

# An Assessment of the Existing Continuously Operating Reference Stations (CORS) in Nigeria: An Exploration Using Geographical Information System (GIS)

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**Abstract** The modernisation of the Global Navigation Satellite Systems (GNSS) has brought about significant changes in the methods of positioning and navigation. More recently, countries are adopting the continuous observation and measurements using a network of GNSS receivers called Continuously Operating Reference Stations (CORS) as the standard. For example, Nigeria has established 11 permanent GNSS Network (NIGNET) or CORS since 2008, which has provided the incentive for the adoption of the geocentric datum in all its geodetic activities. Unfortunately, the spatial coverage of the Nigerian CORS stations on a distance of more than 300km (between the stations) seems inadequate based on the global station densification standard of the International Terrestrial Reference Frame (ITRF). This study explores the CORS network and determines the suitability of improving the density of the existing CORS stations with a view to extending their spatial coverage in Nigeria. Data obtained from various sources are processed and analysed using buffer and Digital Elevation Model (DEM) techniques. The result shows that the existing CORS stations in Nigeria only covers about 25% of the country. Therefore, the study proposes new CORS stations that improve the distribution and the spatial coverage of the existing stations (to about 96%) in line with the ITRF's standard.

**Keywords** CORS, AFREF, Nigerian Geocentric Datum, GNSS, NIGNET

## 1. Introduction

The establishment of survey control points involves the transfer of the control points closer to the site of the survey, which provides a geospatial data infrastructure in the area, and also assist the user with an easy access to reliable controls. Survey control points helps in the sustainable management of spatial data [1] and also plays a vital role in Navigation, Geodetic Surveying, Mapping, Photogrammetry, Civil Engineering and Geographic Information Systems (GIS). This present study investigates the existing surveying control points used in Nigeria and offers recommendations to improve their spatial coverage.

The national mapping of Nigeria relates to the old systems of surveying (basic surveying procedures), which depended on using chains, the odolites and traversing techniques to establish the primary triangulation network of the country in the 1960s [2]. These traditional survey control systems are referenced to a non-geocentric datum (based on Clark 1880 ellipsoids) referred to as the Minna

datum (L40) [2]. The L40 datum, which is regional in nature, has the following adopted geodetic co-ordinates; Latitude  $\phi = 09^{\circ} 38' 09''$  N, Longitude  $\lambda = 06^{\circ} 30' 59''$  E, Height  $H = 279.6\text{m}$  above the geoid [3]. The old survey technique faces some deficiencies such as the absence of Geoidal height model [4]. The Geoidal height model is a mathematical model of the earth that uses gravity measurements to correspond with the mean ocean surface level on the earth [5]. Another deficiency that the old survey technique faces is that of transformation parameters, which involves the shift from one datum to another (local datum to global datum and vice versa). These are difficult to determine due to the old methods used in establishing the datum [5]. This suggests that there is a need for an upgrade (of the old survey techniques) to improve the accuracy of surveys and mapping activities in Nigeria for suitable and sustainable development.

The adoption of geocentric coordinate frames as a national geodetic datum has now become the common trend [2] in both developed (for example, United States of America (USA), United Kingdom (UK), Austria) and developing countries (for example, South Africa and Kenya). For example, the space based technology made it possible using satellite to establish geocentric datum [2]. The high level of developmental activities in Nigeria in the

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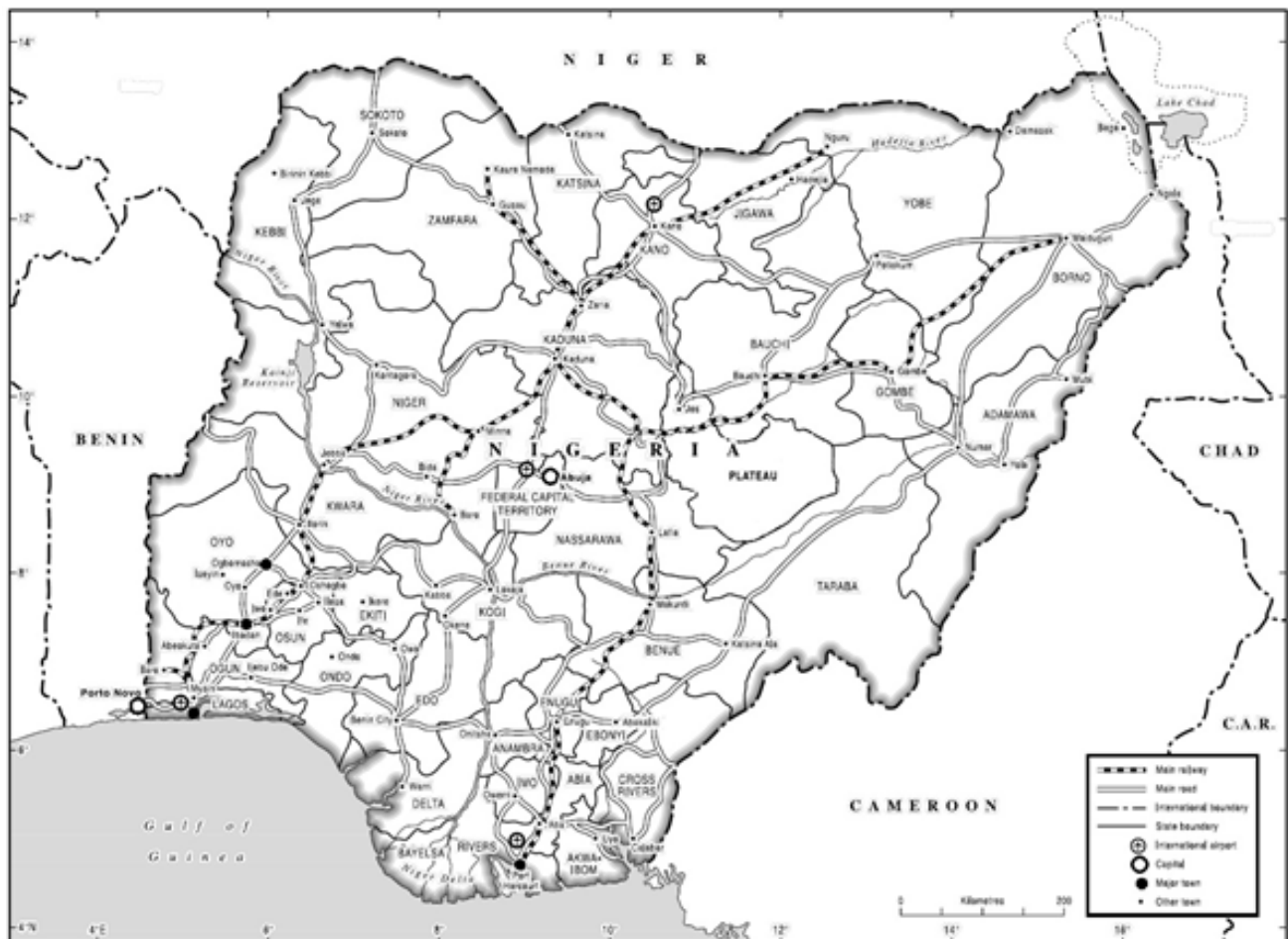
areas of construction, power transmission, mechanised farming and so on, suggests the need to expand and update the Nigerian Primary Geodetic control Network (NPGN), and employ the geocentric datum that are commonly used in other countries. This will provide an avenue to meet up to the world standard, as well as to satisfy user's high expectations (engineers, town planners, surveyors, geographers etc.). Even though, Nigeria has already established 11 permanent GNSS Network (NIGNET) of Continuously Operating Reference Station (CORS), this study examines the spatial coverage of these existing CORS network (as part of the Nigerian Geocentric Datum (NGD)), with a view to suggesting ways of improving their standard in line with the International Terrestrial Reference Frame (ITRF).

