Adequate Geodetic Infrastructure:
The First Step to Sustainable Development

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SUMMARY

Sustainable development is the development that meets the need of the present without compromising the ability of future generations to meet their needs. It is a pattern of resource use that aims to meet human needs while preserving the environment so that these needs can be met not only in the present, but also for generations to come. To continually meet the needs of the present generation means that there must be continued economic growth. Economic growth in turn must ensure that minimum damage must be done to the environment. Land is one of the most important economic assets, it supports all human activities and provides energy, food and raw materials needed for human existence and must therefore be judiciously and efficiently managed. This judicious and efficient management of land is a matter of sustainability. Land management can never be effective if an adequate geodetic infrastructure is not in place. Geodetic infrastructure comprise of both the horizontal and vertical coordinate systems. It is therefore paramount that for land to be effectively managed in any country, the 3D Geodetic Network of that country has to be efficient. This involves the establishment of the horizontal networks as well as the vertical. The horizontal coordinate system in most countries seems to be more developed than their vertical counterpart. This is partly due to the relative ease in the establishment of the horizontal system and partly due to the enormous cost of the vertical network. The establishment of the vertical network can be made easier with the availability of a Geoid Model. In recent times, the capabilities of Space Geodesy allow for the establishment of the Global Geoid Models, but Regional Models affords better accuracy than the Global. This paper looks at the establishment of a Regional Geoid Model as a way of establishing an adequate geodetic infrastructure which will in turn engineer adequate planning and promote the sustainability of our development. It adopts the GPS/Levelling method of Geoid determination which is a less costly and easier method. It is recommended that in order to achieve sustainable development, it is very important for the geodetic infrastructure be developed as a foundation for other developmental projects.

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1. INTRODUCTION

The history of Sustainable Development dates back to the period when man understood what comfort and comfortableness means. Man has always been a complex creature and has over the centuries described himself in different ways. These descriptions include a political animal, a social animal, a competitive animal, and many others. These descriptions altogether points to the fact that man is a being that seeks comfort. Comfort within himself, with fellow humans and indeed with his environment. It is in the spirit of this comfort that humans started to seek ways to feel at home and comfortable in their planet, Earth. This need, or better put, desire gave rise to the construction of houses for shelter, construction of roads for communication and transportation, construction of bridges, dams, invention of electricity, discovery of the process of mining and oil exploration, just to say the least.

These developmental efforts to better his environment made man to start utilizing some of the materials available in his environment and suddenly he realized that these materials are exhaustible. In order to manage these materials, which are vital to his continued comfortable existence, he started to think of how to achieve comfort in the present and also enjoy comfortability tomorrow. This then developed into the idea of sustainable development. This sustainable development is what Akindoyeni (2011) defined as development that meets the need of the present without compromising the ability of future generations to meet their own needs.

While enjoying this wonderful environment, man then had the need to determine the shape and size of his planet the Earth. He started engaging in measurement processes, using stones, ropes, metals, chains, tapes and E.D.M. He furthermore started generating models in order to define the extent (size) and shape of his Earth. This in its development over the years gave rise to the discipline known as Geodesy. Geodesy has lots of definitions but is basically the branch of science that studies the shape and size of the Earth and its gravity field in a time dynamic space. To be able to do that, it was expected that some problems will be addressed. Some of these problems are the ability to define position and to get an accurate model of the earth surface. It is the science of accurately measuring and understanding three fundamental properties of the Earth: its geometric shape, its orientation in space, and its gravity field as well as the changes of these properties with time (BESR and DELS, 2010). To be able to do this, a geodetic framework needs to be put in place. This framework provides not only an accurate and efficient means for positioning data, but also provides a uniform, effective language for interpreting and disseminating land information (NRC Panel on Multipurpose Cadastre, 1983). This infrastructure is a fundamental part of a Geodetic Infrastructure.

2. SUSTAINABLE DEVELOPMENT

According to Akindoyeni (2011), sustainable development is a pattern of resource use that aims to meet human needs while preserving the environment so that these needs can be met not only in the present, but also for generations to come. It defines development that meets the needs of the present without compromising the ability of future generations to meet their own needs. In practice, the concept is very difficult to define exactly (Field and Field, 2002). According to Atilola (2003), sustainable development is a dynamic process.

