Towards a Unified Vertical Datum in Arab Region

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Abstract

In Arab region, there are several Local Vertical Datums (LVD). Most of these datums are based on averaging sea level measurements of a single Tide Gauge (TG) or from multiple TGs.

One of the main reasons which negatively affecting the huge regional projects between Arab countries as transportation lines, Petroleum Pipelines, electricity, and other projects which require heights, is the difference in SST at tide gauge sites and differences in measuring techniques. Therefore the Precise geoid determination is considered an important step in eliminating these differences as it represents the base for determination the regional geoid model. This study focuses on presenting two proposals for unification the vertical datum in Arab region and the proposed implementation strategy. Review of available data from previous studies. Provide the best techniques to update, tie, and unify the data in all Arab countries, commensurate with the modern technological development.

Introduction

In Arab countries, the strategy of utilizing mean sea level as the reference for heights have been widely accepted up to now. As known, that the mean observations of the local sea level at the tide gauge locations cannot be exactly considered to be the geoid. That means, the mean sea level at one site has not the same geopotential surface as that at another site and using the mean sea level as a height reference shall cause some problems in the applications of the vertical datum. One problem is according to use of several restrictions on mean sea levels in a single vertical datum, because of the difference between the mean sea level and the geoid which reaches to ± 2m [1].

In order to overcome these problems, it was necessary to think about a unified vertical datum for all Arab countries, thus ensuring the completion of large investment projects between Arab countries.

This study, which is considered as an initiative to establish a unified Arab vertical control which guarantees that each user can determine his exact height at the same time with high accuracy.

The benefits of replacing the official leveling-based vertical datum by unified geoid and GNSS convenient with vertical datum will be:-

- All Arab countries together with desert, remote and extremist areas will have vertical control network.
- Consistency with space-based positioning (e.g., GNSS, altimetry) are going to be guaranteed;
- The maintenance of datum is going to be less expensive. .
- The vertical datum is going to be fairly stable due to the actual fact that the geoid surface changes at a rate of 1 mm annually compared to 1 cm annually for the physical benchmarks related to the regional geodynamics [23].

1. Unification and Tying the Data in all Arab Countries.

1.1. Distribution of tide Gauge Stations in Arab Countries.

In Arab countries there are at least twenty-two tide gauge stations were fixed to mean sea level. These stations are considered the origin of the vertical datum where they are scattered and distributed in the Arab world as a whole, where at least one tide gauge station in each country. Figure (1) shows the location of each one.

Figure (1): The country with defined datum origin. The tide gauge stations.

The old kinds of tide gauges are still working until now as pressure gauge, floating gauge, acoustic gauge. These kinds of tide gauge meters need a lot of continues maintenance to guarantee the specified accuracy. So an Arabian tide gauge stations network should be formed, it'll be a continuous observation network and it'll introduce a continuous enhancements for all stations. This study proposes using the radar tide gauge device to measure water depth by radar waves. For coastal tide stations, the advantage of those ultra-frequency radars is that they have a fixed speed (the speed of light) giving height measurements over short distances that are not affected by environmental conditions. Radar gauge allows contact-free measurements without bio-fouling as the old kind of tide gauge devices. These gauges meet all the accuracy requirements. Nowadays, radar level sensors are widespread in hydrometry and are becoming the standard for tide stations all over the world because of the increased require for accurate measurements. Figure (2) shows example of shape of radar tide gauge station. The radar sensor calculates the distance by converting it into a digital signal reduced by the data recorder to a water depth referenced to the port datum.

Figure (2): shows the proposed radar gauge station [12].

The tide gauge is permanently connected to the port tide station by levelling, its reference point in relation to the tide bench mark close to the station. Some of the radar sensors have a "reference" for levelling (antenna phase center, zero point (ZP) or provide calibrated offsets for their ZP. This permits a direct connection of the radar readings to the Tide Gauge Zero point (TGZ) [12].

This study recommends using radar gauge because it became obtainable and more reliable and more precise than pressure and acoustic sensors. a common source of error appears when measuring sea levels is associated to tide gauges consistently measuring sea levels differ to the actual ones by a factor known as scale error, it increases by increasing the distance to the device, and scale error in radar is less than acoustic or pressure sensors where evidenced that most pressure and acoustic gauge give a scale error that varies between 1% and 2% for the stations with larger tidal range. Therefore selecting a radar gauge must depend on the following criteria [13].

- It must achieve high-precision of the individual measurements and select data sampling (1 min or less);
- It must take 2 Hz original raw data sample that allowed wind wave or agitation (short waves within the harbour) parameters to be estimated (needed in some harbours).
- It must achieve high performance and constancy of the datum.
- It must achieved precise and easy communication with the manufacturer for implementation of additional needs as data formats, time control, etc…..[29].

Radar gauge is a kind of tide gauge, which is not monitored and unsupported by local operators as old tide gauge technique. This is a negative effect on the ability to check the tide gauge readings. Therefore to confirm the correct maintenance of the Tide Gauge Zero (TGZ) the dipper readings with the radar gauge whereas dipper measurements shall be used to monitor and determine the Zero Point (ZP) offset of the radar gauge by obtaining several readings during a high-to-low tide cycle then comparing it with the radar gauge measurements. Regular repetitions in dipper approach is sufficient for locations. It has been recommended weekly repetitions for dipper measurements to achieve the precision and accuracy of dipper measurements in general. This technique is suitable for establishing a height reference to better than ±2.5cm repeatability with SD of ±2 cm [9].

1.1.1. Changing the Old Gauge by New Accurate One.

Up to twenty-two old tide gauge stations in the Arab world must be replaced by radar tide gauges around the red sea, Mediterranean Sea, and the Arabian Gulf, in order to fulfill the requirements for unifying the vertical datum all over the Arab region.

Overlapping among old and new stations should be suitable periods for recording the observations in different frequency ranges. These will be performed in different time series, in one year, monthly, daily, hourly, and five min, in order to determine the effect of instruments on the long-term on sea level products such as tides and mean sea levels [13]. For the precise relation between the sea level time series from the old and the new tide gauges, the data must be combined from tide gauge stations and altimetry near to each station for comparison and accurately determine the sources of error.

If the new tide gauges will be installed at precisely the same position as the old tide gauge, this make the expected differences at all frequencies will be small and the datum connection will be easier. In the other hand, if the new tide gauge will be installed at another position in the harbor with various frequency, just the lower frequencies of sea level will be expected to be coherent with the old station, and a high precision levelling is required to unify both tide gauges to the same datum.

1.1.2. Using GNSS at the Tide Gauge Station.

GNSS antenna receives the satellites signals to be processed, and analyzed, thus the sea level and its variation may be measured up to twenty times per second. The new GNSS tide gauge can measure, both land and sea variations at the same time and location. Which means both long-term and short-term land movements (post-glacial rebound and earthquakes) shall be taken into consideration.

Figure (3): Antenna placed on the roof of the tide gauge hut [9].

The sea level could be measured related to both the coast and the center of the Earth, which shows the difference between variations in the water level and variations in the land. For this GNSS antenna may be placed on the roof of the tide gauge hut as shown in the previous form in figure (3) for monitoring the height and vertical motion of the tide gauge.

Moreover GNSS antenna may be placed close to the tide gauge station as shown in the following form in figure (4) for monitoring the height and vertical motion of the land and its effect on the tide gauge.

