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Suitability Study of the Locations of Continuously Operating Reference Stations (CORS) in Southwestern Nigeria

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ABSTRACT

The Study evaluated the locational suitability of established Continuously Operating Reference Stations (CORS) in Southwestern Nigeria and proposed optimum locations for additional CORS in the study area. These were with the view of determining the sufficiency of the existing CORS distribution for various applications in the study area. Secondary data were used for the study. The secondary data used were the shapefiles of the states and local governments as well as the positions of the CORS. The optimum locations of proposed additional CORS were based on 35km buffer distance and which is based on globally acceptable practices for Network Real-time Kinematics (NRTK) distance standard. The study proposed twenty-two new locations in Oyo, Lagos, Ogun, Ekiti and Ondo states for new CORS so as to achieve optimum distribution of CORS for efficient network operations and improved coverage within the region based on globally acceptable practices. The study concluded that the existing and proposed CORS in the study area achieved uniform distribution for accurate geospatial applications in the region.

Keywords:

CORS, GNSS, Spatial Distribution, Buffer, Location

1. Introduction

1.1. Continuously Operating Reference Station (CORS)

Continuously Operating Reference Station (CORS) is defined as a stable platform occupied by a Global Navigation Satellite System (GNSS) receiver which collects data continuously (Uzodinma et al, 2013). It is an integration of a GNSS receiver, GNSS antenna, a permanent survey point (with a known position) and supporting equipment. CORS is also called "Reference Station". CORS can operate in post-processed mode and real-time mode. It continuously collects and records data. Thus, providing reference station data to users that collect rover data. It is worthy of note that GNSS operation is not based on a line of sight, unlike the conventional surveying method.

One of the operational GNSS is the Global Positioning System (GPS) which originally was designed for the military to guide their bombs, aircraft and other operations as well as to assist sailors in navigation (Deggelen, 2009). Today GPS is used for many civilian purposes for several applications, such as navigational, metrological and geodetic use. These requirements are what brought about the development of CORS. GPS is one of the GNSS that has global coverage, amongst others such as GLObal NAvigation Satellite System (GLONASS), European Global Navigation Satellite System (Galileo) and BeiDou Global Navigation Satellite System (BeiDou or BDS or Compass).

In Nigeria, a total of 23 CORS have been established as at 2019 and more are expected to be established (Abomehin, 2016; ACSM Bulletin, 2010; GIM International, 2009; Lucas, 2015). The first CORS in Nigeria was established in African Regional Institute for Geospatial Information Science and Technology (AFRIGIST) (formerly Regional Centre for Aerospace Survey (RECTAS)), Ile-Ife, Nigeria in July 2007 (AFREF, 2007) as part of the African Geodetic Reference Frame (AFREF) programme. AFREF is a primary positioning initiative which will give rise to a uniform and consistent coordinate system in Africa. A system that will cumulatively serve as the fundamental reference system for all regional and continental geo-spatial information planning and development projects across a wide spectrum of disciplines.

1.2. Classification of CORS

CORS can be classified into 'Tier I', 'Tier II' and 'Tier III'. Tier I are the CORS established and used by IGS or any other equivalent ultra-high accuracy stations to support geoscientific research and global reference frame definition. Tier II are the high accuracy CORS operated by national geodetic agencies for the purpose of maintaining national geodetic datums and providing the fundamental backbone of the national geospatial reference frame. Tier III are the CORS that densify the national COR stations network, operated by agencies, state governments and private companies (Rizos, 2010). They provide commercial DGNSS services or support for the national network.

In Nigeria, most surveyors still use passive controls as their means of referencing for property surveys, engineering projects and other geospatial works, however, these passive controls are vulnerable as they are exposed to human and environmental distortions such as mutilation or uprooted while some were completely destroyed or removed" (Ono, 2013). This challenge can be solved with the CORS network which aim at enhancing the geospatial referencing system by solving the challenge associated with passive control network.

Over the years, CORS network has increased in number and usage, however, they are not evenly distributed across the states and their effective utilisation has been undermined. Consequently, the objectives of this study are to examine the distribution of CORS and propose locations for siting additional CORS in the study area. This will enable uniform distribution of CORS which will enhance acurate and timely acquisition of geospatial-based information in the study area.

2. Literature review

2.1. CORS Network

CORS network is simply a network of CORS. CORS are usually established as a network over an area to enhance higher accuracy as well as enabling several area of applications simultaneously (Dabove *et al*, 2012; El-Mowafy, 2012). A CORS network can serve as a Network Real Time Kinematic (NRTK) where corrections are broadcasted, available over the internet or through other medium for retrieval. NRTK is also referred to as Real Time GNSS Network (RTN). Ojigi (2014) opined that NRTK data processing option is a more integrated, robust and economically viable approach to GNSS positioning and other applications, which requires several widespread and dense CORS network as well as real-time data processing.