### 1.1. Geographical Location of Nigeria

Nigeria lies between latitudes 4 ° and 14 °N and longitudes

2 ° and 15 °E, and is located in the western part of Africa [6]. The country has a total area of about 923,768km<sup>2</sup> making it the 32<sup>nd</sup> largest country in the world [7]. It shares about 4,047km borders with four countries (Benin Republic to the west, Niger Republic to the north, Chad to the north-east and Cameroon to the east- see **Figure 1**). It has a coastline of at least 853 km that stretches along the Atlantic Ocean in the southern border.

Nigeria has a varied landscape; to the southwest of the Niger is a rugged highland and to the southeast of the Benue is the Mambilla Plateau, which forms the highest Plateau in the country. The highest elevation point in Nigeria (2,419metres above sea level) is located in Chappal Waddi in the northern state of Taraba. The country has two major rivers, namely; the River Niger and River Benue that converged in a "Y" shaped valley in Lockjoja, and emptied its waters into the Atlantic Ocean in the Niger Delta area of the southern part of the country [6].



**Figure 1.** Map of Nigeria (Source: Adapted from Porter et al. [8], p.372)

## 2. Background

### 2.1. Continuously Operating Reference Station (CORS)

Nicholas ([8]) defines CORS as Continuously Operating Reference Station, which can take the place of a traditional base station used in differential GNSS positioning. CORS can give an instant high positional accuracy of  $\pm 20$  mm. CORS Network began in 1994 when NGS officially installed permanent GPS receiver in the National Institute of standards and Technology, Gaithersburg Campus, Maryland, and few months later in Colorado, which were later incorporated with three other continuously operating GPS stations that are originally part of CIGNET to become the first five stations in CORS Network ([9 -10]). By 2000, more than 200 CORS stations are installed and incorporated into the NGS' CORS Network. By the first quarter of 2014, the CORS network increased to more than 1,900 sites, which is why it is now regarded as the primary source for geodetic survey community to access National Spatial Reference System (NSRS) data.

CORS networks are now established in different countries and by different organisations due to its high geodetic data accuracy ( $\pm 20$  mm). The development of CORS networks are categorised into three tiers as noted by Rizos ([11], p.10). These are as follows;

- (1) Tier 1 stations are the stations with International Global Service (IGS) grade 1 standards
- (2) Tier 2 stations as National Geodetic Network, and
- (3) Tier 3 stations are networks established by private institutions, state and local agencies.

Schwieger et al. ([12], p.7) noted that the Tier 1 stations are high accuracy stations ( $\pm 20$  mm) with class 1 geodetic receivers and well stabilised antenna monument capable of tracking any Regional Navigation Satellite System (RNSS) and GNSS signals. These stations are used to define and establish global reference frame and are also used in scientific research and geodetic sciences. Similarly, the Tier 2 are also high accuracy stations, but are maintained at state and national government levels. They are also equipped with good quality geodetic receivers and their antennas are stationed on a stabilised monument. They can also track signal broadcast from GNSS and RNSS. These stations are mostly established for the purpose of national geospatial reference frame (geocentric datum). Conversely, the Tier 3 are high stations but with minimum requirements compared to tier 1 and 2 stations. The Tier 3 stations are mostly established by local government, state, private organisations and agencies for positioning purposes. They are also referred to as "fit for purpose" stations. They are equipped with receivers that can track interoperable GNSS and RNSS signals.

CORS stations are now established as networks that define regions at local, continental and global level due to its stability, continuity and effectiveness [9]. However, associations of scientists, geodesists and other earth observing bodies that form the first global reference frame

(consisting of GNSS sites) established specifications for establishing CORS stations across the globe through the ITRF [12]. The ITRF reference systems are made to be a standard for all geodetic and earth science fields (see for example, [13-15]). The main task of the ITRF as noted by Schwieger et al. ([12], p.2) is to "maintain the stability and to provide open access to the geometric and gravimetric reference frames as well as time series of data and products, by ensuring the generation of uninterrupted state-of-the-art global observation". It should be noted that all the stations are situated in open accessible areas (especially public places) to provide security and less obstruction to the sky by tall buildings and trees, which may cause multipath errors and reduces accuracy.

