GNSS CORS, the Bedrock of Sustainable Development[1]

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Abstract

The realization of the objectives of the United Nations' Sustainable Development Goals (SDG) 2030, the First Ten-year Implementation Plan of the African Union (AU) Agenda 2063 and other national, regional and global development initiatives will require a vast amount of fit-for-purpose. Moreover, most of the national socio-economic development challenges articulated in the aforementioned regional and global agenda, such as climate change, natural disasters, water-borne diseases, HIV-AIDS, desertification, food insecurity, etc. do not recognise boundaries and therefore require coordinated multi-national efforts. Finding solutions to these challenges require availability of appropriate, adequate and reliable geospatial information that are based on a consistent, unified geodetic reference system. However, there are more than 50 countries in Africa each with its own geodetic reference system and datum. As a result of these disparate reference frames and associated geospatial information, the planning and execution of cross-border, and even national development projects, is exceptionally difficult. Consequently, concerted global, regional and national efforts are being made to unify reference frames based on the International Terrestrial Reference Frame (ITRF) through a network of continuously operating GNSS reference stations. A review of these efforts in Nigeria and Africa is highlighted in this paper including the potential contributions of GNSS-based geodetic reference frame to sustainable development.

1.0 Introduction

Inadequate geodetic infrastructure has been acknowledged as one of the challenges facing geospatial information management in Africa (Kufoniyi, 2009, UNECA, 2016). The lack of a consistent, common coordinate reference frame has been pointed out many times by Spatial Data Infrastructure (SDI) and Geographic Information System (GIS) professionals working in various parts of Africa who voiced difficulty about not having sufficient ground truth or common coordinate systems for related projects – often they are forced to develop a special coordinate system just for a specific project which has no relation to other projects or national datum. This assertion was confirmed by the 2008 USGS Africa Remote Sensing Study (USGS, 2008), which reported that more than 57% of the respondents of the survey mentioned a lack of current and accurate ground controls

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as one of the key challenges facing their effective utilisation of geospatial information for developmental activities. About the same number of respondents reported that elevation data are not adequate in many African countries. At the moment over 50 countries in Africa have their own individual geodetic system and reference frame with some having two or more systems. It is also known that many private commercial enterprises are setting up own reference frames particularly in the oil industry. Thus, there is a preponderance of inconsistent and inadequate national geodetic controls in African countries. Apart from the fact that the planimetric controls may be based on different coordinate systems, they are usually not unified with the vertical control points whereas many applications such as urban and land management in cities with multi-level buildings require 3D geospatial data.

It is axiomatic to state that development projects requiring community access to (geospatial) information cannot be implemented without national and/or regional spatial reference frame on which to base all these information products. And as indicated in the AU Agenda 2063 "The Africa We Want", African leaders have a pressing need to eradicate poverty and place their countries on the path of sustainable development. This and many other objectives and goals of the AU Agenda 2063 and the post-2015 sustainable development goals (SDG) rely on sound and reliable geospatial information. To be useful however, it is essential that the co-ordinate reference system and its related reference frame on which the geospatial information are based be both uniform and based on modern positioning technology. This has led to the initiation of the African Geodetic Reference Frame (AFREF) project and its national domestication, to unify horizontal and vertical co-ordinate reference frames in Africa to meet the developmental needs of the continent. Similarly at the global level, in recognition of the need for the coordinated production and management of, and faster access to geospatial information for development programmes, the United Nations has established the UN Global Geospatial Information Management (UN-GGIM) initiative to create a formal geospatial information coordination mechanism involving Member States as the key stakeholders. Part of the activities of the UN-GGIM is to facilitate a global geodetic reference frame that would eventually lead to a consistent, well-aligned national, regional and global geodetic reference frame based on the global navigation satellite systems (GNSS).

This presentation attempts an overview of the implementation of continuously operating reference stations in Africa and Nigeria and the potential contributions of this cross-cutting infrastructure to sustainable development.

2.0 Overview of the African Geodetic Reference Frame (AFREF)

2.1 Principle, Objectives and Scope of AFREF

2.1.1 Principle

The primary principle of AFREF is that it is being designed, managed and executed by and for African countries with assistance from the international community. At the same time, data from AFREF contributes to the global pool of GNSS data through the IGS and provides a better understanding of global geodesy and geophysics (Wonnaccot and Nonguierma, 2016).