To continually meet the needs of the present generation means that there must be continued economic growth. The economic growth in turn must ensure that minimum damage must be done to the environment. In general, the supply and quality of major consumables and input into our daily lives and economic production must be considered and taken care of. These include shelter, air, water, energy, food, raw materials, land and environment. Land is a very basic resource, which can hardly be renewed without adverse consequences (Atilola, 2003). This judicious and efficiently management of land is indicated in Magel (2001) as a matter of sustainability. Yeh and Li (1996) in Atilola (2003) indicated that land supports all human activities and provides energy, food and raw materials needed for human existence and must therefore be judiciously and efficiently managed.

Kiehl (2001) in Magel (2001) indicated that sustainability is a continuing process without finally determined problems and aims. This is why the mandate of sustainable action is in the first instance a mandate to pause, to reflect and to discuss values and guiding concepts. Reflection and contemplation must lead to future orientated and well grounded proposals and, it is to be hoped, to be the necessary changes in the behavior of people (Magel, 2001)

Atilola (2003), analyzing the importance of sustainable development to the environment, indicated that the areas of urbanization, infrastructure and utilities, solid waste and health facilities, land degradation, coastal degradation require serious attention. This is in support of the important sectors listed out by Magel (2001) as secure tenure, access to land, land administration and land management including land use, land registration, cadastre and many uses. Most rural and urban areas of many developing countries are currently not being developed and managed in a sustainable manner; the degree of non-sustainability may differ from place, programme of action for the planning, development, monitoring and management of the built environment. For this purpose, adequate Geospatial Information (GI) is needed on the location and quality of the existing infrastructural network as a starting point for initiating improvements (Atilola, 2003). To this fit, Magel (2001) pinpointed that it is very clear from all indications that sustainable land development and management are not possible without the fundamental contributions of Surveyors (the Geodesist).

As indicated for the Oil/Gas Industry, surveying and mapping constitutes the bedrock of all socio-economic development and national security (Fubara, 2011). Surveying and mapping which depend on geodesy, and geodetic infrastructure, precede every human/societal developmental activity. Surveying and mapping precede all land acquisition for all industrial and commercial ventures, agriculture, dams, construction industries, roads and highways, pipelines and power lines, political/administrative boundary to maintain peace, transporting, military logistics, etc. Other areas of involvement include population census, location of voter's registration centers, voting units and attendant material distribution logistics. Then there are hydrographic and hydrodynamic surveys for flood and erosion control, land reclamation, dredging of waterways and habour maintenance, all of which depend on geodesy (Fubara, 2011). It is then imperative to affirm the view of Olekannma (2011) indicating that there cannot be any meaningful development without the invaluable contributions of Surveyors.

3. ADEQUATE GEOSPATIAL INFRASTRUCTURE

According to Rizos (2009), Infrastructure can be defined as the basic physical and organizational structure needed for the operation of a society or enterprise, or the services and facilities necessary for an economy to function. Geodetic infrastructure includes technologies, techniques, facilities and services to address the mission of modern geodesy. Research in the field of geodetic infrastructure is carried out with the aim of maintaining and developing geodetic reference frames so that the national implementation as a basis for the spatial infrastructure, including Surveying and Mapping, meets its users' requirements for accuracy and integrity at all times (National Space Institute, 2012). This geodetic infrastructure includes what Rizos (2009) defined as Positioning Infrastructure: which is the passive ground marks and the active CORS to support positioning and mapping within a datum. This implies that all the geodetic controls, irrespective of the order, all CORS, and all the technologies and techniques (involved in their establishment) build up to what we call geodetic infrastructure.

For geodetic infrastructure to be sustainable and in turn support sustainable development, it has to be adequate. Adequate geodetic infrastructure is the foundation for sustainable surveying and mapping. It is a geodetic infrastructure that is efficient, precise and most importantly as pointed out by Rizos (2009) addresses the mission of modern geodesy. Efficient infrastructure has a very fine difference with an effective infrastructure. Effective as seen in Scocco (2010) means adequate to accomplish purpose: producing the intended or expected result (irrespective of cost and time) while Efficient means performing or functioning in the best possible manner with the least waste of time and effort (cost). This indicates that for a geodetic infrastructure to be sustainable, it has to be time and cost conscious, yet achieve the desired purpose.