### 2.2. Nigerian GNSS Reference Network (NIGNET)

Reflecting on the geodetic datum (Minna datum (L40) in Nigeria [2], which is not compatible with satellite derived positioning system, suggests that the new geocentric datum (CORS networks) should be adopted. This need prompted the Office of the Surveyor General of Nigeria (OSGOF) to initiate the NIGNET project in 2008 that derive the establishment of the 11 CORS stations in various locations in the country (see for example, [2] & [17]). These stations are coordinated by nine international Global Navigational Satellite System (GNSS) and IGS that are part of the International Terrestrial Reference Frame (ITRF2008) [2].

However, since the establishment of the 11 CORS stations in the country covering only 25% of the country, no attempt has been made to upgrade and extend their coverage. Conversely, developed countries with more CORS stations focuses on both improving the integrity of their CORS stations as well as improving the distribution and density of the spatial coverage of these stations. Such countries include Australia with about 250 CORS stations at regular intervals of between 50km to 100km [11], United States of America with over 1,350 stations (as of 2008) at an average spacing of 70km between stations [9-11] & [18], and United Kingdom with about 110 stations at an average spacing of 60km [19]. Naturally, the availability and spatial coverage of the stations increases the number of IGS stations globally to strengthen the ITRF. Overall, geospatial applications are better with higher spatial coverage (density of the stations), because higher density provides good reception coverage for positioning results, prediction and monitoring of natural disasters.

In 2007, prior to the establishment of CORS by OSGOF, the GPS team of OSGOF obtained the WGS 84 values of L40 (Nigerian Datum) by repeated GPS measurements using differential positioning techniques on the station (L40) [1]. A mean of means was obtained from the measurements and the value was used for adjusting a nationwide surveying campaign that commenced from Minna in Niger state, Nigeria [1]. By the end of 2007, the Regional Centre for Training in Aerospace Surveys (RECTAS) established the first permanent reference station (CORS) in Ile Ife, Ibadan,

Nigeria, which consist of a receiver, an antenna, operating software, site server software for quality control and data analysis (see **Figure 2**). This was done in line with the African Reference Frame's (AFREF) project initiative [20].



**Figure 2.** First CORS station in Nigeria (Source: [20])

The 11 CORS networks in the country are linked with ITRF2008 by acquiring GPS data from nine International GNSS Service stations (IGS) as shown in Table 1 [2]. The new reference frame that this present study is proposing will also be linked with the existing reference frame of Nigeria to enhance understanding and preserve legacy for geospatial data, and will create a platform for use in modern space techniques of positioning [21].

**Table 1.** IGS Stations used

Station ID	Station location	Country	Ellipsoidal Height (m)
HARB	Pretoria	Republic of south Africa	1555.0000
NKLG	Libreville	Gabon	31.4800
RABT	Rabat	Morocco	90.1000
RBAY	Richards bay	South Africa	31.7927
SUTH	Sutherland	South Africa	1799.7659
CAGZ	Capoterra	Italy	238.0000
MAS1	Maspalomas	Spain	197.3000
NOT1	Noto	Italy	126.2000
SFER	Sanfernando	Spain	85.8000

Source: Nwilo et al. ([2], p.5)

NIGNET, which is a tier 1 station, was set up with up-to-date geodetic equipments. The data from these stations are processed at the central station located in Abuja where it is corrected, computed and provided to the users [21]. The optimisation of efficiency is a priority to the system and their location, which are mostly positioned on concrete rooftops for security reasons and signal obstruction [18]. **Figure 3** is one of the 11 CORS and **Figure 4** shows the locations of the 11 existing stations across Nigeria.

The objectives of creating the 11 CORS stations by the OSGOF is to cover the country with a relatively homogenous distribution of CORS stations in order to increase the spatial coverage of the networks and to provide an up to date

networks that are compatible with GNSS, GIS and ITRF based datum [21].