2.1.2 Objectives

The objectives of the AFREF project at conception are to:

- Define and establish a continental geodetic reference frame for Africa - a network of permanent GNSS stations, operating continuously or otherwise, such that a user anywhere in Africa would have free access to GNSS data and products, and would be at most 1000 km from such stations;
- Establish precise and uniform African Geoid;
- Establish an in-country expertise for implementation, operation, management, analysis and presentation of GNSS data and products;
- Determine transformation parameters between GNSS and ITRF to/from local reference systems;
- Promote the use and application of GNSS technology for Africa's development;
- Identify the necessary geodetic requirements of participating nations and international agencies;
- Promote Africa's development through GNSS and ICT (Information and Communication Technology) products and technology transfer within the continent and at international level.

2.1.3 Scope of AFREF

The scope of the project is as summarized below:

i. Inventory of existing continuously operating reference stations (CORS) GNSS network;
ii. Densification of the existing continuously operating IGS stations in Africa to have at least one GNSS COR Station in every African country such that the network of CORS will form the basis of and act as focal points for the establishment of national GNSS networks and integrated with IGS global network;
iii. Determination of the relationship between the national geodetic systems, GNSS geodetic systems and the ITRF;
iv. Refinement of the transformation parameters necessary to relate the national systems to ITRF;
v. Densification by individual nations by establishing national GNSS networks through either continuously or semi-continuously operating permanent GNSS stations;
vi. On full realisation of AFREF as a programme, every country shall have a CORS GNSS network with capabilities to broadcast differential corrections and other useful products to users;
vii. Development of a more refined geoid model for Africa and the definition of a common vertical datum for the continent which shall also be done on country basis with regional and continental coordination;

viii. For project's realisation, African countries are expected to actively participate by establishing tracking sites, data holding and analysis centres, with the necessary equipments and personnel for smooth and sustainable implementation and management.

2.2 AFREF Progress to Date

As reported by Wonnaccott and Nonguierma (2016), since about 2006, there has been a steady progress with the installation of permanent GNSS base stations in Africa. In 2005 there were 15 IGS approved stations in Africa whereas at the end of 2015 there are approximately 65 stations that contribute data to the AFREF Operational Data Centre (ODC) which was established in 2009. Data from approximately 45 stations is streamed to the ODC on a daily basis although these are not necessarily the same 45 stations each day. Only data that is free to users and openly available is accepted by the ODC. Moreover, many countries have also established a number of CORS in their countries. The increase in contributing stations has been attributed to a large extent, to scientific groupings such as Africa Array, SCINDA, AMMA-GPS, etc. who have co-located permanent GNSS receivers with seismometers, meteorological sensors and so on. In addition, a number of countries have installed their own permanent networks and have made data from these networks available to AFREF through the ODC.
According to the authors, in December 2012, two weeks were identified when data from approximately 50 stations was archived by the ODC. Four processing centres either in Africa or with African affiliations processed and computed a set of static AFREF co-ordinates. The centres involved were:

- HartRAO South Africa;
- SEGAL (UBI/IDL) Portugal;
- Directorate of Surveys & Mapping Tanzania; and
- Ardhi University Tanzania

The combination of the results of these 4 independent computations was done by the Institut Géographique National in France which resulted in a weighted RMS of approximately 3.0 mm in planimetry and 7.5 mm in height for the co-ordinates. The resulting co-ordinates have been computed on ITRF 2008 Epoch 2012 Day 340 23h 59s (GPS Week 1717) and are available on the AFREF ODC (ftp.afrefdata.org) (Figure 1).