2.2. CORS Distribution

The suitability of the locations of CORS has become imperative since GNSS is increasingly becoming an important geospatial infrastructure. Very few studies have been carried out on the locations and distributions of CORS. Ojigi (2014) carried out a study on the development of RTK Network service model for Nigeria, based on GNSS CORS Network. The requirements and feasibility of RTK services in Nigeria were identified. Network densification and return on investment planning scheme were carried out. A Network RTK Service Model was developed by first identifying the 15 existing CORS and a proposal of a minimum of three CORS infrastructure for each of the 36 states and the FCT. Based on this, a total of 111 CORS were arrived at. The administrative map of Nigeria was used to extrapolate the proposed locations for the additional 96 CORS.

Furthermore, a study carried out by Naibbil and Ibrahim (2014) on the assessment of the existing CORS in Nigeria using Geographical Information System (GIS), assessed the CORS network and determined the suitability of improving the density of the existing CORS. The Nigeria administrative boundary map, Nigerian Primary Geodetic Network (NPGN), GPS control points, the existing CORS datasets, the U.S. Geological Surveys (USGS) Earth Explorer of satellite-derived digital elevation models (DEM) (Global Multi-resolution Terrain Elevation Data 2010) (GMTED2010) of northern and southern Africa, geo community data of vector files of road networks, rail network and water bodies of Nigeria and Diva-GIS of airports and elevation shapefiles of Nigeria were used. The study adopted the United States of America's COR stations distribution standard, which was based on National Geodetic Survey's (NGS) guidelines for establishing new COR stations. The distribution standard states that "proposed CORS will not be closer than 70km from an existing CORS". Based on this buffers of 100km radius from the existing 11 COR stations at that time was done in order to observe their spatial coverage. The buffers established from the existing CORS stations were converted to line features, and then to polygon features using ArcGIS 10.1 software. Spatial coverage in relation to the Nigerian area polygon was calculated. Data obtained were analysed using a buffering and Digital

Elevation Model (DEM) techniques. The result showed that the existing CORS stations in Nigeria only covers about 25% of the country. It was observed that a quarter of the country was covered.

The study by Ojigi (2014) did not consider existing Tier III CORS and minimum distance between stations was not considered, while the study of Naibbil and Ibrahim (2014) used a minimum distance of not less than 70km with a buffer of 100km. Our study was based on determining optimum locations for additional CORS in Southwestern Nigeria using 35km distance to achieve complete coverage.

2.3. Nigerian Permanent GNSS Network (NIGNET)

Nigeria's national CORS network is known as NIGerian Permanent GNSS NETwork (NIGNET) (Nwilo *et al*, 2013a). This network consists of Tier II COR stations. It is the Nigerian CORS network initiated in 2008 in line with the recommendation of the United Nations Economic Commission for Africa (UNECA) through its Committee on Development Information, Science and Technology (CODIST) (Jatau *et al*, 2010). The Office of the Surveyor General of the Federation (OSGoF) is in charge of NIGNET. It is the Nigerian contribution to AFREF being the African reference Frame. In Nigeria, the establishment of CORS network began in 2008 (apart from AFREF's maiden CORS at AFRIGIST, Ile-Ife in 2007). A minimum of 50 stations were planned under the NIGNET programme (Okeke, 2011) and presently, there are sixteen CORS under the programme. Eleven of the stations were established by the OSGoF while the other four stations were established by the Presidential Technical Committee on Land Reform (PTCLR) (Adebomehin, 2016). Among the NIGNET stations in Southwestern Nigeria are those located at the Federal University of Technology (FUTA), Akure, Ondo State and the University of Lagos (UNILAG), Lagos State.

NIGNET will be serving many different applications at the national and continental level. NIGNET will serve primarily as the fiducial network that will define and materialize a new reference fully consistent with the modern space-geodetic techniques for geodesy and surveying as well as for other geospatial data acquisition purposes. At present NIGNET comprise 16 COR stations (Adebomehin *et al*, 2013). The AFRIGIST CORS at Ile-Ife is also included as part of NIGNET CORS, although established through AFREF initiative. The national geodetic network is a pivotal infrastructure of any country by providing the foundation for all geo-referencing activities. It is the base for coherent multipurpose Land Information System (cadastre) and its subsequent maintenance. Such system plays a vital role in the economic development of the country by delimiting and monitoring changes in property, environment, and biodiversity.

2.4. Tier III CORS

Furthermore, there are seven other COR stations in operation in Southwestern Nigeria. These are stations established by the state governments. Such stations are those established by the Osun, Ogun and Lagos state governments. One of the stations was established by the Lagos State government in 2010, three stations were established by Ogun state government at Abeokuta, Ijebu-Ode and Agbara (ACSM Bulletin, 2010; GIM International, 2009; Lucas, 2015). The remaining three CORS were established by Osun State government.