**Figure 3.** Trimble R8- CORS at OSGOF roof top Abuja (Source: [22])

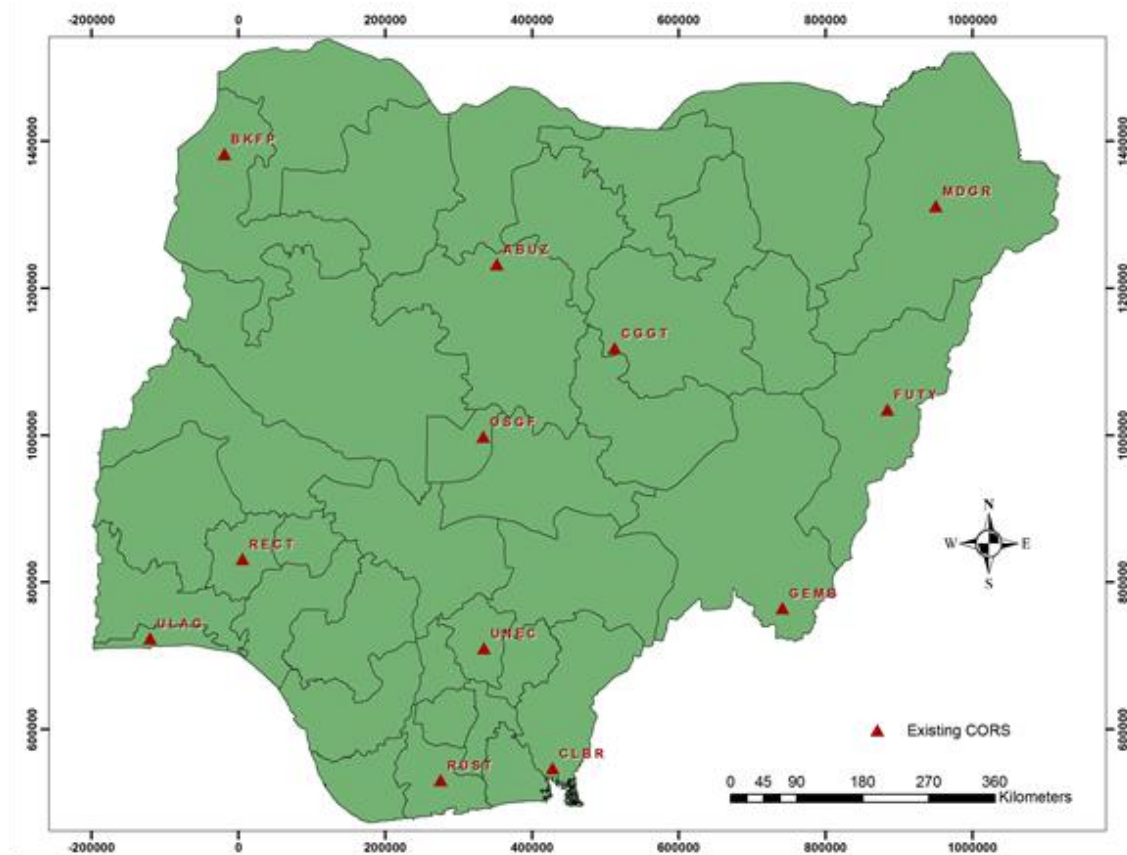
Overall, the existing 11 CORS stations in Nigeria (with an average spacing distance of over 300km apart) seems inadequate given the size of the country (about 923,768km<sup>2</sup>) as compared with the less than 100km spacing (based on the NGS's requirements) adopted in the USA and United Kingdom. Therefore, increasing the number of the CORS network in Nigeria as suggested in this study will improve the signal multipath issues, site issues, and signal environment issues experienced in the country. Also, sufficient and well-defined networks of geocentric datum (CORS) will provide among others; direct compatibility with GNSS measurements, mapping and GIS. It will also promote and optimise the use and application of spatial data through single user friendly data environment, thereby increasing efficiency in spatial data resource by reducing duplication and unnecessary translation ([4], p. 979).

## 3. Methods

### 3.1. Data Sources

The data used for this study are obtained from different secondary sources. A vector map of the Nigeria's administrative boundary, Nigerian Primary Geodetic Network (NPGN) GPS control points as well as the existing CORS stations datasets are provided by the OSGOF. Other data sources include the U.S. Geological Surveys (USGS) Earth Explorer, Geo Community and Diva-GIS (see table 2 for more details).

The data obtained from Earth Explorer are two satellite derived digital elevation models (DEM) (Global Multi-resolution Terrain Elevation Data 2010) (GMTED2010) of northern and the southern Africa, which has an improved detail elevation data, spatial resolution and topographic data. The satellite image obtained is a 7.5 arc-seconds resolution and has a Root Mean Square Error (RMSE) of between 26 and 30 metres. The Geo Community data are vector files of road networks, rail network and water bodies of Nigeria. The Diva-GIS data includes airports and elevation shape files of Nigeria.



**Figure 4.** The Nigerian Permanent GNSS Reference Network (NIGNET) (Existing CORS stations) (Source: Adapted from Nwilo et al. [2])

**Table 2.** Summary of data and processing

Data Source	Data Type	Data format	Data processing
Office of the Surveyor General of Nigeria (OSGOF)	1) Base map of Nigeria's administrative boundaries. 2) A vector map of Nigeria's boundary and Nigerian Primary Geodetic Network (NPGN) GPS control points. 3) Existing CORS stations in Nigeria.	1) Portable Document Format (PDF). 2) The vector map is provided in a shapefile format, and the NPGN GPS points are provided in a Microsoft office Excel and Word. 3) The existing CORS stations points are provided in PDF format.	1) The administrative base map was provided in PDF format, which is georeferenced and digitized in order to extract some important features. 2) Both the administrative map and the Nigeria boundary polygon were set to WGS84 geographic coordinate projection system. 3) The GPS coordinates the existing CORS stations are then imported into ArcMap as a text (*.txt) file, and converted to Esri database files (*.dbf),
U.S Geological Surveys (USGS) -Earth Explorer	Two satellite images of derived Digital Elevation Models (DEM)	Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010). The images are 7.5 arc-seconds resolution with a Root Mean Square Error (RMSE) of between 26 and 30 metres.	The DEM (GMTED 2010) are two separate images, which are mosaicked and clipped with the boundary map of Nigeria to trim the image to the area of interest. The DEM images are later converted to points heights.
Geo Community data	Nigeria's Road Networks, Rail Network and Water Bodies	Vector shapefiles	

### 3.2. Data Preparation and Analysis

#### 3.2.1. Data Processing

The processing of the collected data to map the existing CORS stations and the proposed sites for the establishment of new ones is summarised in table 2. From the table, the various data formats are standardised. This enables the integration of the various data sets into the research process. However, an interoperability issue was observed in the datasets, which are presented in both vector and raster formats, and most of them are in different referencing formats as they are acquired from different sources. As such, the files were converted to one projection system (World Geodetic System 1984 (WGS84)). The study used ESRI Arc GIS 10.1 software version to perform the analysis. This is because the software allows the exploration of the various data formats and has vast functionalities that suit the analysis conducted here.

#### 3.2.2. Data Analysis

The analysis commences by creating buffers of 100km radius from the existing 11 CORS stations in the country in order to observe their spatial coverage. This is because the study adopted the United States of America's CORS map stations as a standard, bearing in mind the NGS's guidelines for establishing new CORS stations which states that "*proposed CORS will be no closer than 70km from an existing CORS*" ([18], p. 5). This cannot be overlooked, as it is a requirement for establishing new CORS stations. The buffers established from the existing CORS stations are then converted to line features, and then to polygon features using ArcGIS 10.1 software, which allows the calculation of their spatial coverage in relation to the Nigerian area polygon.

