University of Nairobi

School of Engineering

An Analysis and Densification of Continuously Operating Reference Stations (CORS) in Nairobi and its Environs: A Geospatial Information System (GIS) Approach

Barasa Anthony Kusimba

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Declaration

I, Barasa Anthony Kusimba, hereby declare that this project is my original work. To the best of my knowledge, the work presented here has not been presented for a degree in any other Institution of Higher Learning.

Barasa Anthony Kusimba …………………
Name of student Date

This project has been submitted for examination with our approval as university supervisor(s).

Dr. - Ing Sammy Mulei Musyoka …………………
Name of supervisor Date

Abstract

Positioning and navigation has revolutionized from traditional surveying approaches, due to the significant developments in Global Navigation Satellite Systems (GNSS). The endorsement of Continuously Operational Reference Station (CORS) in Kenya has paved way for the use of Real Time Kinematic (RTK) network in provision of geospatial infrastructure for spatial data management. The spatial coverage of operational CORS within the Country as well as the Areas of Interest seems inadequate based on International Terrestrial Reference Frame standards.

Consequently, the study explored existing, operational CORS as well as determining suitability of densifying them with the intent to expand their spatial coverage within Nairobi County and its environs. The study primarily employed spatial data from various sources including: Ministry of Lands; Ministry of Mining; Ministry of Transport, Infrastructure and Housing, Ministry of Environment and Natural Resources and Volunteered Geographic Information, that was manipulated using a GIS approach that is suitability analysis. Suitability analysis exploited Multi-criteria Evaluation (MCE) through defining the goal: densification of tier three CORS; determining the base criteria: Accessibility, Security, Power supply; Network density and analysis: Proximity analysis; and intersection; hence establish optimum locations/sites for establishment of CORS. The proposed CORS were subjected to another intersection in order to determine an optimum distance between the stations using Triangulation matrices of various designs: Random; East-West and North-South Triangulation Matrices, to ensure a positional accuracy of +/- 20mm is always achieved on its various applications. Consequently, IGS standards of establishing CORS stations were met through employing MCE and Triangulation Network Matrices to ensure a well-conditioned network of triangles.

The approach resulted into thematic maps relaying areas with inadequate coverage, and suitable areas for CORS stations within Area of Interest.

Acknowledgement

I appreciate the inspiration of various people and the institution, the University of Nairobi for the support and assistance offered within the duration that I conducted this project.

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List of Acronyms

AOI:	Area of Interest
BTS:	Base Transceiver Station
CORS:	Continuously Operational Reference Stations
DWG:	Drawing (Computer Aided Design Program File Extension)
ESA:	European Space Agency Missions and Programmes
ESRI:	Environmental Systems Research Institute
GNSS:	Global Navigation Satellite System
IGS:	International GNSS Service
ILRI:	International Livestock Research Institute
JAXA:	Japan Aerospace Exploration
KCAA:	Kenya Civil Aviation Authority
KeNHA:	Kenya National Highways Authority
KeRRA:	Kenya Rural Roads Authority
KURA:	Kenya Urban Roads Authority
MAC:	Master Auxiliary Concept
MCE:	Multi-criteria Evaluation
RCMRD:	Regional Centre for Mapping of Resources for Development
SEGAL:	Space and Earth Geodetic Analysis Laboratory
SOK:	Survey of Kenya
UTM:	Universal Transverse Mercator
VGI:	Volunteered Geographic Information

CHAPTER 1: INTRODUCTION

1.1. Background

1.1.0. Global Navigation Satellite Systems

Advancement in technology specifically in Global Navigation Satellite Systems (GNSS) has triggered new approaches in both positioning and navigation. The adoption of Continuously Operational Reference Station (CORS) in Kenya and most countries has supported the use of GNSS receiver network to provide a geospatial infrastructure for spatial data management (Awange, 2018). CORS is a collection of RTK base stations that normally transmits corrections over the internet with improved accuracy due to the number of base stations within the network hence guarding against false initialization on a single base receiver (US Department of Commerce, NOAA, National Geodetic Survey, 2009, July 29).

The setting up of survey controls involves transfer of controls to the survey site (Figure 1.1). CORS play a crucial role in mapping (land acquisition to pave way for infrastructural projects; civil engineering works (setting out of structures); and Geodetic Survey (US Department of Commerce, NOAA, National Geodetic Survey, 2009, July 29).

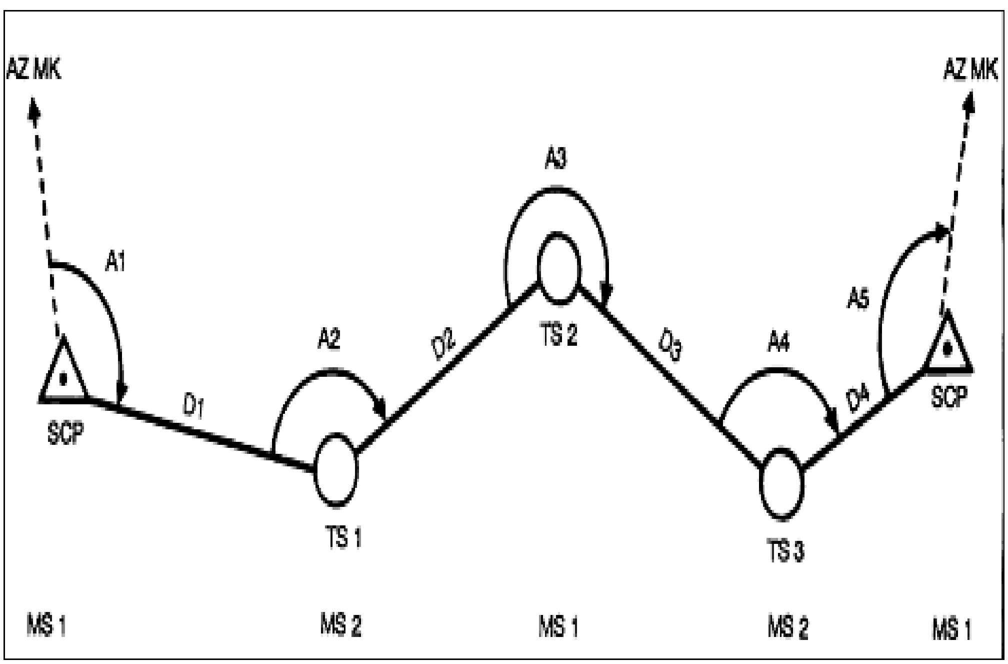


Figure 1.1: Transfer of Control Points closer to site by Traversing

1.1.0.1. Application of GNSS (CORS)

In general, CORS ensures accurate positioning of land parcels and extension of existing geodetic controls. Specific applications of CORS include:

Table 1. 1: Application of CORS

Field of application	Specific areas of application
Surveying	Geodetic Surveying – establishment, densification, maintenance of national geodetic networks; establishment and maintenance of national geoidal models and height networks,
	Cadastral surveys – establishment of survey control points, relocation of property boundaries, subdivision and consolidation of properties,
	Topographical surveys – determination of elevations and positions of points and features of interest so as to produce topographic or large scale maps showing an area's terrain and other required detail,
	Engineering Surveys – determining the absolute and relative positions of features existing on the site of the proposed works, setting out, monitoring and deformation surveys, maintenance of infrastructure and facilities, machine guidance, and as built surveys (showing the actual positions of works as constructed),
Mining	Exploration, Surface surveying, Monitoring of ground surface response to resource extraction, machine guidance, collision avoidance,
GNSS Location Based Services	Cargo Fleet Tracking, Fleet Control/Dispatch, Emergency Operations, Road Maintenance, In Vehicle Navigation, GNSS Positive Train Control, GNSS Maritime Applications, GNSS Recreation Applications, Aero navigation,
Defense and public security	Food security; emergency response; disaster management,
Geodynamics	Local deformation monitoring and geo-hazard studies, Crustal motion

	and continental deformation monitoring,
Agriculture	Precision farming, National crop assessment,
Climate	Determination or retrieval of Precipitable Water Vapour (PWV) in real-time, capturing the signature of severe weather events,
Scientific research	inter/intra tectonic plate deformation, sea level monitoring, climate change, Ionospheric and tropospheric Studies,
Geolocation of Aerial Moving Platforms	Remote sensing applications, positioning of aircrafts employed in aerial mapping, mapping terrain applications using innovative technologies such as scanning radar, light detection and ranging (LiDAR), inertial systems, interferometric synthetic aperture radar, and/or sonar.

1.1.1. Benefits of CORS

1.1.1.1. Benefits in terms of cost and accuracy:

The significant advantage of CORS network is provision of a uniform geodetic control. Moreover, one does not have to budget for the second receiver that acts as the base station that is rather costly running to tunes of millions of shillings. Therefore, investment in such a venture would not only provide high accuracy in spatial data infrastructure due to its versatility but also optimize on capital investment. Initially the basis for the establishment of CORS was to support geodesy as well as other applications both regionally and globally. However, CORS operators have sought a way of making profit out of the network infrastructure. Various applications have endorsed the technology such as engineering survey: constructions of civil works; precision agriculture to support advanced arable farming and land management practices. The aforementioned will mainly optimize capital investments in all its applications (Rizos, 2008). CORS can give a positional accuracy of up to +/- 20mm.

1.1.2. History of CORS in Kenya

Geodetic activities within Kenya trace back in the late 19^{th} century characterized by observation of sizeable triangulation networks by various organizations and localized to their area of interest. The organizations chose their own coordinate system and datum for both horizontal and vertical control, based on their intended use and availability. This in turn resulted into a number of different reference systems (Survey of Kenya, 2000). The need to register land prompted the nation to start its own triangulation network for provision of controls that chiefly employed for title surveys, topographical surveys and other forms of survey. The triangulation network were mainly in Cassini coordinate system done between the years 1906 and 1914. Kenya has mainly two coordinate systems UTM and Cassini coordinate systems. This was a major setback in projected affiliated georeferenced spatial data thus, prompting the need to harmonize the controls to a system that is globally accepted and allow for use of latest technology as envisaged in the National Land Policy, Sessional Paper No. 3 of 2009, section 3.5.4 on Land Surveying and Mapping, part 155 (b):

155. The Government shall:

a) Amend the Survey Act (Cap 299) to allow: (i) for the use of modern technology such as Global Navigation Satellite system (GNSS) and Geographical Information Systems (GIS), and streamline survey authentication procedures; and (ii) regulation of non-title surveys;

b) Establish a unitary and homogenous network of control points of adequate density, preferably using dynamic technology such as GPS; and

c) Improve mapping standards in general boundary areas so that they fit into a computerized system.

1.1.3. Current state

Kenya largely relies on conventional approaches such as traversing to either extend or establish triangulation networks done during the 1990s. This prompts the use of new methods that are more accurate and affordable to foster sustainability of geospatial infrastructure.

Kenya in line with African Geodetic Reference Frame (AFREF) adopted the methodology of unifying and modernizing the geodetic reference frame. When achieved, it will consist of a network of continuous permanent GPS stations accessible to everyone consisting of public and private CORS (AFREF, 2010).

1.1.3. Public CORS stations

There are at least three IGS (International Global Navigation Satellite System Service) CORS in Nairobi (RCMN), Eldoret (MOIU) and Malindi (MALI) established by European Space

Agency missions and programmes (ESA). Currently, the operational CORS include; RCMN hosted by RCMRD; in Embu; and in Dedan Kimathi University (DeKUT) Nyeri established by Japan Aerospace Exploration (JAXA) in collaboration with RCMRD. There are also proposals for other sites yet to be established under the initiative of Kenya Geodetic Reference Framework (KENREF) spearheaded by Survey of Kenya (SOK), to modernize Geodetic Control Network and surveying approaches (AFREF, 2010).

Existing and Proposed CORS in Kenya

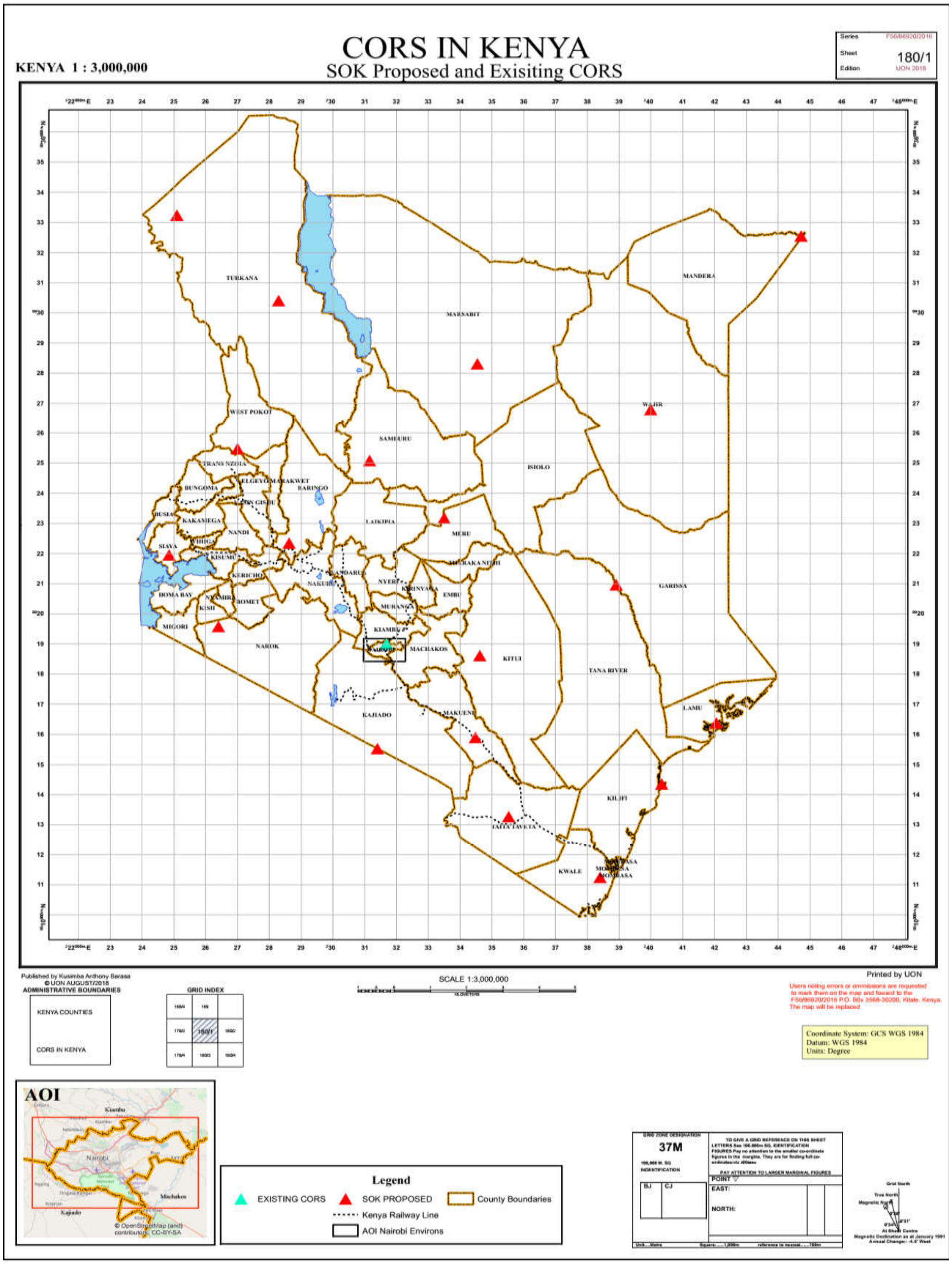


Figure 1. 2: Existing and Proposed CORS in Kenya

Figure 1.2 relays the current state of Existing CORS in Kenya and the proposed stations that are yet to be established by SOK meant for the public. Table 1.2, below shows their current state:

Table 1.2: Status of CORS in Kenya (SOK)

FID	SHAPE	NAME OF CORS LOCATION	SOC	STATUS
1)	Point	***Lokitang***	Ken	Yet to start
2)	Point	***Moyale***	Ken	Yet to start
3)	Point	***Lodwar***	Ken	Completed
4)	Point	***Marsabit***	Ken	Yet to start
5)	Point	***Meru***	Ken	Completed
6)	Point	***Mandera***	Ken	Yet to start
7)	Point	***Wajir***	Ken	Yet to start
8)	Point	***Garissa***	Ken	Completed
9)	Point	***Bondo***	Ken	Completed
10)	Point	***Libai***	Ken	Yet to start
11)	Point	***Habasweni***	Ken	Yet to start
12)	Point	***Lokichogio***	Ken	Yet to start
13)	Point	***Sabarei***	Ken	Yet to start
14)	Point	***RCMRD***	Ken	Completed
15)	Point	***Malindi***	Ken	Completed
16)	Point	***Kanziku***	Ken	Yet to start
17)	Point	***Elwak***	Ken	Yet to start
18)	Point	***Maralal***	Ken	Yet to start
19)	Point	***Kapenguria***	Ken	Yet to start
20)	Point	***Kilgoris***	Ken	Yet to start
21)	Point	***Kajiado***	Ken	Yet to start
22)	Point	***Wunganyi***	Ken	Completed
23)	Point	***Kwale***	Ken	Completed
24)	Point	***Malindi***	Ken	Completed
25)	Point	***Eldama Ravine***	Ken	Completed

1.1.3.1. Private CORS stations

Kenya is characterized by privately owned CORS. For instance, one in Kisumu – Kenya Sugar board, Eldoret – Moi University as well as individually owned by companies such as Embakasi – Fininfo Co. Ltd; Upper-hill – Metrysis Co. as well as newly developed station by Oakar Services Kenya – Upper-hill and Kenya Power and Lighting Company (KPLC) who have 15 stations in Gatundu, Chemosit, Musaga, Kitale, Marigat, Lodwar, Marsabit, Isiolo, Mwingi, Habaswein, Wajir, Kiboko, Hola, Garsen and Galu. Privately owned CORS are established by commercial agencies that operate less GNSS stations for the purpose of satellite positioning needs to local users with similar necessities. The said agencies provide "ad-hoc" services for a short term or seasonally say 5 years (US Department of Commerce, NOAA, National Geodetic Survey, 2009, July 29).

1.1.4. Institutions involved

The African Geodetic Reference Frame (AFREF) is an initiative with a primary agenda of unifying all geodetic reference frames within African through spatial data from a network of Permanent GNSS stations. AFREF initiative stands in tandem with International GNSS service (IGS) which supplies data in RINEX data format of 30-second epoch. Employing such technology comes with various advantages pushing the GPS community towards employing Network Real Time Kinematic GPS (NRTK). GPS has been encourage to a broad percentage of users due to its accessibility and usability. Therefore, being in possession of NRTK with a CORS network, one is required to have simple knowledge of using a receiver. The summed up cost of using NRTK is significantly lower than compared to the cost of implementing a GNSS setup, since the only requirement is a GPS receiver. AFREF initiative through SOK, the custodian of spatial data in SOK promotes use of GNSS (AFREF, 2010).

1.2. Problem Statement

Given the geographical extent of the County and its environs, the current operational CORS are inadequate. The area covers more 20km from the operational CORS hence making the areas beyond the 20km radial range out of the coverage taking more time to fix. Private, public, existing and operational CORS are limited in number, can only be used by private institutions, and are paid for by private individuals in order to access spatial corrections. Moreover, there exists only one operational CORS within the area that can be used freely by the public. Consequently, densifying the Tier 3 CORS stations was meant to improve the signal strength and make available the use of CORS within all areas in the Area of Interest. Apart from that, a well-defined network provides for optimized compatibility with GNSS measurements and other supported functionalities such as mapping.

Kenya currently employs geodetic networks established in the early 20th century. The current network does not support the ever-growing mapping needs and other affiliated geo-related applications such as precision agriculture, homogeneous cross border mapping homogeneous spatial mapping and geographical dynamics due to its inconsistencies. In view of the abovementioned, the issues are well solved through adopting CORS system that is most versatile. Consequently, CORS can be employed in numerous geo-related applications due to its scaled down cost that is an individual would only invest in one receiver rather than the conventional two receivers for RTK.

1.3. Objectives

1.3.1. Main objective

To densify Tier 3 Continuously Operating Reference Stations (CORS) in Nairobi and its Environs.

1.3.1.1. Specific objectives:

1. To evaluate the current state of Continuously Operating Reference Stations (CORS) in Nairobi and its Environs.
2. To use a GIS approach (suitability analysis) to determine optimum sites for CORS (Tier 3) stations.
3. To assess the suitable locations for CORS stations in various areas in the County and its Environs.

1.3.2. Research Questions:

1. What is the current state of CORS within the County and its Environs?
2. What GIS approach can be employed for densification of the current CORS stations?
3. Are the proposed CORS stations feasible in terms of signal strength i.e. coverage?

1.4. Justification for the Study

The advancement in GNSS brought changes in positioning as well as navigation. A proposal to densify the current network to match up to International Terrestrial Reference Frame (ITRF) standards will not only be economically sound but also spatially sound with respect to its area of application. The final information after GIS analysis, mainly in form of maps either thematic, cadastral or topographic maps provides universal compatibility in offering seamless spatial data portrayal from various fields for instance, engineering survey, geology and civil works among others. Therefore, such compatibility aids users from all aspects combine information generated to assist in decisions making.

1.5. Scope of work

The study used Multi-Criteria Evaluation (MCE) to determine optimum sites for establishment of CORS, hence focusing on the spatial aspects of the establishing CORS stations. However, it was limited to other aspects such as equipment specifications, data as well as communication procedures between the equipment. Moreover, there were other aspects for example, site configurations like monumentation and obstructions put during configuration.

CHAPTER 2: LITERATURE REVIEW

2.1. Evolution of Satellite Survey Methods

2.1.1. Real-Time Kinematic Positioning (RTK)

GPS receiver working as a standalone provides an accuracy of up to 5m or even poor. Such accuracy is not appropriate for surveying, consequently most professionals with respect to surveying employ differential correction to supplement on the accuracy. It is a common occurrence nowadays to use Real-Time Kinematic (RTK) positioning with GPS. On this event, it allows the use of a static reference station normally known as a base station with known coordinates that is X, Y, Z or E, N, H while the second receiver tracking the same satellite signals. For that reason, when the carrier phase measurements from the two receivers that is the base Station receiver and the Rover receiver are combined and processed the rover's coordinates are determined relative to the Base station (Higgins, 2001).