Figure (4): the antenna closed to the tide gauge hut [14][28]

Continuous GNSS observations near to the Tide Gauge Benchmark (TGBM) will be needed for all Arabian Tide Gauge Stations Network (ATGSN). This proposed observation technique shall support satellite altimetry calibration and will determine the regional changes in sea level. Most vertical land movements can altogether modify the rates of sea-level rise which expecting from the sole climatic contributions of ocean thermal extension and land-based ice melting. The precise impacts of sea-level rise on the coast can be determined by focusing on advantage of existing GNSS receivers at this stations.

1.1.3. Connection between Tide Gauge and GNSS.

To achieve connection between tide gauge and GNSS, coastal Tide Gauge Bench Marks (TGBMs) situated as near as possible to the tide gauges are utilized. These are connected to the real tide gauge readings by water level calibration. Usually establishing these network of bench marks to examine the relative height history of the marks, this indicates to any local subsidence or any stability problems with the marks.

Generally the work concerned with using the spirit levelling to complete the connection, and using GNSS to derive, monitoring ellipsoidal heights on TGBMs. As needed by the Global Sea Level Observing System (GLOSS), the accurate monitoring of sea level as the ellipsoidal heights will be related to global reference frame, where the orthometric spirit levelling can just define local change in benchmark heights to other monuments.

Height connections are to the TGBM from the GNSS mark at tide gauge Stations by both of orthometric height from levelling and differential GPS. The targets of these connections were to determine the relative height differences between the Permanent

GNSS and the Tide Gauge Benchmarks, and to derive an ellipsoidal height at the tide gauge benchmarks. As mentioned before, this connection gives important data for monitoring long term sea level change. Else this connection is required to help to better determine the separation between MSL and derived ellipsoidal heights from GNSS. Thus a levelling control network should be at each tide gauge station to confirm long-term stability and for establishing the connection between the Vertical Control Network (VCN) and the tide gauge reference height. Therefore precise geodetic tying to the Arabian Tide Gauge Stations Network (ATGSN) can be implemented using precise levelling, after re-adjust the benchmark related to the high accuracy tide gauge stations.

1.1.4. Utilizing satellite altimetry data at tide gauge stations.

Many problems appear from neglecting (SST). There are many permanent effects depending on tide gauge location in spite of considering long periods of sea level observation, strong winds, and even the type of device that still effect on the resulting of MSL. In some countries the vertical crustal movements due to Post Glacial Rebound (PGR), are responsible for strong rising sea level. Finally, bias in the vertical datum definition with sea level observations can be introduced by local disturbances of the Earth's gravity field.

Satellite altimetry is considered one of the most important tools for unification the vertical systems between countries, as it provides valuable information for a precision realization of "Global Geoid". In the last years it gives good results but in coastal areas these results are still need to be improved. Nowadays the connection of the reference levels from satellite altimetry and tide gauge data which will permit finding and applying corrections for SST at tide gauges, thus the utilizing of satellite altimetry to homogenize the tide gauge reference levels will be a tool in a new promising thinking[17].

The decision makers should take in their account that Arabian Tide Gauge Stations Network (ATGSN) must have high accuracy devices with the same specifications at all stations in all Arabian countries to observe and monitor mean sea level changes for providing high-quality and homogeneous estimation of the vertical movement. All stations must give observations in the same time with the same accuracy to provide and report data in near real time, which will be tracked at a Sea-level stations for monitoring easiness. ATGSN will include, data acquisition systems, and communication packages; what these improvements are cost-effective in expressing of the benefits that a real-time system will supply for mean sea level observing and monitoring and will enhance station performance related to early discovery of stations malfunctions. The Specifications of proposed devices that may be taken into account when establishing ATGSN.

Levelling Works.

In the proposal, precise spirit levelling will be done for the whole gravity stations which include in its turn the GNSS stations. Levelling will be done with unified standard to insure the same accuracy. The levelling works will be based on the tide gauge station in every country. The whole old and new levelling works will be collected in the main center which will be suggested in coming steps.

Vertical control surveys are to be classified related to the planned and achieved accuracy. This goes to be a function of;

- The design of networks.
- The different surveying practices.
- The instruments and equipment which used.
- The employing different reduction techniques.

The misclose or the difference between the start and end point in a levelling of the area between each consecutive marks and between the points of a closed level route, is ≤ to the value (e) using the following formula [34]:

$$e = c\sqrt{k} \qquad (1)$$

Where:

e = the allowable max error, in mm.

c = constant factor related to each levelling CLASS.

k = distance in km.

Table (1): the values of 'c' according to each CLASS of survey [34].

Differential levelling $\mathbf{e = c\sqrt{k}}$	
CLASS	C (for 1 σ)
L2A	2
LA	4
LB	8
LC	12
LD	18
LE	36

ORDER is set to the height of a mark, following adjustment will be proportional to:

• The new differential levelling class or trigonometric levelling class or GPS height.

• The constraining heights order.

• The transformation from one height datum to another one and its precision.

• The magnitude of the inconsistency between the recently observed height and ready existing height variations of the survey benchmarks at the project of the new and existing levelling routes/vertical networks.

• For the ellipsoidal height and the accuracy of the geoidal undulation.

Table (2): Highest ORDER (R) that may be set to a height from a given CLASS surveying [34].

Differential levelling	
CLASS	**ORDER**
L2A	R0
LA	R1
LB	R2
LC	R3
LD	R4
LE	R5

1.2. Existed GPS points distribution in Arab world.

Figure(5) shows the distributions of available GPS points which cover the Arab region according to what have been collected via internet and previous studies. It shows 30 GPS points represent the High Accuracy Reference Network (HARN) and 112 GPS points represent (NACN) stations which cover Egypt. A network of about 30 GPS sites covers the Republic of Djibouti, GNSS/levelling data at 19 stations distributed over the area of Sudan. 3750 leveled benchmarks with GPS ellipsoidal heights were made available by Dubai Municipality.105 Continuously Operating Reference Stations (CORS) network covering Saudi Arabia, six Continuously Operating Reference Stations are in six different sites in Bahrain.

In Algeria, 1290 GPS points, 07 permanent GNSS stations and 258 leveled benchmarks with GPS ellipsoidal heights. 45 Continuously Operating Reference Stations (CORS) In Libya. 403 GPS/Leveling points cover Palestine area beside 19 Active Permanent Stations (APN). The available GPS points, which cover Arab countries as in figure (5).