3. Methodology

3.1. Study Area

The area covered is Southwestern Nigeria. This area lies between latitudes 2° 00' 00'E and 6° 00' 00"E and longitudes 6°00' 00"N and 9° 00' 00"N (Figure. 1). The study area consists of six states (Figure. 1).

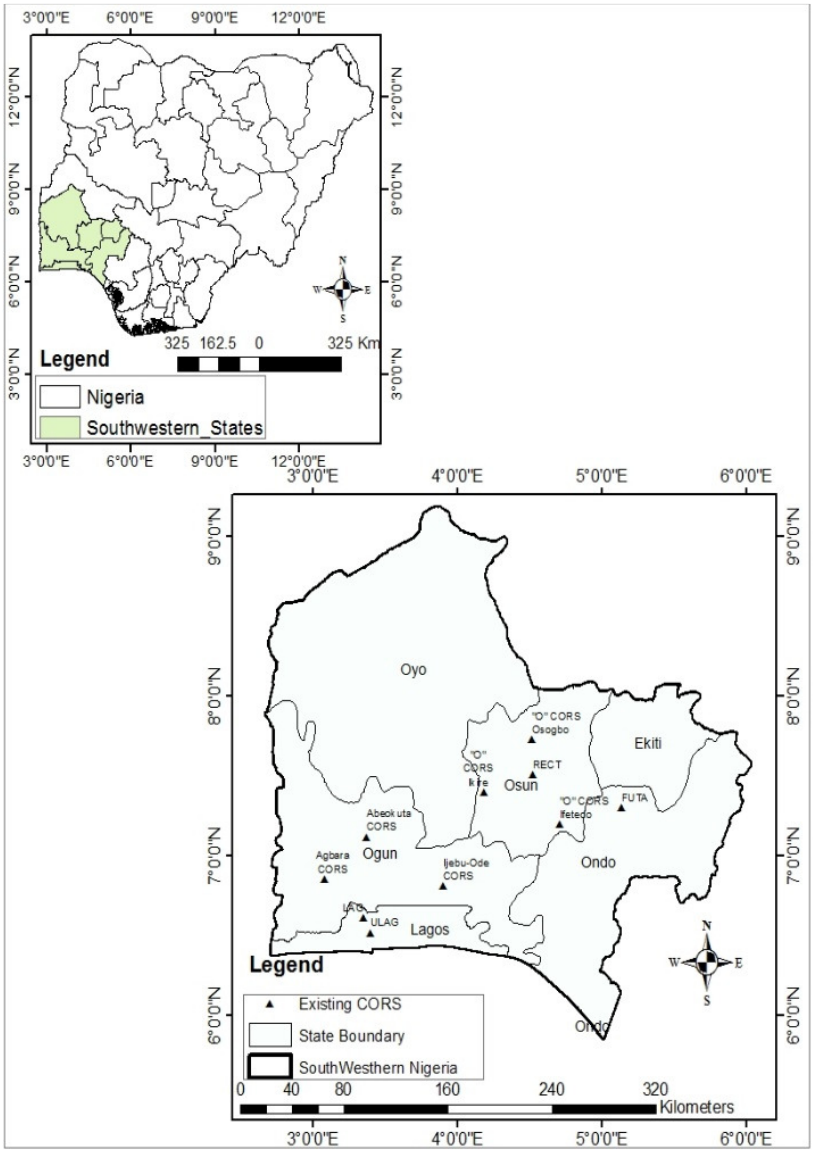

Figure. 1. Map of the Study Area showing the existing CORS Locations

It is an area of approximately 78000 sq km. The current population of the South West area of Nigeria based on the National Population Commission is 27.7 million as of 2016. Lagos state is the most populated state while Ekiti state is the least populated state within the area.

There are ten CORS in the study area. Three 'Tier II' CORS and Seven 'Tier III' CORS. The Tier II COR stations are at Akure, Lagos and Ile-Ife established by PTCLR, Office of the Surveyor General of the Federation (OSGoF) and AFREF initiative respectively. The three state-owned COR Stations in Osun were established at Osogbo, Ikire and Ifetedo. Lagos State government has one CORS station located at Ikeja, at the premises of the Office of the Surveyor General of Lagos State (ACSM, 2010; GIM

International, 2009). Ogun State has three stations at Abeokuta, Ijebu-Ode and Agbara (Lucas, 2015). The locations of the existing CORS were plotted out as shown on the map of the study area.

3.2. Data

Secondary data were used for this study. The secondary data were the coordinates of the CORS obtained from and shapefiles of states and local governments in Southwestern Nigeria. The NIGNET CORS coordinates were obtained from the site log file of the stations while the tier II coordinates were obtained from the Office of the Surveyor General of Osun, Ogun and Lagos states. The shapefiles were obtained from OSGoF.