Corrections are sent from the base station receiver to the rover receiver to determine its precise position. The whole process can be done on the go that is Real-time Positioning while the Rover receiver is moving. Employing the equipment only needs a few seconds of data to resolve for any ambiguities related to the GPS phase data observable and compute the baseline hence the latitude, longitude and height of the rover position (HNTB, 2004). The implementation of such an approach in known as RTK has the potential of achieving up to an accuracy of centimetre level under constrained conditions (Figure 2.1).

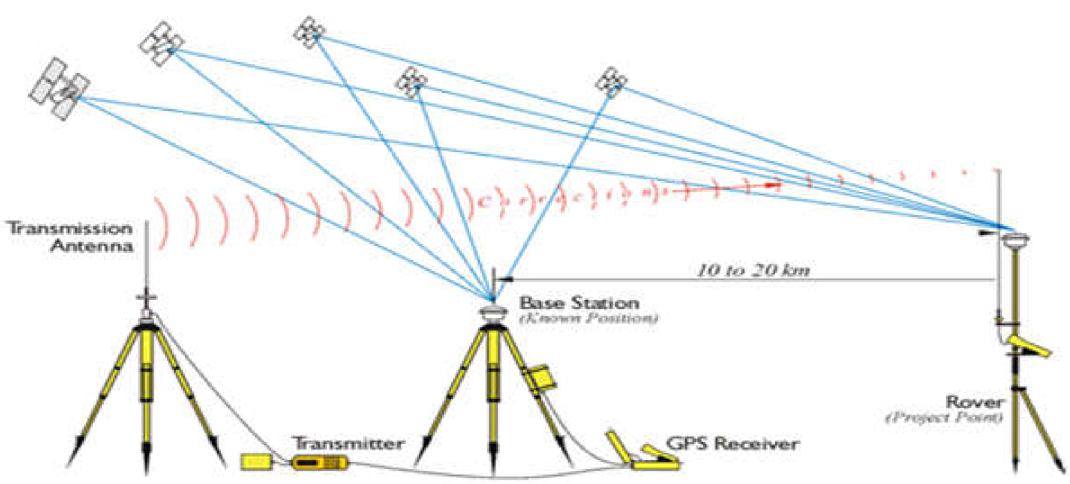


Figure 2.1: RTK GPS Range (Source: Higgins, 2001)

2.1.2. Limitation of RTK positioning

Over the past years, GNSS surveying employing RTK approach has been preferred in various areas for instance, engineering survey, mapping, mining, and precision agriculture. Usually traditional RTK uses a single reference receiver also known as the base station that relays precise coordinates and observables to a moving receiver that is the rover. This approach normally limits the baseline length up to approximately 10km. "For RTK GPS the distance between the Base Station Receiver and the Rover Receiver should not exceed 10 Km in order to achieve an accuracy of less than 10mm (Snay, 2005)". One of the main limitation of RTK GPS is the distance between the Base Station receiver and the Rover Receiver, where the accuracy normally diminishes with the increase in distance between the two. For the approach to be able to resolve for ambiguities, the distance should be less than 10Km, a limitation because of distance biases for instance: tropospheric and ionospheric signal refraction, as well as satellite orbit error. As a remedy of the aforementioned issues Network Real Time Kinematic (NRTK) approach is most suitable, a logical extension of the RTK to cater for geometric biases (HNTB, 2004).

2.2. Continuously Operational Reference Stations

2.2.1. Conception of CORS

CORS approach began in the early 1990s when National Geodetic Survey (NGS) installed the initial permanent GPS receiver in Gaitterburg Campus in USA that culminated into more installations in Maryland, Colorado and other networks that formed part of the CIGNET network. In the early 2000, more stations had been installed raising the number to almost 200 stations steadily increasing to 1400 as at 2014; thus adopted as the primary geodetic spatial data infrastructure. CORS is not a new thing in most of the countries for instance the continent of Africa with the initiation of AFREF, has triggered en-masse adoption of the approach in Kenya, Nigeria, South Africa and Benin among others. As a result, of its geodetic accuracy, it is more attractive to invest in such a venture. "The goal of AFREF is to promote the adoption of modernized geodetic reference in Africa as well as its unification that is seamless reference ensuring uniformity. Therefore, it ensures the nations within the African continent implement the aforementioned using modernized GNSS technologies, hence the establishment of CORS network that will support various activities affiliated to mapping such as cadastral survey, engineering survey and geodynamics (AFREF, 2010)".

Table 2.1. shows national mapping authorities responsible in management of GNSS infrastructure.

Table 2.1: National CORS Mapping Authorities

S/No.	Network Name	Country	No. of CORS	Data
1.	TrigNet	South Africa	55	Rinex & Network RTK corrections
2.	RwandaGeonet	Rwanda	8	Rinex & Network RTK corrections
3.	BotswanaNET	Botswana	10	Rinex & Network RTK corrections
4.	NIGET	Nigeria	15	Rinex & Network RTK corrections
5.	SOK	Kenya	25 (Proposed)	Rinex & Network RTK corrections
6.	Zambia CORS Network	Zambia	70 (Proposed)	Rinex & Network RTK corrections
7.	Mauritius CORS Network	Mauritius	19 (Proposed)	Rinex & Network RTK corrections

2.2.2. Continuously Operating reference stations (CORS)

CORS is normally GNSS receiver that is permanently located on a monument with antennae with accurately predetermined coordinates. On the other hand, CORS can take place on the classical Base station used by GNSS (Figure 2.2). It usually tracks satellites continuously and might be a single station or a network of receiver stations within a region referred to as a CORS network spanning a large geographical area; for instance the Nigerian GNSS Reference Network – NIGNET (11 in existence). Other Networks could be continental such as AFREF that had more than 37 stations spread across Africa as at May 2010. Currently, Kenya has already designed a network on the location of the CORS primary and secondary stations where 21 primary stations and 71 secondary stations were proposed. The implementation was planned to take place in phases through establishing the primary stations and later the secondary stations. Thus, the sites have been prepared awaiting mounting of antennas (AFREF, 2010).

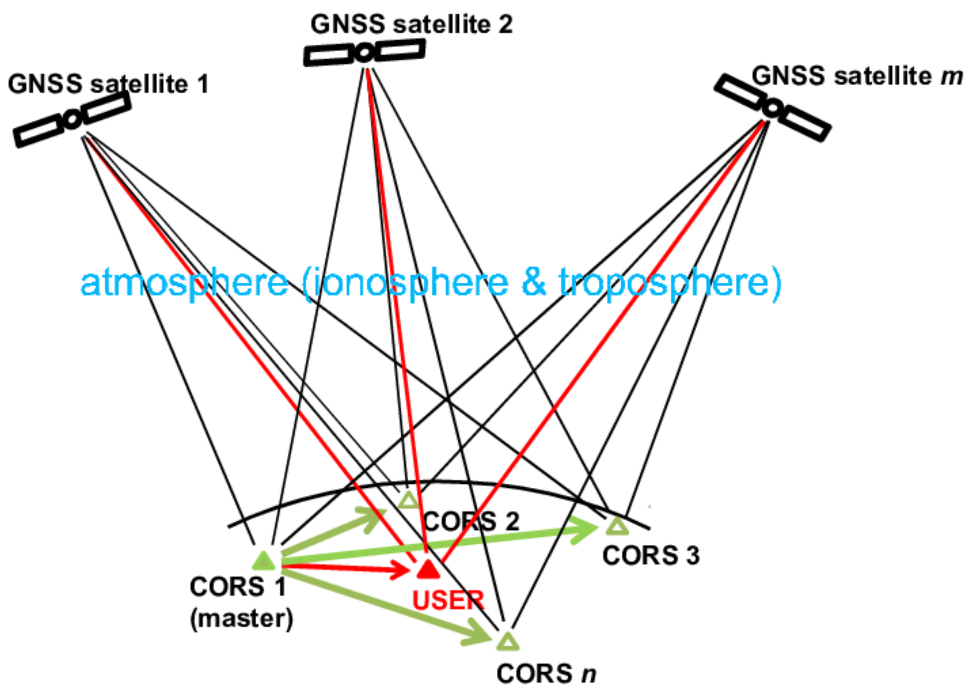


Figure 2. 2: CORS Network

2.2.3. Network Real Time Kinematic

Consequently, the NRTK takes advantage of CORS network to spatially model biases that would have otherwise been experienced with the former. The method heavily utilises multiple reference stations to improve the Rover's receiver positioning. The accuracy of RTK is completely dependent on the distance between the Base and Rover keeping all factors constant; its productiveness diminishes considerably with increased distance from the reference station (Higgins, 2001). Greater baseline lengths do not sufficiently offer for cancellation of atmospheric errors. This will not allow for ambiguity resolution. Real Time GNSS Networks can considerably minimize such limitations affiliated to baseline length. NRTK uses a network of reference stations in order to interpolate atmospheric delays hence reducing satellite orbit errors (Zhang et al., 2006).

The GNSS reference station transmit data to a central network-processing server as well as the rover through a cellular data plan using wireless communication. Therefore, data from the reference stations are used to generate corrections through fixing integer ambiguities of double differenced GNSS phase observables. The rover will then be able to compute its precise position. RTN has two common approaches:

2.2.3.1. Virtual Reference Station (VRS)

VRS is a concept developed by Trimble. It is an extension of RTK purposefully developed for high precision positioning systems. The approach operates in a CORS network. VRS uses the existing CORS network to determine the reference base station that is close to the Rover receiver, receive corrections from the satellites and send them back to the rover receiver. VRS uses a network of CORS reference stations but only relay it as one (Cislowski & Higgins, 2006). Moreover, it only needs one receiver rather than the RTK that need two receivers because there is no real base station receiver, as long as a communication signal can be established. This approach is crucial since it does not restrict the extent the rover can go as long as it remains within the CORS network. Multiple users can use the similar system however; it will depend on specific user. The VRS gathers spatial data through a central server that establishes a bi-directional communication between the Rover receiver and VRS server. The rover receiver has to provide the server with approximate location (autonomous) hence request the server to send data to the Rover receiver (Landau et al., 2002).

VRS server normally have spatial data of the existing CORS stations capable of determining the expected signal that a Base receiver near the user would be able to see and correct the position with respect to Ionospheric, tropospheric delays and satellite clock offsets. The effect is similar to the user doing a classical RTK since the VRS will shift the receiver base station depending on the user's position, consequently maintaining its precision (Landau et al., 2002). "The Rover receiver communicates with the server giving its approximate position, the server will then generate corrections as if there was a Base reference stations at the approximate position of the Rover receiver (Landau et al., 2002)"

As a result, VRS enjoys overwhelming advantage over classical RTK where it covers a larger geographical area, and high positional accuracy. The latter uses multiple reference stations overcoming RTK shortcomings such as of establishing base station every time one wants to run his GPS receiver; the limitation of range of radio communication has been overcome by use of mobile phone technology; and numerous reference stations amplifies redundancy hence increase positional accuracy of the rover receiver (Landau et al., 2002).

2.2.3.2. Master Auxiliary Concept (MAC):

This kind of concept involves the rover transmitting an uncorrected positional data to the central server and then the server would then search and select a "cell" of reference stations primarily for generating corrections. MAC usually assigns the nearest stations as the reference station and several auxiliary stations within the chosen cell. The corrections are adjusted with respect to the reference station, afterwards residual corrections between the said reference station and the auxiliary stations are transmitted to the rover receiver. The rover would then interpolate network information and the corrections to derive its actual position on the ground (Martin and McGovern, 2012).

2.2.4. CORS Hierarchy

According to Rizos (2008) CORS' hierarchy is based on tiers determined by the primary purpose for which the station was established and the expected stability of the station monument. The implementation of CORS network can be categorised into:

2.2.4.1. Tier one CORS:

This tier usually require high stability monuments in order to support the definition of the reference frame and geoscientific research. The services are established to support high accuracy networks with respect to IGS.

Application:

The tier is employed in determination of the International Terrestrial Reference Frame (ITRF).

2.2.4.2. Tier two CORS

This tier of CORS also needs high stability monuments. They are implemented by national geodetic agencies in order to maintain national geodetic reference frames. They are also known as the primary national geodetic network within a country or region.

Application:

Tier two CORS are characterised by ultra-high accuracy networks formed on the basis of Tier 1 CORS. They usually provide a seamless tie between the national geodetic network datum and ITRF. For the realisation of the ITRF spatial data from TIER 2 CORS from regional networks should be made available.

2.2.4.3. Tier three CORS

This tier also need stable monuments and customarily implemented by the national or commercial agencies principally for the regional CORS network to support real time position survey services.

Application:

They normally give access to geodetic spatial data rather than define it. They are also known as fit for purpose stations.

2.2.5. Current state of CORS

CORS stations have now been established in manner that can define regional, continental as well as global because of continuity that is the seamless link between tier 1, tier 2 and tier 3. Earth observing bodies came up with specifications meant to guide in the implementation of CORS stations through the ITRF; a standard for geodetic sciences. The purpose of ITRF is provision of access to geometric and gravimetric reference frames. This is possible through provision of continuous global observation. Most CORS stations should be situated in places that are easily accessible to enhance provision of security and less obstacles by structures/objects like tall buildings and vegetation canopy that would result into multipath errors, consequently, compromise on the resultant accuracy (Rizos, 2008).

2.2.5.1. CORS status:

There are numerous CORS, both private and public established to date and a proposal for more stations in Africa as shown in Table 2.1. Most of the stations have been established by efforts from IGS, AfricaArray, National Geospatial Service-USA as well as Space and Earth Geodetic Analysis Laboratory (SEGAL). For instance, IGS establishes CORS stations for the sole purpose of research and provision of GNSS services to the public. On the other hand, AfricaArray has established more than 25 CORS stations. SEGAL maintains a network of more than 100 stations spread across Europe, Africa, South America and Asia.

2.3. Employing GIS in decision-making

2.3.1. GIS on trend analysis

Geographic Information Systems has a variety of applications for example, creation of suitability maps for determination of optimum locations employing suitability analysis using overlays with Boolean Operators. Suitability Maps relay locations best suited for a specific purposes for instance establishment of CORS. GIS develops trends on spatially referenced data for a detailed analysis based on location, suitability and record events on a specified area over a certain epoch to observe the transformations of things with respect to time (Riguax, Scholl & Voisard, 2002). Decision-making is based on the factors that influence the determination of suitable sites (Aronof, 1995). Consequently, GIS makes the complex surrounding a simple and comprehensible for procedural decision-making (Figure 2.3).

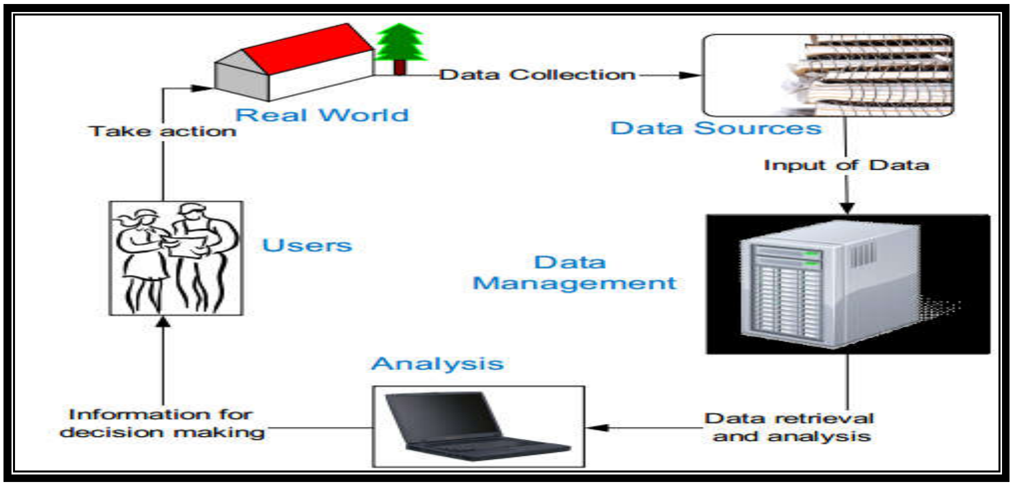


Figure 2. 3: Modern Planning process in GIS (Source: Aronof, 1995)

Visual spatial-data is easy to comprehend rather than unprocessed data itself. Furthermore, GIS facilitates the recognition of various relationships of spatial-data (OLooney, 2003). For instance, in strategizing a new project such as suitable sites for CORS within an area, their status, sustainability issues, and the population it serves, the population of the underserved as well as accessibility of the existing ones. Consequently, maps are core in transforming raw data into easy to use information. A map facilitates the ability to achieve a virtual perception of the real world. Vast amount of data becomes more imaginable as well as comprehensive with maps (Longely et al., 2006).

2.3.1.1. Overlay with Boolean Operators

Spatial intersections normally leads into new features being created. Thus, one should be able to distinguish the new spatial units that are created that is the relevant units and the less relevant units. The overlay approach is based on Boolean algebra using binary logical operations forming a mathematical structure based on values true (1) or false (0). It provides two options that can either be true or false but never both. The approach uses operators such as AND: Conjucntion; OR: Disjunction; XOR: Exclusion; and NOT: Negation (Longely et al., 2006). The approach works best on suitability analysis with a clear exclusionary criteria.

2.3.1.2. Multi-Criteria Evaluation (MCE)

GIS aids in decision making in various ways through the creation of suitability maps or hazard maps. They show areas that are well suited for a specific purpose. Before making decisions various considerations are made where conflicting information avails (Longely, 2006). Consequently, with one objective with a variety of factors Multi-Criteria Evaluation comes in handy.

2.3.1.3. Standard Procedure for MCE

Define Goal

The initial phase involve the definition of the problem at hand, for instance, the determination of optimum sites for location of CORS.

Select the criteria

The criteria reflects the factors for existence of the defined goal. For example, factors for the establishment of CORS sites; factors for establishment of BTS stations.

Operationalization of the criteria

After the determination of the criteria they are translated into measurable indicators in a GIS environment data layers in form of shape files, then integrated into a common scale for instance similar data types, vector or raster; same resolution and reference system.

Intersection

Identification of optimum sites using different approaches:

- Boolean: Each layer is in binary format true or false
- Weighted overlay: spatial data identified in a more definite distinction through application of weights
- Fuzzy overlay: Cancellation of sharp boundaries with transition zones.

Verification

Determination of the resultant output with what is typically on the ground through ground-truthing using high-resolution aerial photos or physically determining the phenomena on the ground.

Summarised procedure:

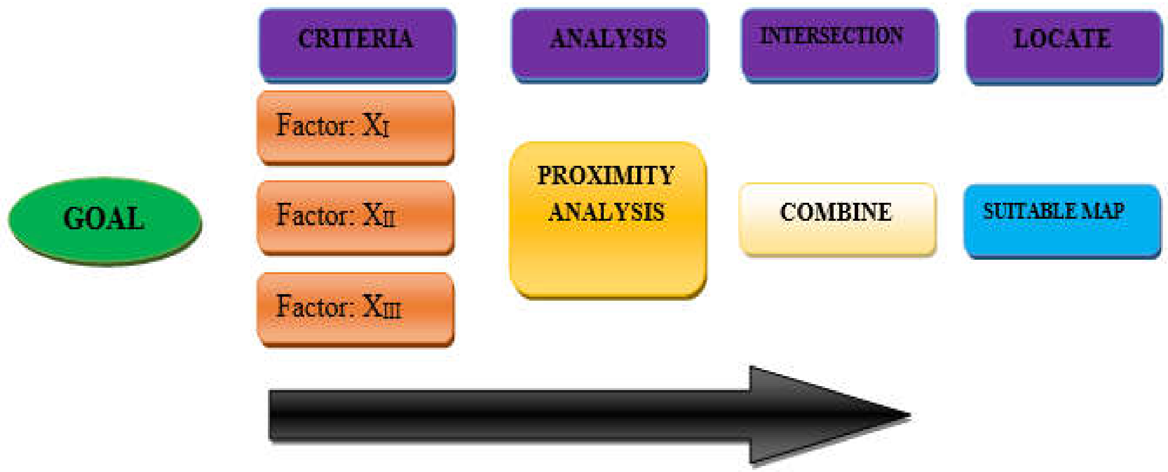


Figure 2. 4: Multi-Criteria Evaluation Summary

2.3.2. Factors affecting Establishment of CORS

The suitability for the establishment of CORS station are dependent upon various factors as outlines in the following sections:

2.3.2.1. Geological:

Stability of the ground

Areas that are dominantly characterised by faults are considered unsuitable areas for establishment of CORS stations. CORS are expected to determine positional accuracy up to millimetre level therefore, ground that experience tectonic movement or movement of mass would hamper one from obtaining true results from measurements made. Measurement obtained would predominantly have either minor or major shifts.

Marks affiliated to survey; in this case, CORS monuments are subject to geological and surface activities. Mainly such activities affect the vertical component of the survey mark as compared to the horizontal component. More often than not, surface activities as well as ground motion happen horizontally unless it is an earthquake or isostatic activity. The stability of the mark on the ground is dependent on the purpose of the survey mark (Dewberry, Jun - 98). According to NGS establishment of monuments should be done on sound bedrock. Earth surface motion are categorised into:

Near surface motions: this are motions that occur within the first 15m of the earth's surface. Surface motion are caused by shrinking and swelling of soil; rock moisture content; frost heave, and compaction due to large structures.

Sub-surface motions: normally happen after 15m below the surface. This kind of motion occurs immediately after the bedrock due to ground fluids mining.

Isostatic motions: are the motions that occur within the earth's lithosphere. Motions of this nature normally affects both the bedrock and the surface above (Dewberry, Jun - 98).

2.3.2.2. Distance factor:

Coverage of Existing CORS

The existing coverage of CORS in Nairobi and its environs reveals that some pockets that are not adequately covered shown in figure 2.3. Having a buffer of at least 20Km from the existing CORS: RCMN station, having in mind that as distance increases away from the stations accuracy diminishes. CORS signals normally fades as one moves away from the base station similar to an RTK situation. In order to accommodate the no coverage areas, densification of other stations is unavoidable that is tier three stations derived from the existing tier 1 stations.

