28 | 3681774.058 | 441942.077 | -1.6033 | 35.7949 |
| BU29 | 3681790.089 | 441784.883 | -1.5983 | 36.8054 |
| BU30 | 3681794.279 | 442322.228 | -1.6142 | 36.6768 |
|   | BU31 | BU32 | BU33 | BU34 | BU35 | BU36 | BU37 | BU38 | BU39 | BU40 | BU41 | BU42 | BU43 | BU44 | BU45 | BU46 | BU47 | BU48 | BU49 | BU50 | BU51 | BU52 | BU53 | BU54 | BU55 | BU56 | BU57 |
|---|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| BU31 | 3681816.006 | 441828.500 | -1.5991 | 36.9286 |
| BU32 | 3681815.803 | 442068.830 | -1.6063 | 36.0285 |
| BU33 | 3681829.915 | 442181.706 | -1.6093 | 37.0610 |
| BU34 | 3681848.047 | 442032.804 | -1.6045 | 36.6358 |
| BU35 | 3681856.927 | 441783.731 | -1.5969 | 36.8991 |
| BU36 | 3681897.294 | 442192.973 | -1.6083 | 36.9576 |
| BU37 | 3681907.554 | 441815.337 | -1.5968 | 36.8975 |
| BU38 | 3681904.639 | 442304.514 | -1.6114 | 36.2736 |
| BU39 | 3681953.127 | 441508.537 | -1.5867 | 38.1284 |
| BU40 | 3681950.55 | 441990.214 | -1.6012 | 36.7407 |
| BU41 | 3681961.748 | 442386.084 | -1.6126 | 36.1429 |
| BU42 | 3681967.438 | 442361.283 | -1.6118 | 36.2206 |
| BU43 | 3681978.494 | 442107.310 | -1.6041 | 36.8795 |
| BU44 | 3681999.104 | 441545.031 | -1.5869 | 37.6213 |
| BU45 | 3682045.226 | 441711.390 | -1.5909 | 35.7953 |
| BU46 | 3682043.878 | 442091.660 | -1.6023 | 36.6071 |
| BU47 | 3682065.388 | 442359.017 | -1.6097 | 35.8174 |
| BU48 | 3682114.854 | 442016.286 | -1.5986 | 35.8943 |
| BU49 | 3682127.942 | 442249.186 | -1.6052 | 36.1382 |
| BU50 | 3682195.436 | 442397.040 | -1.6081 | 36.1525 |
| BU51 | 3682228.475 | 442434.745 | -1.6086 | 35.8645 |
| BU52 | 3682315.141 | 442517.779 | -1.6092 | 35.9953 |
| BU53 | 3682331.657 | 442485.023 | -1.6079 | 35.8087 |
| BU54 | 3682344.097 | 442464.661 | -1.607 | 35.9833 |
| BU55 | 3682393.138 | 442556.525 | -1.6087 | 36.0747 |
| BU56 | 3682402.161 | 442697.561 | -1.6124 | 36.1722 |
| BU57 | 3682442.613 | 442679.433 | -1.611 | 35.7626 |
5. Conclusions

By comparing the data of the orthometric heights (H) values, (H) practically measured by the level with the data obtained from the after processing by the EGM2008 model, which is obtained by Raster. This study indicates small and very close differences as the accuracy reached the standard deviation (SD) equal to $[\pm 0.152 \text{ m}]$. This means that the level still one of the most accurate devices in this field and in various projects.

The RMSE is used to describe the long wavelength of Earth's gravitational field. The EGM2008 model produces the smallest differences in terms of the Root Mean Square Error (RMSE), which is equal to $[\pm 0.187973 \text{ m}]$, and the method of the calculation by Raster is within the arc GIS program.

The orthometric Heights from DGPS Data can thus be considered a modern tool for converting the height.

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