Satellite elevation image or Digital Elevation Model (DEM) is used in proposing the location of the new stations because CORS, unlike its predecessor (Theodolites) in the field of surveying [13], are GPS instrument and do not use line of sight for baseline establishment (triangulation). Also, higher grounds have less obstruction of rarely more than 10 degrees above the horizon [18].

The DEM, which is a raster image, has been converted to points that allows for the determining of the height points and further classifications. The points are then classified according to the elevation difference. Care was observed during the classification in order to obtain a smooth and average spacing between the points. When selecting the proposed stations, it occurred that points lower than 100metres close to the riverside appeared in the valley (water bodies). Therefore, an effective measure was taken to move them further away from the water bodies by increasing the measurement of the height while avoiding random selection, as station stability is a priority. Also, the majority of the points are selected according to their proximity to public facilities, such as road networks. This is because accessibility is one of the priority factors in any developmental project and one of the core objectives in the

guidelines for establishing bench marks and CORS stations ([18] & [22]).

However, the stationing of some of the points on low land areas is to regulate the physical effect of soil characteristics. For example, areas with coarse-soil are best siltation sites because fine-grained or clay soil are susceptible to variation in moisture content and susceptible to erosion [22]. These areas (coarse-soil) are also easier to be accessed for maintenance than the stations on highlands or hillcrests.

## 4. Results and Discussions

### 4.1. The Spatial Coverage of the Existing and Proposed CORS Stations in Nigeria

As highlighted earlier, CORS are categorised in tiers and the Nigerian CORS are operated under Tier 1 stations. Therefore, this study used the NGS's benchmark guidelines for creating CORS stations, which was promoted by the United States NGS ([18], P.6).

**Figure 5** shows the coverage of the existing 11 CORS stations in Nigeria at 100km buffer. From the figure, it can be observed that the existing 11 CORS stations based on the 100km buffer covers only a quarter of the country's area (306,598km<sup>2</sup> covered and 605,131km<sup>2</sup> uncovered). This is relatively poor at this radius and it is clear that there is a requirement for an increase in the number of the CORS stations to enhance the spatial coverage and distribution of the stations in order to meet up with the global standard. Hence, the need for proposing more condensed networks in the country.

One possible way of achieving this is to propose at least one CORS station in each of the 36 states in the country and the capital city Abuja. The idea of using each of the states to propose the allocation of the stations was derived from the USGS' High Accuracy Reference Network (HARN) (also referred to as precise geodetic controls), which used similar method in the late 1980s (see for example, [9]). **Figure 6** shows the proposed stations in each of the country's state using the Nigerian Primary Geodetic Network (NGPN) GPS points, which gives broader area coverage across the country.

While there is an improvement of coverage (77% of the total area of the country) from the existing CORS stations in the country (see figure 6), the proposed state coverage is yet to cover many parts of the country. Particularly, uncovered areas are observed in the west-central, north-east and south-eastern parts of the country. Therefore, despite providing a remarkable result by tripling the spatial coverage of Nigeria (see figure 6), the 23% uncovered by the proposed state cannot be ignored, as it is almost the spatial coverage of the existing 11 CORS stations in the country. Given that this study intends to propose CORS stations that can cover the entire country, there is also a room for improvement to accommodate some of the uncovered spaces. **Figure 7** shows a different criterion used to establish the CORS that



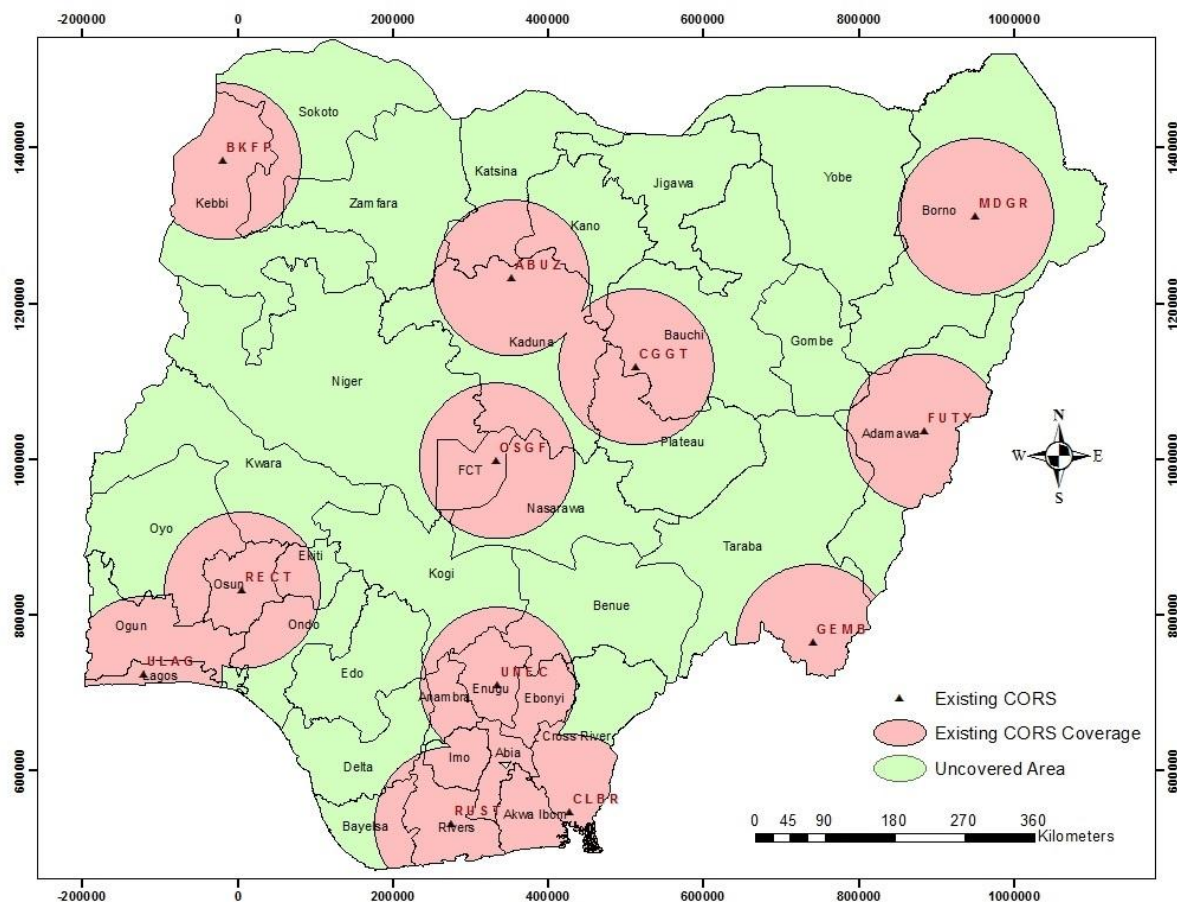
partially covered the entire country by incorporating the elevation point data (DEM) of the country in the analysis.