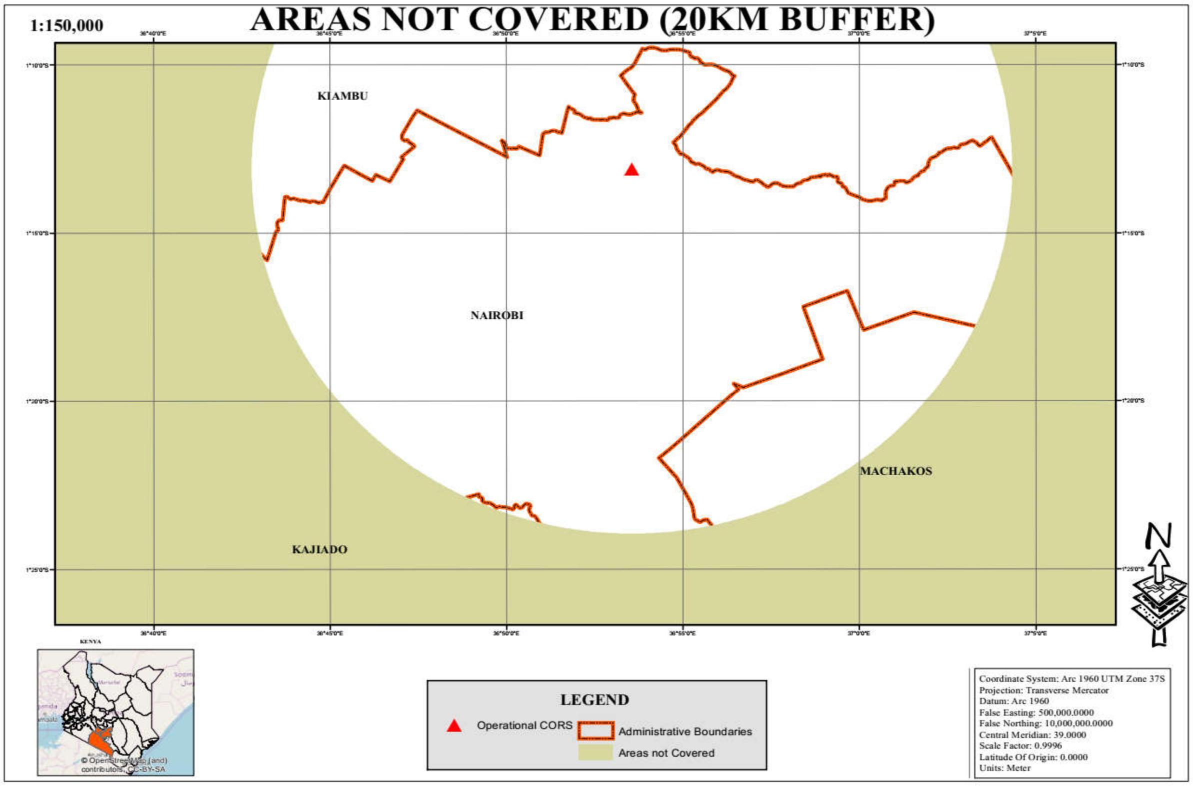


Figure 2. 5: Areas not covered (delayed time to fix)

For effective performance of CORS, there are various parameters that come into play, the distance between the base station and receiver, and Time To First Fix (TTFF). Therefore, a graph of first fix against baseline plotted indicates that the longer the baseline the longer to TTFF and the shorter the baseline the shorter TTFF. For that reason, network RTK can provide instant solution for up to 20Km figure 2.5 shows how the TTFF would be affected by the baseline length (Lachapelle, Ryan & Rizos, 2002).

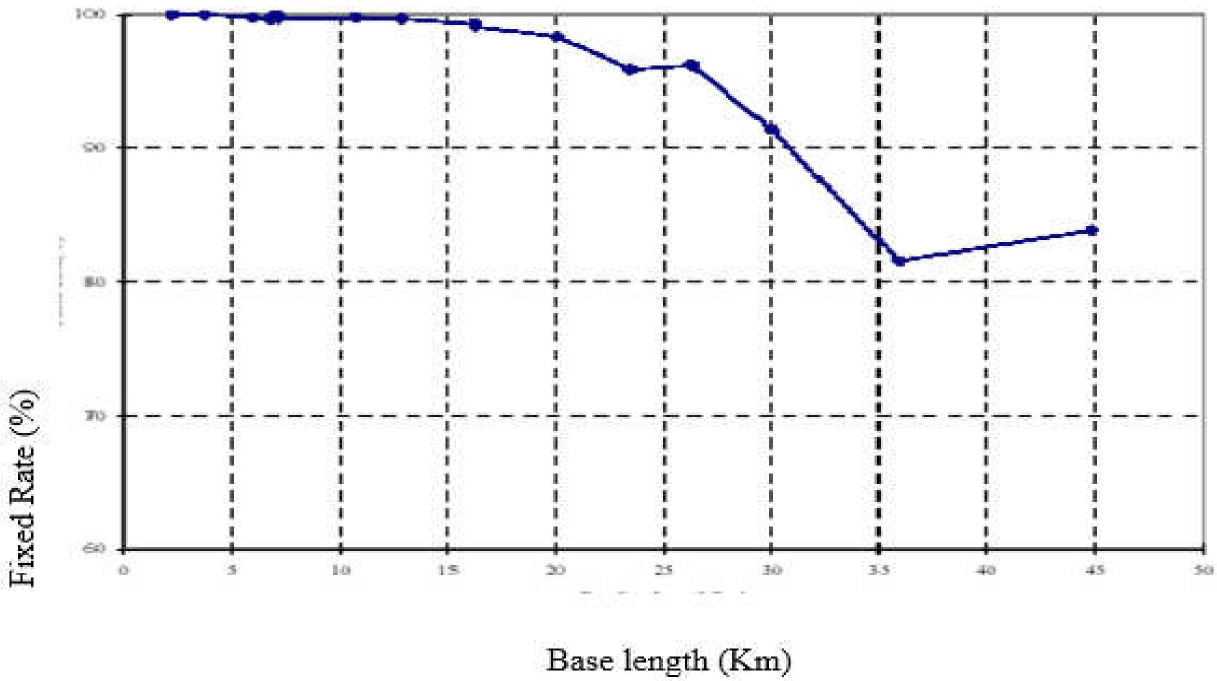


Figure 2.6: Baselines distance vs Positioning Accuracy (Lachapelle, Ryan & Rizos, 2002)

The above graph relays that operating range affects positional accuracy. The degrading positional accuracy is because of the increase in initialization.

Distance away from protected areas/Zones

Locating CORS within a national park poses a security risk to the operator while performing routine maintenance of the appliance. Moreover, placing CORS within a forested area would hamper communication of the receiver and base. Therefore, it is advisable that such areas should be avoided. Similar to the performance of RTK, CORS signal when subjected to areas that are highly vegetative signals are blocked, attenuated and reflected resulting to loss of lock. Consequently, when under such condition a fast solution would be difficult.

Distance away from water bodies

Water bodies include rivers, lakes, and large artificial reservoirs. Usually the surface neighbouring water bodies is loose and prone to surface movement due to activities experienced on/in the neighbouring water body. For instance when heavy rains occur up stream more than the usual capacity, activities does stream tend to appreciate for example sail erosion, and flooding. These occurrences would alter the location of any permanent structure along its path. Therefore, establishment of CORS should be done far from water bodies to avoid such activities.

2.3.2.3. Accessibility & security:

Roads and security

The establishment of CORS stations is based on trade-off between security and accessibility. Even though the site requires infrequent visitation there will be times when the equipment need maintenance. Therefore, the site should be reached with uttermost minimal logistical interferences. On the other hand, the site should be protected from unauthorised individuals who could distort data transmitted as well as protection against vandalism. It is much easier to operate the stations within BTS stations that is constantly guarded, monitored, and located in suitable areas that can be accessed via road. Apart from that, BTS stations normally house their accessories with a structure avoiding exposure to unauthorised personnel and other forms of vandalism.

2.3.2.4. Continuity of operation:

Power Supply and telecommunication utilities

For routine operation of CORS, stations power supply and telecommunication utilities are a necessity. Normally BTS stations have constant supply of power even when the grid is down due to pre-installed generators that are in stand-by. BTS stations are critical when it comes to housing CORS antennae sine they have similar needs in terms of power supply.

2.3.2.5. Network density and spacing (Distance):

Using RCMN CORS station as the subject, it normally covers a range of 20Km. It was however, noted that there is a degradation of accuracy as the rover moves father away from base station. Manufacturers advises a radius of approximately 50km on the other hand, in application within the AOI a guaranteed accuracy was limited to 30km. Therefore, with a proper network design as well as increased density of substations that is Tier three station increases the range of coverage. The element that is readily associated with design of the network is spacing as well as geometry. Equilateral triangles are best suited for a network design since they provide an optimal geometry for network modelling and post-processing services.

In this study, various triangulation matrices were considered to provide more coverage that hinged on the base station as the reference point included:

Random Network Design Matrices

This design does not consider any direction however, it assumes once the base station is catered other substations will be well distributed maintaining well-conditioned triangles.

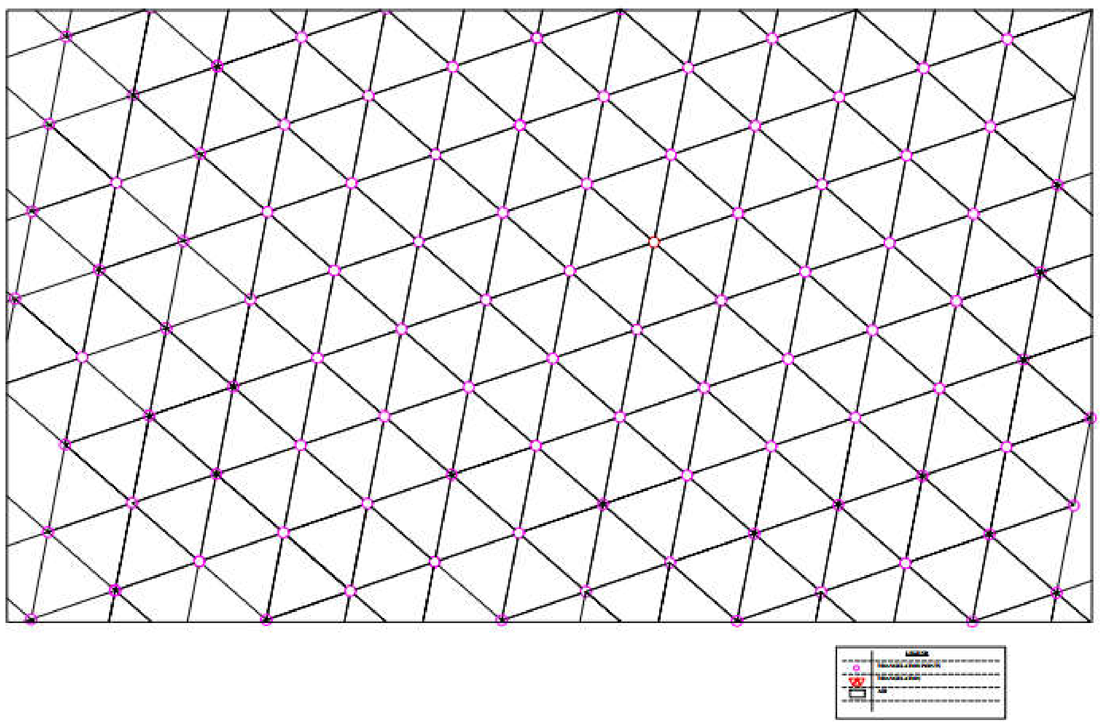


Figure 2. 7: Random Network Design Matrices

North – South Network Design Matrices

This design ensured that the triangulation nodes are aligned from North to South ensuring the base station is used are the pivot point.

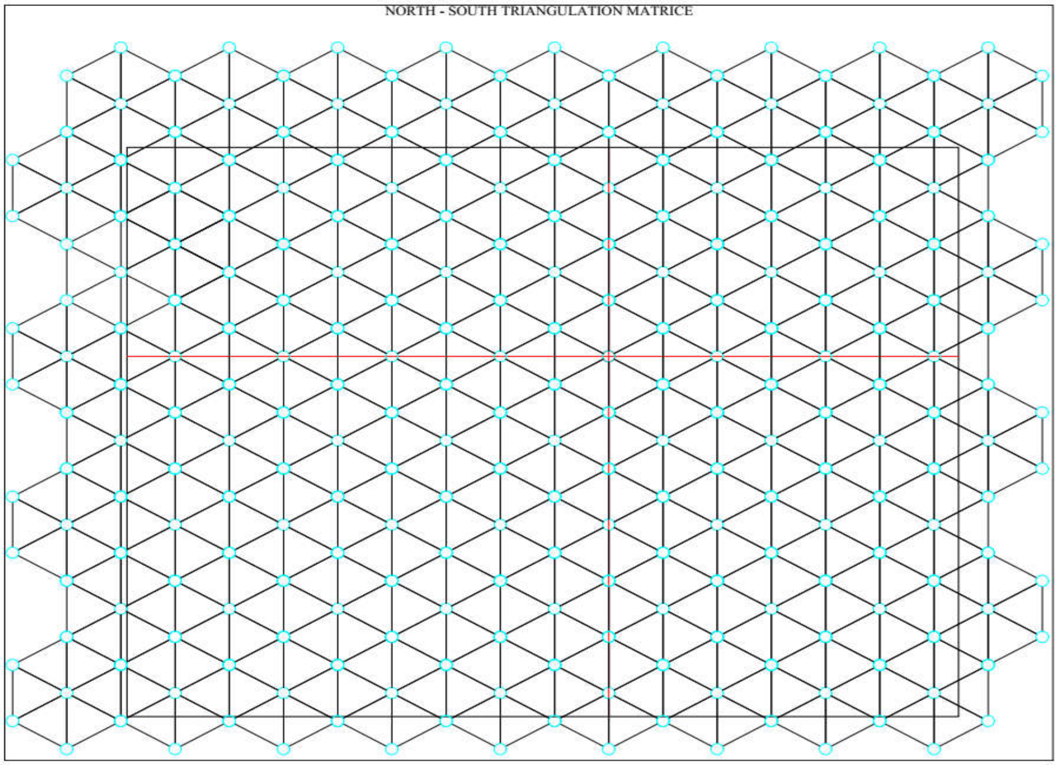


Figure 2.8: North – South Network Design Matrices

East – West Network Design Matrices

This design ensured that the triangulation nodes are aligned from East to West ensuring the base station is used are the pivot point.

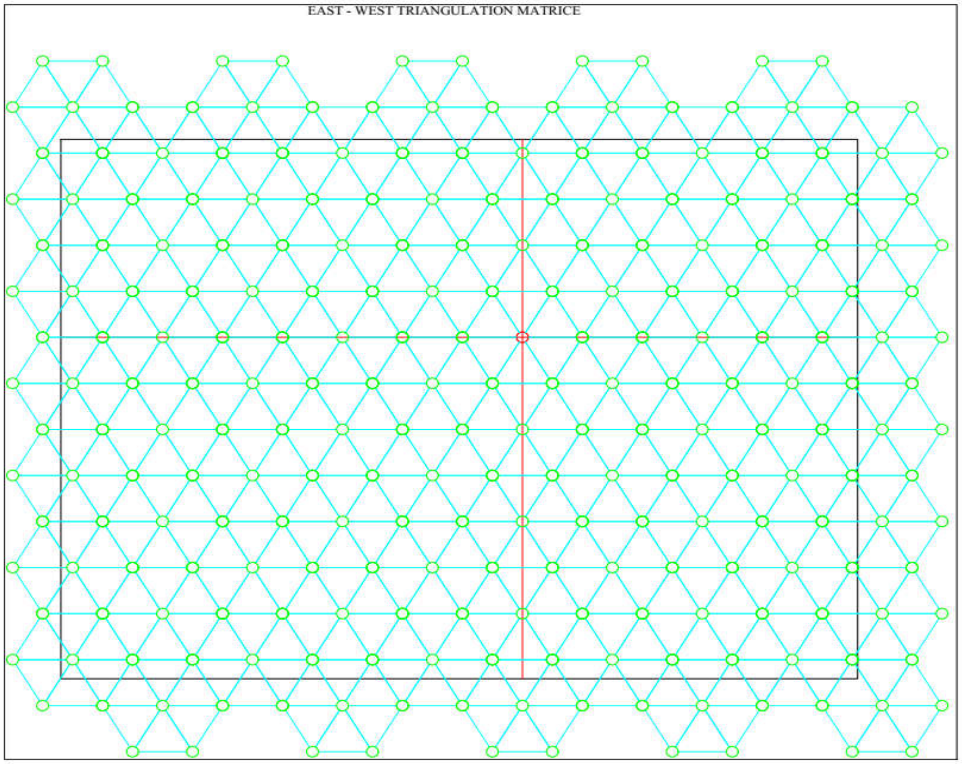


Figure 2.9: East – West Network Design Matrices

CHAPTER 3: MATERIALS AND METHODS

3.1. Materials and Equipment

3.1.1. Hardware:

The hardware used in the study include, a personal computer with specifications: Core i7 – 6500U CPU @ 2.50 GHz with 8 GB RAM.

3.1.2. Software:

The software used in the study comprises of ESRI ArcGIS 10.3 version; AutoCAD Civil 3D 2018; Google Earth pro; Microsoft Office 2016 and Global Mapper.

3.2. Study Area:

Geographical Location:

Nairobi County and Environs:

Nairobi is the capital city of Kenya, apart from being a County. The County has a geographical extent of 684 square Kilometres. The area has an average altitude of 1684m above sea level. It boarders and is surrounded by Kiambu county on the Western side, Kajiado county on the southern side and Machakos County on the eastern side (Schmid, 1998). The area has vast geographical features with Ngong Hills on the western side; it is also characterised by a river cutting across the city, Nairobi River. It also has a population of 3.134 million as per the census of 2009 (KNBS, 2009).

Figure 3.1 shows the study area that is within Nairobi and its environs.

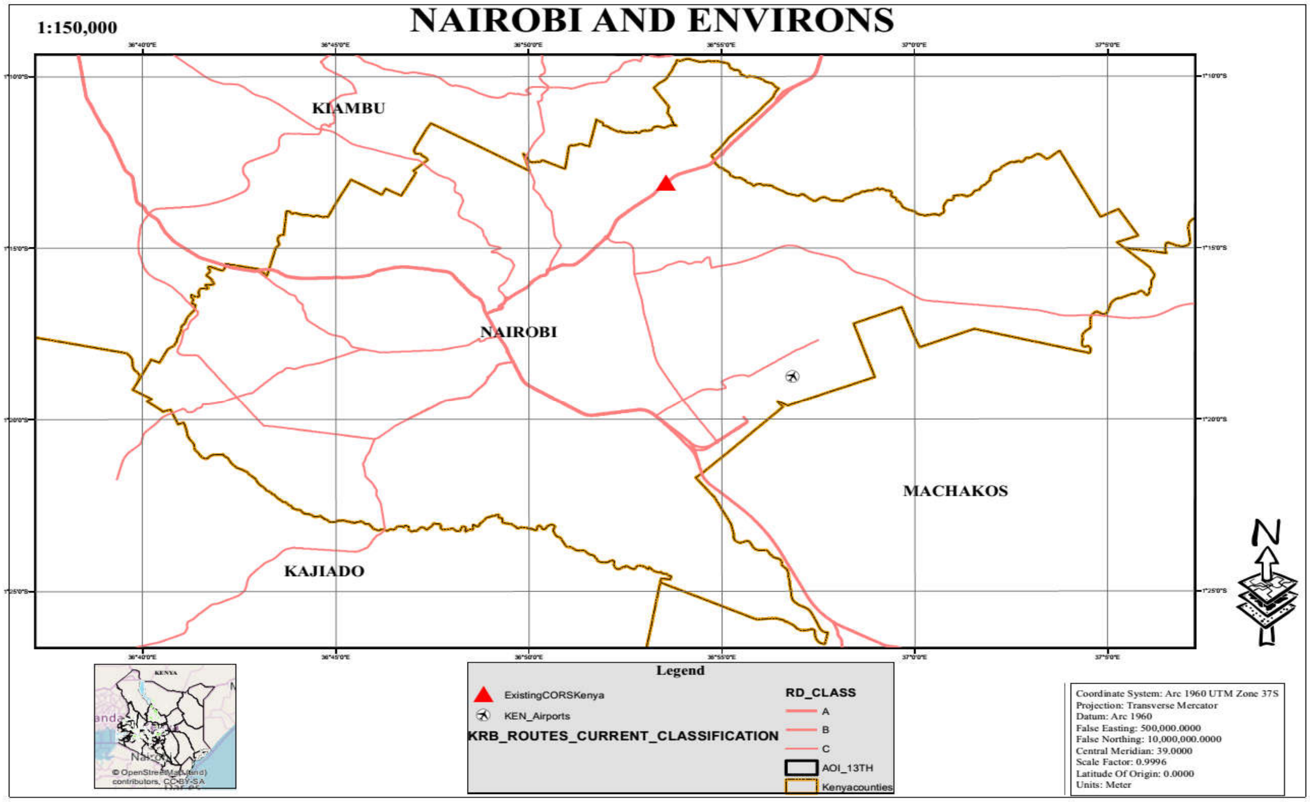


Figure 3. 1: Study Area

3.3. Methodology

In order to locate optimum sites for CORS; the initial phase was to locate the existing CORS stations and those proposed to be established, from its custodian SOK. Data sets for Roads, Protected Zones, Geological data, Water bodies, Existing CORS and Existing BTS from various organisations as tabulated in Table 3.1, were identified. The spatial data were then harmonized for ease in manipulation in a GIS environment. Using spatial overlays and proximity analysis tools and employing factors that promote the location of CORS; data overlays were created then combined and intersected with existing CORS and later intersected with existing BTS as well as a network matrices including: Random; North – South and East – West Network Designs to create a suitability map employing Boolean Overlays using Multi – Criteria Evaluation.

3.3.1. Procedure: Multi Criteria Evaluation

Since there are more than one criterion: roads for provision of access; fault lines to indicate places characterised by unstable ground; existing BTS for provision of constant power supply and security; existing CORS to establish the starting point; water bodies, and protected zones to meet one main objective; multi-criteria evaluation (MCE) was employed to determine the optimum sites for establishment of CORS. MCE procedure is summarized in the Method-flowchart Figure 3.2.

Define Goal

Define the problem: the initial step in MCE is to define the problem at hand (Locate CORS with the intent of densifying them through determining suitable sites).

Base criteria

Select the criteria: determine the factors that are key in determining suitable sites for establishment of CORS: stable ground, security, constant power supply, away from protected zones, accessibility and distance between stations (network densification).

GIS analysis

Operationalization of the criteria: the criteria are operationalized to computable indicators that is a model. Verification and evaluation of suitability map.