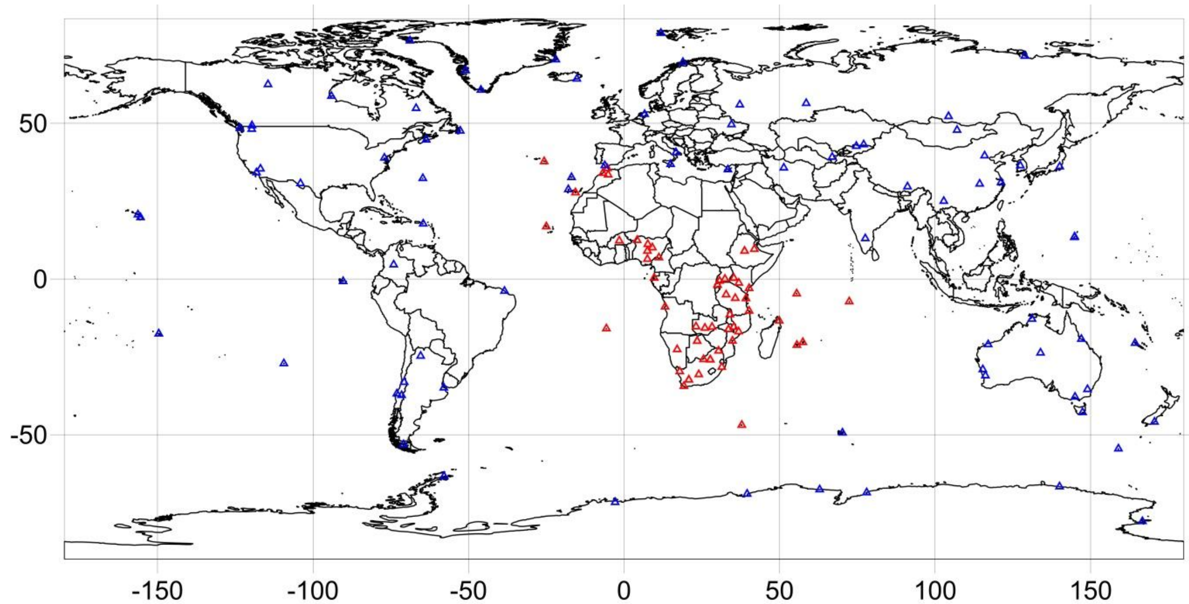

Figure 1 AFREF stations (red triangles) and global stations (blue triangles) used to compute static co-ordinates for AFREF based on ITRF 2008 (epoch 2012.934) (Wonnaccott and Nonguierma, 2016)

3.0 Similar Regional and Global Reference Frame Initiatives

3.1 Other Regional Initiatives

In line with the recommendations of the United Nations/United States of America international meeting on the Use and Applications of Global Navigation Satellite Systems in 2004 (UNOOSA, 2004), other regions of the world such as Europe and South America are also implementing similar projects in a more coordinated manner than hitherto done. Two of these are highlighted in the following sub-sections.

3.1.1 European Reference Frame (EUREF):

In Europe, the EUREF (see www.euref-iag.net) project has become well established since it was started in the 1950's. As at early 2000 it already included nearly 100 permanent tracking stations covering virtually the whole of Europe. It also has a number of receivers outside Europe in North Africa and the Middle East which contribute to the project's data sets. The objectives of EUREF are: the realization of a geocentric reference frame for geodetic geodynamical applications; and the determination of transformation parameters for the national networks. EUREF also includes the implementation of a uniform vertical reference system for Europe which is known as the European Vertical Reference System (EVRS).

3.1.2 South and Central American Geodetic Reference Frame:

In South and Central America, the SIRGAS Project (Sistema de Referência Geocêntrico para a América do Sul) was initiated in October 1993 and includes most South American countries. This has also proved to be a very successful project which now includes a component to define a vertical datum. The initial objectives of the project were to: define a reference system for South America; establish and maintain reference network; and define and establish a geocentric datum.

Similar projects have been established for Asia-Pacific, North America and Antarctica (Wonnaccott, 2005a).

3.2 Global Geodetic Reference Frame (GGRF)

In recognition of the growing global demand for more precise positioning services, the economic importance of a global geodetic reference frame and the need to improve the global cooperation within geodesy, the UN-GGIM decided at its 3rd session in July 2013 to formulate and facilitate a resolution for a global geodetic reference frame (GGRF). The GGRF aims at

- promoting global cooperation in providing technical assistance in geodesy for those countries in need to ensure the development, sustainability and advancement of GGRF;
- facilitating implementation of open geodetic data sharing;
- improving and maintaining national geodetic infrastructure;
- enhancing multilateral cooperation that addresses infrastructure gaps and duplications globally; and
- improving outreach to make GGRF more visible and understandable to society.