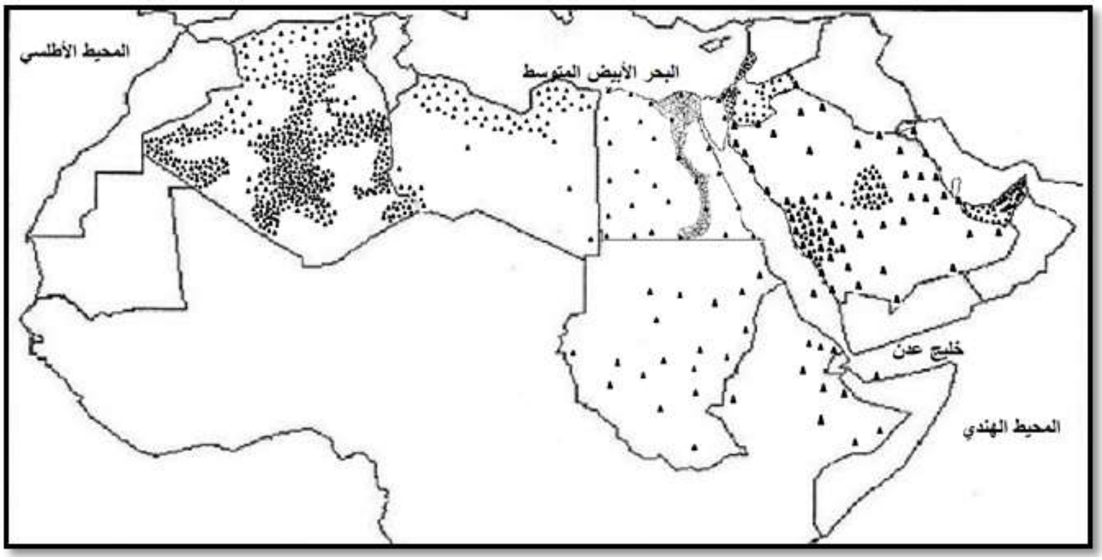

Figure (5): shows the distribution of GPS points in Arab countries.

These are the information which have been collected from the internet along with previous studies, but the supervision side- the Arab league- can communicate the involved countries to obtain the real situation and the data itself. From the previous figure we notice that there are many gaps in all states with a concentration of points in certain regions that serve specific projects and studies. The GPS points in all Arabian countries aren't homogenous and there is not any existed scenario to tie these point. The point's distribution in this way does not serve the current study to unify the vertical datum. Therefore, the integrity and reliability characteristics of control networks in Arab regions vary seriously from one network to another. Moreover, many of these networks have not tied to a high-precision GPS datum that can be used to unify them.

Therefore a precise GNSS network is proposed to the Arab region. The points of the proposed network will be homogeneously distributed in the Arab countries. A number of points will be in every country related to the area of the country. Existed points will be used with the proposed points. Core points will be observed simultaneously and their data will be processed with the data of the IGS stations using the more accurate precise ephemeris to obtain the more accurate absolute position.

Those points (core points) will be used as base stations to the rest of the points in every country. One of these points in every country will be beside the tide gauge station in that country. The core points along with the other points (the whole proposed network) can be prepared to serve the users as permanent stations (CORS). The users in Arab area will have their position in unified accurate absolute homogeneous system of coordinates wherever he is.

1.3.1. Specifications for establishing a Regional PORS.

For importance of the PORS, it'll take similar international specifications of CORS stations.

- The observation system includes an antenna with choke ring, to eliminate multipath effects.
- Requirements of PORS, appropriate horizon and elevation should be established to minimize multipath GPS observations errors.
- Concrete monument must be established to give mechanical stability.
- Antenna Reference Point (ARP) must be for each PORS which is the point on the external surface of the antenna, which it is considered a reference for antenna phase center positions.
- Unique and permanent companion point must be for each PORS on or near the PORS monument, where the ARP is measured. That mark must be fixed with respect to the monument.
- The site of every station is chosen to be at least fifty meters away from any artificial buildings to minimize the harmful multipath effects. Location accessibility should also be considered in the reconnaissance stage [3].

1.3.2. The Proposed GNSS Points, Number and Distribution in all Arab Countries.

The area of Egypt is about 1000,000 km^2 and it has a high accurate reference network (HARN) established in 1995. This HARN consists of 30 GPS stations, well distributed with point spacing about 200km. The accuracy of this network is 1:10,000,000. Five among the thirty stations were chosen to be core points whom are firstly observed, processed, and adjusted with the IGS station using the best precise ephemeris at that time. Those five core stations are then used as base stations to the other 25 stations. The same pattern is proposed here for all the study area. Every country will have its core points and among the stations of its own network. The number of the stations in each country will depend on its area. The core points will be observed in one session in the whole Arab area, processed, and adjusted with highest GNSS standards. After that and in every country, the other stations will be observed as rovers with respect to the core (base) stations. Those GNSS observations will be processed and adjusted using the same adopted standards. Finally an accurate coordinates for the whole Arab GNSS stations will be defined in one accurate unified coordinate system. Again these stations can be prepared to serve as permanent stations to serve the users with the suitable corrections in the whole study area in real time service through the main center. The proposed shape for permanent GNSS/levelling distribution in Arab countries and high precision GNSS points appears in Figure (6) and their locations in table(3)

Table (3): shows the proposed GNSS points distributions all over the Arab countries

N o.	The Arab Countries	Area $(km)^2$	Coast line (km)	The proposed no. of permanent GNSS Stations	The proposed no. of GNSS St. in the precise GNSS networks	The minimum no. of tide gauge stations related to the coast length
1	Bahrain	740	590	1	1	1
2	Iraq	435,052	58	2	14	1
3	Kuwait	17,818	499	1	1	1
4	Oman	309,500	2092	1	10	2
5	Qatar	11,427	563	1	1	1
6	United Arab Emirates	83,600	1318	1	3	2
7	Saudi Arabia	2,250,000	2640	12	72	2
8	Djibouti	23,200	370	1	1	1
9	Jordan	92,300	26	1	3	1
10	Somalia	637,657	3025	3	20	3
11	Sudan	2.505,000	853	13	78	1
12	Comoro	2,236	340	1	1	1
13	Yemen	555,000	1906	3	18	2
14	Egypt	1,002,000	2450	5	30	2
15	Palestine (Gaza Strip)	27,000	40	1	1	1
16	Lebanon	10,452	225	1	1	1
17	Syria	185,180	193	1	6	1
18	Algeria	2,381,741	998	12	75	1
19	Libya	1,775,000	1770	10	57	2
20	Mauritania	1,030700	754	6	33	1
21	Morocco	710,850	1835	4	22	2
22	Tunisia	165,150	1148	1	5	1
23	Total	14211.60 3	22.10 5	82	455	31

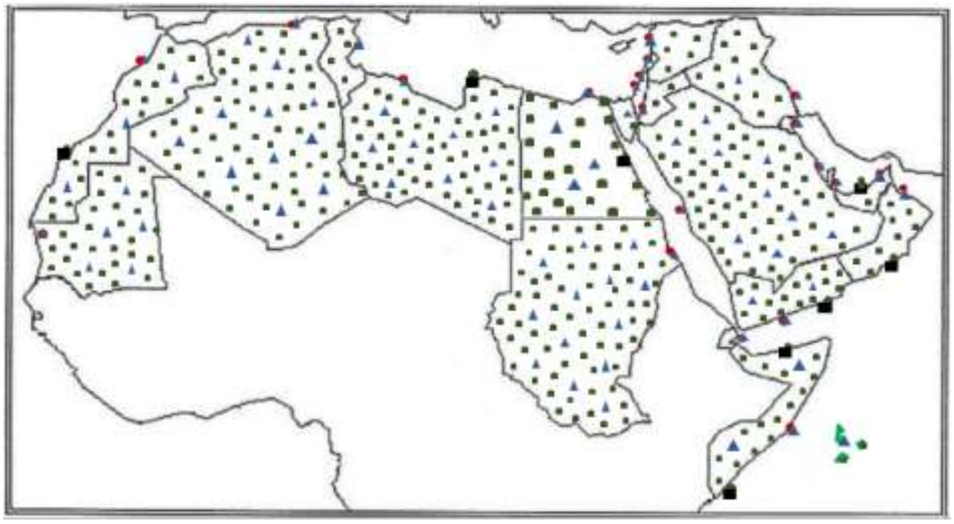

Figure (6): The Tide gauge location (the vertical datum origin). The proposed new Tide gauge location. The permanent GNSS/levelling/gravity points tying on IGS stations . GNSS/ levelling/gravity points tying on permanent GNSS stations.