3.3.2. Summary: Multi-Criteria Evaluation

The flow diagram on Multi-criteria evaluation relays a systematic procedure that was employed to determine suitable sites for Tier III CORS.

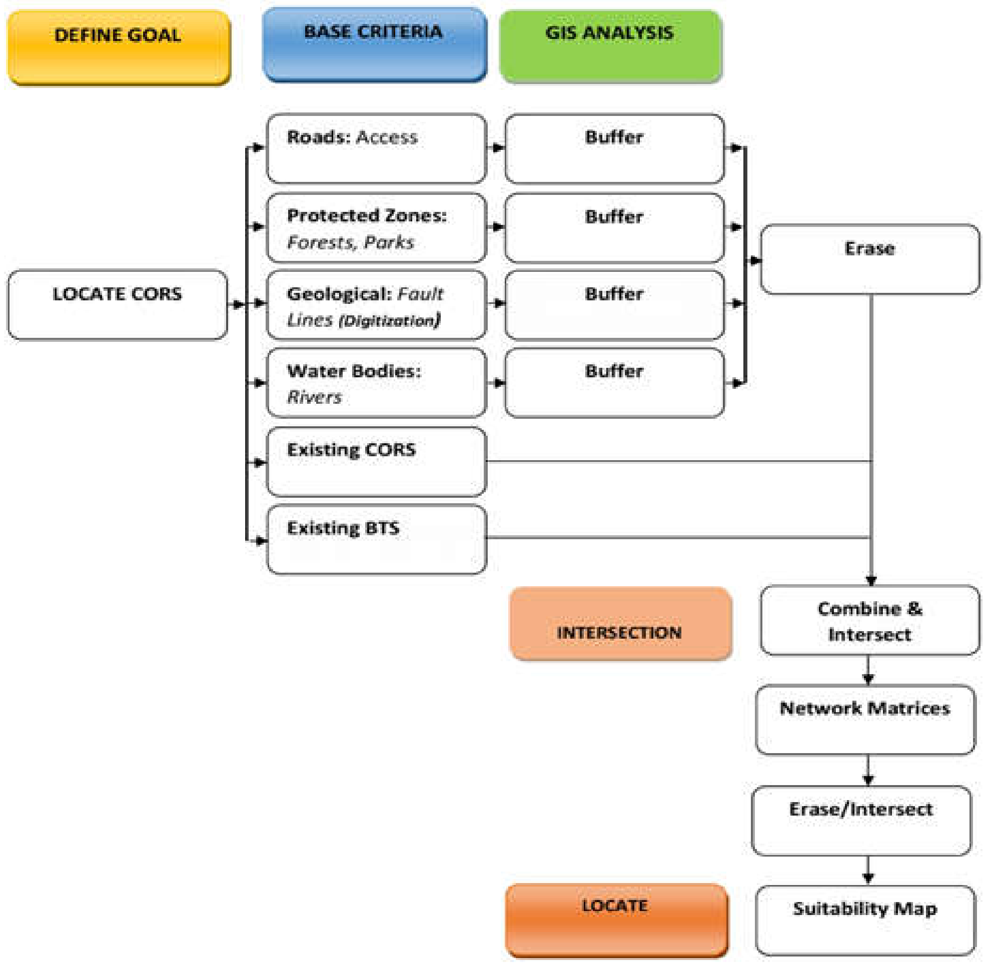


Figure 3. 2: Flow of Methodology: Multi-Criteria Evaluation

3.4. Data Collection and Harmonization

Spatial data obtained was processed as relayed in Table 3.1 after being standardized. The latter aided in the integration into the research process thus easy manipulation. The spatial data obtained were in various systems and formats. Therefore, they were converted into a uniform projection system using Esri ArcGIS software. Esri ArcGIS allows for various spatial data formats to be operated on.

Table 3.1: Summary of Data and Data processing

Data Source	Data Type	Data Format	Data processing
SOK	Vector map of Kiambu, Nairobi, Kajiado and Machakos County administrative boundaries	Shapefile format	Administrative boundaries set to ARC 1960, UTM coordinate system was clipped using data frame (avoiding fixed scale)
	Existing and proposed Tier 1 CORS stations within the region (Kenya) (Coordinates: X, Y, Z)	Existing CORS stations points in csv. File format Excel file	X, Y, Z coordinates were imported in Arc-map and converted ESRI shape file.
Ministry of Transport: KeNHA, KeRRA, KURA & KCAA	Road network, Railway networks and Airports	Vector shapefiles	○ Clipped with the area of study to only remain with the AOI features. ○ Buffer a distance of 60m on Roads from class A to C and 10m on all classes below C.
Ministry of Environment	Protected areas (Forests)	Vector shapefiles	Buffer of 200m away from the protected sites.
	Water Bodies	Vector shapefiles	Buffer of 200m away from the protected sites.
Safaricom, Airtel	Telecommunication masts (Coordinates: X, Y, Z)	Existing BTS stations points in csv. File format Excel file	Buffer with a radius of 300m then weights will be applied on them i.e. the far the station is the more unsuitable the station is and vice versa.
Ministry of Mining	Geological Map	Hardcopy maps	Digitization; Determine stable grounds and establish fault lines. Buffer 200m out of the fault lines.
Custom network matrices	Network Matrices	Dwg File format and Vector shapefiles	Ensure well distribution of stations ensuring distance factor is maintained 5km radius.

3.5. Overview of Methodology

Spatial data was obtained from various sources indicated on table 3.1 and loaded onto Esri ArcGIS software as tabulated:

3.5.1. Nairobi and Environs Road Network

Classified roads were obtained from the ministry of infrastructure containing various classes of roads on shapefiles. Road network is one of the modes of transport within the country offering accessibility to numerous places within the nation.

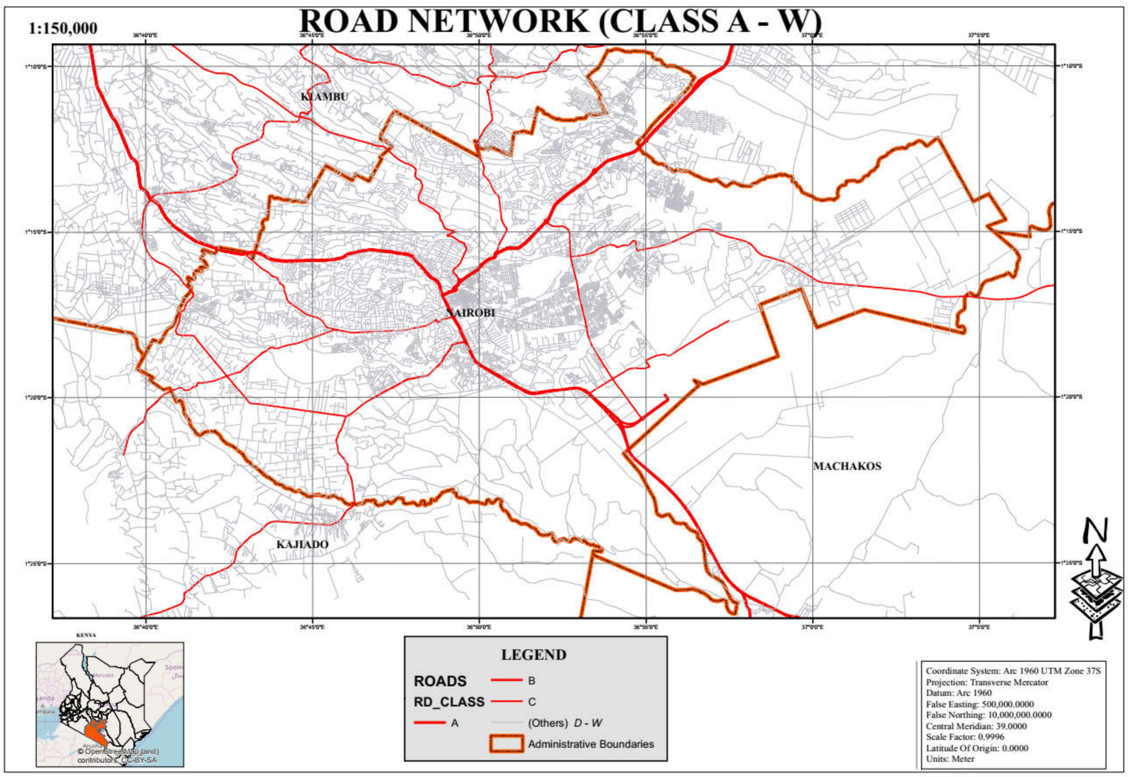


Figure 3.3: Road Network in Area of Interest (Class A – W)

3.5.2. BTS Stations in Area of Interest

The coordinates of telecommunication masts were obtained from various telecommunication companies for instance Safaricom, Orange and Airtel. The stations mainly have constant power supply even if the power grid goes down and are mostly accessible in case any maintenance issue arises. Moreover, they are usually guarded offering a good security for the appliance.

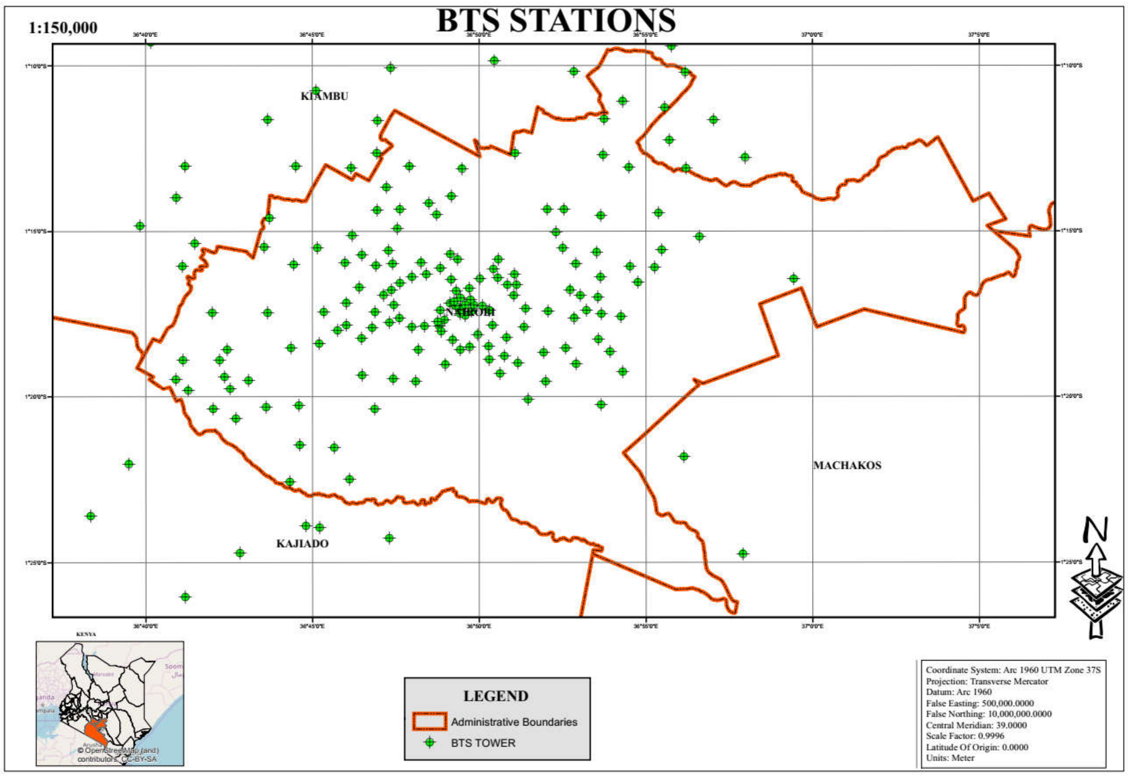


Figure 3.4: BTS Stations in Area of Interest

3.5.3. Geological map

Geological data in form of maps obtained from Ministry of Mining indicating lines of weakness that are a negative aspect in the establishment of CORS. The maps were digitized showing areas that have fault lines. The reliability of the coordinates and corrections from stations near such phenomena diminishes as we near the region due to unstable grounds.

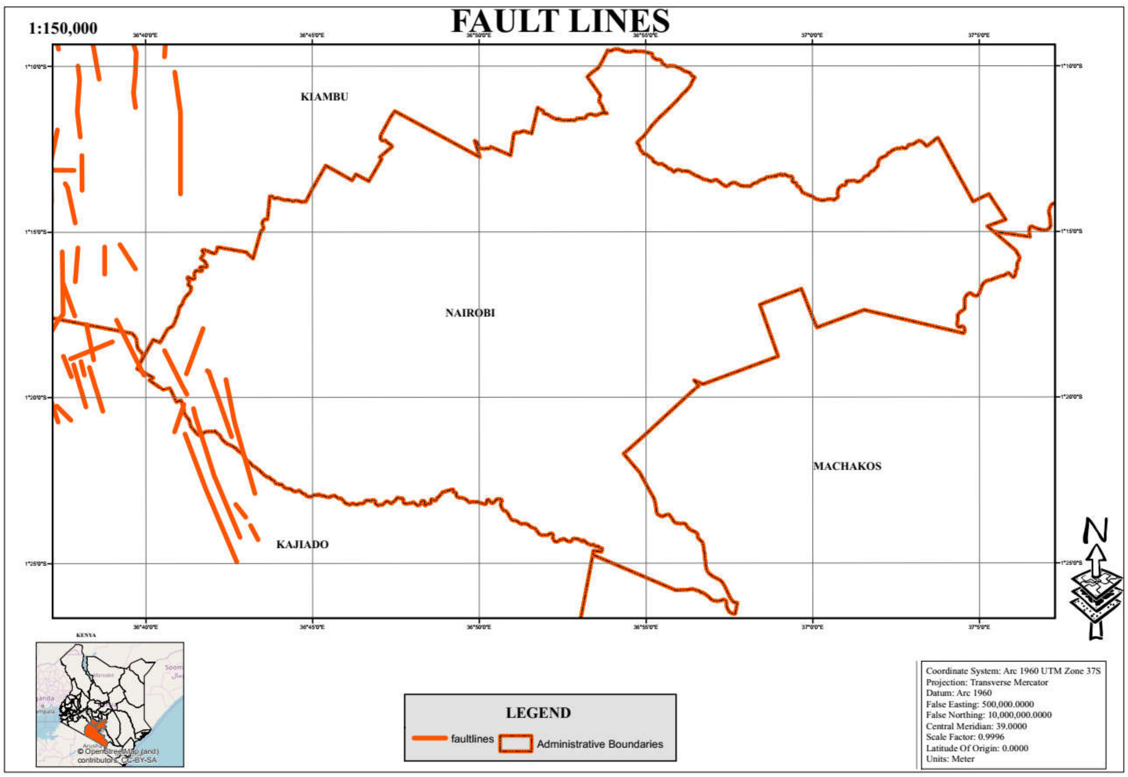


Figure 3.5: Fault Lines in Area of Interest

3.5.4. Water bodies

Water bodies' shapefiles were obtained from the Ministry of Environment and Natural Resources. The establishment of CORS cannot be done near or above water bodies, hence exclude the areas that are occupied by water bodies.

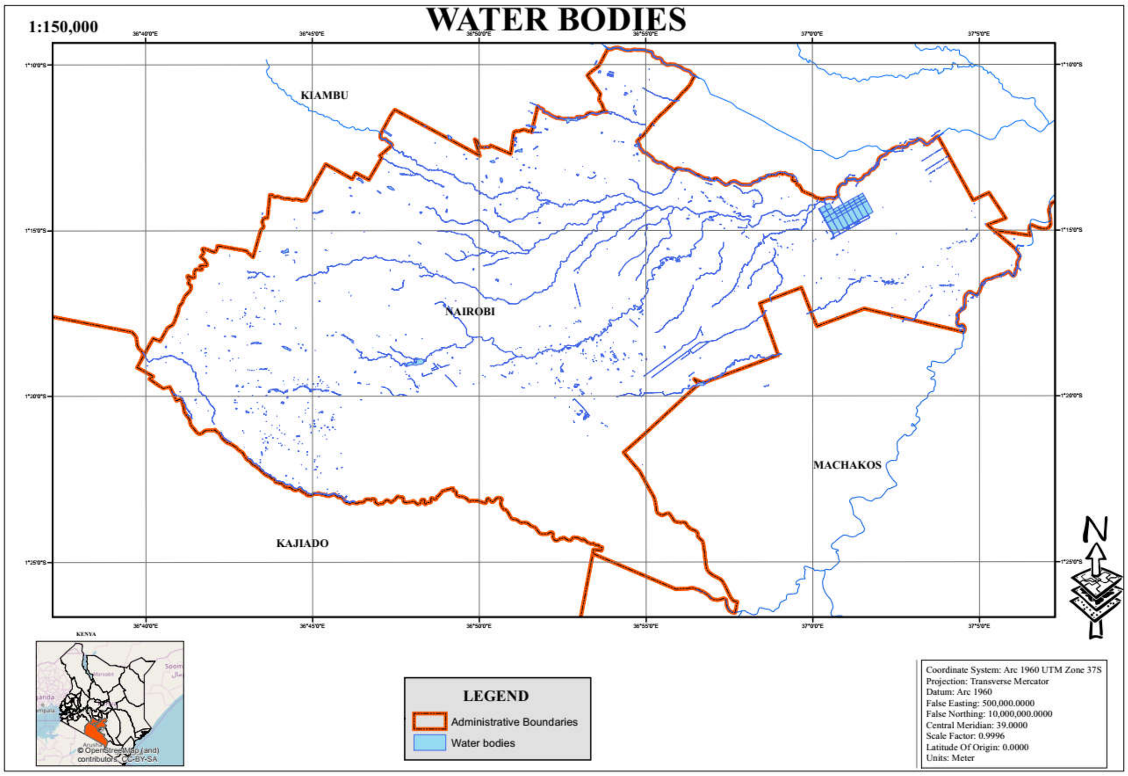


Figure 3.6: Water Bodies in Area of Interest

3.5.5. *Protected zones*

Protected areas include National parks, recreational parks, and forests. Spatial data in form of shapefiles were obtained from the Ministry of environment and natural resources. Forests are characterized by various form of security threats including vandalism of electrical appliances found within such areas.

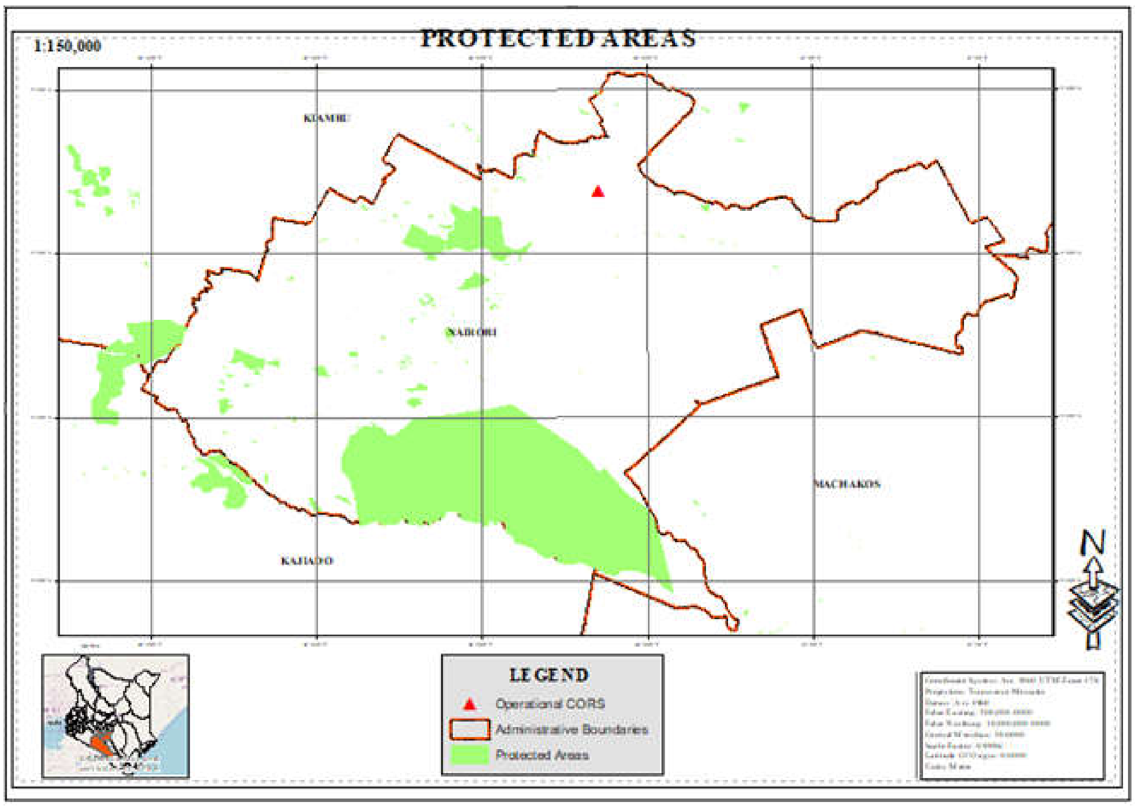


Figure 3.7: Protected zones

3.5.6. Distance (Network matrices)

Computer Aided Design program (AutoCAD Civil 3D 2018) was employed to design the outline geometry for the proposed densification of the network and used as an overlay made up of equilateral triangles of progressing length of approximately 5km on each vertex with a central circle of 1000m radius. Various network designs were employed including:

Random Network Design: No particular orientation of the nodes

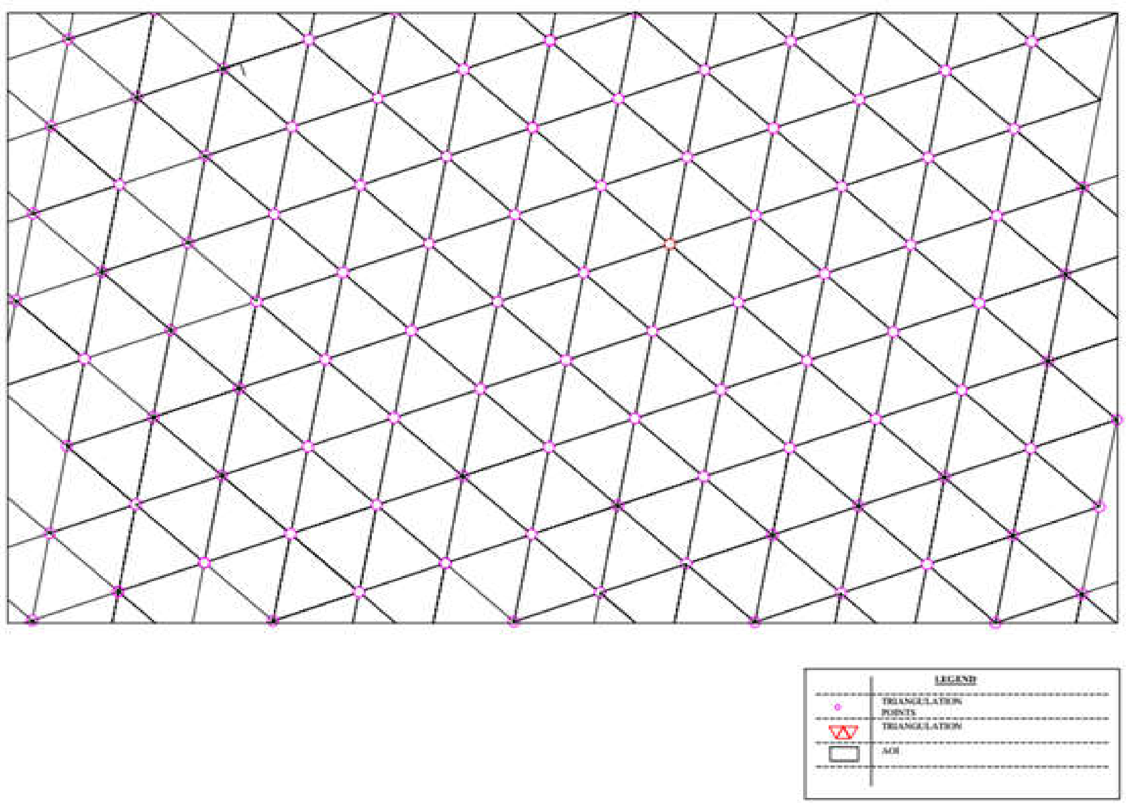


Figure 3.8: Triangulation Matrices

North – South Network Design: Triangulation nodes oriented North to South.