4.0 Nigerian Permanent GNSS Network (NIGNET)

In recognition of geodetic network as an essential framework dataset for the implementation of Spatial Data Infrastructure (SDI) at any level, the country has included it as one of the ten fundamental datasets of Nigeria's National Geospatial Data Infrastructure (NGDI), even before the advent of AFREF. Until the year 2006 when the first continuously operating reference station was established in the Regional Centre for Training in Aerospace Surveys (RECTAS) as part of AFREF, all the survey controls in the national geodetic network were passive. As at 1997, there were 600 passive GPS controls, 550 other passive conventional geodetic controls and unspecified number of (many) lower order controls (Federal Surveys Department, 1997). In an effort to provide a unified national geodetic frame for surveying and mapping as well as other national and regional developmental projects, the Office of the Surveyor General of the Federation (OSGoF) commenced the establishment of the Nigerian Permanent GNSS Network (NIGNET) in 2008 and by 2011 the Office has established 11 GNSS Continuously Operating Reference Stations (CORS). By May 2013, the country already has 16 zero-order CORS comprising one (1) established by the Regional Centre for Training in Aerospace Surveys (RECTAS) for AFREF in 2006 and 15 NIGNET stations (11 by OSGoF and three (3) by the Presidential Technical Committee on Land Reform) all strategically located in different parts of the country. The NIGNET stations are shown in Figure 2 (Edozie and Adebomehin, 2013). Many other State Governments have established or are also planning to establish CORS in their respective states as part of their mapping and GIS projects; these include one (1) by Lagos State Government and three (3) by the State Government of Osun.

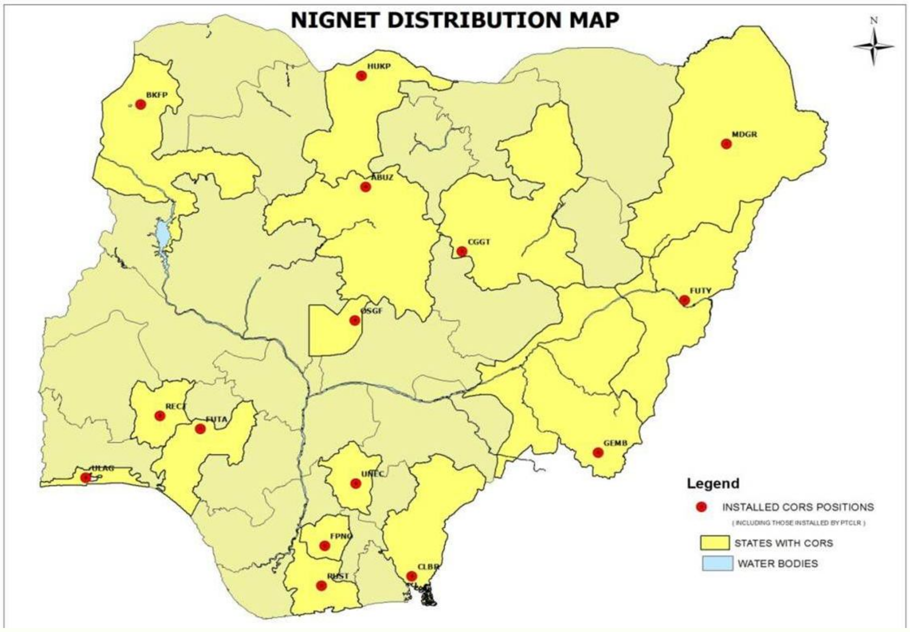

Figure 2: Nigerian GNSS-based Geodetic Reference Network as at May 2013 (Edozie and Adebomehin, 2013)

5.0 Contributions of GNSS CORS to Development

The importance and contribution of GNSS-based geodetic reference frame to national and regional development programmes cannot be overemphasized. In recognition of this, the implementation strategy of the cross-cutting spatial data infrastructure (SDI) initiative at every level has placed great emphasis on geodetic controls and frames by dedicating working groups for them. For example:

- The United Nations Global Geospatial Information Management (UN-GGIM) initiative has a working group on Global Geodetic Reference Frame (GGRF), created in January 2014 to develop a global geodetic roadmap for the GGRF among other activities;
- The African cluster of the GGIM (UN-GGIM:Africa) has African Geodetic Reference Frame (AFREF) as one of its working groups. The GGIM:Africa declaration further encourages Member States to adopt unified national geodetic reference frames that are consistent with the African Geodetic Reference Frame (AFREF) and the Global Geodetic Reference Frame (GGRF) (UNECA, 2015);
- The ECOWAS Geospatial Data Infrastructure (EGDI) has ‘Geodetic controls’ as part of the terms of reference of its working group on Geospatial Datasets; and
- Nigeria’s NGDI has geodetic control as one of the infrastructure’s ten fundamental datasets and has a working group devoted to it.