.13.3. GPS Static Observations Specifications.

GPS survey (high accuracy static) will be used which needs a geodetic quality, dual frequency, and GNSS receivers of full wave length with several channels to track GNSS satellites. It is preferred a choke ring antenna, while any geodetic ground plane antenna has high quality may be used. Any antenna type must be calibrated before and during the work [3].

Recording epochs will be 15-seconds, which ought to agree with the recording time interval of the reference stations (PORS) utilized to post-process the data. The elevation mask angle goes to be typically set for 10 degrees; low angle satellites can reduce the efficiency of the final solution.

The greatest possible amount of GNSS data must be collected if time and schedule permit, therefore the errors or invalid data, can be removed through the processing operation, which remain leaves the minimum observations needed for a single GNSS session. The minimum requirement is 4 hours or 7200 observations of GPS data will be collected on a water level (tidal or geodetic) bench mark for one GNSS session [29].

- The relation of tidal datums to geodetic datums and ellipsoid heights supply several hydrographic, coastal mapping, and engineering applications containing the monitoring of sea level, and the Vertical Datum (VDatum) transformation tool, etc.
- ellipsoidal GPS tie is needed at each water level station which has at least one GBM is located nearby (within 1.6 km (1 mi) levelling distance of a water level station)[29].

1.3.4. GPS data processing.

Similar to the globally GPS specifications for high-precision networks, the following procedures are designed:

- For Arabian network, the iono-free L1/L2 fixed solution must be obtained.
- Ionospheric and tropospheric models ought to execute.
- Rejected measurements percentage should be less than 10%. Maximum standard deviation of a base line is ± 2 centimeters.
- The tolerance of base line processing must be better than ± 2 cm for horizontally distance and ± 4 cm for vertically.

- Precise ephemerides should be utilized because they are preferable rather than the broadcasted values [21].

1.3.5. Satellite Visibility.

The utmost desired GNSSBM must have 360 degrees allowance around the mark at 10 degrees and greater above the horizon. The new mark must be tied to the station bench mark network during conventional geodetic leveling, and GNSS observations shall be made.

1.3.6. Safety and Convenience.

The GNSSBM must be sited on public property not on private property, to avoid taking permissions from private property owners may be needed in the future to reach to the bench mark and to collect GNSS data. The distance should be no greater than one mile to the GNSS mark from the station to Data Collection Platform (DCP) [32].

1.4. The available Gravity data in Arab world.

Figure (7) shows the distribution of gravity points in the study area. Such distribution will affect the proposed vertical datum for the Arab world. These are the collected information about the gravity points in the study area as appeared to the authors. The supervision side (Arab League) can communicate each country to collect the whole required data they have. So, the discussion and the proposals in this thesis will be limited to the collected information.

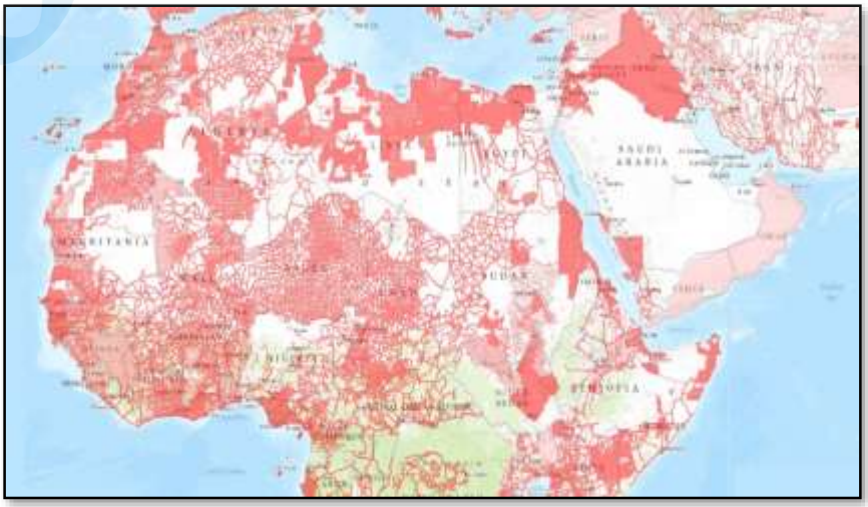

Figure (7): The gravity points. The gravity line.

The proposed gravity network in the study area consists of two sets of gravity stations. The first set will be observed using absolute gravimeters. The supervision side (Arab League) will communicate the world wide agencies whom have absolute gravimeters and arrange time table with them. The first set stations will be the same core GNSS stations mentioned above. After that every country with its relative gravimeters will define the gravity values at its stations of second set of the gravity stations. The same kind of relative gravimeters will be used in the whole study area, as long as the same style of observations will be followed. The whole observations will be sent to the main center for processing and getting the final values. The second set of gravity stations consists of 50km spacing stations including the already existing stations. In Egypt, for example, 400 stations will be required. At least 150 stations already exists since the last gravity network has been made in 1997.

Every country will establish the rest of its required stations. The FG5 absolute gravimeter is suggested to be used; it can determine the gravity acceleration value with precision of 2-4 μGal. Its accuracy is greater than the relative gravimeters [32] [22].

1.4.1. Connection of gravity values in Arab region. .

In order to grantee the gravity value's precision in all countries in Harmonized uniform system;

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- The first point is using the same method for determining the gravity value in each local reference network. It is proposed to use Forward Looping Method, this method is called step method where the base stations are tied together in a regular arrangement is called A-B-AB sequence. The measurements will be taken at the base station A and the instrument is then transmitted as quickly as possible to the other base station (B), then the measurements will be repeated at both stations. Taking reading should be fast, this makes the user able to assume the linearity of zero drift. From the four readings at A-B-AB the gravity differences can be estimated. If the divisions between the two differences are larger than the precision of the device, the readings will be repeated. The final measurement at the base station (B) will serve as a basis for the next connections for example if the next base point is (C) the similar sequence will be used as B-C-BC.

-The Second point, using the same type of instrument which used in observation.

-The third point, applying the same adjustment methods of the local survey network [42].

❖ **<u>The First Proposal.</u>**

-The proposed work plan for unifying the Arab vertical datums.

The proposed work plan will be explained as follows;

- Main center for the geodetic services in the Arab region will be established in Egypt.

Egypt occupies a distinctive geographical position as an intermediate place and it can be named Arabian Geodetic Service (AGS), it will be under the supervision of the Arab League. Members of this center could be the surveying authorities in Arab countries, universities, research centers, and any other concerned institutions. AGS will introduce all the geodetic services concerning data and consultations, and it will be in continuous cooperation with the similar worldwide services. AGS will have subservices among them the Arabic vertical datum service (AVDS).

Table (4) shows the techniques and basic components that will be associated with AGS.

Table (4): Techniques and basic components that will be associated with AGS. Where E means the observation at certain time and C is continuous observations.