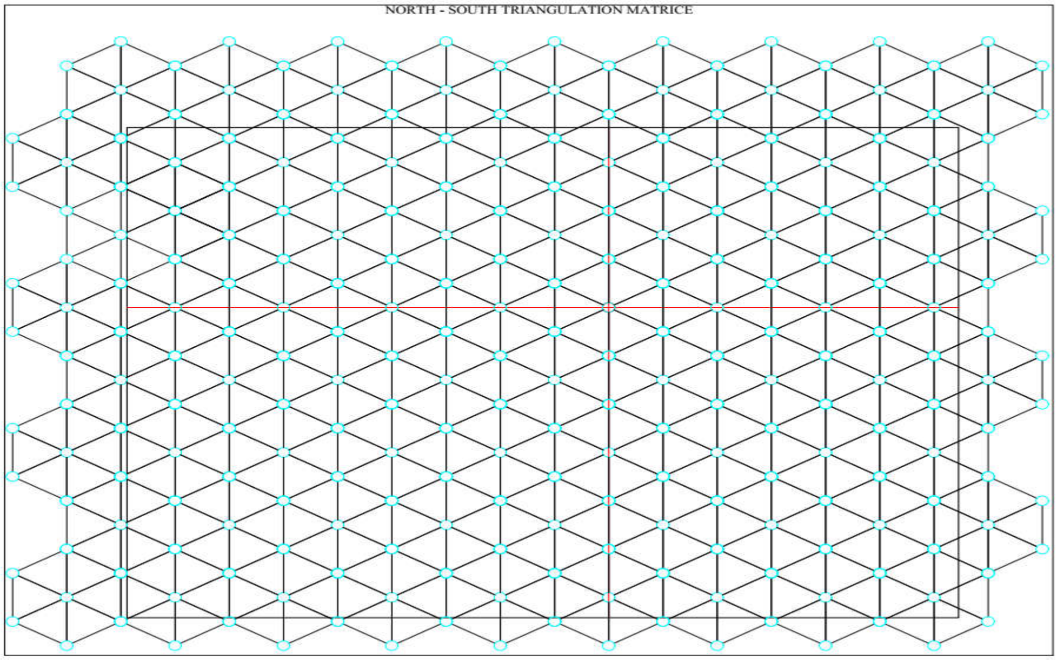


Figure 3.9: North – South Network Design

East – West Network Design: Triangulation nodes oriented from East to West.

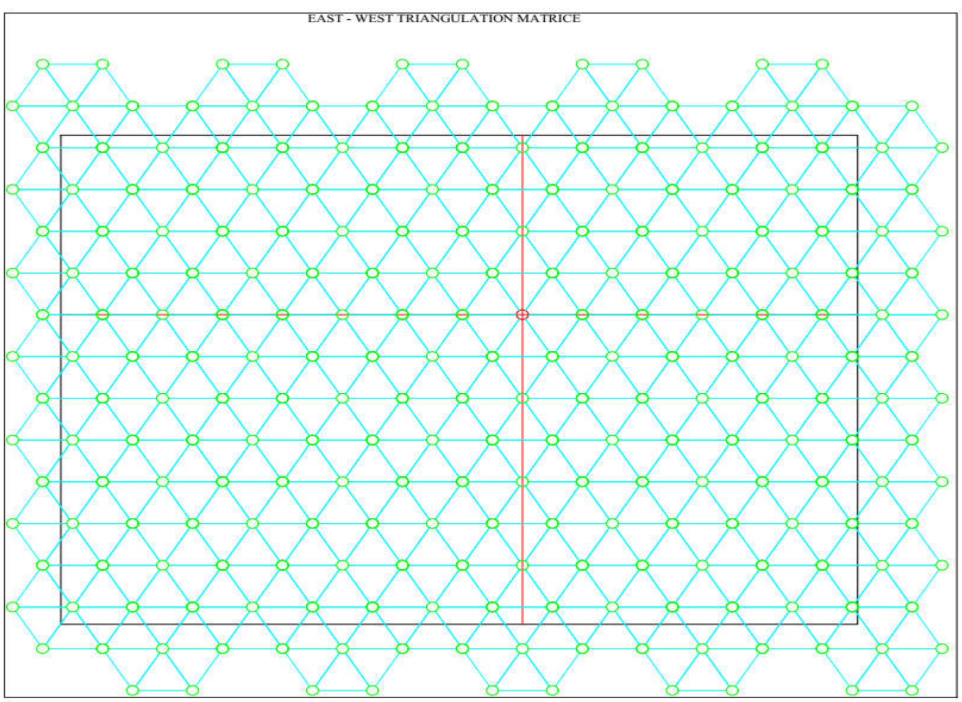


Figure 3.10: East – West Network Design

3.6. Data Analysis and Processing

A model was developed within a GIS environment leaving the GIS user with uncertainty on what will happen in the real world scenario. Therefore, modelling will allow for experimentation on “what if scenarios” allowing for visualization of alternative prospects. Thus, a model is a simplified presentation of phenomena in the real world for instance: a theory, an equation, or a structured idea. The model will aid in better understanding phenomena that is suitable sites for the establishment of CORS through retaining all characteristics of the real world illustrated on Figure 3.11. On this event, static model that is embedded will be employed involving the representation of phenomena at a single point in time integrating the above formulae.

Operationalisation of the Model

Datasets of Roads, Protected Areas, Water Bodies, Fault lines, Existing CORS and BTS stations were added to the model in Model Builder. The model was then ran to relay the suitable sites adhering to the MCE criteria. Boolean operators will operate on the datasets in the background when the model is operationalized to give an output.

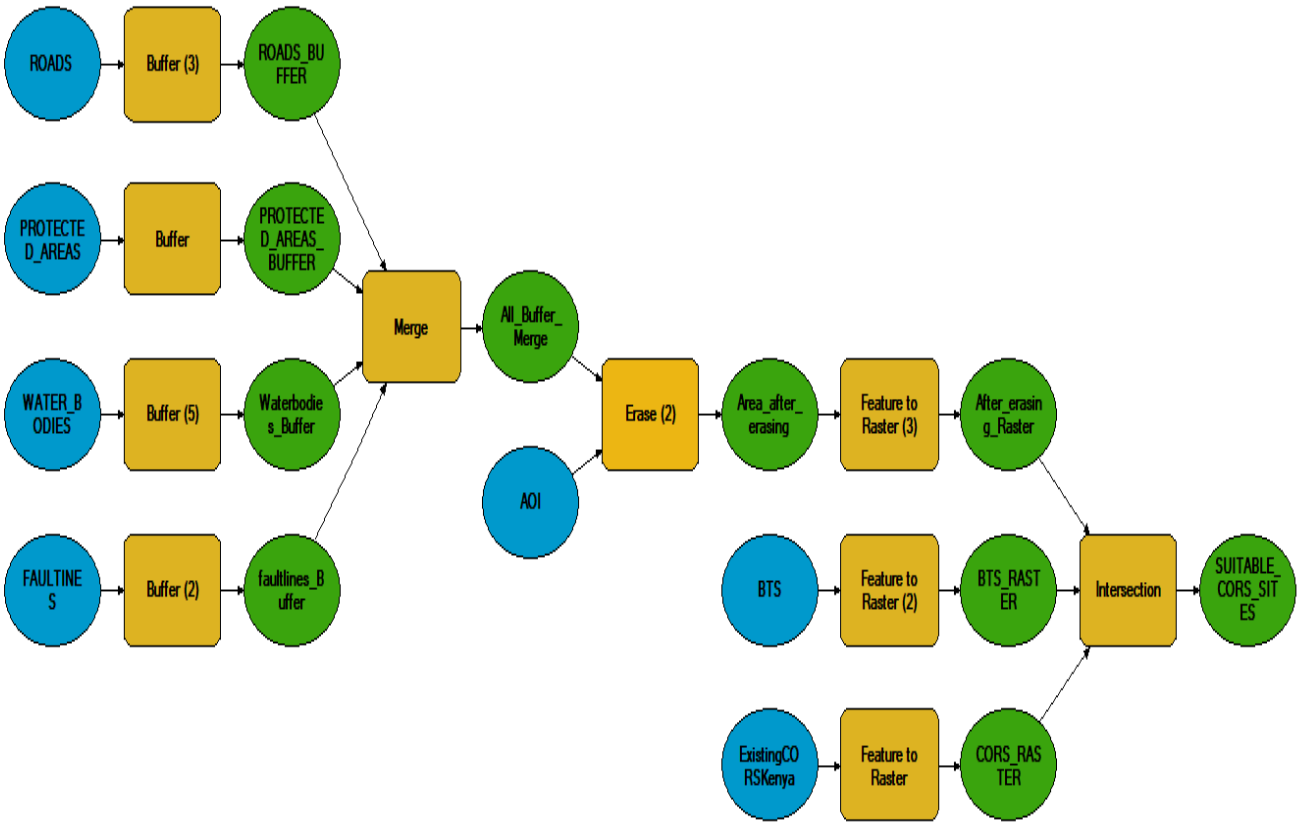


Figure 3.11: Operationalization of the CORS Model

CHAPTER 4: RESULTS AND DISCUSSIONS

Chapter 4 primarily describes the outcomes that were obtained in tandem with the objectives:

4.1. Results and Analysis

4.1.1. Factors for establishment of CORS

The aforementioned MCE criterion for suitability analysis was employed through incorporating datasets on protected sites (forest, national parks and recreational Parks); roads, BTS stations, existing CORS, fault lines and water bodies. Using proximity analysis, clustering of proposed sites was avoided, on this event; create a balance of their distribution with a minimum distance of 5km. Roads offer access to places, hence CORS stations. Moreover, establishment of the stations close to the road would reduce land issues because land adjacent to the road are normally road reserves not allocated for private individuals.

After considering the Right of Way (ROW), the road usually remains with adequate reserve that is if well planned and predominantly away from urban areas. The stations have to be established on a stable ground not prone to crustal deformation, distorting its normal location as a result consider fault lines to relay any line of weakness or proximity to unstable ground. Water bodies are significant entities, are a source of making the ground loose through periodic expansion and contraction of soils neighbouring the body. The latter can transform the landform to a certain extent even to centimetre level significantly affecting the accuracy of the station. CORS usually give results up to millimetre level changing the landform would highly affect this level of accuracy. Water bodies, protected areas, roads and fault lines give flawed areas not to establish the stations.

4.1.2. Proximity analysis

The accuracy of a CORS station normally diminishes with increase in distance from the base station.

1. Protected sites 200m buffer:

A buffer of 200m was applied on protected areas that include National Parks; Recreational Parks and Forested areas. Such areas are deemed existing natural resources and any disturbance would hamper its existence. A 200m belt buffer was employed because most if not all areas within the protected are characterised by vegetation canopy that would prevent communication between the proposed appliance and the satellites.

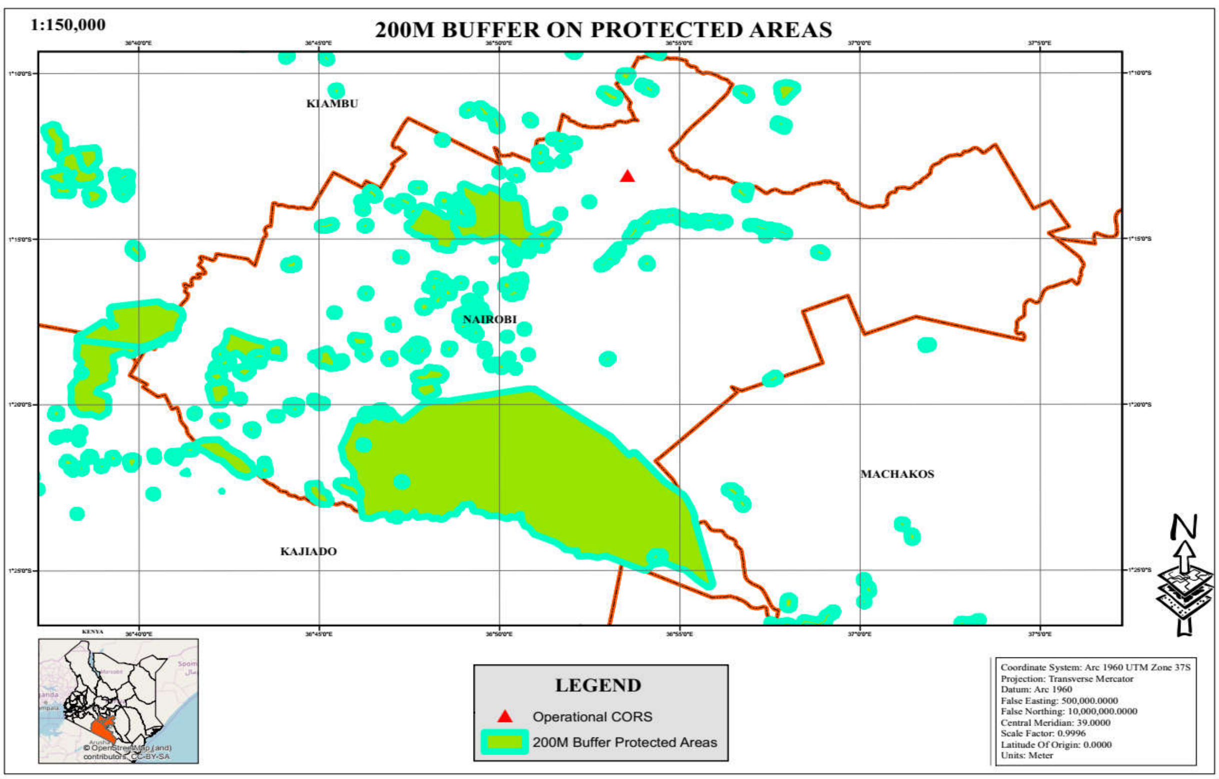


Figure 4.1: Protected areas 200m Buffer

The proposed station should be established at least 200m away from protected areas to avoid disruption of the natural and the aesthetic nature of the surrounding. Apart from that, most protected sites for instance National Parks are inhabited by wild animals that will dangerously expose personnel when carrying out maintenance works.

2. Water body buffer:

Water bodies normally include Rivers, lakes, swamps, and dams. Such places without the presence of proper infrastructure are difficult to get to; more so constructions of structures above or below water bodies is unsound for establishment of CORS thus, a buffer of at least 200m away from such areas was applied to offer sound ground for establishment.

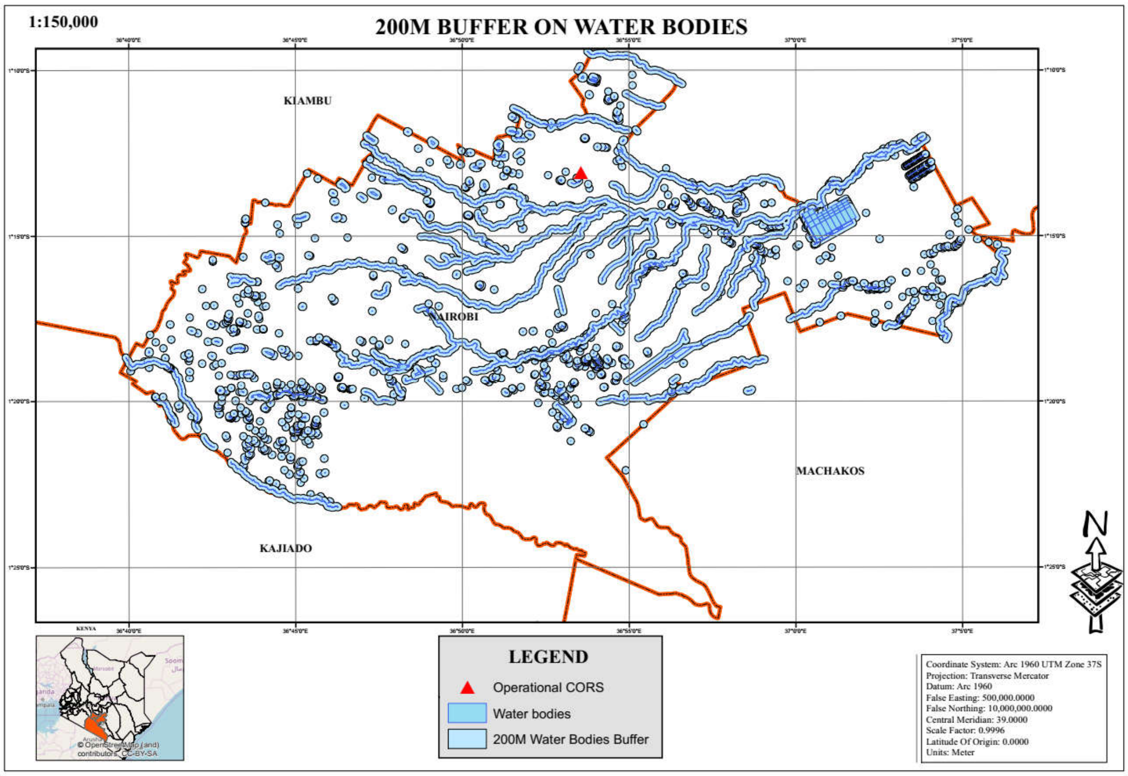


Figure 4.2: Water Bodies 200m Buffer

The surface near water bodies are prone to shifting periodically due to activities such as erosion that would misrepresent the accuracy of the stations once established. The flow of water bodies as well as its neighboring surfaces are composed of loose soils that are less viable for establishing structures.

3. *Road Network Buffer:*

The current situation in Kenya is Roads Authorities including KeNHA, KeRRA and KURA have the mandate to provide safe and quality roads. Through the later different road classes, have different road widths that provide for sustainable planning shown in Table 4.1. As a result, a buffer of at least 60m was applied on all KeNHA roads from class A, B and C; 10m on all KURA and KeRRA roads.

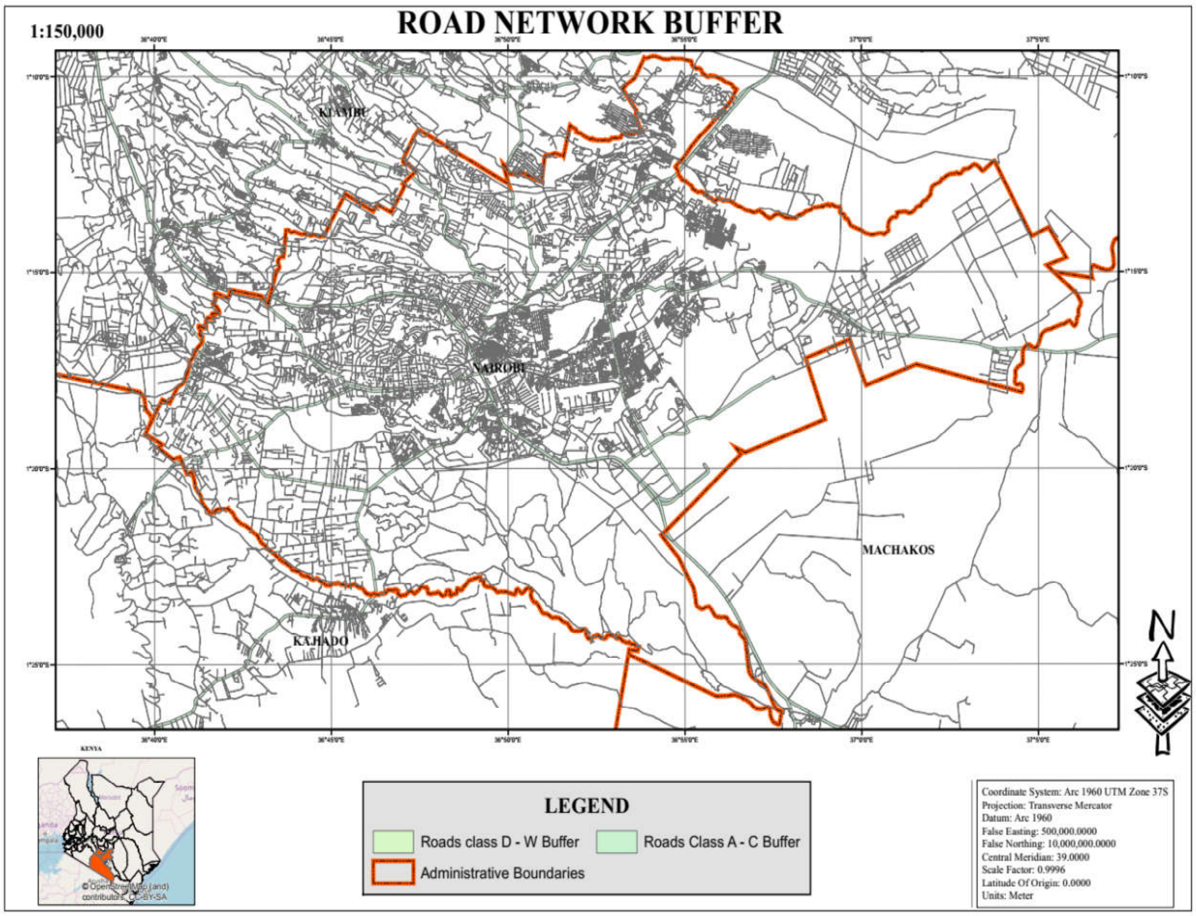


Figure 4.3: Road Network 60m and 10m Buffer

Table 4.1: Road Classes

AUTHORITY	ROAD CLASS	WIDTH (M)
KeNHA	A	60 - 120
	B	60 - 120
	C	60 - 40
KURA	Urban Roads	Vary depending the area

AUTHORITY	ROAD CLASS	WIDTH (M)
KeRRA	D, E, F, G, K, L, P, R, S, T, U, & W	40 - 30

Apart from roads providing access to the stations, roads also provide a good environment for establishment of CORS. Most road corridors are less prevalent to land issues as compared to private land parcels. Moreover, road corridors consider the physical nature of the ground avoiding unstable grounds that are likely to change over time. Road corridors also have conspicuous demarcation evading encroachment into private property reducing risks of vandalism.