3.3. Analysis

Nearest Neighborhood Analysis was used to examine the spatial distribution of CORS in the study area, while buffering of the CORS was performed at a distance of 35km to determine the coverage of existing CORS and the locations in need of COR stations. The choice of 35km was based on the on El-Mowafy (2012) submission. In addition, Federal government location preference – "present of state or federal institution offering course in Surveying" was used in determining suitable location for the proposed CORS.

3.4. Spatial Distribution of Existing CORS

A total of ten CORS are located in different states of the study area. In terms of ownership three were owned by Federal government/International and seven by State governments based CORS. The Federal government owned CORS are located in Surveying and Geoinformatics Department of Federal government owned tertiary institutions while State government owned CORS were located at Local government offices or office of the Surveyor General of the state. The reasons may be attributed to issues such as security concerns, technical supervision and electricity supply for the facilities.

Analysis revealed that the spatial pattern of CORS in the study area is dispersed in nature. The average neighborhood analysis showed that the distribution of CORS is dispersed with a p-value of 0.000011, z-score of 4.403635and nearest neighbor ratio of 1.727915 (Figure 2). The positive z-score, the nearest neighbor ratio above 1 indicated that a dispersed distribution exists. Furthermore, the minimum distance between the existing CORS is 11km existing between ULAG and LAG, The maximum distance is 64km between LAG and Ijebu-Ode CORS and the average distance is 37.6km (Table 1).

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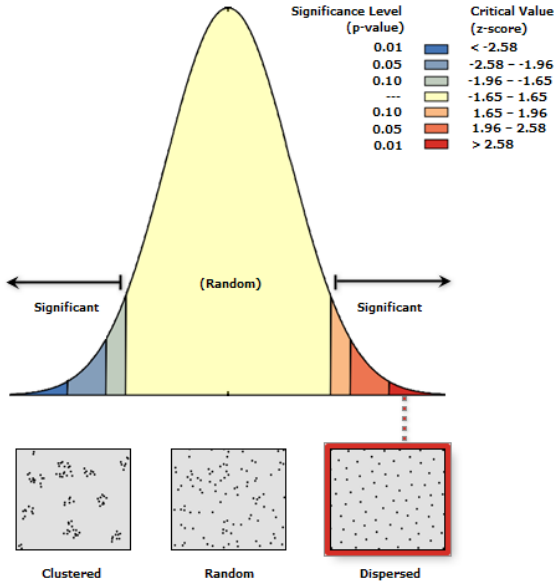

Figure. 2 Results of Spatial Distribution of the Existing CORS

Table 1 Nearest Existing CORS

CORS	Nearest CORS	Dist. (km)
ULAG	LAG	11
LAG	Agbara CORS	40
Agbara CORS	LAG	40
Abeokuta CORS	Agbara CORS	43
Ijebu CORS	LAG	64
'O'CORS Ikire	RECT	40
RECT	Osogbo	25
'O'CORS Oshogbo	RECT	25
'O'CORS Ifetedo	RECT	40
FUTA	Ifetedo	48

3.5. Coverage of existing CORS

A buffer of 35km was created around existing CORS to determine their catchment areas (Figure 3). In addition, States without CORS were also identified (Figure 3). The figure shows that Oyo state, part of Ekiti and Ondo states are excluded from the buffered zones indicating potential areas for sitting of additional federal or state CORS.

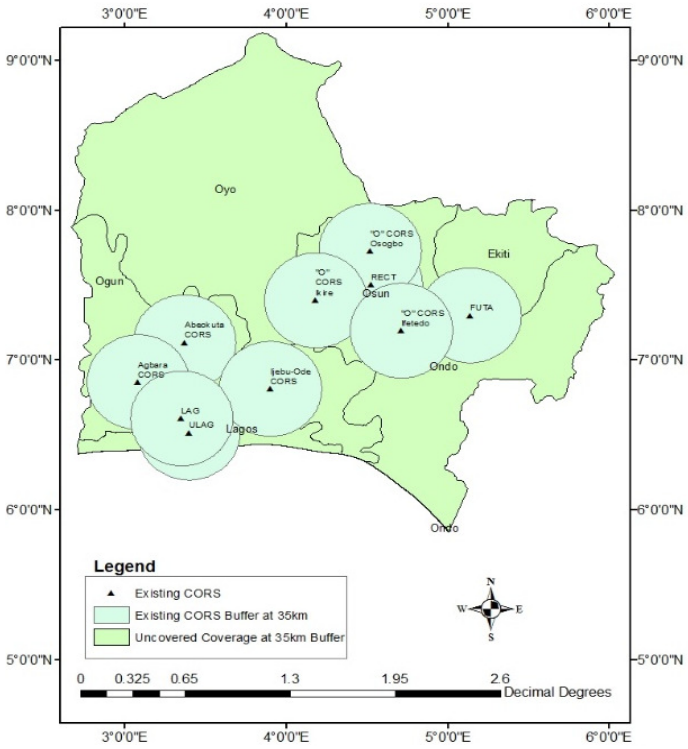

Figure. 3 Buffer of Existing CORS at 35km.

