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Preliminary Adjustments for Establishment of the Lagos Gravity Network (LAGGNET) 017

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Abstract

Preliminary adjustments for the establishment of the Lagos gravity network (LAGGNET) is herein presented. A gravity network is highly required for proper definition of a regional height system and also geophysical exploration activities. Horizontal control reliability test for the proposed network has been done using the Gauss Marcov functional model in a single constrained network with observation equations formed from the vector of baselenghts. Also the drift rate, atmospheric pressure corrections and latitude corrections have also been computed within the study area along an observation baseline called the Yaba – onipanu calibration line comprising of 4 control points within a total observation time of 77mins. The standard error of horizontal positions within the control network was found to be $\pm 0.0051m$. The drift rate of the gravimeter was found to be 0.0007mgals/min and atmospheric pressure correction values between -0.009 to 0.027mgals were obtained. Insignificant latitude correction was observed due to the near-equatorial nature of the study area.

Keywords: Gravity control network, Horizontal suitability test, functional models, Least squares adjustment.

Introduction

Measuring the Earth's gravity field is one of such tasks that is often considered as an exclusive preserve of the geoscientist especially geodesists and geophysics (Gooma, 1998); though the resulting gravity data is extremely useful to other disciplines such as geology, geochemistry, geography, solid earth physics, oceanography and hydrology (Novotny, 1998). In exploration geophysics, the gravity method is one of the several investigation techniques utilized in detection and determination of quantity and volume of underground mineral where density contrast is significant in the underlying geologic formation (Telford et al, 1990). Regional gravity anomaly maps are particularly useful for mapping geographic distribution and configuration of the basement rocks, structural and lithologic provinces, zones of crustal weakness, mass imbalances within the lithosphere, geometrical configuration of sedimentary basins, and the distribution of extrusive and plutonic rocks (Odumosu et al, 2013).

The Earth's gravity is a science studying the temporal and spatial distribution of the gravity field and its physical mechanism. The gravity field includes Earth's gravitational force and the inertial centrifugal force caused by self rotation of the Earth's mathematically expressed as equation 1 (Sneeuw, 2006). In addition, it also includes the gravitational force caused by the Sun, the Moon and other celestial bodies, as well as the inertial force related to the translation movement of the Earth's center (Chen et al, 2015).

$$F = V + w \qquad (1)$$

Where
F = Gravity
V = Gravitational Attraction
w = Centrifugal Rotation

Gravity is measured via gravity survey and gravity surveys (just as other geodetic exercises) requires that the measurements carried out are appropriately tied to a control network whose parameters (gravity, scale, orientation and calibration values within the reference frame) are precisely known (Torge, 2001). A set of control points upon which such a national gravity framework is defined is usually referred to as a "Gravity standardization Network" (Osazuwa and Ajakaiye, 1987).

The Nigerian Gravity Standardization Network 1984

A national gravity network has been established in Nigeria by Osazuwa and is known as the Nigerian Gravity Standardization Network of 1984 (NGSN-84) (Osazuwa, 1995a, Odumosu 2019) consisting of seventy four (74) points; but consolidatory efforts towards its nation-wide densification and subsequent maintenance were lacking (Osazuwa, 1995b, Nwilo 2013). The reciprocating effects of this neglect resulted in:

1. Physical destruction / inaccessibility of some of the national gravity reference stations (Osazuwa, 1995a, Nwilo, 2013)
2. Vertical and horizontal movements over the years leading to alteration of gravity values at base stations (Ajakaiye et al, 1989; Osazuwa, 1995a; Oluwafemi et al, 2018)
3. By implication of the first two identified problems, changes in the parametric integrity of the national gravity reference stations.
4. Due to wide apart station distribution, data observational criteria and subsequent reduction techniques used by various observational crews were inconsistent leading to inhomogeneous data sets (Osazuwa, 1993; Nwilo, 2013)

Consequent upon these identified issues, it has become scientifically impossible to develop any physically meaningful national geoid or carry out homogenous gravity observations across the country without a modernization of the NGSN-84. Furthermore, since the NGSN-84 is already older than ten (10) years, it suffices that the network be reviewed on the basis of the internal consistency of the points and the overall parametric integrity of the network in accordance with international best practice (Osazuwa, 1995a; Bamisaye, 2019; Odumosu, 2019).