4. *Fault lines buffer:*

Faults are normally fractures on the surface of the earth. The occurrence is because of rocks sliding past each other or slip away from each other. Fault line have various characteristics one can be as slim as a hair strand while others can stretch meters apart.

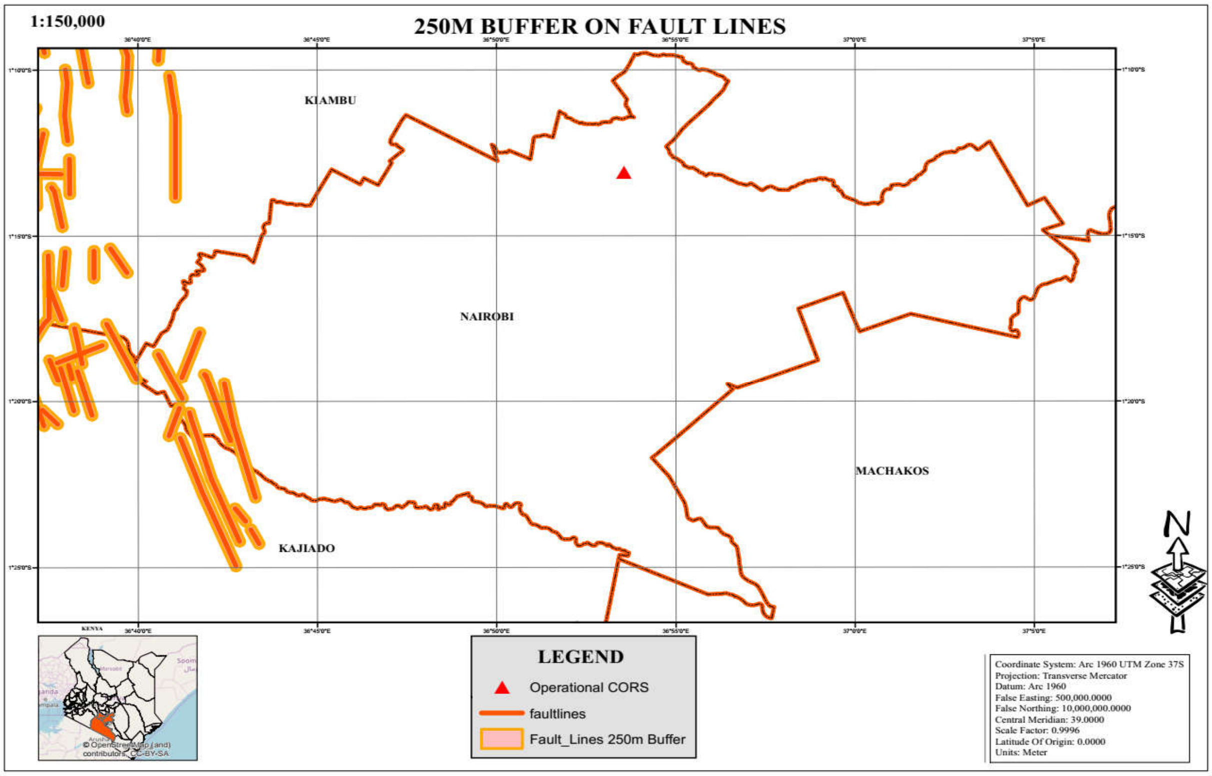


Figure 4.4: Fault-Lines 250m Buffer

From figure 4.4 fault, lines are observed mainly on the western side of the AOI, which hampers the establishment of CORS within such regions. Application of a restrictive belt of at least 250m would prevent instances of crustal movement that would distort CORS accuracy by a large margin.

5. BTS buffer:

BTS stations provide a good and secure site for CORS as relayed in Figure 4.5. Most if not all stations have constant power supply even if the Grid goes down. Moreover, they have a perimeter wall that offer great security for the set-up.

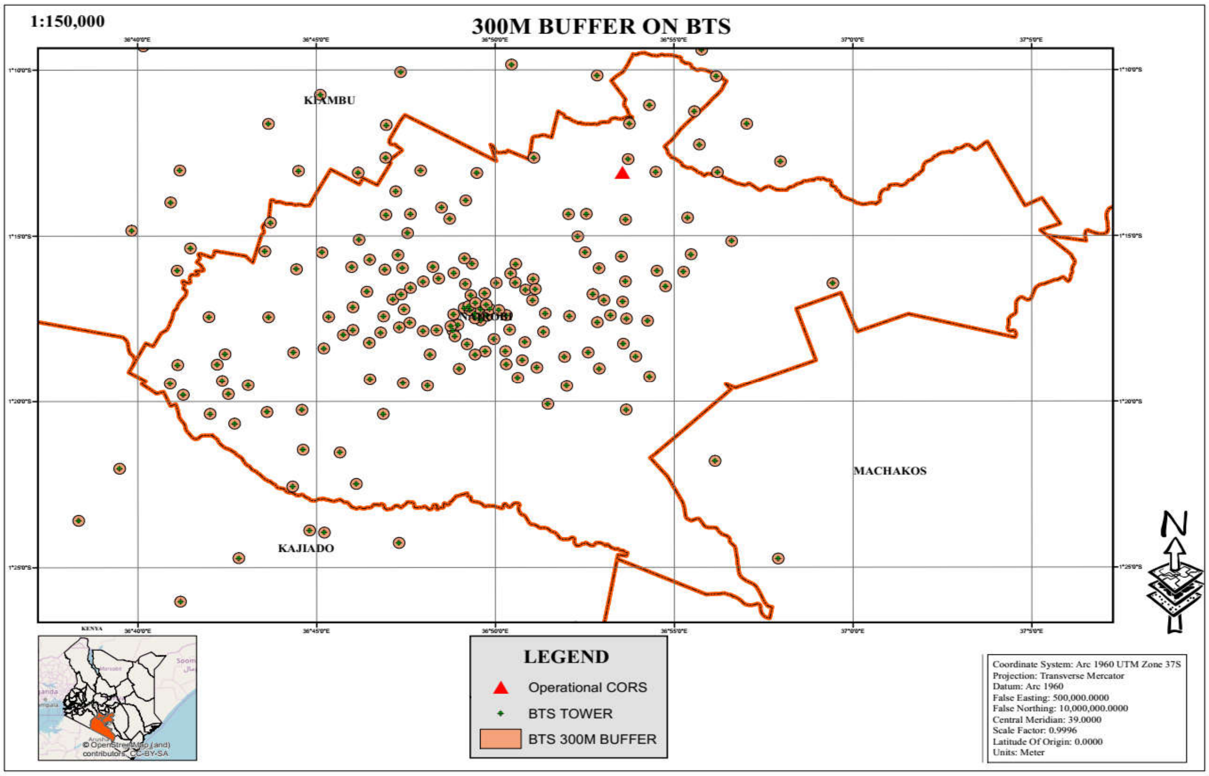


Figure 4.5: BTS 300m Buffer

Therefore, setting-up CORS within such sites would enhance its working even when the grid is down and offer better security and accessibility rather than being exposed on bare and insecure areas.

6. Combined unsuitable areas:

All areas that were unsuitable for the establishment of CORS were combined: unstable ground (areas near fault lines); lose ground (areas that are close to water bodies); protected areas (areas that have dense forest cover and national parks) and exclude areas that are suitable for example BTS stations that provide security and constant power supply shown in Figure 4.6.

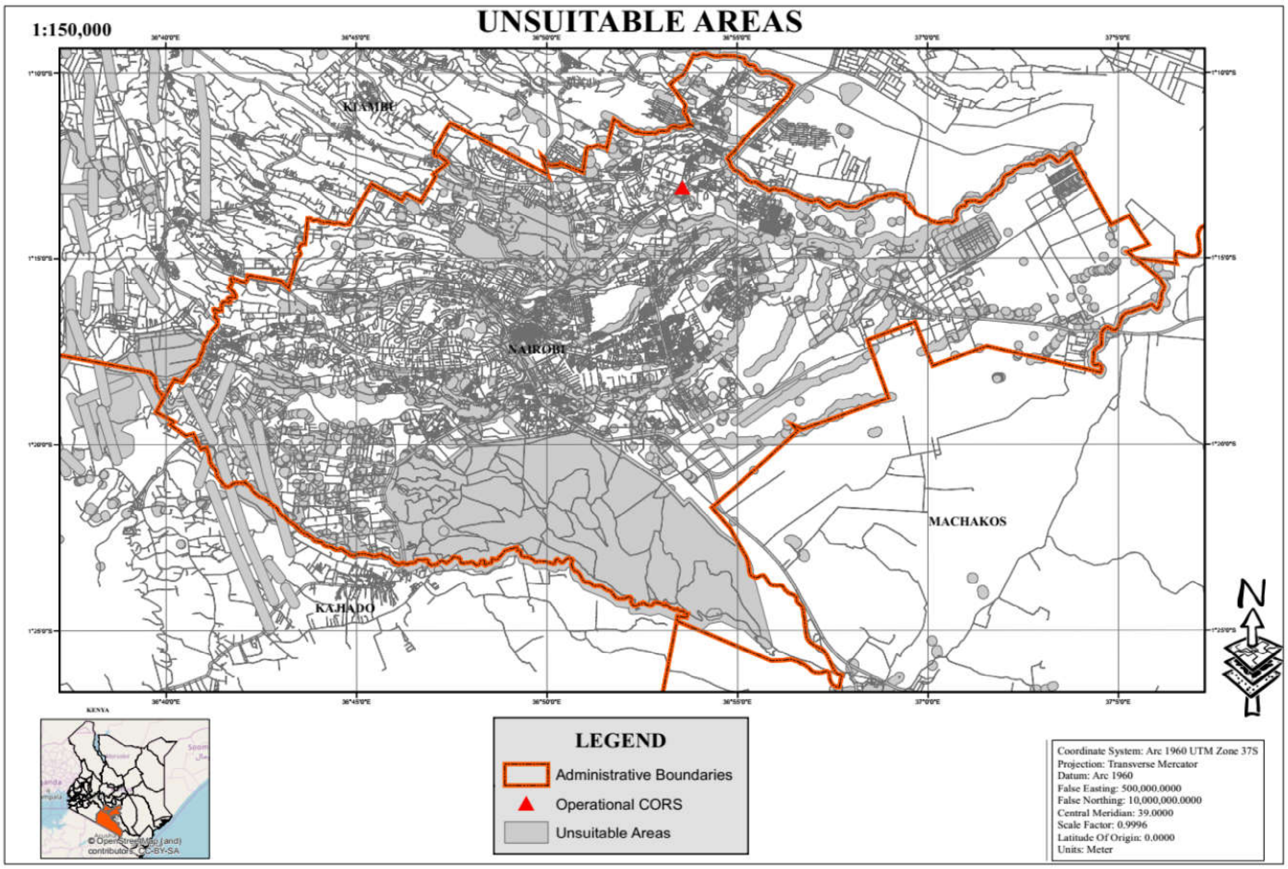


Figure 4.6: Unsuitable Areas

Consequently, one shapefile was created containing all the unsuitable areas within the Area of Interest hence, aid in the establishment of places that are suitable for establishment of CORS. These areas will be subtracted from the area of interest to provide suitable areas, that is, it would pork holes on the area of study leaving suitable areas conspicuous. The approach would create a feature class through overlaying input features with the polygons of the erase feature, which are unsuitable sites shown in Figure 4.7.

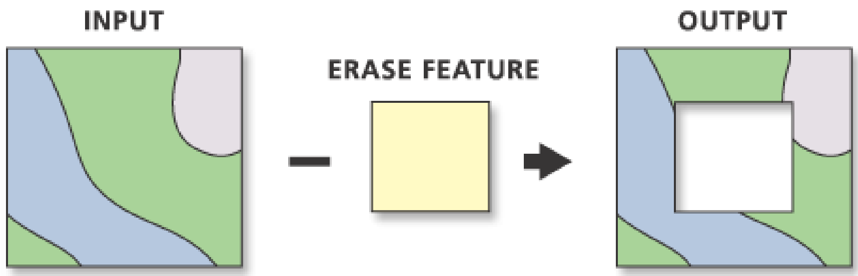


Figure 4.7: Subtraction in ArcGis

7. ***Suitable areas:***

In order to obtain suitable areas, the unsuitable area was subtracted from the AOI that created a new output coverage relayed in Figure 4.8.

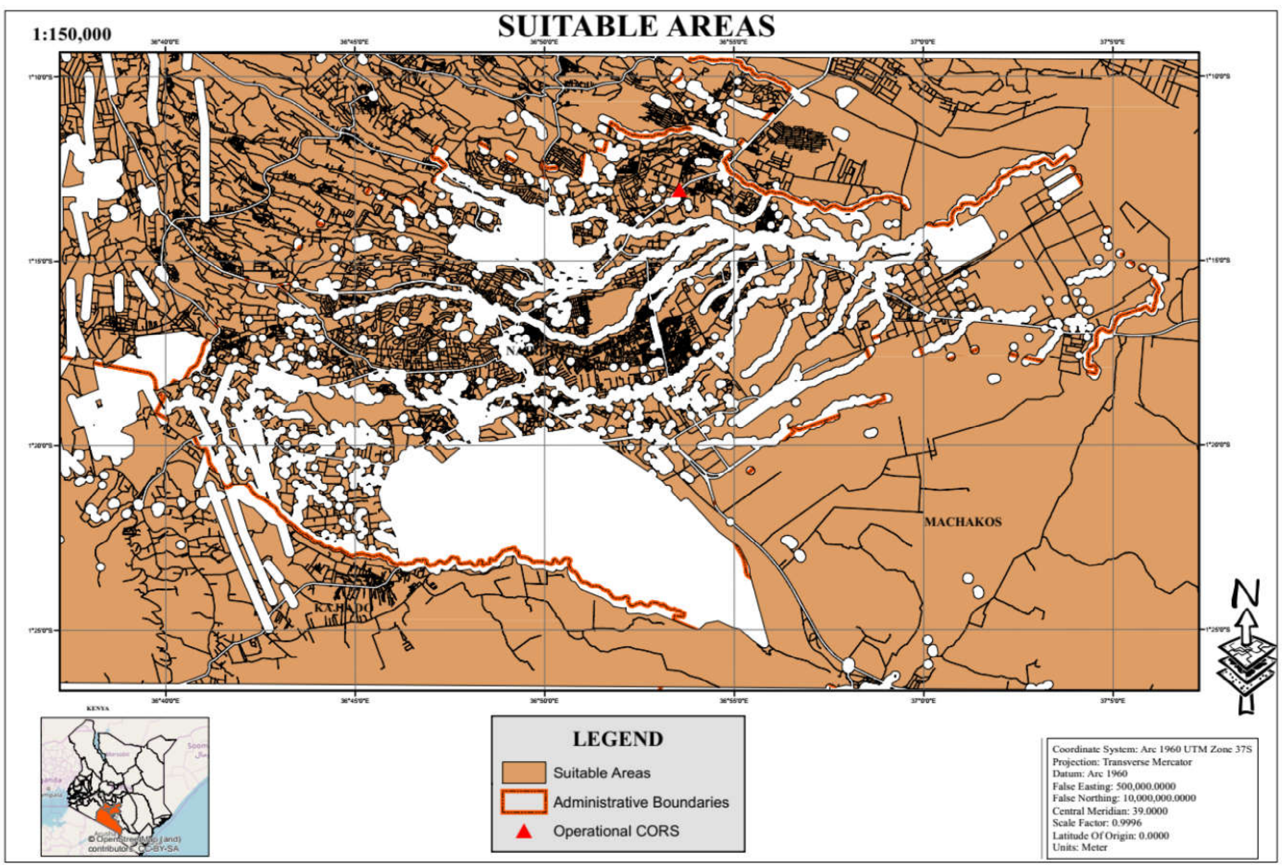


Figure 4.8: CORS Suitable Areas

The procedure was achieved through overlaying polygons of erase coverage with the features of input coverage. The remaining portion only showed features that were outside the erase polygon. In this case, erase polygon was the unsuitable areas to achieve suitable areas.

Intersecting the suitable areas with BTS stations:

8. Intersection: BTS and Suitable sites

The suitable area was intersected with BTS stations whereby the input feature was the suitable area and the intersecting features BTS stations shown in Figure 4.9.

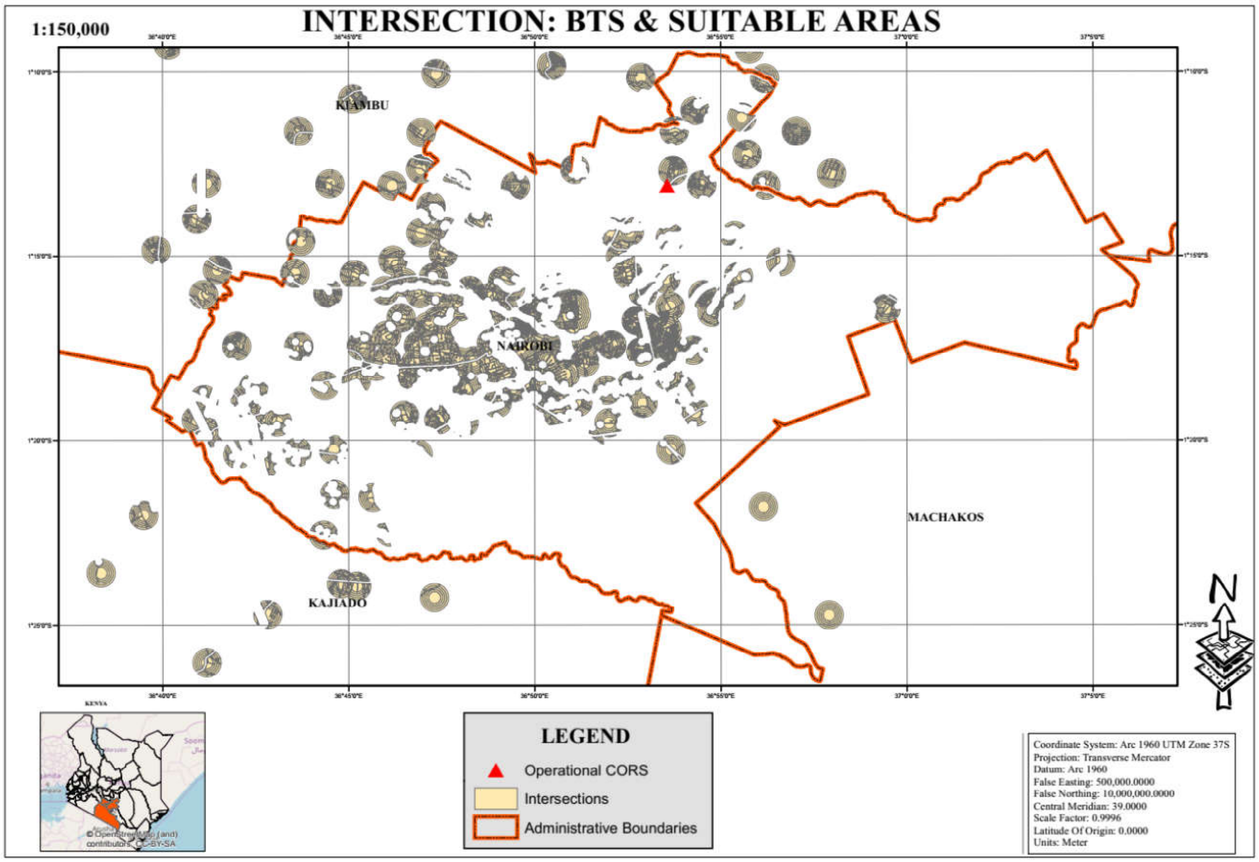


Figure 4.9: Intersection BTS and Suitable Sites

The resultant feature are features that overlap in all layers. The feature normally creates coverages through computing the geometric intersection of the input feature that were the suitable areas.

9. ***Application of Triangulation matrices and intersection:***

Triangulation marices that were developed were used in ensuring distances, well conditioned triangles and the geometry of the stations are adhered to, to forster a good network balance and distribution.

Random Triangulation Matrice:

Random Triangulation matrices did not take into consideration any particular consideration on the orientation of the stations but based on the RCMN station as the basis for developing well-conditioned triangles as relayed in Figure 4.10.