In order to accommodate the existing post-processing operation of CORS, the spacing should be within a distance for users to access the CORS within a defined time frame. This requires that users get data within the minimum time and travel distance possible since there was no online presence for most of the stations. Therefore users should be able to travel to the CORS location within the shortest time. This study proposed the time range between 40 to 45 minutes from any farthest distance to the CORS location. The farthest was considered rather than the nearest to consider the worst case scenario. According to the Nigeria Highway Code, the speed limits for private cars, taxis and buses is 50km/h (FRSC, 2008). With a speed limit of 50km/hr and average travelling time of 42.5 minutes ((40+45)/2), i.e 0.7083 hrs (42.5/60), we calculated a proposed distance of approximately 35km (50* 0.7083) between two CORS.

Therefore, this study chose a 35km buffer to allow the users to meet up within a feasible travel distance. The choice of 35km used in this study was based on El-Mowafy (2012) submission.

According to El-Mowafy (2012) explained that:

> "The operating range of RTK positioning is thus dependent on the existing atmospheric conditions and is usually limited to a distance of up to 10-20 km. In addition, no redundancy of the reference stations is usually available if the reference station experiences any malfunctioning. The constraint of the limited reference-to-rover range in RTK can be removed by using a method known as Network RTK (NRTK), whereby a network of reference stations with ranges usually less than 100 km is used."

This means that any distance less than 100km between any two stations in the network can be used in the case of NRTK. A buffer of the existing CORS at 35km was carried out as shown in Figure. 3.

3.6. Location for Proposed Federal Government CORS

A clip of the merge of 35km buffer around the ten existing CORS was carried out using geoprocessing tools. Erasing the clip of merged buffer at 35km buffer from the map revealed the coverage of the uncovered area. The uncovered area was the area required to establish the proposed CORS. The analysis of the uncovered area revealed that Ekiti, Oyo and Ondo states require CORS. Meanwhile, based on the Federal government CORS location preference, Ekiti state has a Federal Polytechnic, thus Ado-Ekiti has a suitable location. Also, Oyo state has Federal School of Surveying, Oyo as the only potential location. Unfortunately, no CORS was located at Ibadan, the Oyo state capital, making it vital for the need to locate one there. It is the only state that there was no suitable location based on the Federal government preference in this study. Nonetheless, the Polytechnic, Ibadan was chosen with a view that it is crucial to locate CORS in the state capital. The responsibility now lies on the Federal government CORS management office to establish an administrative office through the OSGoF office at Ibadan, Oyo state.

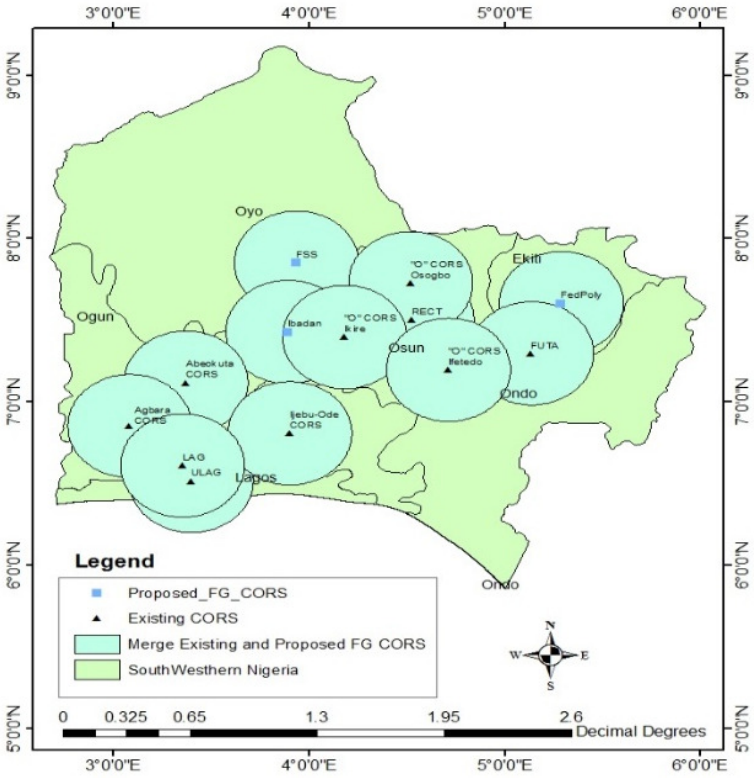

Fig. 4. Buffer of Existing and Proposed FG CORS at 35km. Source: Shapefile of Map courtesy of OSGoF

Therefore, this study proposed three new Federal government-based COR stations to be located at the Polytechnic, Ibadan and Federal School of Surveying, Oyo in Oyo state as well as Federal Polytechnic, Ado-Ekiti in Ekiti state.