Technique	The objective	The expected	Results and Contributions
Tide gauges	The point's height related to	E: 10 cm C: 1 cm	The displacement of Surface, vertical
GNSS	The position of point related to a	E: 1-2 cm C: 1-2 mm	The displacement of Surface , 3-D reference
Levelling	The height differences of	< 2mm/km½	The displacement of surface, vertical
Absolute	Absolute gravity	2-4 µGal	The displacement of
Altimetry		2cm[25][26]	It directly measure the height of the ocean
Meta database	Access to the		

The tasks and Objectives of AGS are going to be as follows:

- To establish a network of stations with several collocated techniques shown in the previous table.

- To access to the needed data. This suggests maintenance of databases, a lot of them via existing elements, similar to a metadata base as a section of the AGS portal.
- For contribution to support the initiative which aim to construct the continuous maintenances and the enhancement of precise geoid models in Arab world.
- To collect the geometric positioning (GNSS time series) with orthometric height and renewed gravity observations by high accuracy, and to supply connection to the sea level and sea level changes by tide gauges in the area.
- For contribution and realization the World Height System (WHS).
- For serving and supply different scientific agencies by data as; geodetic surveying, bathymetric surveying, cadastral surveying, aerial surveying, construction and engineering surveying and town planning….etc.
- AVDS will be organized by selected team work members from the experts, geodesists from different Arab countries.
- AVDS will communicate the surveying authorities, universities, research centers, and other concerned Institutions (its members) to collect the geodetic data; GNSS, TG, gravity, and levelling. The old already existed and the proposed data as mentioned before, will be sent from every AVDS member to the main center of AVDS via the internet without needing to go to the field. This saves both time and money. The following chart shows the proposed shape for Arabian network.

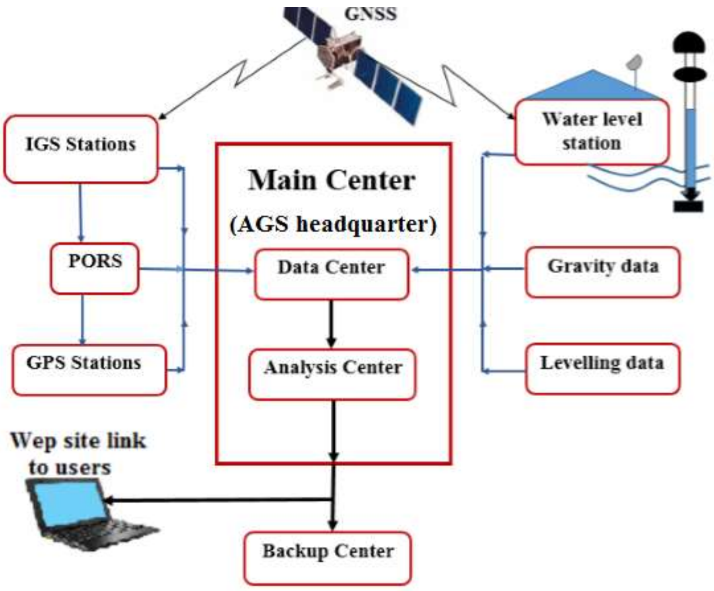

Figure (8): shows the proposed network chart for AGS.

The main components of AGS are the Arabian Observing Stations (AOS) which form the national station networks, a second component is the Arabian Data Centers (ADC), and its operation is storing the tide gauge data and GPS, levelling, gravity, and metadata for long-term. The third component is the AGS Analysis Centers (AAC) responsible to daily analysis of AGS data and must be extended to all Arab countries. It will process GPS data on a uniform basis with a very short latency giving orbit and clock products of different quality and the coordinate time series of stations, therefore it completely supplies time series of vertical movement for a network of tide gauge stations.

The fourth component is the Arabian Backup Centers (ABC) which will keep data from mislaying.

Arabian Geodetic Services, (AGS), will integrate precise absolute and relative gravity, levelling, tide gauges, and local processing of GNSS data. For reduction the network error on station positions with passing time especially in the vertical component. It will serve as a regional network and it will provide necessary data and infrastructure for the initiative of (WHS).

- The coming steps mentioned in this proposal will be done either on the old (existed) data only or on the old and the new proposed data together. The steps can be done using the old collected data until the new data are available, so the work can be repeated and updated.

- Generally the implementation of AGS services will be started with the tide gauge observations: the new observations at every tide gauge station will be collected for one year and them added to the old observation and sent together to AVDS.
- The data will be reviewed, filtered, and processed to obtain the current mean sea level at every country.
- New observations can be compared with the old observations to define the change of the mean sea level w.r.t. time.
- Mean sea level for every country will be obtained during the same time period using the same instruments and methodology to assure homogeneity and same precision.

▪ All the old and new B.Ms in every country will be shifted to the new mean see level value in that country.

- AVDS will define certain time for the whole countries, start and end time, for GNSS observations at the core GNSS stations.
- Those observations will be collected at AVDS to be filtered, processed, and adjusted in addition to the observations of the nearest IGS station. IGS stations will be chosen at the main four directions' w.r.t. the study area. The most accurate precise ephemeris will be used while processing.
- AVDS will define certain period of time for the countries individually to observe the rest of its GNSS stations.
- The GNSS observations will be collected, filtered, processed, and adjusted using the core stations as base stations.
- At that moment, all GNSS stations in the study area will have their homogenous, accurate coordinates defined on WGS84 and the current ITRF.

▪ The old and the new absolute gravity observations will be collected at AVDS to be filtered, processed, and adjusted. The final absolute values of the gravity acceleration will be obtained. They will be homogeneous and having the same accuracy and datum.

- The old and the new relative gravity observations will be collected at AVDS to be filtered, processed, and adjusted. The absolute stations will be used as reference stations.

- The whole gravity stations in the study area will have homogeneous, accurate gravity values referred to one reference.
- Finally, the study area will have a dense, well distributed, homogenous, accurate data of:

-A tide gauge station at every country.

-GNSS stations, and the considered value here is (h).

-BMs with orthometric height (H) related to the new value of their TG.

-Gravity network.

- AVDS could adopt the last global DTM (STRM) and the global geoid model (EGM 2008) for the computation of the geoid in the area.
- A precise geoid model for the study area will be computed in AVDS using the above mentioned results and data.
- The adopted EGM will be tailored, modified to fit the study area using the resulted:

- Ellipsoid heights at GNSS Stations (h) and the corresponding orthometric heights (H) from levelling.

- Gravity anomalies at the gravity network stations.

- Fixing the new values of MSL to zero in the solution (at T.G stations).

- Altimetry data will be used for the red sea and the south of the Mediterranean Sea.

- Tailoring EGM using terrestrial observations to fit some area.
- When using (EGM2008) to be tailored by;

-T.Gs using Radar Level Sensor by accuracy: ±10 mm.