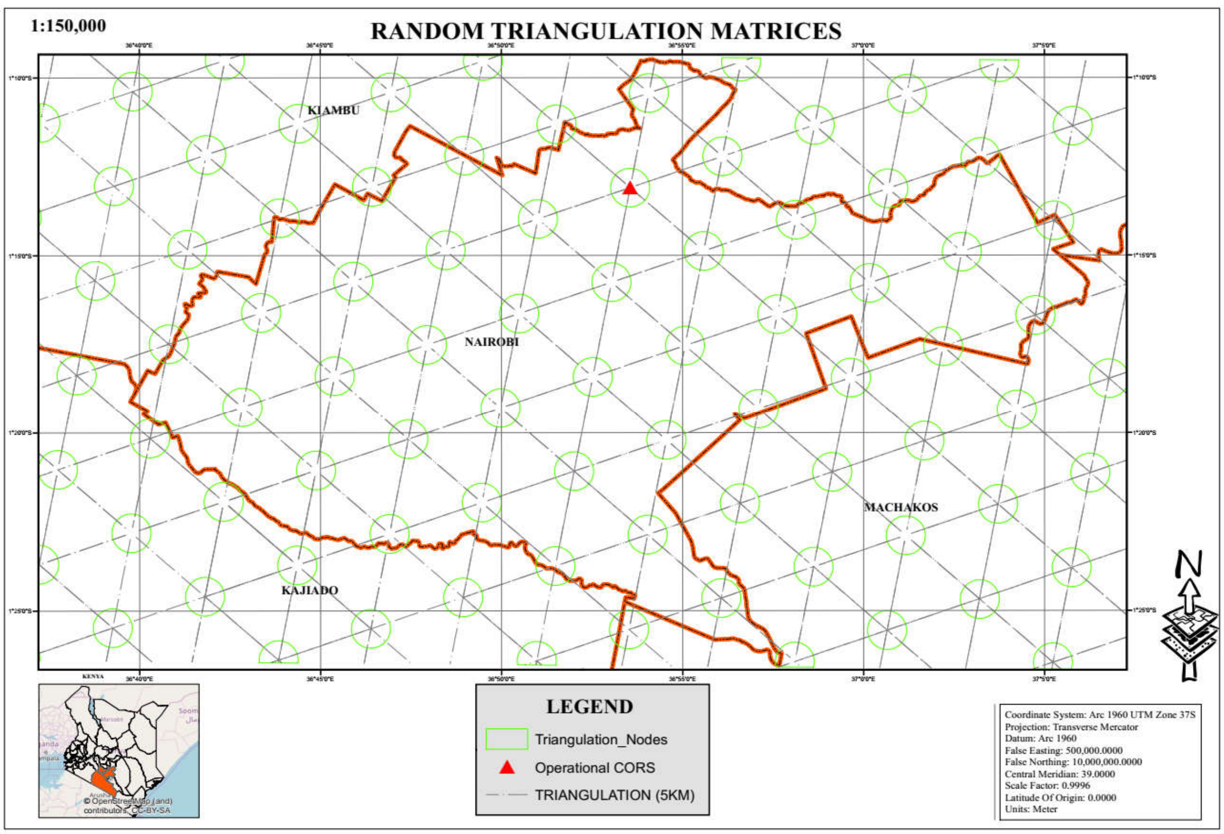


Figure 4. 10: Random Triangulation Matrices

Option (i): Resultant intersection on Random Triangulation Matrice

The outcome of Intersecting BTS and Suitable sites was then subjected to another intersection with the Random Triangulation Matrice to obtain the most suitable sites with consideraion of distance between stations, and their geometry that is their relative position. The outcome was relayed in Figure 4.11 as well as the resultant coordinates on Table 4.2.

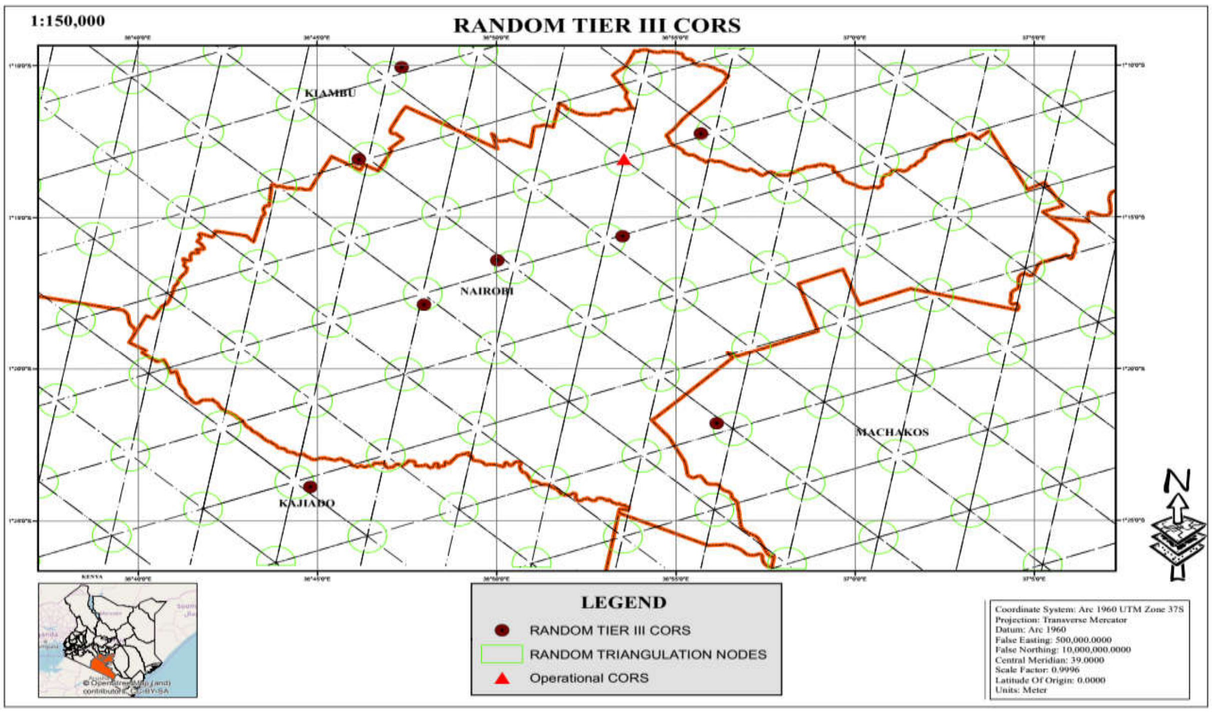


Figure 4. 11: Random Tier III CORS

Table 4. 2: Random Tier III CORS Coordinates

FID	EASTING (M)	NORTHING (M)	DESCRIPTION
1	251793.851	9865248.464	R/1
2	264290.527	9859939.249	R/2
3	270310.816	9849216.733	R/3
4	269495.079	9866810.817	R/4
5	253993.777	9870836.026	R/5

FID	EASTING (M)	NORTHING (M)	DESCRIPTION
6	265447.768	9860592.767	R/6
7	249273.261	9845359.462	R/7
8	258957.564	9859127.386	R/8
9	255163.555	9856447.344	R/9

North – South Triangulation Matrices

The results of Intersecting BTS and Suitable sites was then subjected to another intersection with the North – South Triangulation Matrice shown in Figure 4.12.

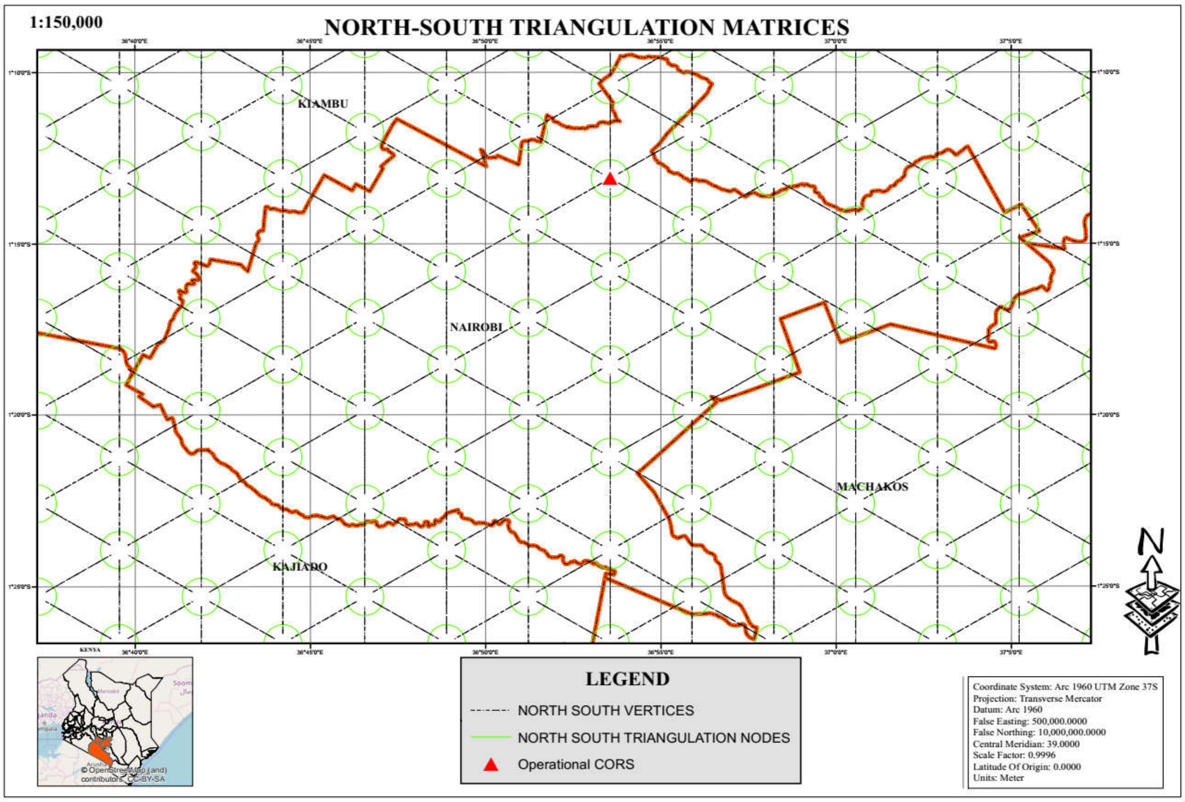


Figure 4. 12: North – South Triangulation Matrices

Option (ii): Resultant intersection on North – South Triangulation Matrices

Consequently, the intersection resulted into a number of suitable locations for CORS shown in Figure 4.12 relaying numerous stations as compared to the Random Triangulation Matrices and cordinates in Table 4.3.

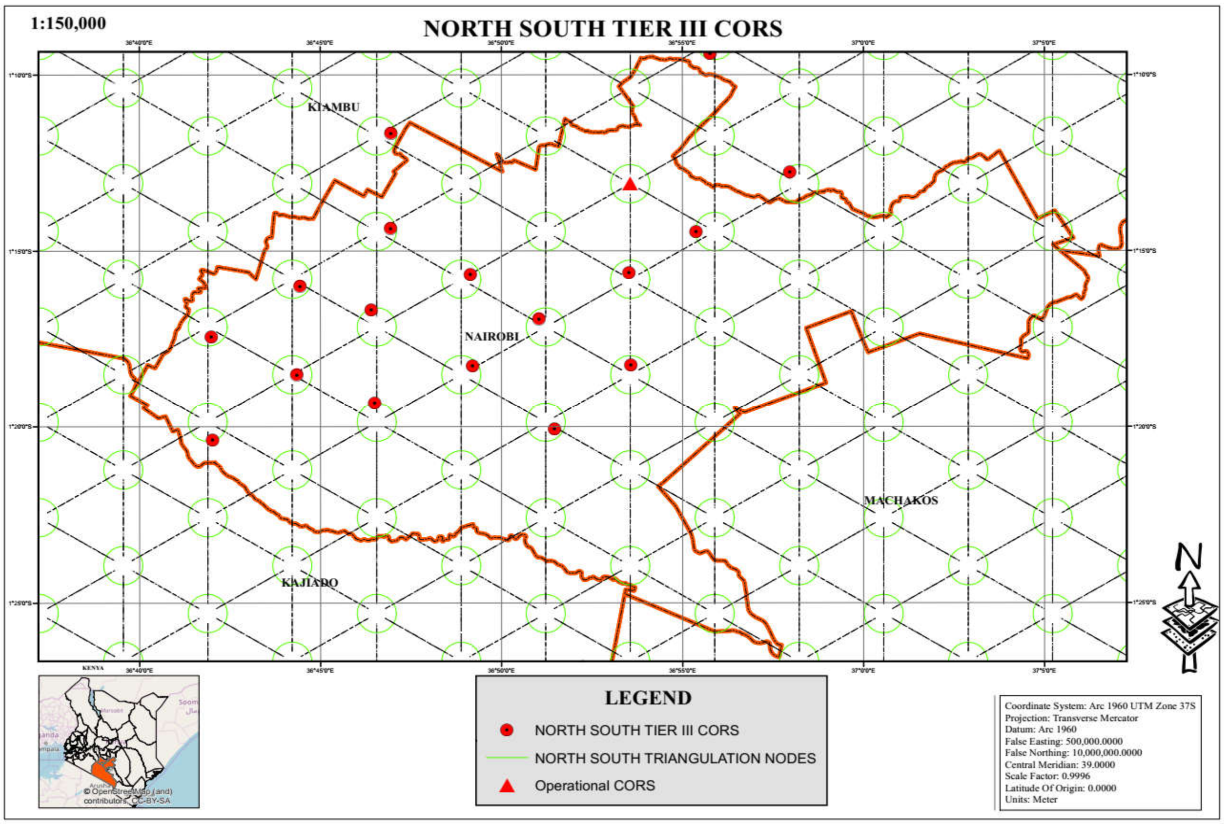


Figure 4. 13: North - South Tier III CORS

Table 4. 3: North - South Tier III CORS Coordinates

FID	EASTING (M)	NORTHING (M)	DESCRIPTION
0	244112.631	9851825.362	N/S/1
1	244051.984	9857223.093	N/S/2
2	248440.472	9855247.159	N/S/3
3	248592.232	9859881.739	N/S/4
4	252245.134	9858635.070	N/S/5
5	253232.373	9862905.239	N/S/6

FID	EASTING (M)	NORTHING (M)	DESCRIPTION
6	253250.537	9867893.495	N/S/7
7	257446.869	9855719.662	N/S/8
8	268885.513	9862752.049	N/S/9
9	261635.691	9852383.187	N/S/10
10	273703.444	9865874.454	N/S/11
11	265551.455	9855748.689	N/S/12
12	265447.272	9860592.705	N/S/13
13	260840.319	9858166.821	N/S/14
14	257309.208	9860486.459	N/S/15
15	269613.202	9872075.633	N/S/16
16	252405.303	9853757.544	N/S/17

East – West Triangulation Matrices

The results of Intersecting BTS and Suitable sites was then subjected to another intersection with the East – West Triangulation Matrice shown in Figure 4.14.

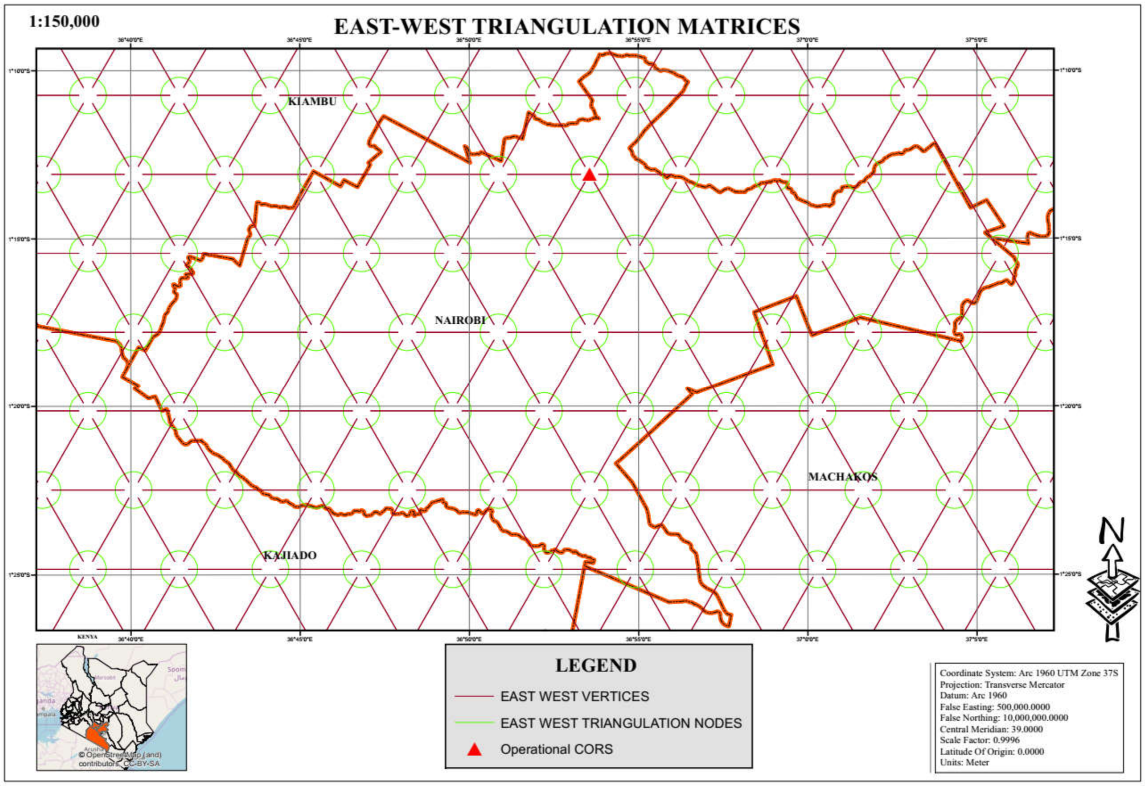


Figure 4. 14: East – West Triangulation Matrices

Option (iii): Resultant intersection on East – West Triangulation Matrices

Consequently, the intersection resulted into a number of suitable locations for CORS shown in Figure 4.15. The intersection resulted into nine stations as compared to the other two Triangulation Network Design. The latter stations had cordinates as shown in Table 4.3.

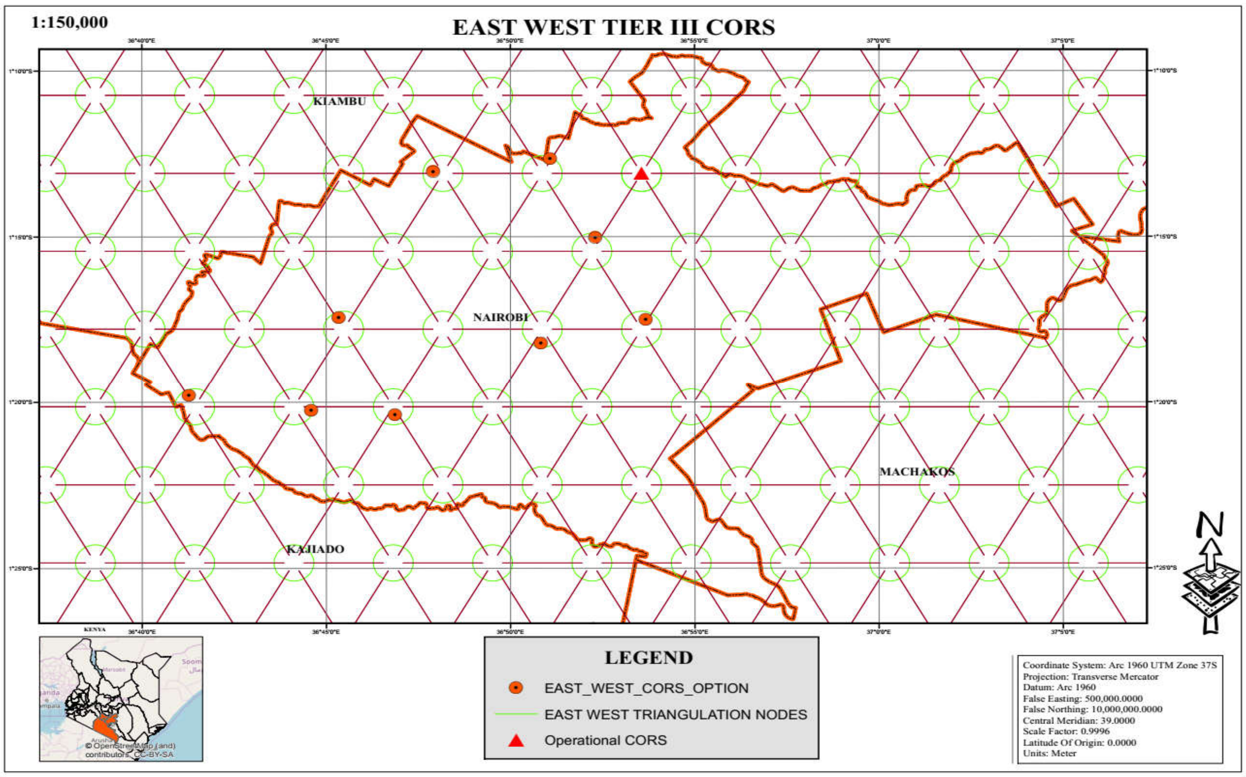


Figure 4. 15: East - West Tier III CORS

Cordinates for Proposed CORS:

Table 4. 4: East - West Tier III CORS Coordinates

FID	EASTING (M)	NORTHING (M)	DESCRIPTION
0	250264.595	9857239.708	E/W/1
1	255033.971	9865362.125	E/W/2
2	265717.281	9857142.335	E/W/3
3	260441.516	9855832.840	E/W/4
4	242719.910	9852885.919	E/W/5
5	248877.590	9852051.009	E/W/6

FID	EASTING (M)	NORTHING (M)	DESCRIPTION
6	253097.304	9851822.591	E/W/7
7	260911.791	9866074.703	E/W/8
8	263186.423	9861707.900	E/W/9

Composite Tier III CORS

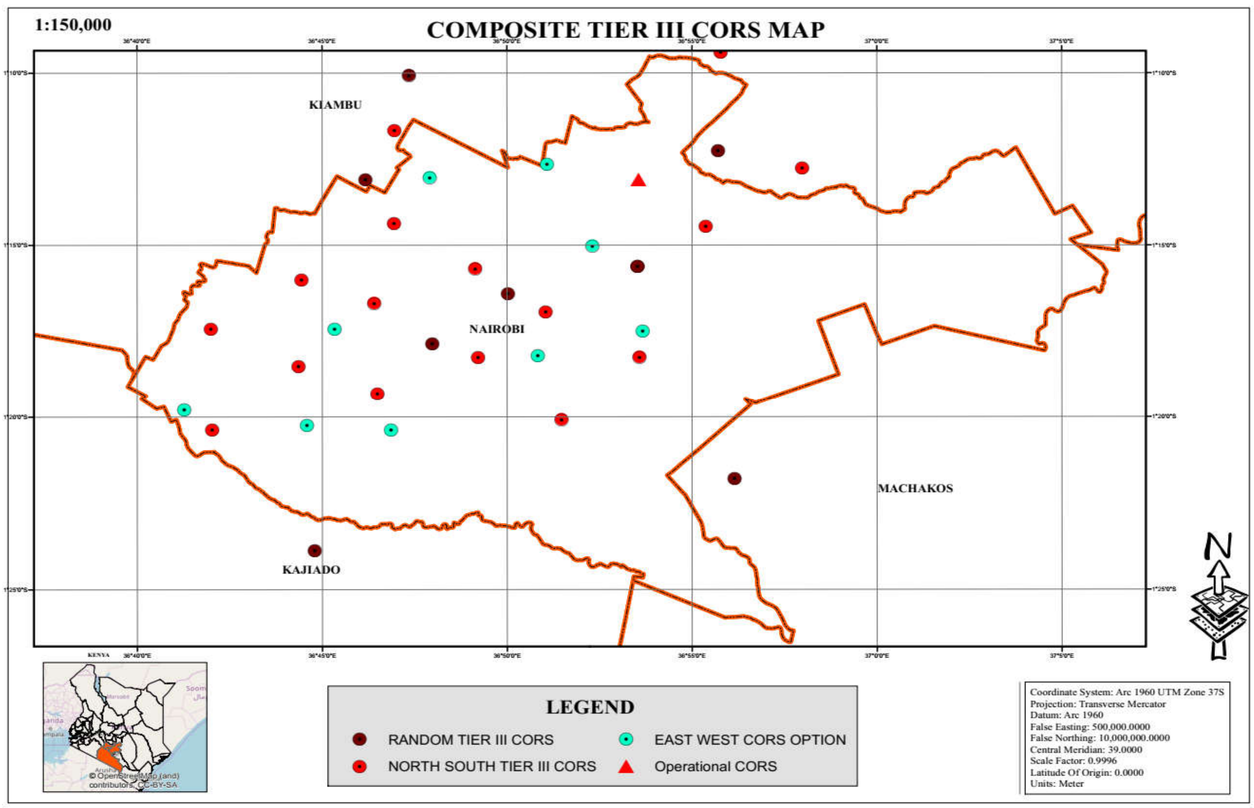


Figure 4. 16: Composite Tier III CORS Map

Figure 4.16 indicates a composite map relaying all proposed stations as well as existing, operational CORS stations.