The elevation data was used to classify the height differences in order to locate suitable areas for the establishment of the new CORS stations. Road networks and water bodies are also used alongside the elevation because of their importance in defining suitable locations. For example, even if the height points are selected, the areas are unknown without reconnaissance survey. The results of this selection (see figure 8) show a spatial coverage of 96% (876070km<sup>3</sup>) which is three times the spatial coverage of the existing CORS in the country. The remaining uncovered areas (4%) are fragments close to the borders and the River Niger. Although, the areas can also be mapped out, site factors were considered, particularly proximity of stations to avoid excess signal multipath errors, and also to balance the distribution of the stations at the minimum distance of 70km and a maximum distance of 100km between each station.

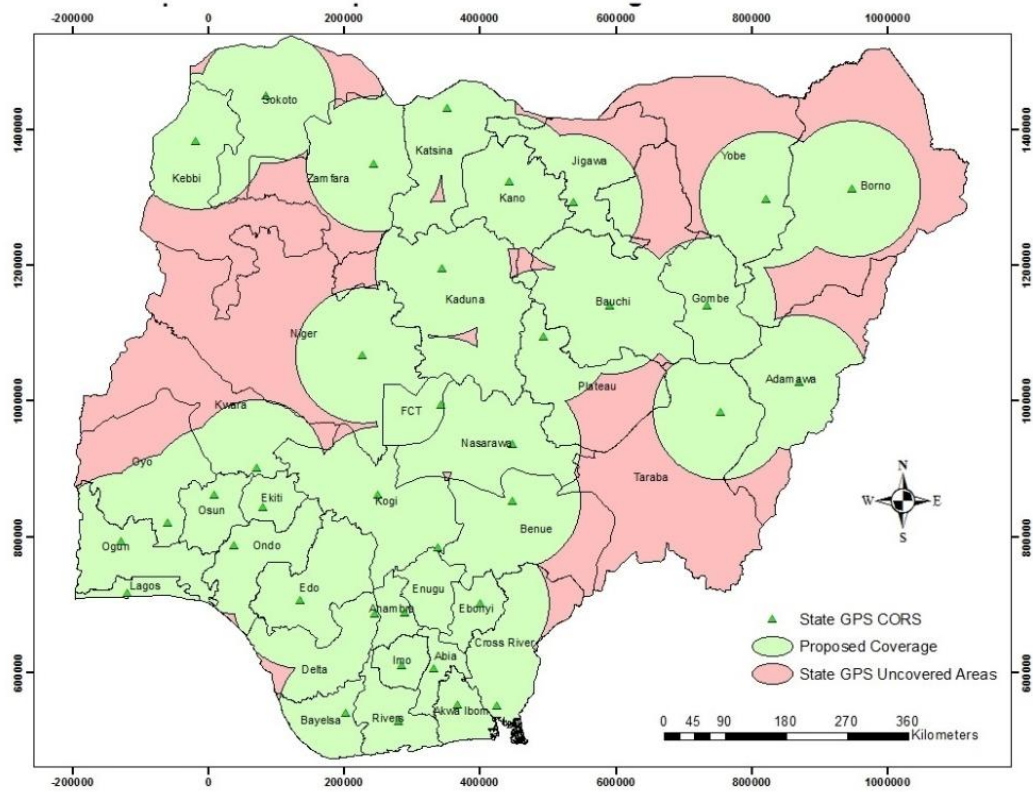
Generally, establishing a station close to the road after considering Right of Way (ROW) serves as a protection to the station as land disputes and mowers may result in areas not being public [22]. Moreover, stability of the station is of

utmost importance, as it has to be made on a stable ground or building structure in order to avoid any future crustal deformation. Water bodies can have a great impact on soil as the flowing water can wash it away. Also, expansion and contraction of the soil may occur, which may change the land formation by centimetres or metres [22], thereby affecting the accuracy of the CORS station. Such areas must be avoided since CORS stations are millimetre accuracy points ( $\pm 20$  mm) [18]. Therefore, the water bodies and road layers used here provide measures for avoiding the error of placing the station points in a river, and the placement of the stations close to the road for proximity and accessibility during future maintenance.