-The approximate precision of Observed undulations will come from the basic relationship between the ellipsoidal height and orthometric height;

-Where the undulation value will be obtained as;

$$N=h-H \quad (2)$$

And in order to compute the standard division of the computed value (N), by differentiate Eq.(2):

$$d_N = d_n - d_H \quad (3)$$

And by squaring Eq. (3);

$$\sigma_N^2 = (1)^2 \ \sigma_h^2 + (-1)^2 \ \sigma_H^2 + 2(1)(-1)\,\mathrm{cor}(h,H) \quad (4)$$

Because the correlation between (h,H) is zero the Eq.(4) becomes as following:

$$\sigma_N^2 = \sigma_h^2 + \sigma_H^2 \quad (5)$$

By using the precise levelling (first order) according to the standard formulation 2√K where K is the length by kilometer(as the distance in HARN network equal 200km and the precise levelling will be in closed loop) so the accuracy of the orthometric height equal

$$2\sqrt{400} = 2\times 20 = 40mm \quad (6)$$

And by using the HARN network by scale 1:10,000,000 and the distance 200km, so the accuracy of ellipsoidal height equals 20mm by substituting in Eq. (5) by centimeter:

$$\sigma_N^2 = (2^2)\ cm + (4^2) cm = 4cm + 16cm = 20cm \quad (7)$$

$$\sigma_N = \pm\sqrt{20cm} = \pm\ 4.5cm \quad (8)$$

The approximate precision of gravity anomalies will be computed from the following basic relationship;

$$g^{-} = g_{obs} + 0.3086\ H \quad (9)$$

Where, H is the height of gravity station in meters above geoid and g^{-} is the gravity on the geoid, and g_{obs} is the gravity on the earth's surface

$$\Delta g = g^{-} - \gamma_o \quad (10)$$

Where γ_o is constant, the precision of g^{-} equals the precision of observed gravity added to the effect of H, in order to compute the st. dv. of the computed value (g^{-}), by differentiating Eq. (9):

$$dg^{-} = dg_{obs} + 0.3086dH \quad (11)$$

And by squaring Eq. (11)

$$\sigma_{g^-}^2 = \sigma_{gobs}^2 + (0.3086)^2\ \sigma_H^2 \quad (12)$$

By substituting in the Eq. (12) with the expected value of observed gravity and orthometric height as mentioned in the first part and equation (6) ; 3µgal and 4cm respectively, the precision of gravity anomaly will equal;

$$\sigma_{g^-}^2 = (0.003)^2 + [(0.3086)^2 \times (0.04)^2] = \quad (13)$$

$$\sigma g^{-} = \pm\sqrt{0.00016} \approx \pm 0.012mgal \approx \pm 12.7\mu gal \quad (14)$$

Improving the gravity anomalies and GPS/levelling data in Arab world can be expected after tailoring the EGM 2008 model (which be recommended in most Arab countries) by using the recommended data with its recommend specifications which previously discussed.

After studying the previously discussed cases for tailoring the GGM by using terrestrial data. The gravity anomalies and GPS/levelling values improved with high percentage after tailoring the GGMs model by using their terrestrial data. The Arab gravity anomaly will improve of more than 90% and GPS/levelling value will improve of more than 50% after tailoring the EGM2008 by the proposed high accurate data which previously discussed in proposal one.

- Expected result after the implementation the former steps, users anywhere in the Arab region can use any of the GNSS stations as a base station and obtain ellipsoidal height so, subtract the undulation value obtained from the Arab geoid to obtain a precise value of its orthometric height. This will happen in one homogenous, accurate vertical control.

-Processing service can be introduced via AGDS, besides the other geodetic services.

-Continuous observations can be done for updating and for the change of MSL, and for crustal movement.

- Nowadays the technological development and the information exchange speed through the internet, this permit establishing backup centers in every Arab countries to protect the data from missing. At least must be constructed two backup centers, in east and west of the Arab region for contain all Arab countries as Algeria and United Arab of Imaret.

The time table (5) in page 24 supports the initiative for establishing a unified vertical datum in Arab region and helps the decision makers and those interested in geodesy for implementation the proposal which presented.

❖ **<u>The second proposal</u>**

The second proposal based on Precise Point Positioning (PPP) technique for positioning and satellite-only gravity model for determining the geoid undulation. In this proposal, the PORS stations and precise GNSS stations in every country will be replaced by PPP and the regional geoid model will be replaced by satellite-only model being not affected by terrestrial non-homogenous observations.

Then the user everywhere in the study area can obtain his orthometric height as: $H = h - N$.

▪ **The benefits of PPP Technique.**

Using PPP Technique is suggested because it has a lot of benefits which be demonstrated in the following points.

• It depends on one receiver, and does not require reference station behind the observers.

•PPP determines the positions related to a global reference frame. PPP gives most positioning consistency than the differential techniques, where it provides position solutions without local base station or stations.

•PPP saves the time and effort because it reduces the number of used receivers and the number of observers facilitates and handles field work where it deletes the dependency on base station(s).

•PPP provides a lot of applications besides determining the position coordinates, as estimating receiver clock and effect parameters of troposphere. It uses a single GPS receiver to give another way for precise time transfer [43].

The following figure shows that PPP service and the ground reference stations used in gathering correction data for the various signals broadcasted by each satellite. The calculation of corrections from this data are broadcasted from geostationary satellites to the user's receivers.

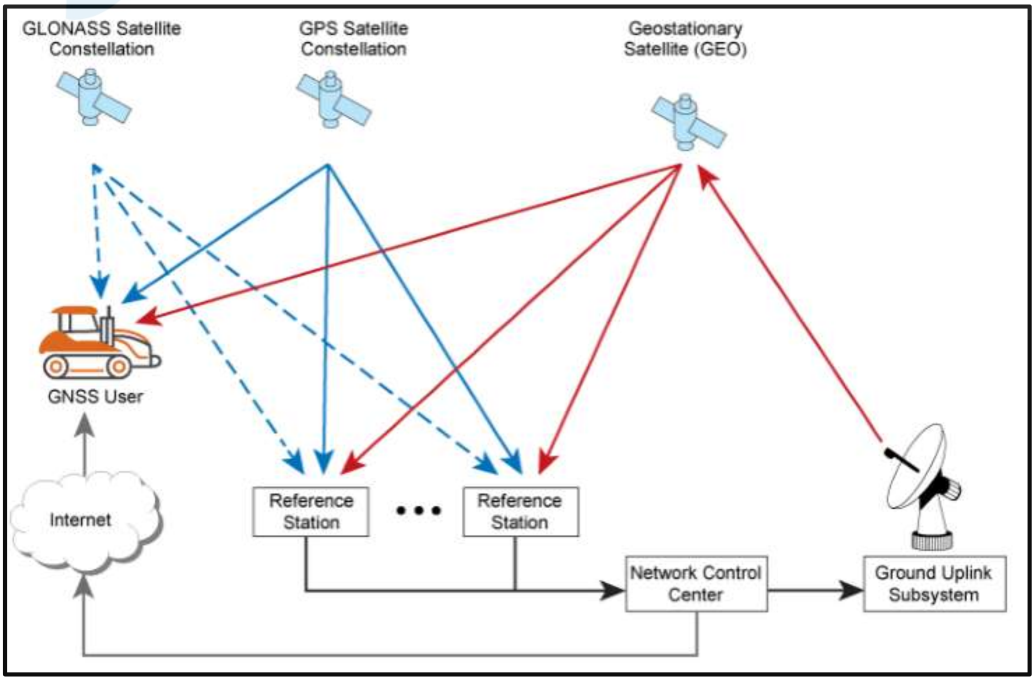

Figure (9): shows PPP system [123].

