Optimum CORS Network Design for Geodetic Applications in Ethiopia

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Abstract

The establishment of the Continuously Operating Reference Stations (CORS) network as a national positioning service enables high precision in surveying, mapping, and navigation applications, thanks to developments in Global Navigation Satellite System (GNSS) technology. In this study, we determined the best CORS network site in Ethiopia by taking into account aspects such as accessibility, internet coverage, and network geometry. We chose an excellent location for Ethiopia out of 228 options based on these parameters. The CORS network's performance was validated by using a network of triangles as a reference station and a virtual reference station (VRS) within the triangles. To validate the performance of the selected networks, simultaneous GNSS observations are conducted on the reference and VRS stations. The idea of VRS generated GNSS observation data utilizing reference station observation data and the location of VRS station using Wav2 Software. For observations based on genuine and created data, we compared the precise coordinates of the VRS station.The comparison showed a standard deviation of 0.65 cm and 2.7 cm in the horizontal and up directions. Therefore, this CORS network design can be used for different applications with 3D accuracy less than 3 cm.

1. Introduction

A country's network of Continuously Operating Reference Stations (CORS) delivers real-time, precise three-dimensional positioning. A CORS network is a collection of Global Navigation Satellite System (GNSS) receivers strategically placed throughout a region as part of the country's geodetic infrastructure. CORS networks can also be used to track and record the movement of the continent, allowing the reference frame and datum for geoscience and spatial datasets to be developed, enhanced, and maintained (ICSM, 2014).

The CORS approach began in early 1990 when National Geodetic Survey (NGS) installed the initial permanent GPS receiver in the Gaitterburg Campus in the USA and culminated in more installations in Maryland, Colorado, and other networks that formed part of the Cooperative International GPS (CIGNET) network. In early 2000, more stations had been installed, raising the number to almost 200 stations, steadily increasing to 1400 as of 2014, and thus adopted as the primary geodetic spatial data infrastructure (Kusimba, 2018).

In Africa, some countries installed CORS with the initiation of the African Geodetic Reference Frame (AFREF) has triggered a group adoption, i.e., Kenya, Nigeria, South Africa, Benin, and 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, a seamless reference ensuring uniformity. Therefore, it ensures the nations within the African continent implement the aforementioned modernized GNSS technologies, hence the establishment of the CORS network that will support various activities affiliated with mapping such as cadastral surveys, engineering survey, and geodynamics (Combrinck, 2010).

In Ethiopia, the first CORS was created in 2007 as part of the international GNSS service (IGS) stationed by the Institute of Geophysics, Space Science, and Astronomy (IGSSA) at Addis Ababa University's Arat Kilo Campus. In 2015, the TANA IGS station was built by the Institute of Land Administration (ILA) at Bahir Dar University. The Ethiopian Geospatial Information Institute (GII) is in charge of establishing the CORS network for geodetic applications across the country. As part of this endeavour, GII collaborated with assistance organizations to create four CORS in Ethiopia: Gondar, Jimma, Dire Dawa, and Addis Ababa. However, the number of CORS already in place does not cover the entire country of Ethiopia. Despite the fact that various research on CORS network architecture have been undertaken around the world and in Africa, there are no comprehensive and substantial studies in Ethiopia. Without a suitable design and installation of the CORS network in Ethiopia, it will be difficult to support the ever-growing geospatial applications.

"To construct the geodetic network, it is important to plan the network beforehand," as Alizadeh-Khameneh (2015) shown. As a result, the goal of this research is to create a CORS network that encompasses Ethiopia. The availability of the mobile network, accessibility, and network geometry should all be considered during the design phase. It also includes a network observation plan as well as some measurement performance recommendations. The ultimate goal of network design is to create a network that is optimal in terms of precision, dependability, and cost. The correctness of the planned network will be verified using virtual reference station principles (VRS).

2. Methodology

In this section, the description of the study area, the data, and the method used for CORS network design will be discussed.

2.1 Study Area

Ethiopia lies between 3 and 15 degrees north latitude and 33 to 48 degrees east longitude in the Horn of Africa. It borders Eritrea and Djibouti in the north and northeast, Kenya in the south, and Sudan in the west, with a total area of 1 127 127 square kilometres, of which 7444 square kilometres is water. Ethiopia's geography varies greatly, with heights ranging from – 125 meters at the Danakil Depression to 4620 meters at Ras Dashen. The East African Rift Valley divides more than 45 percent of the country, which is dominated by a high plateau (see Fig. 1) with a chain of mountain ranges. Ethiopia is both a highland/mountainous (with elevation greater than 1500 m) and a lowland (with elevation less than 1500 m) country (Legesse, 2016; Miskas & Molnar, 2009). Therefore, far, Ethiopia has four CORS (see Fig. 1) and 30 zero-order geodetic stations that can be upgraded to CORS.