Mobile technologies are now playing, and will continue to play a big role in the use of geospatial information for sustainable development and daily human activities. Many of the mobile phones now come with geospatial solutions such as GNSS-based location devices, navigators, trackers and street maps; this will make mobile devices an increasingly important medium for communication, emergency management and location-based services, especially when the devices are equipped to operate in real time with CORS.

Furthermore, the realization of the objectives and goals of the United Nations' post-2015 development agenda – the Sustainable Development Goals (SDG) 2030, the First Ten-year Implementation Plan of the African Union (AU) Agenda 2063 and other national, regional and global development initiatives will require a vast amount of geospatial information, which, for the majority of African countries, are not available and accessible in a usable form by governments and society and are not based on a uniform geodetic reference system. A successful implementation of the national geodetic and AFREF projects has vast potentials in resolving this through its contribution to surveying and mapping, natural hazards mitigation, climate monitoring and weather prediction, earth sciences, security, unique international boundary definition, integrated water resources management, precision agriculture, science and research, infrastructure planning and development (including telecommunications and transportation), and regional integration among others. Indeed, the benefits of AFREF in some of these areas have been addressed in various forums and publications (e.g.: Fajemirokun (2009), Dodo (2009), Wonnacott (2005b), Georgiadou (2004)). Some examples of potential contributions to regional development are however presented in the following paragraphs.

(i) Spatial Data Infrastructure Development: A spatial data infrastructure (SDI) is an enabling framework for the cooperative and participatory production, management and dissemination of geospatial information. SDI enables decision makers and the general community to find what geospatial information exist, where they exist, how to get access to them and how to use them. An accurate geodetic framework is unarguably the first core dataset for a spatial data infrastructure at any level, whether local, national, regional or global. All other fundamental and thematic geospatial datasets are based on a geodetic reference system; and to enable data integration, re-usability and interoperability, a uniform geodetic reference frame is a sine qua non. In other words, it is axiomatic to state that the production of base maps and thematic maps require accurate geodetic framework. Furthermore, to integrate various maps and geospatial data within a country and across two or more countries for planning purposes and other applications, a uniform coordinate reference system is required. To further emphasise this, one of the resolutions of the Geoinformation subcommittee at the second meeting of the UN ECA Committee on Development Information (CODI), later called Committee on Development Information, Science and Technology (CODIST) is that "For regional applications, Regional Spatial Data Infrastructure (RSDI) be established with an African Regional Database as a component, based on a unified African Reference System" (CODI, 2001, p.38). Towards achieving this resolution, ten fundamental datasets have been identified for the regional spatial data infrastructure (See list in Clarke, 2005 and Kufoniyi, 2005). One of the ten fundamental datasets is the regional spatial reference frame which AFREF constitutes.

(ii) Aerial and Satellite Mapping: AFREF and national CORS are particularly essential for airborne and satellite remote sensing for accurate geo-referencing of images before extracting information from the images for the production of the fundamental datasets for national and regional SDI's as well as for the integration of the extracted information with other vector-based geospatial datasets. Moreover, satellite positioning techniques have the potential for long-term climate monitoring, ground-based weather forecasting, and marine and coastal activities and management. Low-earth orbiting satellites and airborne digital aerial camera with on-board GNSS receivers working in real-time differential mode with national and AFREF COR Stations will also contribute to mapping with minimum ground controls thus leading to faster production of the fundamental datasets (Kufoniyi, 2011).