3.7. Location for Proposed State Government CORS

Furthermore, a buffer of the existing and the three proposed CORS at 35km was carried out in order to evaluate the efficiency of the two sets of CORS.

Table 2 Covered, Partially Covered and Uncovered Local Governments after 13 CORS

State	CORS	LGA No	Covered	Partially Covered	Not Covered
Ekiti	1	16	3	12	1
Lagos	2	20	15	5	0
Ogun	3	20	5	13	2
Ondo	1	18	3	6	9
Osun	4	30	17	11	2
Oyo	2	33	10	12	11
Total	13	137	53	59	25

The map of the intersection between the buffer at 35km of the existing and proposed Federal government based CORS is shown in Figure 5. It reveals that several local government areas at state levels are either fully or partially covered by the federal government CORS. Table 2 shows the analysis of the map, it reveals the number of covered, partially covered and uncovered Local governments in the states. Ondo and Oyo states with nine and eleven Local governments respectively have the highest uncovered Local governments.

Table 2 was produced using GIS 'selection by location', where the existing Federal, existing State and proposed Federal government CORS buffer at 35km serves as the source layer, the local government areas serves as the target layer and the 'target layer intersects the source layer' and 'target layer within the source layer' were the spatial selection methods. Based on the analysis of the uncovered Local governments at Oyo and Ondo States and the partially covered Local government areas, it became necessary to propose State government based CORS.

Based on this selection analysis, all the Local governments except Ese-Odo Local government in Ondo state and Irepo, Olorunsogo, Orelope and Saki-west Local governments in Oyo state were suitable locations for State-based CORS. One CORS were located at Atiba, Atisbo and Iseyin Local government areas in Oyo state and Owo and Okitipupa local government area in Ondo State. These proposed state-based CORS were located to establish a reasonable coverage at 35km buffer. Additional five more State based CORS were proposed to be located in Oyo and Ondo State.

After a total of 18 CORS, all the CORS were buffered and another 'selection by location' analysis was carried out, using the existing Federal and State and proposed Federal and State government CORS 35km buffer serves as the source layer, the local government areas serves as the target layer and the 'target layer intersect the source layer' and 'target layer within the source layer' were the spatial selection methods.

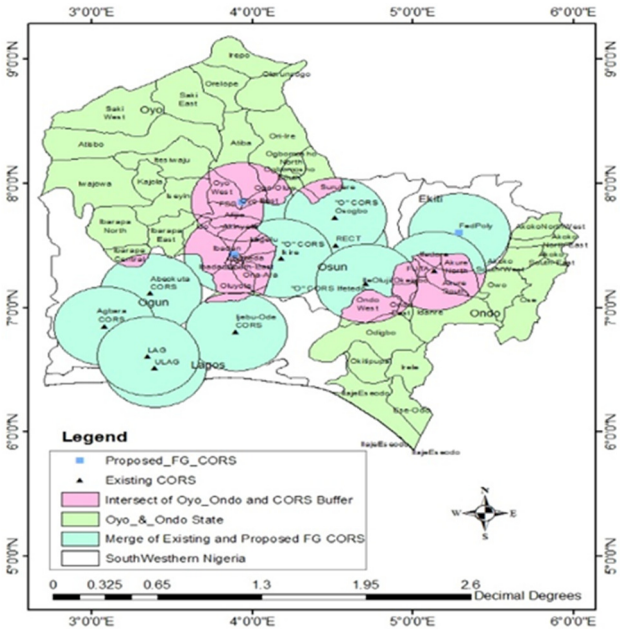

Figure. 5. Map of Intersecting Area and Uncovered Area of 35km Buffer.

The map reveals pockets of the uncovered area as shown in Figure 6 and the 'selection by location' reveals that there were 9 uncovered and 73 pockets of partially covered Local government (Table 3). Therefore it was necessary to proposed more state based CORS to cover this outstanding portions. More State based CORS were proposed at such uncovered Local governments to cover the outstanding portion. Such locations were at Itesiwaju, Ogbomosho North, Irepo and Saki East Local governments in Oyo State; Badagry and Ibeju/Lekki Local governments in Lagos State; Ijebu East, Imeko and Egbado North Local governments of Ogun State; Ilaje Ese-Odo, Akoko North East and Idanre Local governments in Ondo State; and Ekiti West and Ikole Local governments in Ekiti State. Table 3 shows the number of the covered, partially covered and uncovered local government after a total of 18 existing and proposed CORS. Eventually, after the locations of these new CORS to cover the observed space, a new buffer was carried out. The resulting buffer showed a suitable coverage of the study area (Figure. 7). The locations of all the CORS were shown in Figure. 8 showing a uniform distribution of all the CORS across the study area.