2.2 Data

In this study, different factors were considered for designing the CORS network. These factors that affect the location of the CORS network were collected from different organizations. The location of towns and roads are downloaded in shape files freely from the internet. The mobile network coverage data are collected from the Ethio Telecom office. To validate the CORS network, a 12-hour GNSS observation was measured using SOKKIA ATLAS Receivers.

2.3 Methodology

To choose an appropriate site for the CORS network, we looked at a variety of variables. Some of these have to do with power supply, mobile network connections, and road infrastructure. We choose towns that meet these criteria. The number of selected CORS networks is also affected by the distance between stations. A maximum distance of 70 km between CORS stations was used in this study (ICSM, 2014). The greater the distance between CORS, the more likely the results will be influenced by high noise, lowering the accuracy of the final point locations. In this case, we employed ArcGIS overlay analysis technique to combine all input parameters into a single output, dubbed the CORS optimal site. The network's geometry was verified by estimating the CORS network's error ellipse to approximate station coordinates and distance while considering a free network adjustment. Except for those near the Ethiopian border, stations with greater error ellipses are deleted and replaced by other stations in the trial and error process.

The CORS network is validated once it is designed by obtaining GNSS measurements on the CORS network site and inside the network. Some of the stations in the CORS network have been chosen. We use GNSS mission planning software to check the selected stations for satellite visibility and measurement quality in advance (Kusimba, 2018;Snay, 2008). The CORS networks are thought of as a triangle of reference stations, with rover stations chosen from within the triangle. The principle of Virtual Reference Station determines the precise location of the rover station (VRS). VRS was designed to allow rover receivers to be accurately positioned in real time anywhere inside the network of base stations. This technique requires at least three measured stations to define (interpolate) the virtual station (Kim Sun & Gibbings, 2005).

As shown in Fig. 2, the computation of virtual reference station observations consists of three basic processing phases. The horizontal coordinates are used as virtual reference station coordinates. The vertical coordinate, on the other hand, is calculated as a weighted mean value of the true reference station's vertical coordinates. The correct modelling of distance-dependent biases, and hence the generation of virtual reference station observations, requires ambiguity fixing in the network of real reference stations (processing step 1).WaV2 software (Wanninger, 2003) was used to identify a master reference station and determine ambiguities in all baselines relative to that station. The network processing is not always conducted for all reference station observations, but it is limited to the duration of the rover observation or, if that duration is quite short, two hours.

Estimating adjustments for ionospheric and non-ionospheric (tropospheric and orbit) biases is the second main processing step. The virtual reference station observations are computed in the third processing step using the master reference station observations, the correction values, and the virtual reference station's selected position. As a result, the antenna and receiver of the master reference station are also regarded as the antenna and receiver of the virtual reference station. For antenna phase centre correction and GLONASS interfrequency receiver biases, this is critical.

To validate the network, the GNSS observed data and generated data on the rover are processed using Bernese 5.2 GNSS software. We compared the coordinates of the real and VRS coordinates.

3. Result

The CORS' optimal network is created by taking into account the station's accessibility, the mobile network's coverage, and the network's geometry. We chose 228 stations to cover the entire country of Ethiopia (see Fig. 3). All stations are located near a town, and the majority of them have mobile networks. However, certain stations were installed to meet the network's geometrical criterion in the absence of a mobile network, believing that it will be covered in the future.

The optimal design of the CORS network was done in a trial and error process by considering factors that satisfy accessibility, mobile network, and good geometry. The strength of the geometry of the network was estimated by calculating the error ellipse for each selected station. We take the approximate geographic coordinates, distance, and direction of the stations to compute the error ellipse using free network adjustment. Those stations with larger error ellipses are eliminated in the design process except for stations on the Ethiopian border as shown in Fig. 4.

We then checked the designed network for whether it gives the required accuracy for rover measurements. For this purpose, we select 8 stations out of the 228 stations that form 6 triangles. We select 6 VRS stations inside the triangle as in Fig. 5. For each reference station that forms a triangle as well as the VRS station inside, we conduct a 12-hour GNSS measurement. The first session was conducted by taking GNSS measurements on reference stations at ADIS, SHEN, and MUKE as well as on the ONOD VRS station. We keep SHEN and ADIS stations for the next session and we move the MUKE station to MOJO. We did a simultaneous measurement on the reference and CHDO VRS stations for this session. The third session takes the measurement on ADIS and MOJO which are part of the previous session as well as on KOND and BISH VRS stations. We take the other three sessions in a similar manner. We then calculate the precise coordinates of the reference and VRS stations by processing with the neighboring ADIS IGS station using Bernese 5.2 GNSS Software.