(iii) Water Resources Management: Regional integrated water resources management initiatives such as the TIGER Africa project (http://www.tiger.esa.int) of the European Space Agency (ESA), the African Water Cycle Initiative being championed by the Group on Earth Observations (GEO), the African Water Information Clearinghouse of the UN ECA and AU (Africa Union), and the UNESCO Water Projects in Africa are all focussing on the use of Earth observation systems for the efficient and integrated management of water resources in Africa. A consistent geodetic reference frame expected to be provided by AFREF and national CORS underpins the success of these various initiatives. For instance, central to all the initiatives are the trans-boundary river basins (such as Nile, Niger and Volta) and lakes (such as Chad and Victoria) which require that Earth observation data covering the entire basin (cutting across many countries) are consistently available for the basin's sustainable operations to supply appropriate water for the various sectors of the national economy of the member states.

(iv) Regional Development Initiatives: Many other regional development initiatives such as the African Monitoring of the Environment for Sustainable Development (AMESD) (see www.amesd.org), the Africa component of the EU Global Monitoring for the Environment and Security (GMES-Africa) (see www.gmes.info), as well as global initiatives such as the Global Mapping Project (www.iscgm.org), the World Summit on Sustainable Development (WSSD) goals (http://www.un.org/summit/html/documents/summit_docs.html), the African Observatory of the AUC/EC Light House Projects (See http://www.uneca.org/codist/codist1/content/E-ECA-CODIST-1-L-EN.pdf), the nine societal benefits (disasters, health, energy, climate, water, weather, ecosystems, agriculture and biodiversity) of the Global Earth Observation System of Systems (GEOSS) (see http://www.earthobservations.org) and the follow-up GEO 2015-2025 goals, the African Union Agenda 2063 and the SDG all require availability of a consistent regional geodetic reference frame. Hitherto, countries have traditionally maintained their own reference frames resulting in maps which cannot be edge-matched properly at the borders. This increases the potential for conflicts and makes it difficult for countries to share information and to implement joint regional trans-boundary projects as information on one country's maps could not be easily referenced to that on another country's maps possibly leading to a situation exemplified by Figure 3. This creates an obstacle to regional integration where maps that are continuous across national boundaries are required for security, environmental management, trade and industry, and other developmental activities. This problem is expected to reduce upon realisation of AFREF and national CORS and implementation of the African Regional Spatial Data Infrastructure such that instead of the hypothetical example given in Figure 3, we would end up with the example in Figure 4.

Source: http://www.geod.nrcan.gc.ca

Figure 3: Hypothetical Case of using geospatial information based on different geodetic reference systems to plan a trans-national infrastructure project

Figure 4: Hypothetical case in Figure 3 now based on a unified reference system.

(v) Volunteered Geographic Information (VGI): Another potential contribution is in VGI where volunteers have been using GNSS to collect geospatial data for the updating of fundamental datasets, production of geocoded Statistical information and production & updating of thematic maps. Examples of successful VGI platforms include the OpenStreetMap (OSM), Google Earth /Google Map Maker, Wikimapia, Wikimapia, TomTom, GeoTweet, Ushahidi and Flickr.

(vi) Contribution to Earth Sciences: GNSS also has great potential contributions to Earth sciences as the technology is widely used to monitor crustal deformation phenomena such as earthquakes, volcanoes, plate tectonic motions and subsidence.

(vii) Application in Systematic Land Tenure and Registration: The importance of an efficient land administration (LA) system for achieving sustainable development goals has been recognised by many national and global development initiatives because land is a cross-cutting fundamental resource. It has also been acknowledged that the countries with proper system of land registration thrive in business than the countries with less efficient registration system. However, over 70% of the world's people-to-land relationships are not documented and are outside the formal land administration domain (Enemark, 2013). For example, since formal land registration began in Nigeria in 1883, not more than 3 per cent of the land in the whole country has been registered in 130 years of its commencement, according to a report of Nigeria's Presidential Technical Committee on Land Reform. Thus it is universally acknowledged that land administration system (LAS) needs to undergo modernisation in order to fit into national SDIs to enable sharing of information on land, its ownership and use across all government departments and agencies. To achieve these, a fit-for-purpose LA approach of Systematic Land Titling and Registration (SLTR) has been recommended by the World Bank, the International Federation of Surveyors (FIG) and other global LA players. The fit-for-purpose approach recommends the use of 'general boundaries' without monumentation to identify the delineation of land rights (Lemmens et al., 2015) as it is thought that establishing survey coordinates and monumentation for an entire country undergoing SLTR is not economically sensible.