Table 3 Covered, Partially Covered and Uncovered Local Governments

State	CORS	LGA No	Covered	Partially Covered	Not Covered
Ekiti	1	16	3	12	1
Lagos	2	20	15	5	0
Ogun	3	20	5	15	0
Ondo	3	18	5	10	3
Osun	4	30	17	11	2
Oyo	5	33	10	20	3
Total	18	137	55	73	9

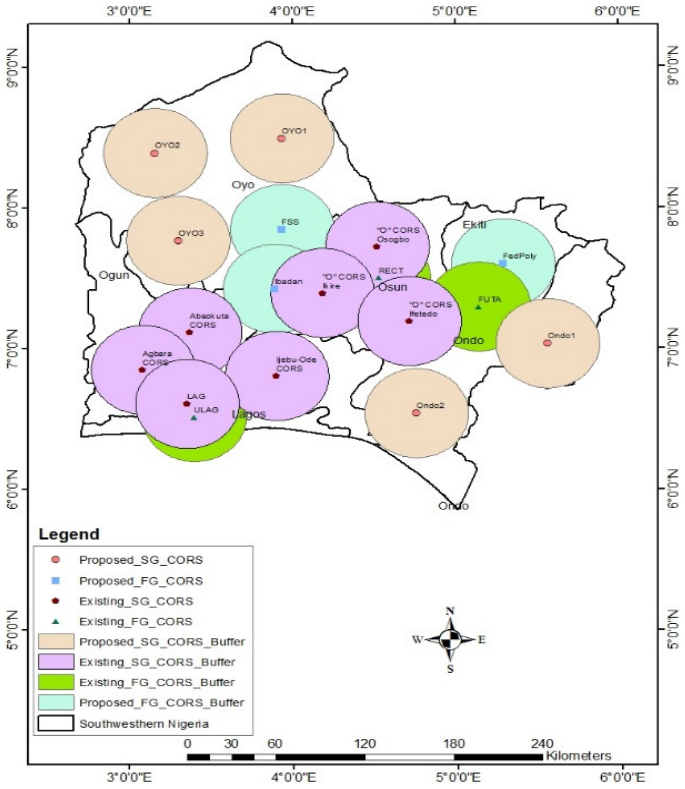

Fig. 6 Map of Southwestern Nigeria Showing 35km Buffer of Existing and Proposed SG and FG CORS.

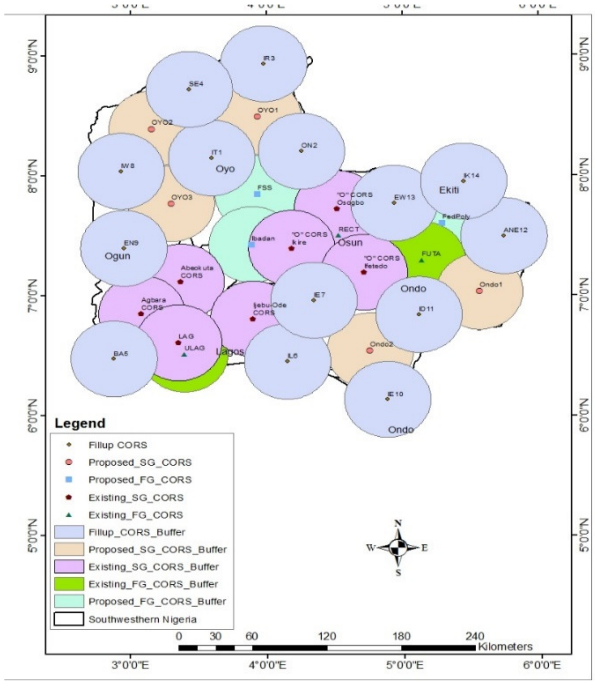

Figure. 7 Map of Southwestern Nigeria Showing 35km Buffer of all the Existing and Proposed SG and FG CORS.