Another important attribute of an adequate geospatial infrastructure is that it has to be precise. In being efficient, it must not sacrifice accuracy to cost efficiency. If a development will be sustainable, it should serve the today's society as well as tomorrow's as seen in Akindoyeni (2011), then the foundation for the development must be precise thereby avoiding duplication of efforts and short-term adjustment and re-establishment. The economy of accuracy needed for the geodetic networks must be adequate and the necessary laws for the protection of the infrastructure must be enforced.

In the words of Rizos (2009), geodetic infrastructure must address the mission of modern geodesy. He further implied that the primary mission of Modern Geodesy can be defined in terms of the three fundamental problems:

- Determination of precise global, regional & local 3D (static or kinematic) positions & surface geometry.
- Determination of the Earth's (time & spatially) variable gravity field.
- Measurement (& modeling) of dynamical phenomena:
  - Solid Earth (including cryosphere): surface deformation, crustal motion, polar motion & earth rotation, tides, mass transport, etc
  - Atmosphere: refractive index (T/P/H), TEC, circulation, etc
  - Ocean: sea level, sea state, circulation, etc.

A geodetic infrastructure that must meet the mission of modern geodesy, must be dynamic, improving with improving technologies. In line with this, the geodetic infrastructure should be aiming at a transformation from classical to modern geodesy. Again Rizos (2009) points out some of the necessary improvements and transformations that geodetic infrastructures should aim at undertaking to achieve the status of adequacy thus:

- From 3-D points and surfaces, to 4-D mapping.
- Increasing time resolution of geodetic measurements & products, from 0.1s position to daily EOP to monthly gravity field models.
- Increasing spatial resolution of geodetic products, from 1m for SAR to 100km for gravity features.
- Increasing accuracy, on both short-term and long-term time scales.
- Increasing reliance on global infrastructure and global services.
- Increasing variety of satellite missions that 'sense' phenomena that also have 4-D geometric and gravimetric signatures or 'fingerprints', requiring cross-mission analysis to ensure 'separability' of Earth processes.

4. THE GEODETIC ISSUE

Olekanma (2011) pointed out that surveying and mapping are very essential for effective management of land resources and this is why the most mapped countries today, are unarguably, the most developed. This assertion was earlier made by Atilola (2010) as seen in Adegboye (2010) stating that the reason the most developed nations in the world are the best mapped is because in those advanced countries, surveying is part of their culture and they cannot move an inch without having the data. This can only be possible where there is a properly defined coordinate frame and coordinate system. Geodetic infrastructural development has the responsibility of developing both the horizontal as well as the vertical coordinate system. However, the vertical coordinate system of most developing countries has been neglected. Whereas the horizontal system has been given a special attention, the vertical counterpart remains either undeveloped or poorly developed.

Owing to the high cost of the establishment of the geodetic controls, especially the vertical system, they seem to be neglected and therefore the geodetic infrastructure becomes deficient. The vertical system is however of paramount importance to surveying, mapping and engineering. In most developing countries, there is an incessant use of Temporary Benchmarks, which is unhealthy and does not support the principle of sustainable development. These temporary benchmarks affect development adversely due to the fact that the vertical coordinates used in different projects are not uniform, and this negates the “whole to part” principle of surveying. It leaves the work hanging and unconnected to the national or regional framework.

One of the certified ways of solving this geodetic problem is the development of a Geoid Model. The geoid is a measured and interpolated surface, and not a mathematically defined surface and the geoidal surface is measured using a number of methods (Bolstad, 2008). Heiskanen and Moritz (1996), while indicating the two major methods of geoid determination as gravimetric and geometric, indicated that the Astrogeodetic methods use the direction of the gravity vector, employing geometrical techniques, whereas the gravimetric methods operate with the magnitude of the gravity vector. The gravimetric method can be classified into space methods and terrestrial methods (Bolstad, 2008). The terrestrial method, which can further be classified into absolute and relative gravimetry, make use of absolute gravimeters such as Sakumo’s Apparatus and the RTK-GPS and relative gravimeters such as the LaCoste-Romberg (LCR GCOOA), Worden and Scintrex CG5 (Biker-Koivula *et al*, 2007).