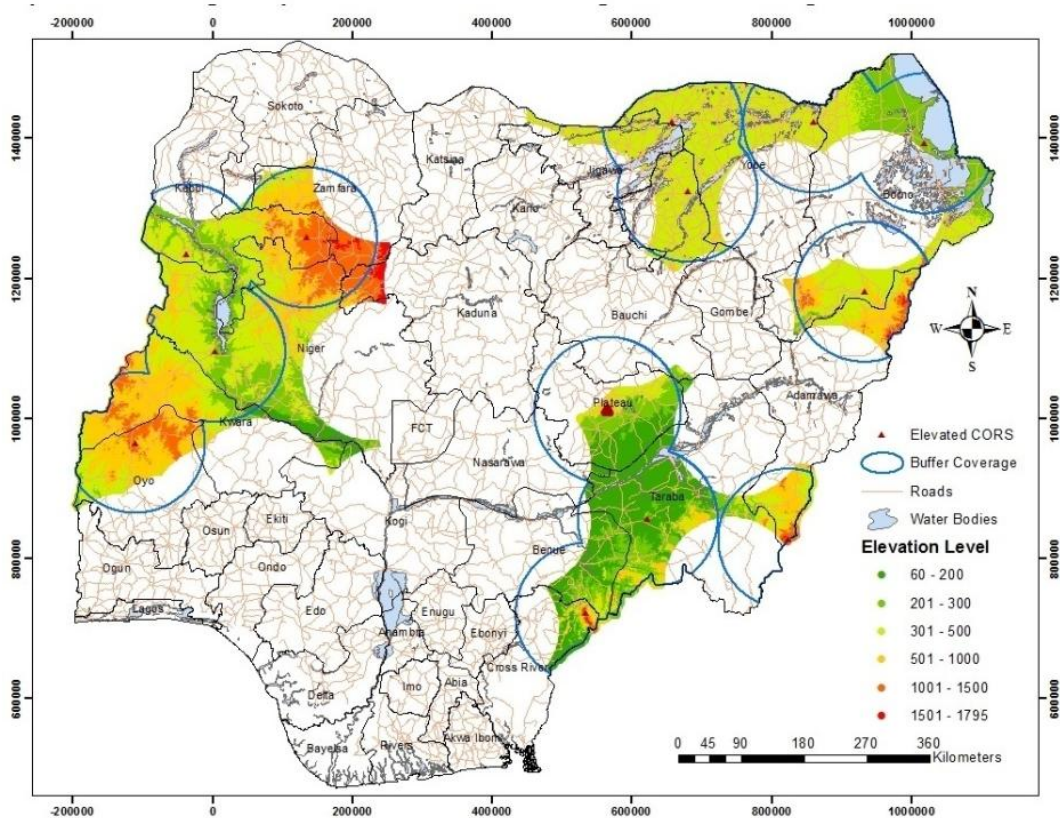
**Figure 9** shows the final output of both the 49 proposed and the existing CORS stations in Nigeria. It provides an improvement in the density and distribution of the stations compared to the existing 11 CORS stations in the country. The map shows that the coverage is denser in the southern part of the country due to the nature of the administrative boundary distribution, which has small area compared to the northern part (see for example, [6]).



**Figure 5.** The spatial coverage of the existing CORS stations in Nigeria at 100km Buffer



**Figure 6.** The state proposed CORS stations using the NPGN GPS control points at 100km Buffer



**Figure 7.** The proposed stations using the elevation data in areas not covered by the marginalisation of the existing and the proposed state CORS stations



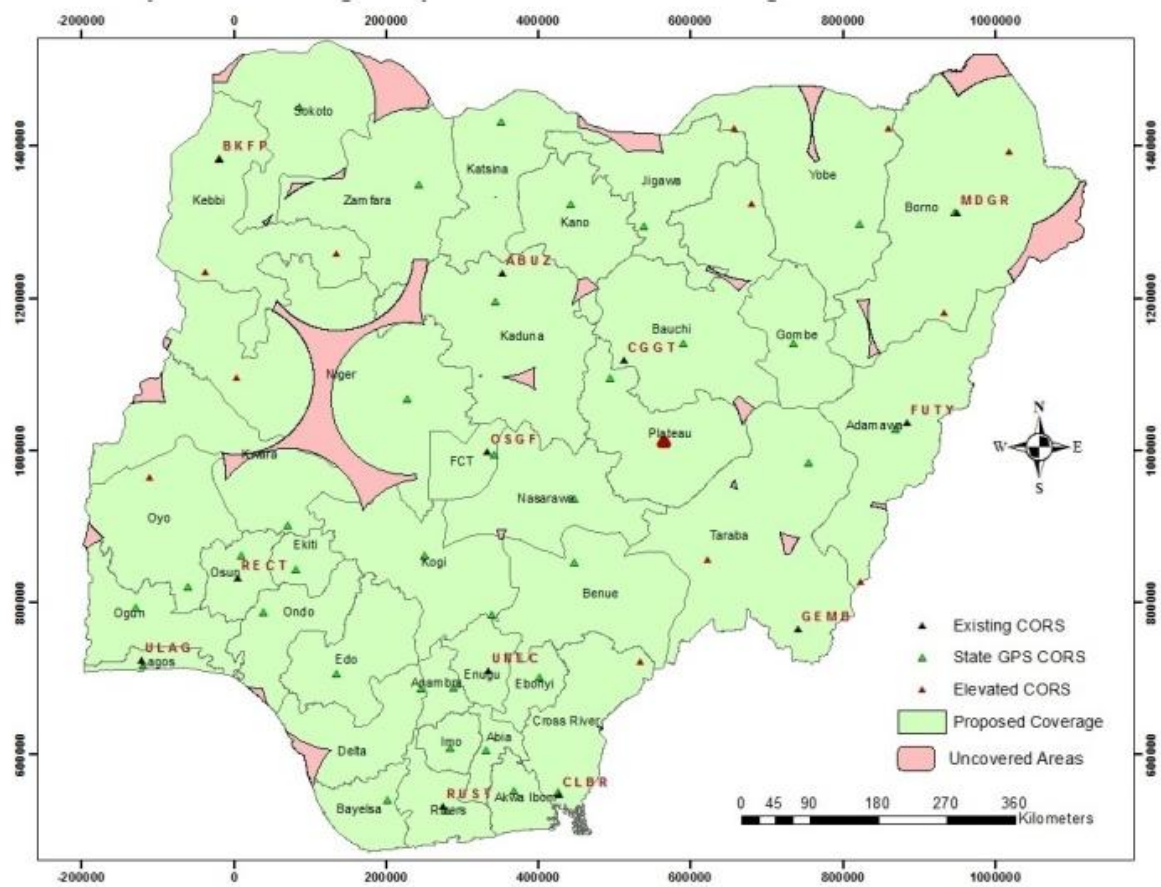


Figure 8. The spatial coverage of the proposed and the existing CORS stations in Nigeria at 100km Buffers