But as argued in Kufoniyi (2015), establishment of survey coordinates and monumentation should be encouraged where continuously operating reference stations (CORS) have been already installed and operational. This will help to 'move from approximate boundary representation towards survey-accurate boundary representation' and facilitate 'expansion from 2D cadastre to include the third (height) and fourth (time) dimensions' thereby enhancing faster realisation of two of the six design elements recommended for land administration by Bennett, *et al* (2010). Again, as indicated in LA literature, for a sustainable SLTR, boundaries of registered land are expected to be captured in terms of unambiguous system of geodetic reference that supports demarcation of the boundaries of the registered land should a boundary dispute arise in future. Consequently, many of the land administration/reform initiatives being undertaken in African countries have the installation of CORS as component (e.g., Burkina, Ghana, Benin and Nigeria). This should be encouraged in subsequent LA programmes because adoption of GNSS CORS technology has made it marginally cost effective to produce georeferenced cadastral plans in conformity with technical regulations subsisting in the countries as reported by countries that have installed CORS prior to their LA programme. From practical experience, the difference in time taken in establishing the coordinates of the boundary points using CORS will not be significantly much, compared with what will be gained by having a complete demarcation and survey. With this approach, the cadastral dataset will be ready to be a component of the fundamental datasets of the national SDI.

6.0 Recommendations and Concluding Remarks

An overview of GNSS-based continuously operating reference frame and its potential contributions to national, regional and global development has been highlighted in this paper. The success of consistent national and regional geodetic reference frames will definitely lead to rapid and sustainable development of the African continent due to the cross-cutting role of harmonized geodetic networks. In order to achieve this, it is necessary to intensify the implementation of AFREF as well as the national geodetic reference frames especially in the central and northern African sub-regions. As indicated earlier, many countries have established CORS apart from those established under the AFREF project; therefore, immediate inventory of the already established CORS in every country is required to confirm the current status. This can then serve as input for the design of a regional continuously operating geodetic network. The regional design is necessary to optimize the design of national networks. Similarly, the national network design should guide the second administrative levels (states, regions, districts, provinces, etc.) in locating CORS in their jurisdictions.

Thus, if AFREF is to succeed and remain sustainable, increased coordinated efforts including formulation of a broad project plan are required at both national and regional levels. Such a plan must include the aforementioned identification and endorsement of potential sites for permanent GNSS stations by the national scientific advisory group (at country level) and the International AFREF Scientific Advisory Group (at regional level), taking note of the primary objective of AFREF. The plan should also include further densification of national CORS to have stations within 50km to improve accuracy for cadastral mapping by imagery and GNSS and other high-accuracy mapping

International and national development programmes that include establishment of CORS (such as the national land reform programmes being undertaken in various countries) should implement this part of the project in close collaboration with the AFREF Secretariat and its national counterparts. The development of AFREF and the national CORS should be compliant with the UN General Assembly Resolution 69/266 of 2015 – A global geodetic reference frame for sustainable development. This includes improving and maintaining appropriate national geodetic infrastructure and sharing geodetic data openly.

Since the infrastructure of a network of permanent GNSS base stations required to realize the geodetic objectives of AFREF can be utilized for other disciplines and applications such as atmospheric and geophysical research and applications, air and road navigation, and disaster mitigation and monitoring, organizations and individuals active in these non-traditional fields of GNSS application should be encouraged by the AFREF implementation committee at national and regional levels to play an active role in AFREF so as to leverage funds, equipment and technical support in an effort to spread the responsibility and interest in the project.

Furthermore, a dedicated budget for the running of the network of continuously operating permanent GNSS stations has to be set aside by countries hosting such stations. Much of the running cost is required for communication (especially internet), power supply and general maintenance while noting that internet and power supply must be provided uninterruptedly.

To put the existing CORS and other future stations into effective use in Nigeria, a data policy (including cost of data and access protocol) has to be quickly finalized. It is also expedient to formally establish the national data centre in OSGoF such that the different stations would be obliged to continuously stream their data for the computation of the national geodetic frame at regular epochs. We also need to decide on the geodetic datum and ellipsoid to adopt (e.g. to adopt WGS 84 for both planimetry & altimetry) while surveyors should be encouraged to start utilising the stations for survey operations including cadastral surveying.

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