Ground truthing:

It was observed that from the provided options:

a. ***Random Triangulation Martrices***:- this option gave 9 suitable stations that were distributed beyond Nairobi County.

b. ***North – South Triangulation Matrices***:- this option gave 16 suitable stations well distributed within the AOI. The option was better compared to other options in terms of distribution of the stations and the number of proposed stations which relayed a higher number than East – West Triangulation Matrices and Random Triangulation Matrices.

c. ***East – West Triangulation Matrices***:- the option gave 8 suitable sations located only within the county of Nairobi thus partially adequate in terms of serving the entire AOI.

The North – South triangulation Matrices Results were converted to KML files to determine the realiability of the proposed station on the actual ground. The circular red marks indicate the proposed stations in Figure 4.16.

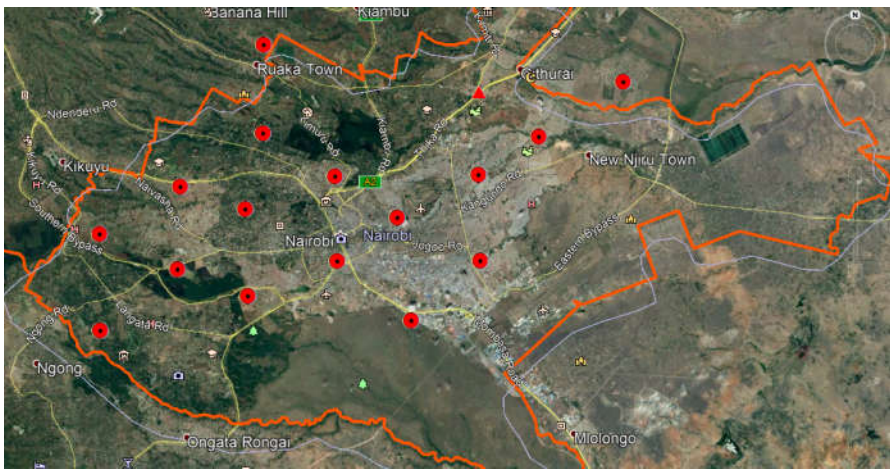


Figure 4. 17: Ground Truthing North South Triangulation Matrices

Figure 4. 18: Ground Truthing: Proposed station in Langata doctors quarters

It was observed that the station was proposed on away from the existing road but in an accessible area that would permit maintenance works.

The North – South Triangulation matrices was the best option given the number of suitable sites as well as the distribution of the stations within the AOI. The other options had fewer number of stations and their distribution were not adequate enough to cover the AOI. The approach utilized well conditioned triangles that ensured that all the stations were placed at sites that offer good geometric network, hence covering the entire area.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Kenya similar to other African countries has adopted the new RTK networks through establishing CORS. Through, its spatial data custodian SOK, some stations have already been established with plans for others. This research study employed internationally set standards as well as standards by AFREF during the adoption of the MCE criterion in determining suitable locations for Tier III stations. However, spatial data used include both open source data and primary data from SOK.

The study has relayed the steps vital in setting up Tier III stations and densifying them hence serving more individuals and improved accuracy. Similarly, the study through adopting well-conditioned triangles and subjecting spatial data on an MCE criterion ensured well distributed network of Tier III stations while keeping the geometric property of the stations. The study will be used as a template for affiliated fields that need spatial coverage for instance SOK. The study has narrowed on the densification of the stations hereafter improving accuracy; however, it has limited information on the equipment specification on the subject such as monumentation, and configurations.

It was observed that the spatial coverage of the existing CORS is not adequate consequently, densification of the existing one was vital. It is evident that more stations met the proposed criteria employing the North South Triangulation matrices.

5.2. Recommendations

Implementation:

Following the research it is recommended any further research done should ensure at well-conditioned triangles if used should at least be hinged on two CORS base stations.

Direct connection of our fundamental networks with neighboring networks is necessary in order to provide Cartographic continuity and to participate in international projects for instance seamlessly connecting the stations to other stations within the country.

Each county should ensure they have a minimum of two operational CORS stations for the approach to be successfully used.

Education and training:

CORS is new to most individuals due to lack of exposure. It is thus, recommended that CORS use and its significance should be publicized to relevant bodies.

REFERENCES

Articles in journals

Brinker, R. C. & Wolf, P. R. (1984). Elementary surveying (7th ed.). New York: Harper and Row. Dana, P. H. (1998). Global positioning system overview. The geographer's craft project. Retrieved August 2, 1999, from http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html

Dewberry Davis. Jun - 98 National Height Modernization Study, Report to Congress http://www.ngs.noaa.gov/PUBS _LIB/1998heightmodstudy.pdf

HNTB 2004 Survey Grade GPS Reference Station technology for the Missouri Department of Transport (technical paper), viewed September 2007.

KNBS. (24th Aug. 2009). "KENYA POPULATION AND HOUSING CENSUS." 2009 KENYA POPULATION AND HOUSING CENSUS, www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=5&ved=2ahUKEwjY5KqYiYHeAhXD8qQKHXh9CLYQFjAEegQIBBAC&url=https://international.ipums.org/international/resources/enum_materials_pdf/enum_instruct_ke2009a.pdf&usg=AOvVaw0-J7skTBWS_tMJoY6pE1WT.

Landau H.; Vollath U.; Chen X. (2002), 'Virtual Reference station' Journal of Global Positioning System, Vol. 1, No. 1 pp 137-143.

Martin, A. and McGovern, E. (2012). "An Evaluation of the Performance of Network RTK GNSS Services in Ireland." *International Federation of Surveyors (FIG)*, Rome, Italy, 6-10.

National Geodetic Survey (n.d.). National Geodetic Survey - CORS, Continuously Operating Reference Stations. Retrieved August 2, 1999, from http://www.ngs.noaa.gov/CORS/cors-data.html

Snay, R. (2005, September 13). *CORS users forum--towards real-time positioning*. Power point presentation presented at the 2005 CORS Users Forum, Long Beach, CA. Presentation retrieved October 26, 2005, from http://www.ngs.noaa.gov/CORS/Presentations/CORSForum2005/Richard_Snay_Forum2005.pdf

Survey of Kenya. (2000). Geodetic Report of Kenya, (January)

US Department of Commerce, NOAA, National Geodetic Survey. (2009, July 29). National Geodetic Survey - CORS. Retrieved February 10, 2018, from https://www.ngs.noaa.gov/CORS/Articles/

Zhang K, Wu F, Wu S, Rizos C, Roberts C, Ge L, Yan T, Gordini C, Kealy A, Hale M, Ramm P, Asmussen H, Kinlyside D, Harcombe P (2006). "Sparse or dense: Challenges of Australian Network RTK", *Proceedings of International Global Navigation Satellite Systems Society Symposium (IGNSS2006)*, Surfers Paradise, Australia, 17-21 July, 13pp

Reports

AFREF. (2010) "AFRICAN GEODETIC REFERENCE FRAME (AFREF)-NEWSLETTER." AFREF News Letter No.11, May 2010.

Cislowski, G.J. and Higgins, M.B. 2006 SunPOZ: Enabling centimetre accuracy GNSS applications in Queensland. Proceedings fron the International Global Satellite Systems Society IGNSS Symposium, 17-21 July 2006, Surfers Paradise, Australia.

Higgins, M. (2001) An Australian Pilot Project for a Real Time Kinematic GPS Network using the Virtual Reference Station Concept, Paper Presented at New Technology for a New Century Conference, Fig Working Week, Seoul, Korea, 6-11 May.

Web-based articles

Rizos, C., Higgins, M., & Johnston, G. (2010). Impact of Next Generation GNSS on Australasian Geodetic Infrastructure. Sydney, Australia. FIG Congress 2010: Facing the Challenges – Building the Capacity, 11-16 April 2010, Sydney, Australia. [Online]. https://www.fig.net/pub/fig2010 /papers/ts10c%5Cts10c_rizos_4148.pdf (Retrieved March 12, 2018).

Books

Aronof, Stan. (1995). Geographic Information Systems: A management perspective.

Awange, J. L. (2018). GNSS environmental sensing: Revolutionizing environmental monitoring. Cham: Springer.

Longely, Paul. Goodchild, Michael F., Maguire, David J., Rhind David W.,. (2006). Geographic Information Systems and Science. New York: Second Edition, John Wily and Sons LTD.

OLooney, J. (2003). Beyond maps: GIS and decision making in local government. Readlands, CA: ESRI Press.

Riguax, P., Scholl, M., and Voisard, A. (2002). Spatial Database: with application to GIS. Massachusetts: Morgan Kaufmann Publishers.

Schmid, R. (1998). Merriam-Websters Geographical Dictionary. Taxon, 47(2), 535. doi:10.2307/1223820

Survey of Kenya. (2002). Land Act.

Lachapelle G, Ryan S, Rizos C (2002). Servicing the GPS user, Chapter 14 in Manual of Geospatial Science and Technology, J. Bossler, J. Jenson, R. McMaster & C. Rizos (eds.), Taylor & Francis Inc., 201-215.

APPENDICES

Appendix A1:

Trimble — *Coordinates Overview*

www.trimble.com

Project : KENREF

User Name	Colin Munene	**Date & Time**	10:43:37 2/8/2016
Coordinate System	UTM	**Zone**	37 South
Project Datum	ARC 1960 (Kenya/Tanzania)	**Geoid Model**	EGM96 (Global)
Coordinate Units	Meter		
Distance Units	Meter		
Height Units	Meter		
Angle Units	Degrees		

Number of Points 20

1. Point Information

Point Name	Point Code	Point Info.	Fix	Adjusted	Local	Control
MAL2	33201M003		Yes	Yes	No	No
RCMN	33203M001		Yes	Yes	No	No
KILG	KILG		Yes	Yes	No	No
GARI	GARI		Yes	Yes	No	No
KITU	KITU		Yes	Yes	No	No
KIBW	KIBW		Yes	Yes	No	No
MAND	MAND		Yes	Yes	No	No
WUND	WUND		Yes	Yes	No	No
KWAL	KWAL		Yes	Yes	No	No
RAVI	RAVI		Yes	Yes	No	No
BOND	BOND		Yes	Yes	No	No
MARA	MARA		Yes	Yes	No	No
LOKI	LOKI		Yes	Yes	No	No
ISIO	ISIO		Yes	Yes	No	No
MARS	MARS		Yes	Yes	No	No
KAPE	KAPE		Yes	Yes	No	No
NAMA	NAMA		Yes	Yes	No	No
LODW	LODW		Yes	Yes	No	No
WAJI	WAJI		Yes	Yes	No	No
LAMU	LAMU		Yes	Yes	No	No

2. WGS84 - Cartesian Geocentric Coordinates

Point Name	X	Y	Z
MAL2	4865385.5568m	4110717.3562m	-331137.4998m
RCMN	5101056.6680m	3829074.3630m	-135016.2060m
KILG	5232802.9242m	3648104.2474m	-110900.8782m
GARI	4910887.5227m	4069702.8805m	-53042.3580m
KITU	5024367.1717m	3927825.1500m	-151329.5647m
KIBW	5024935.2391m	3920535.7484m	-266366.2603m

MAND	4738932.7662m	4246795.9608m	434780.5643m
WUND	4993491.7260m	3952352.5750m	-376186.4270m
KWAL	4911933.1689m	4042727.1871m	-461770.2766m
RAVI	5179435.7020m	3725800.3350m	5153.4674m
BOND	5270637.5291m	3593983.9336m	-10879.3489m
MARA	5114971.4882m	3811537.7771m	120777.4848m
LOKI	5250093.6649m	3592772.6989m	464319.7672m
ISIO	5055038.8333m	3890930.9451m	40096.9031m
MARS	5023974.6253m	3923160.4967m	257191.9876m
KAPE	5217963.9011m	3668972.4564m	137989.3973m
NAMA	5104032.8933m	3816587.2165m	-281430.8003m
LODW	5178623.2042m	3707994.8005m	344632.5798m
WAJI	4879324.0074m	4103453.7373m	192985.2842m
LAMU	4820988.3095m	4168612.7106m	-246352.4925m

3. WGS84 - Geographical Coordinates

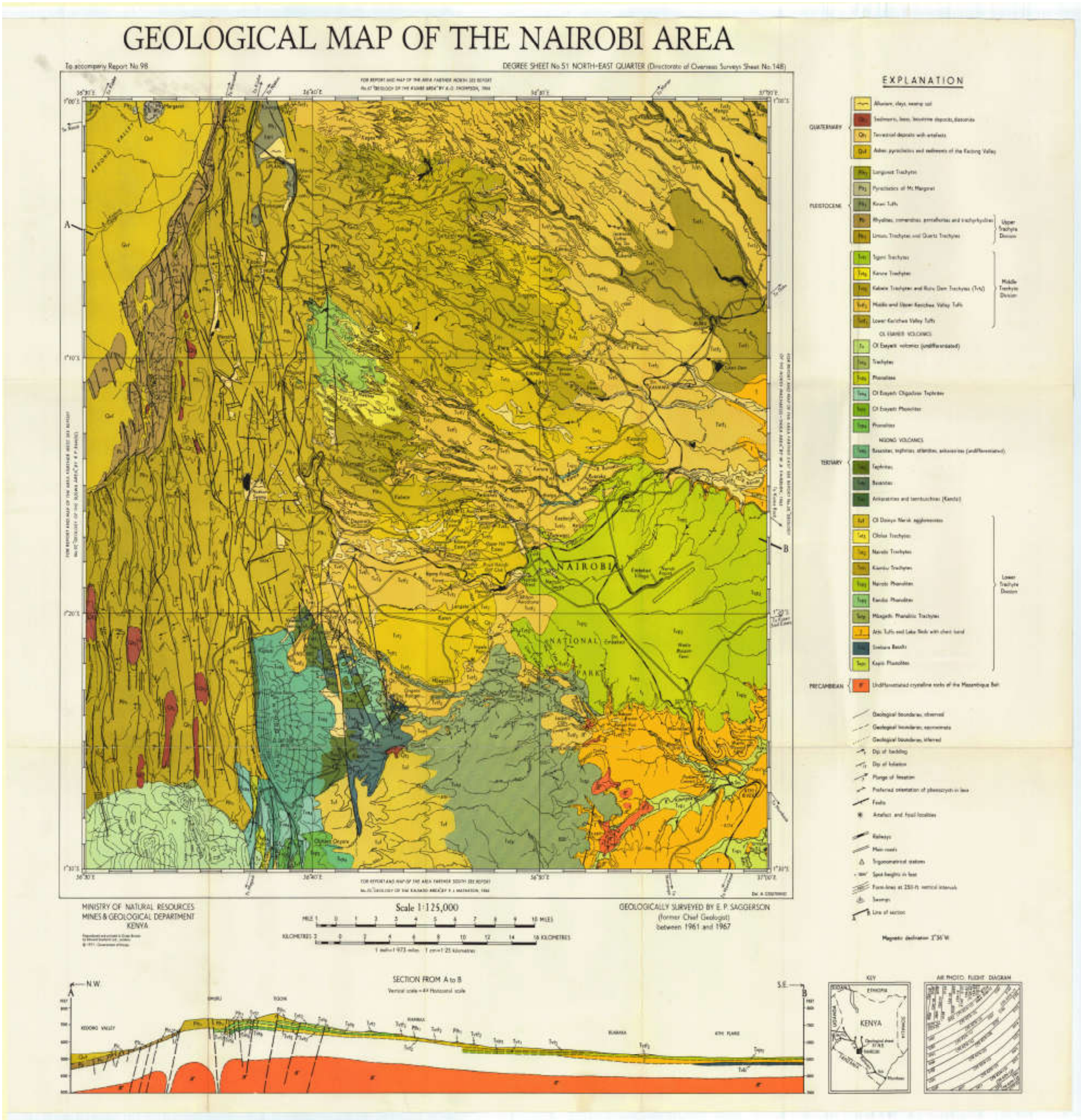
Point Name	Latitude	Longitude	Height
MAL2	S 2° 59' 45.79500"	E 40° 11' 38.92099"	-20.9110m
RCMN	S 1° 13' 14.98486"	E 36° 53' 36.53611"	1591.9762m
KILG	S 1° 00' 09.80274"	E 34° 52' 57.68806"	1774.6698m
GARI	S 0° 28' 46.90377"	E 39° 38' 56.00806"	117.4829m
KITU	S 1° 22' 06.45749"	E 38° 01' 00.13006"	1136.5349m
KIBW	S 2° 24' 33.45107"	E 37° 57' 42.95092"	891.4372m
MAND	N 3° 56' 05.76508"	E 41° 51' 54.41696"	190.9777m
WUND	S 3° 24' 11.96372"	E 38° 21' 41.91127"	1402.1887m
KWAL	S 4° 10' 46.18004"	E 39° 27' 20.93136"	373.7465m
RAVI	N 0° 02' 47.72587"	E 35° 43' 44.96692"	2158.3744m
BOND	S 0° 05' 54.13306"	E 34° 17' 22.57300"	1240.6841m
MARA	N 1° 05' 31.21570"	E 36° 41' 32.92141"	1944.4284m
LOKI	N 4° 12' 08.80797"	E 34° 23' 05.38589"	620.3122m
ISIO	N 0° 21' 45.23346"	E 37° 35' 09.45445"	1077.6712m
MARS	N 2° 19' 33.92135"	E 37° 59' 09.03570"	1369.4655m
KAPE	N 1° 14' 51.40756"	E 35° 06' 45.66296"	2119.6968m
NAMA	S 2° 32' 43.70012"	E 36° 47' 15.49766"	1300.8070m
LODW	N 3° 07' 04.86003"	E 35° 36' 12.23722"	494.1812m
WAJI	N 1° 44' 43.79939"	E 40° 03' 48.37770"	235.0224m
LAMU	S 2° 13' 42.58137"	E 40° 50' 57.55149"	-21.3864m

4. National Grid Coordinates

Point Name	Northing	Easting	Height	Elevation
MAL2	9669071.1451m	632613.1336m	-20.5646m	9.5747m
RCMN	9865269.9858m	265503.0328m	1606.3449m	1607.8695m
KILG	9889181.0434m	41425.5309m	1793.2022m	1790.0234m
GARI	9947275.8528m	572109.7771m	131.1611m	143.8633m
KITU	9849021.5235m	390514.9951m	1148.3811m	1156.1094m
KIBW	9733955.6951m	384489.6517m	898.2623m	910.9433m
MAND	10435780.0863m	818105.0041m	225.2806m	220.4701m
WUND	9624103.0100m	428995.3021m	1403.6672m	1422.7523m
KWAL	9538317.7933m	550492.8571m	369.8799m	401.6470m
RAVI	10005458.3942m	135744.6296m	2181.0464m	2172.2077m

BOND	9989390.9258m	-24836.9444m	1264.7391m	1257.9141m
MARA	10121097.7092m	243113.5849m	1971.1964m	1958.1989m
LOKI	10466319.6068m	-12825.0680m	668.2347m	632.6516m
ISIO	10040386.4369m	342545.8031m	1099.1216m	1094.1903m
MARS	10257443.6139m	387142.3152m	1401.0100m	1389.3267m
KAPE	10138519.0853m	67114.0322m	2149.7184m	2132.1073m
NAMA	9718736.4965m	253905.2558m	1308.8360m	1317.4523m
LODW	10345546.3708m	122285.3292m	533.9516m	509.9736m
WAJI	10193263.4985m	618191.4113m	259.8990m	260.0909m
LAMU	9753854.5223m	705569.6259m	-18.4901m	8.6408m

Appendix A2:


GEOLOGICAL MAP OF THE NAIROBI AREA
To accompany Report No.98
DEGREE SHEET No 51 NORTH-EAST QUARTER (Directorate of Overseas Surveys Sheet No.148)
EXPLANATION
QUATERNARY
PLEISTOCENE
TERTIARY
PRECAMBRIAN
NAIROBI
NATIONAL
PARK
MINISTRY OF NATURAL RESOURCES
MINES & GEOLOGICAL DEPARTMENT
KENYA
Scale 1:125,000
GEOLOGICALLY SURVEYED BY E. P. SAGGERSON
(former Chief Geologist)
between 1961 and 1967
SECTION FROM A to B
N.W.
S.E.
KEY
KENYA
AIR PHOTO FLIGHT DIAGRAM