Considering the advent of the space methods, Hofmann-Wellenhof and Moritz (2005), postulated that immediately after the first launch of artificial satellites (Spunik 1957 and Explorer 1958), their use for geodetic purposes was initiated. Bolstad (2008) indicated that satellite based measurements in the late 20th century sustainably improved the coverage, quality and density of geoidal height measurements across the globe. These satellites employs the principles of Satellite Altimetry, where a short wave electronic ray is sent from a satellite flying over the oceans, vertically down to the ocean surface, reflected there and received by the satellite again. The measured travel time immediately gives the height (H) of the satellite above the ocean surface. Knowing the orbital position of the satellite with respect to the global reference system, we can compute the satellite height (h) above the ellipsoid. Then the difference h – H is the geoidal height N (Hofmann-Wellenhof and Moritz, 2005).

5. NUMERICAL EXAMPLE

The fact that most governments, especially in the developing countries, pay little or no attention to research and development of geodetic infrastructures and that the determination of the vertical coordinate system is very expensive is quite understandable. The GPS, however, provides a way out of this problem. The GPS/Levelling method of Regional Geoid Model determination proves to be an efficient method of providing adequate geodetic infrastructure, especially with regards to the vertical system. Its relative cheaper cost and less tedious operation compared to the conventional geodetic levelling method. The GPS provides the Horizontal coordinates as well as the Ellipsoidal height while the precise levelling provides the orthometric heights. Using equation 1

$$h - H - N = 0$$

$$\therefore N = h - H \qquad (1)$$

This method was adopted for the realization of the Local geoid model of Nnamdi Azikiwe University, Awka. With the model, two interpolation models were used to estimate the orthometric height of twelve stations adopted as estimation points. The interpolation methods used were the Geometric Interpolation Technique given by Heiskanen and Moritz (1967) as:

$$U_k = \frac{(x_2 - x_k)(y_3 - y_2) - (y_2 - y_k)(x_3 - x_2)}{(x_2 - x_1)(y_3 - y_2) - (y_2 - y_1)(x_3 - x_2)} U_1 + \frac{(x_3 - x_k)(y_1 - y_3) - (y_3 - y_k)(x_1 - x_3)}{(x_3 - x_2)(y_1 - y_3) - (y_3 - y_2)(x_1 - x_3)} U_2 + \frac{(x_1 - x_k)(y_2 - y_1) - (y_1 - y_k)(x_2 - x_1)}{(x_1 - x_3)(y_2 - y_1) - (y_1 - y_3)(x_2 - x_1)} U_3 \quad (2)$$

And the Polynomial Regression Method Model D given by Isioye and Youngu (2009) as:

$$H_x = h - N_{EGM\,96} + \delta N \quad (3)$$

Where δN = *corrective term* = $\sum(N_{residual})/n$ and

$$N_{residual} = N_{local} - N_{EGM\,96} \quad (4)$$

Then (3) becomes

$$H_{(x)} = h - N_{EGM\,96} + \sum(N_{residual})/n \quad (5)$$

In place of the $N_{EGM\,96}$, three different Undulations from Global Models EGM 86, EGM 96 and EGM 08 were used.

The interpolated values obtained from the four estimations (three estimations using the Polynomial Regression Model together with the three Global Models; and the Geometric Interpolation Technique) were found to differ slightly numerically, but the root mean square error (rms) of $\pm$0.003 was identical.

With the realization of this model, it is easier to derive the orthometric height of further points and by extension, solve the problem of 3d geodesy. This will reduce the inherent danger from the use of temporary bench marks and arbitrary datums for surveying and engineering purposes.

6. CONCLUSION/ RECOMMENDATIONS

Development in its simplest meaning can be seen as the act of growth or causing to grow. Growth or improvement has to be sustainable since it has been discovered that the resources used for its purpose are scarce as well as exhaustible. For this to be possible, adequate geodetic infrastructure has to be in place. This infrastructure becomes the foundation upon which accurate geospatial information is generated for further planning of developmental projects. Since every other developmental project has to build on the product of surveying and mapping, and the accuracy of survey products depend a great deal on the geodetic infrastructure it is connected to, it is very important that this infrastructure receive a very paramount attention and be seen as the first step to a sustainable development.

It is further recommended, that most developing economies look at the developing of an adequate geodetic infrastructure as a very fundamental need of their developments and adopt the GPS/Levelling method of Geoid Model realization in order to start solving the problems of geodesy in their localities.

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