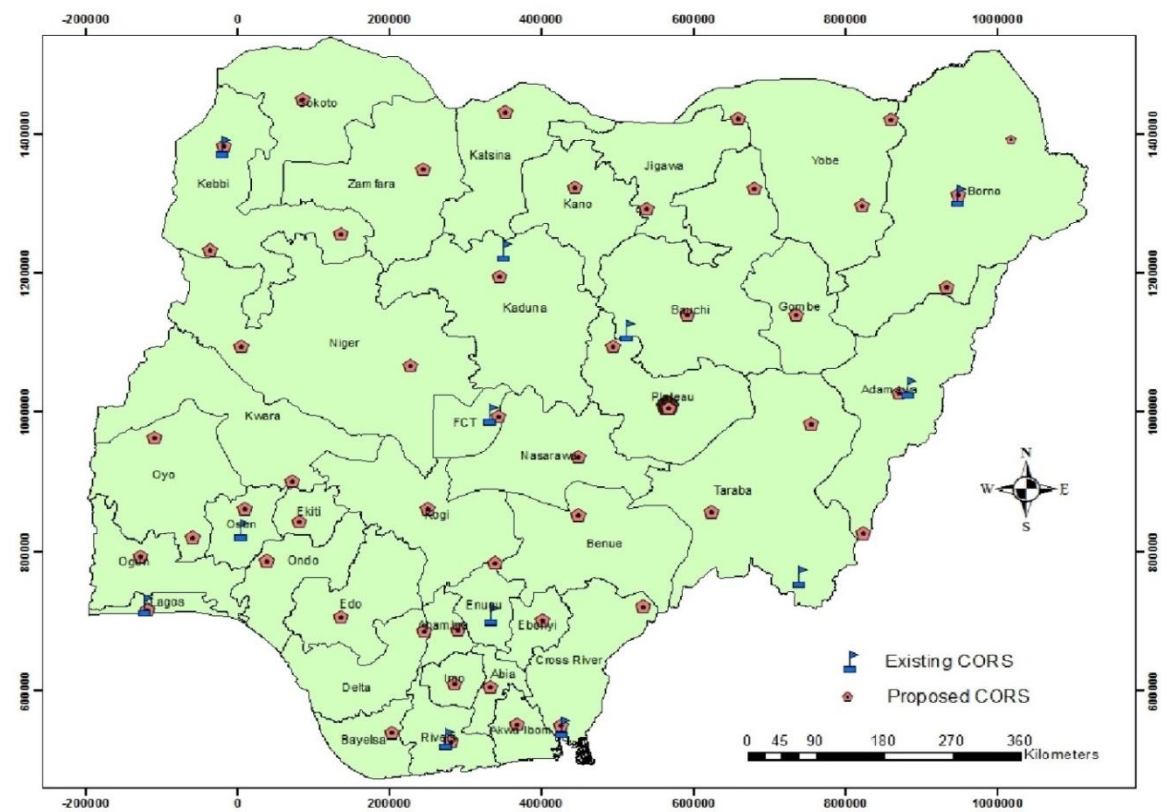


Figure 9. The proposed map of Existing and Proposed CORS stations in Nigeria

## 5. Conclusions

Nigeria has already adopted the new geocentric datum, which commenced in 2007/2008 by installing CORS networks across the nation. This study used the international standard criteria for CORS establishment, as well as the objectives of the ITRF, AFREF and OSGOF to propose a condensed and more robust spatial network of CORS stations in Nigeria with baselines shorter than the existing 300km apart. However, the data sets used for the study are obtained from secondary sources and are only verified using other means such as the Google earth. Even though, the new proposed CORS stations maps are unable to provide any further detailed information about the landscape at each of the proposed stations due to the large area coverage and insufficient data, the study has highlighted the steps and potentiality of improving the existing CORS coverage map of the country. Therefore, the study serves as a template for future applications and fields that requires spatial coverage for their research or commercial use such as geospatial institutions and communication institutions.

It should be noted that the study only focussed on spatial coverage, which limits other aspects of establishing CORS stations such as equipment specifications, data and communication procedures to be considered in this study. Also, there are many practical aspects of site configuration (for example, site monumentation, obstructions etc.) ([10], p.4 & [18], p.7) that are considered during the establishment of CORS stations that this study overlooked because of lack of data.

So far, it is evident from the results that the spatial coverage of the existing 11 CORS stations in Nigeria is inadequate, and therefore the proposal for the establishment of new ones is paramount. The new proposed 49 and the 11 existing CORS stations (totalling 60 CORS stations) established here covered about 96% of the total area of Nigeria as compared to the 11 existing stations that covers only 25% of the country. Also, the proposed stations have baseline distance of less than 200km apart, which provides a denser and well-improved distribution of networks.

The proposed CORS networks can be linked to other existing CORS network within and outside the country, which can help reduce baseline dependent errors, improve positioning services and continuous referencing of GNSS measurements to the reference frame and datum, which is the sole objective of ITRF (see for example, [12] & [23]). It will also provide a common reference frame across the country and other continents for optimal collection, storage, exchanging and visualisation of information [12]. Similarly, the availability of well distributed CORS stations in Nigeria will make it possible to understand, expand and answer relative GNSS and GPS questions since it is the common standard technology in Navigation. This study opined that updating the current CORS stations in the country would accelerate the evolvement of the Nigerian terrestrial reference system into a complete NIGNET of 60 stations, which would potentially strengthen the Nigerian Primary

Geodetic Network (NPGN). Overall, achieving a wider spatial coverage of the CORS networks (at near regular intervals), particularly now that the government is advocating for new reforms on infrastructural development across the nation is paramount.

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