The establishment of such a well defined national gravity reference network will not only help resolve the issue of a national geoid, but will also contribute immensely in improving the prospects of geophysical exploration across the country (Idowu, 2007) as well as provision of the needed gravity values for the computation of orthometric heights of leveling networks rather than the normal-orthometric values presently in use across the country (Isioye et al, 2010; Odumosu et al, 2015)

In this paper, the results of the preliminary adjustments for the establishment of a statewide gravity network in Lagos state called the LAGGNET 2017 is herein presented.

Study Area

Lagos State is a Low-lying coastal state having a fairly stable terrain with minimal undulation and an approximate landmass area of about 3600 Sq km. Bounded in the South by the Atlantic Ocean and the Lagoon; several other tributaries from the Lagoon extend into the state some of which include the five cowries, the Iddo Port, Apapa port amongst others. Being the host state where the nation's vertical datum (Apapa Datum) is established, most control points within the state have spirit leveled elevation differences observed on them but gravity observations were not observed. The state also plays host to three absolute gravity stations (Figure 1) all established as part of the IGSN but one re-established as part of the NGSN network (Table 1). Unfortunately most of the gravity controls are gone except 03663L which is located inside Muritala Mohammed International airport in Lagos.

Materials Used

The materials used for this study are:

1. A scrintrex CG-5 gravimeter for relative gravity measurement
2. An aneroid barometer for atmospheric pressure measurement
3. Handheld GNSS receivers for tracking control points
4. The coordinates of the selected control points obtained from the office of the Surveyor General of Lagos state.

Method for Preliminary Adjustments of Gravity Observations:

The establishment of a regional gravity network depends basically on: (i) development of appropriate mathematical models based on network configuration/geometry (ii) preliminary and post processing estimation (iii) assessment of optimal method for estimation and (iv) assessment of quality mathematical models and optimization criteria (Peneva et al, 2015). The preliminary estimation consists basically of the controls reliability test, drift correction, instrument calibration, earth's and ocean tides correction, local latitude correction and atmospheric pressure correction. In this work, results of the instrument calibration correction and ocean and earth tide loading are not presented.

The basic formulae used in this preliminary study for evaluating the other adjustments carried out are:

Control reliability using the Gauss marcov covariance estimation approach

$$(C_v) = \sigma^2{}_0 \, Q_{L^a} \quad (2a)$$

$$\sigma^2{}_0 = {V^T PV}/{r} \quad (2b)$$

Where:

V = Observational Residuals

r = Number of conditions

$$Q_{L^a} = P^{-1} - P^{-1}B^T M^{-1} B P^{-1} \quad (2c)$$

Table 1: IGSN-71 stations within Lagos state state.

IGB Number	Locality	Latitude (deg)	Longitude (deg)	Altitude (m)	Gravity Value (mgal)	Standard Error (Microgals)
03663B	Lagos	6.447	3.398	6.000	978121.630	0.030
03663K	Lagos	6.583	3.330	39.000	978114.660	0.030
03663L	Lagos	6.585	3.330	38.000	978114.270	0.031

Adapted from Morelli et al, 1972 and Bureau Gravimetrique International (BGI) website (2016)

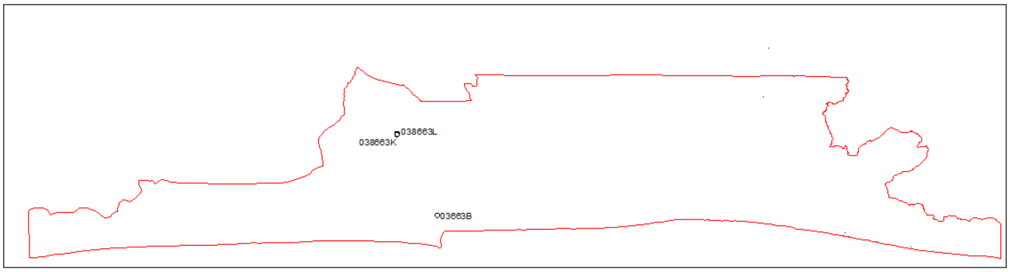

Figure 1: Study area and the IGSN stations.

Before implementing the gauss marcov functional error analysis model, observation equations based on the baseline condition between successive points was used formulated (Ogundare, 2019; Even-Tzur & Shahar, 2015).