▪ **Satellite-only precise geoid models.** The discrepancy between the GPS/leveling geoid undulations (h_{GNSS} – H) and gravimetric geoid undulations (N_{grav}) should be zero. However, gross, random, and systematic errors and datum differences involved in the three heights (h_{GNSS}, H and N_{grav}) cause discrepancies between the gravimetric geoid undulations and the ones obtained from these two independent sources, GNSS and leveling measurements.

The long wavelength components of the gravity field can be obtained from satellite-only solutions, but they do not provide any local details. On the other hand, the terrestrial data can provide local details, but they generally contain systematic errors (e.g., datum inaccuracy) which propagate biases in the long-wavelength components.

An optimum regional geoid solution can be obtained by the combination of the satellite-only solutions with terrestrial data. The method which use for the combination of satellite and terrestrial gravity data, remove-compute- restore technique.

The contribution of the satellite-based gravity technology is one critical component to the geoid-based vertical reference frame. Satellite-based and terrestrial datasets are the sources that need to be investigated in the following experiments to develop a cm-accurate geoid model as a vertical datum in Canada.

- In an accurate study in 2015, GOCE-only solutions determined from the first two, eight, and eighteen-month observations, i.e. first, second and third generation models, were assessed in Canada and two sub-regions (the Great Lakes and Rocky Mountains). The global geo-potential model EGM2008, Canadian Geoid model CGG2005 and Canadian GPS/leveling-derived geoid undulations were used in the evaluation of the GOCE-determined gravimetric geoid models.

In Canada, the GPS measurements benchmarks were collected over three decades, their precisions range from millimeters to a few decimeters at the 95% confidence level. The GOCE-only solutions expanded up to different spherical harmonic degrees 90 to 180 are compared with the GPS/leveling-derived geoid heights on 2579 benchmarks in Canada, 652 and 659 benchmarks points in Great Lakes and Rocky Mountains respectively [44].

The accuracy assessment shows that the GOCE-only models agree well with EGM2008 for Canada; 12.2 cm, which becomes 4.8 cm for the Great Lakes area and 6.0 cm for the Rockies. It is shown that the GOCE models generally confirm to the accuracy of terrestrial data within the spectral band of degree 90 to 180, and deteriorate beyond degree 180. Moreover, their comparisons confirm that the new generation models developed by using longer observation series provide more accurate models than the first two months observation based models [45].

The results of the satellite-only models comparisons with GPS/leveling-derived geoid heights including GOCE latest models as well as EGM2008 show the differences between the geoid undulations derived from GPS/leveling and EGM2008 (degree 2190) reached to 10cm. standard deviations of the mis-closure between the GPS/levelling-derived geoid undulations and gravimetric geoid models from satellite-only model show that the satellite-only model reduces the EGM2008 commission error, thus leading to a better agreement in the GPS/leveling comparison.

The second and third generation GOCE-only satellite models DS03 and TW03 are combined with the regional terrestrial data to analyze the possible improvement from the recent GOCE models. This process was done to determine the optimum combination for the satellite model and the terrestrial data. Where the Canadian Gravimetric Geoid Model (CGG2005) includes 2.2 million gravity measurements obtained from different sources, used in the evaluation with combined GRACE model.

-The GPS/leveling comparison results for EGM2008, CGG2005, and the 8 GOCE-combined models are obtained. Those results indicate the standard deviations of the combined models range from 12.2 to 12.7 cm for Canada, 4.7 to 5.3 cm for the Great Lakes and 6.0 to 7.1 cm for the Rockies. The GOCE combined models are comparable with EGM2008 and CGG2005 in terms of their standard deviations of GPS/leveling comparisons. These results suggest that the recent GOCE models are spectrally consistent with the gravity field in Canada up to degree 180.

- In another study, different combinations of GOCE-based models and terrestrial gravity data are tested in

Yukon Territory, British Columbia and Nunavut regions on 291 benchmark points. The results show that GOCE can contribute to the geoid model in the region close to cm level compared to EGM2008 [47]. Also, new Canadian geoid model CGG2010 shows an improvement as large as centimeter or few centimeters over some regions such as the provinces of British Columbia and Alberta, Rocky Mountains, Yukon area compared to CGG2005 and EGM2008 due to the contribution of GOCE [16].

- In a special study in year 2015 carried out in Finland to compare altogether 16 GOCE models, 12 GRACE models and 6 combined GOCE+GRACE models with GPS-levelling data and gravity observations in Finland. The satellite-only models were compared against high resolution global geoid models EGM96 and EGM2008.

-The coverage of the gravity dataset (altogether 39318 points) is presented with the GPS-levelling. For the comparison of the height anomalies, two GPS-levelling datasets were used: The European Vertical Reference Network - Densification Action (EUVN-DA) dataset and a dataset of the National Land Survey (NLS) of Finland. For the comparison of the free-air gravity anomalies the gravity database of the Finnish Geospatial Research Institute (FGI) was used. The database contains gravity observations from early 20th century to present where the observations include terrestrial gravity measurements.

-The models were evaluated up to four different degrees and order: 150 (the common maximum for the GRACE models), 200, 240 (the common maximum for the GOCE models) and maximum.

-Generally, all of the GOCE and GOCE+GRACE models give standard deviations of the height anomaly differences of around 15 cm and of gravity anomaly differences of around 10 mgal over Finland, when coefficients up to 240 or maximum are used. The results are comparable with the results of the high resolution models. The best performance of the satellite-only models is not usually achieved with the maximum coefficients, since the highest coefficients (above 240) are less accurately determined. Even at the lower degrees and orders, the high resolution EGM96 and EGM2008 models performed very well over Finland when compared to the satellite-only models.

-The GOCE-based models perform better than EGM96 and quite equally with EGM2008 when developed up to degree and order 200. This proves that GOCE has improved the knowledge of the long wavelengths of the Earth's gravitational field. When developed up to degree and order 240 the best satellite-only models are at the same level as the high resolutions models in Finland. Everyone should keep this in mind when using GOCE-only models in the unification of height systems.

-This study prove that, there is a small tilt may be present in the EGM96 over Finland due to long wavelength errors in the model, EGM96 and EGM2008 models do not perform equally well everywhere due to the inhomogeneous distribution of the terrestrial gravity data, and the excellent performance of these models are due to the good high resolution terrestrial data that was already available in the study area.

But the satellite-only models do not show any tilt over Finland, as well as, they will perform homogeneously everywhere on the globe [139].

- In a study has been carried out on the territory bounding the continental part of Norway and most of Fennoscandia in 2011, GOCE derived satellite-only GGMs have been compared with EGM2008, the OCTAS (The OCTAS geoid represents a high resolution gravimetric geoid model covering the north Atlantic, the Arctic Sea and Fennoscandia) geoid and terrestrial gravity anomalies.

-In the first numerical experiment in the study area, it was compared geoidal surfaces computed from four satellite-only global gravity models based on GOCE observations. Three of them have been determined by independent strategies using pure GOCE satellite-to-satellite tracking and satellite gravity gradiometry observations. The fourth model has been computed from a combination of GRACE and GOCE observations (GOCO01S) as well as the OCTAS geoid to EGM2008.

Spherical harmonic expansions have been truncated at maximum degree and order 200 corresponding to a spatial resolution of 100km. Higher frequencies of the OCTAS geoid and of the terrestrial gravity anomalies have been removed by either subtracting the signals computed from EGM2008 above degree 200.