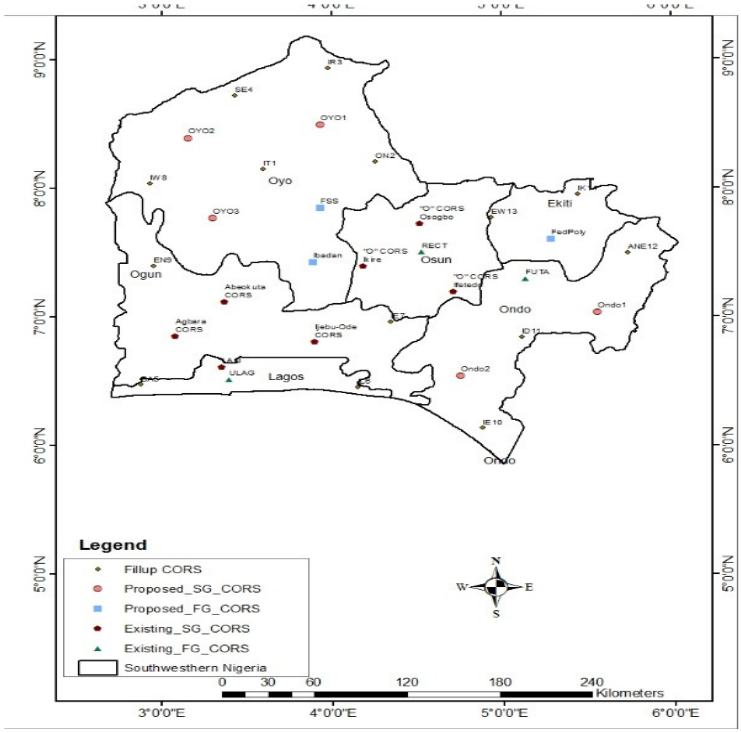

Figure. 8 Map of Southwestern Nigeria Showing the Existing and all the Proposed CORS.

4. Results and discussion

This study proposed the location of new CORS based on the 35km buffer for the Southwestern region. This study proposed three new Federal government based COR stations to be located at the Polytechnic, Ibadan and Federal School of Surveying, Oyo as well as Federal Polytechnic, Ado-Ekiti. Since there were no Federal government suitable locations for additional CORS, three State government based CORS were proposed, at Atiba, Atisbo and Iseyin Local government areas of Oyo State as well as two State-based CORS at Owo and Okitipupa Local government areas of Ondo State. For a cover-up of the study area, fourteen more CORS were proposed. This study proposed three new Federal government based COR stations to be located at the Polytechnic, Ibadan, Federal School of Surveying, Oyo and Federal Polytechnic, Ado-Ekiti. In addition, three State government based CORS proposed at Atiba, Atisbo and Iseyin Local government areas of Oyo State as well as two State government based CORS at Owo and Okitipupa Local government areas of Ondo State. Fourteen CORS were used to fill up the pockets of areas remaining to achieve a cover-up of the study area. Twenty-two proposed CORS and ten existing CORS achieved the required coverage of the study area. Based on these, Ogun, Osun, Oyo, Ondo, Ekiti and Lagos states of the Southwestern Nigeria got five, four, ten, six, three and four respectively. These make a total of thirty-two COR stations.

This study can be compared with the study by Naibbil & Ibrahim (2014) and Ojigi (2014) that proposed new CORS. Naibbil & Ibrahim (2014) study used a minimum distance of not less than 70km with a buffer of 100km and existing Tier III CORS were not considered. Also, Ojigi (2014) did not consider existing Tier III CORS and minimum distance between stations was not considered within the Southwestern region. This study was based on 35km buffer for CORS distribution and an average nearest distance of 36.7km obtained. It is also noteworthy to now that there were just two existing

stations considered by Naibbil & Ibrahim (2014) and three existing stations considered by Ojigi (2014) in the study area, unlike ten stations that exist now.

5. Conclusion

This study proposed the location of new CORS based on the 35km buffer for the Southwestern region. Twenty-two CORS locations in total were proposed to achieve the coverage of the study area. The implication of the result of this study is that GIS can enhance the even distribution of CORS across the territory. The uniform distribution obtained in this study will be effective and convenient for NRTK implementation in the study area. It is also hoped that it would encourage multiple CORS application areas and provide data redundancy for users.

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7. Key terms and definitions

Continuously Operating Reference Station (CORS): This is defined as a stable platform occupied by a GNSS receiver which collects data continuously.

Network Real Time Kinematic (NRTK): This is a network of CORS that continuously collect satellite observations and send them to a central processing facility where the observations are processed in a common network adjustment and observation errors and their corrections are computed. These corrections are broadcasted over the internet or through other medium for retrieval. NRTK is also referred to as Real Time GNSS Network (RTN).

Classification of CORS: CORS can be classified into Tier 1, Tier 2 and Tier 3. Tier 1 are the CORS established and used by IGS or any other equivalent ultra-high accuracy networks to support geoscientific research and global reference frame definition. Tier 2 are the high accuracy CORS networks operated by national geodetic agencies for the purpose of maintaining national geodetic datums and providing the fundamental backbone of the national geospatial reference frame. This is the appropriate classification of all NIGNET CORS. Tier 3 are the CORS that densify the national COR stations networks, operated by agencies, state governments and private companies

Mode of Operations of CORS: There are two modes of operations of CORS namely post-processed CORS and "Real-time" CORS. Post-processed CORS is when the observations are processed after the field observation. Real-time operation is when the processing of the observations is carried out in the field, just as the data are captured. The final data are obtained on the field.