The baseline equations were formed using a single constrained loop system wherein the control point YTT17/11 was taken as base. Example of the baseline condition formed is as given in equation (2d).

$$X_B = X_A + \Delta X_{AB} + V_{\Delta X_{AB}} \qquad \text{(2d (i))}$$

$$Y_B = Y_A + \Delta Y_{AB} + V_{\Delta Y_{AB}} \qquad \text{(2d (ii))}$$

Drift correction

$$D(t) = d_1(t - t_0) + d_2(t - t_0)^2 + \ldots\ldots \qquad (3)$$

Observed gravity changes as a function of time at a given location, these changes are due to tidal effects, instrument drift, and in some cases real changes (e.g. motions on faults, swelling magma chambers). Tidal effects have a period of roughly 12 hours and on Worden gravimeter drifts the rate is about hundreths of a milligal per hour. However for the Scintrex CG5 used in this research, drift is at a much lower rate and typically it is automatically set to take care of tidal correction internally. Therefore drift is internally taken care of by the instrument during field observation.

Latitude correction

$$(g_{\emptyset}) = 0.811 \sin(2\emptyset)\ mgals/km \qquad (4)$$

Atmospheric pressure

$$\text{correction} = 0.3\mu gals\ hpa^{-1}\ (P_z - P_0) \qquad (5)$$

Where

Pz = atmospheric pressure at station with elevation z

Po = atmospheric pressure at mean sea level.

$$P_0 = 1013.25\ (1 - \frac{0.0065 * z}{288.25})^{5.2550} \qquad \text{(5b)}$$

Observational Scheme

The observational network is as shown in Figure 2. The step observational procedure is proposed for the network using the airport station (03663L) as the base station. However, the gravity observations presented in this paper were observed along what we called the Yaba – Onipanu calibration line comprising of four control points namely (YTT28/185, YTT28/201, MCS228s/a and MCS 229s/a).

Results

Table 2 shows the results obtained by the use of the Gauss Marcov model for determination of variance between obtained and adjusted coordinates of the control points selected as part of the LAGGNET 17

The observation was done within 77minutes and a simple algebraic equation was used to model the drift. Results obtained after drift, latitude and atmosphere corrections are as presented in table 3.

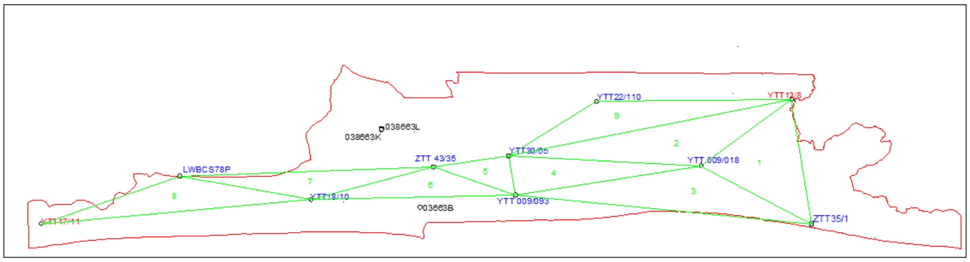

Figure 2: The proposed Lagos Gravity Network 2017 (LAGGNET 17)

Table 2: Error propagation analysis for the proposed control stations

	Adjusted Values (Standard error = 0.0051)			
Station ID	**Eastings (m)**	**Std_Deviatn**	**Northings (m)**	**Std_Deviatn**
YTT 17/11	470236.746		709273.491	
LWBCS 78P	497230.764	± 0.0051	718568.848	± 0.0051
YTT 18/10	522755.213	± 0.0066	713978.946	± 0.0066
ZTT 43/35	546627.925	± 0.0066	720349.084	± 0.0066
YTT 30/65	561240.484	± 0.0078	722486.728	± 0.0078
YTT 22/110	578378.410	± 0.0078	733101.650	± 0.0078
YTT 009/093	562602.498	± 0.0088	714876.925	± 0.0088
YTT 009/018	598700.533	± 0.0088	720584.187	± 0.0088
YTT 13/8	616339.142	± 0.0097	733512.477	± 0.0097
ZTT 35/1	620236.413	± 0.0097	709223.942	± 0.0097