Standard deviation of OCTAS geoid reaches only 0.139 m. All geoid models are only slightly biased within few millimeters as the corresponding mean values indicate. Where the standard deviation was 0.057m, 0.073m, 0.080m, and 0.072m to all the four satellite-only global gravity models based on GOCE observations.

-In the second numerical experiment, they compare gravity anomalies from all the four GOCE satellite-only global gravity models, EGM2008 and terrestrial mean free-air gravity anomalies. The standard deviation of differences between gravity anomalies with respect to EGM2008 were 1.694mgal, 2.572mgal, 2.778mgal, and 2.570 mgal to all satellite. But in the case of terrestrial mean free-air gravity anomalies reaches to 7.977mgal [46].

As previous section referred to that on the world level the global geoid models do not perform equally well everywhere due to the inhomogeneous distribution of the terrestrial gravity data, whereas the satellite-only models will perform homogeneously everywhere on the globe, and focusing on the static part of the global gravity field, GOCE is expected to provide a geoid model with an accuracy of 1 cm and gravity anomalies with an accuracy of 1 mgal at a spatial resolution of 100km [139] [46].

From the above studies, the second proposal depends on the PPP technique and gravitational geoid model which determined from satellite-only data, by using GOCE-only or a combination of GRACE and GOCE at degree and order 200. This gravity only model should be enhanced by one method of tailoring the global geoid model. The proposed accurate data with its higher specifications which mentioned in the first proposal will be used for this purpose in order to improve and rise the resolution for the Arab region.

The second proposal will reduce the large numerical effort and costs required when using the traditional methods. So this method suggested to be used.

In twenty three from November at 2016, a conference has held by United Nations committee of experts on global geospatial information management for Arab state. Where it's headquarter in Saudi Arabia.it has already started to implement the first steps to establish ARABREF. It present a strategy for states cooperation to establish a unified geodetic reference and called it WG3 provided that to be a main purpose from its objective is establishing a unified vertical reference in the next step.

Conclusions.

This study focused on presenting two proposal for unification the vertical datums between the Arab countries this related to a plan of complete elements for unification the vertical datum in the Arab world. This study clarified the following points

1. Most Arab countries using old tide gauge stations and they still use by ancient techniques. For example, old tide gauge in Alexandria in Egypt has been operated since 1906. .

2. There are old benchmarks networks depend on observations from this old tide gauge. If the observations have been updated, the tide gauge would still effect on the observations.

3- A lot of benchmarks are damaged, and a levelling network still depends on that existing old benchmarks in their observations.

4- A precise GPS network such as HARN have not been updated a long time ago despite some of its points have been exposed for damage.

5- The gravity networks in all Arab countries are likewise the other networks are suffering from its lack data and existing a lot of gaps without any gravity data in some areas. Besides that, these networks have not updated their stations.

So this study firstly focuses on unifying and tying the Arab geodetic data depending on the modern technological instrument and determination its specifications. Which can work in the same time and give the same accuracy at the different location in all Arab countries.

The locations of tide gauge stations Appears that there is only tide gauge station in long harbor for example Libya and Morocco harbor, table (3) recommend that there are two tide gauge stations at least for long harbor.

The newest good distributions of the PORS stations which have the same specifications of IGS stations and their distributions related to the Area of each country.

These proposed specifications and using the Arab proposed gravity anomaly data grid and GPS/leveling grid, these make the proposed Arab geoid will provide orthometric height with precision within ±4.0cm, and gravity anomaly with precision ± 12.7 μgal.

The second proposal based on Precise Point Positioning (PPP) technique for positioning and satellite-only gravity model for determining the geoid undulation.

An optimum regional geoid solution can be obtained by the combination of the satellite-only solutions with terrestrial data. and EGM2008 models which recommended in most Arab countries do not perform equally well everywhere due to the inhomogeneous distribution of the terrestrial gravity data, and the excellent performance of this model are due to the good high resolution terrestrial data that was already available in the study area.

But the satellite-only models will perform homogeneously everywhere on the globe.

The second proposal will reduce the large numerical effort and costs required when using the traditional methods.

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Table (5): Shows time table for executing the proposed works.

No	Items in all Arab countries	First year in months												Second year in months												Third year in months												Forth year			
		1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4
1	Presenting this proposal to decision makers.	■																																							
2	Communication with the surveying authorities, universities, research center and all interested in surveying and geodesy in each Arab country.		■																																						
3	A number of sessions must be held to discuss the implementation of this huge project in presence of the delegates from each Arab country;			■																																					
	A-The signing of the Convention on the implementation of this huge project.				■																																				
	b Establishment protocol to exchange the available data between all Arab countries.					■																																			
4	Preparing and establishment the main center (Arab Geodetic Services).						■	■	■																																
5	Preparing and establishment the backup centers.						■	■	■																																
6	Selection the experts and geodesists team work members from different Arab countries.									■																															
7	Collection the old geodetic data by every AVDS member and sending them via internet, and using it until be establishment the new data.									■																															
8	**Concerning tide Gauges works.** A-renewal the tide gauge stations in all Arab countries										■																														
	B- Construction of new Tide gauge stations on long harbor										■																														
	C- Collection the observations at every Arab T.G stations for one year instead of 18.6 year and sending them by internet.										■	■	■	■	■	■	■	■	■	■	■	■																			
	D- Reviewing, filtering and processing the data to obtain the current mean sea level at every country.																						■	■	■	■															
	E- Defining the change of M.S.L. with respect to time by comparing the new observations and old observations.																										■	■													
	F- Obtaining the difference between the old and new value of M.S.L. at any Arab country.																												■	■											
	G-All the old and new B.Ms in every country will be shifted to the new mean see level value in that country.																														■	■									
9	**Concerning the satellite positioning work.** A- Choosing and Construction of permanent GNSS stations (core stations), AVDS will define certain time for the whole countries, start and end time, for GNSS observations at this core GNSS stations.											■	■	■	■																										

No	Items in all Arab countries	First year in months												Second year in months												Third year in months												Forth year			
		1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4
	B-Those observations will be collected at AVDS to be filtered, processed, and adjusted in addition to the observations of the nearest IGS station. The most accurate precise ephemeris will be used while processing.											■	■	■																											
	C-Choosing and Construction precise GNSS stations and tying them on core stations (base stations)														■	■	■																								
	D-AVDS will define certain period of time for the countries individually to observe the rest of its GNSS stations.																	■	■	■																					
	E-The GNSS observations will be collected, filtered, processed, and adjusted using the core stations as base stations																				■	■	■	■																	
10	**Concerning the gravity work.** A-Choosing the absolute stations in all Arab countries														■	■	■																								
	B-The old and the new absolute gravity observations will be collected at AVDS to be filtered, processed, and adjusted																	■	■	■																					
	C-The old and the new relative gravity observations will be collected at AVDS to be filtered, processed, and adjusted. The absolute stations will be used as reference stations.																				■	■	■																		
11	AVDS could adopt the last global DTM (STRM) and the global geoid model (EGM 2008) to compute the precise geoid in the area. By using the above mentioned results.																																■	■	■	■	■				
12	The adopted EGM will be tailored and modified to fit the study area using the new results, h, H, gravity anomaly at the gravity network stations, and altimetry data will be used for the red sea and the south of the Mediterranean sea																																					■	■		