Table 3: Summary of drift, latitude and atmospheric pressure corrections

Statn ID	**Locality**	**Time**	**Drift corr**	**Lat. Corr (mgals)**	**Atm Corr (mgals)**
YTT28/185	Yaba	3/25/2017 9:06		0.0010	0.0096
YTT28/201	Jibowu	3/25/2017 9:19	0.0090	0.0010	0.0190
MCS228s/a	Fadeyi	3/25/2017 9:26	0.0138	0.0010	-0.0094
MCS229s/a	Onipanu	3/25/2017 9:39	0.0227	0.0010	-0.0063
MCS228s/a	Fadeyi	3/25/2017 9:47	0.0283	0.0010	-0.0094
YTT28/201	Jibowu	3/25/2017 10:04	0.0400	0.0010	0.0280
YTT28/185	Yaba	3/25/2017 10:23	0.0531	0.0010	0.0096
Drift Rate =	**0.0007**	Total time elapsed = 77mins			

The drift curve and an overlay plot of the uncorrected and drift corrected gravimeter readings are also shown in Figure 3.

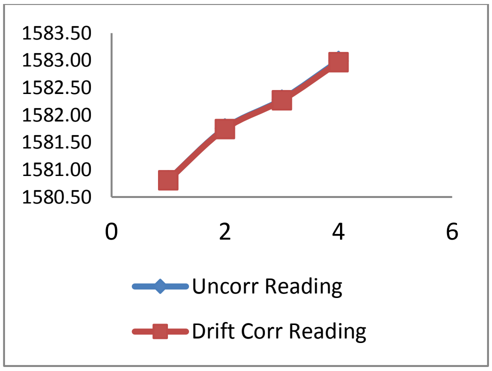

Figure 3(a): Overlay of uncorrected and drift corrected readings

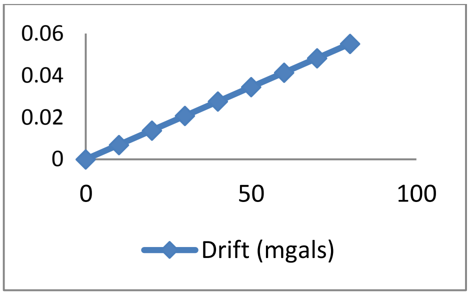

Figure 3(b): Drift curve

Discussion of Results

From table 2, we see that the control points selected have high level of horizontal reliability with a standard error of 0.0051m in horizontal position. This shows that the stations have sub-millimeter level horizontal accuracy which makes them suitable positions for geodetic use. Besides, it is observed that the standard deviations increase as the points move away from the adopted computational origin or base

(YTT17/11). This is due to the single constrained adjustment performed on the network. A double constrained adjustment might produce improved results.

From Figures 3a and b, we see very minimal drift which is quite unnoticeable in the overlay plot and a maximum drift value of 0.06mgals in 80mins (a drift rate of 0.0007mgals/minute). This confirms manufacturers claim that the scrintrex CG5 gravimeter has very minimal drift which is automatically compensated within the instrument during use.

Table 2 also shows that latitude corrections are 0.001mgals within the observed line. The negligible value of latitude correction is expected since the study area is within the equatorial regions and latitude correction is expected to increase proportionally with latitude.

The atmospheric pressure correction is however found to be significant as the values range from -0.009 to 0.027mgals. This therefore suggests that neglect of atmospheric pressure in gravity observations could result in significant errors.

Conclusion

Preliminary adjustments for the establishment of a Lagos state gravity network (LAGGNET) have been presented. Control suitability test on the selected control points show sub-millimeter accuracy standards of the control positions. The drift rate of the gravimeter has also been computed to be 0.0007mgals/minute while atmospheric pressure and latitude corrections have been computed along the Yaba – Onipanu calibration line presented in this report. Significant values were obtained in the atmospheric pressure correction computed along the baseline presented. It is therefore recommended that atmospheric pressure correction must always be applied whenever gravity observations are to be conducted especially in the temperate and humid regions. Owing to the rise in seismic activities emerging in several parts of the country as a result of likely re-awakening of the Ifewara-Zugeru fault-line, the establishment and subsequent maintenance of this (Yaba – Onipanu) calibration line is an essential geodetic infrastructure. Consequently, Geodynamic and Geospatial related professional bodies within the region should take advantage of this for regular gravity observations for mineral exploration and subsurface deformation modelling.

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