We applied the precise coordinates of the reference station and the coordinates of the VRS station to generate the Receiver Independent Exchange (RINEX) file for the VRS station. We used Wav2 software to generate VRS RINEX data. We processed the generated VRS RINEX data using the same software and compared their coordinates with the real measured data as in Table 1. The comparison of the real and generated VRS stations for the first session of ONOD showed a 0.9 cm, 0 cm, and 0.5 cm difference in the Easting, Northing, and Up coordinates, respectively. In general, the standard deviations of the 6 sessions between the real and VRS are 0.6 cm, 0.3 cm, and 2.7 cm in Easting, Northing, and Up, respectively.

The statistics in Table 1 showed a maximum magnitude difference of 1.1 cm. 0.7 cm and 6.2 cm in Easting, Northing, and Up directions, respectively. In a similar manner, the minimum differences are 0.3 cm, 0.1 cm, and 0.5 cm in Eastin, Northing, and Up directions, respectively. The standard error of the difference in the horizontal direction is 0.65 cm.

Table 1
Comparison of the real and VRS Coordinates in Easting, Northing and Up

Station Name	Easting (m)	Northing (m)	Up (m)
ONOD (Real)	510707.659	1026090.876	2827.968
ONOD (VRS)	510707.668	1026090.876	2827.963
	-0.009	**0.000**	**0.005**
CHDO (Real)	513121.537	991233.579	2302.653
CHDO (VRS)	513121.534	991233.578	2302.655
	0.003	**0.001**	**-0.002**
BISH (Real)	492241.076	963983.796	1891.933
BISH(VRS)	492241.087	963983.803	1891.975
	-0.011	**-0.007**	**-0.042**
ALTE (Real)	494995.123	917891.182	1528.259
ALTE (VRS)	494995.122	917891.183	1528.313
	0.001	**-0.001**	**-0.054**
DERA (Real)	535765.690	919810.469	1566.048
DERA (VRS)	535765.691	919810.469	1566.086
	-0.001	**-0.001**	**-0.037**
ADHI (Real)	564960.550	942283.285	1121.436
ADHI (VRS)	564960.548	942283.287	1121.497
	0.002	**-0.002**	**-0.062**

4. Discussion

Similar studies examining the CORS network's performance were carried out in Italy and Thailand (Charoenkalunyuta et al., 2012; Arianna et al., 2008) investigated the CORS network's suitability for measuring ground displacement in landslides. To assess the technique's performance, some experiments were carried out, including measurements on an actual landslide. The results point out that the standard deviation of the obtained solutions is about two or three times larger than that which can be reached using a real local network.

Charoenkalunyuta et al. (2012) investigated the position performance of the CORS network in Thailand in a similar way. They used all accessible Continuous GPS (CGPS) stations in the central region of Thailand to test with a large number of GNSS observations and varied reference receiver spacing, 10–20, 30–50, 50–60, and 60–80 km. When the reference station spacing is increased, the NRTK positioning performance degrades according to the test data. The statistics of the CORS network performance for receiver’s stations separated between 60–80 km showed 3.5 cm and 7.2 cm root mean square error in the horizontal and up directions, respectively. In our study, which is in the similar range between 60–80 km spacing, we obtained a standard deviation of 0.65 cm and 2.7 cm in the horizontal and up directions, respectively.

In Southern Ontario, Canada, Saeidi (2012) studied the performance of commercial network RTK services and discovered that the user horizontal solution had an overall precision of ∼2.5 cm (95 percent).

Another study was done by (Edwards et al., 2010) which evaluated RTK network services in the United Kingdom. This study focused on the performance of privately-run networks in terms of solution accuracy of the networks at their coverage edges and in the presence of significant height differences. In general, the study concluded that the accuracies of network RTK in Great Britain range from 1.0 to 2.0 cm in horizontal and 1.5 to 3.5 cm in height. Another similar study was conducted Rubinov et al., (2011) in Victoria, Australia. In this study, both kinematic and static aspects of network services were studied. The results showed a general height error of 2.5 cm. Three different test runs were performed at 9 km, 23 km, and 35 km from the nearest reference station, all of which are approximately 5–10 minutes. The height deviation results for each baseline length showed sub-centimeter accuracy at 9 km, as well as ~ 1 cm and ~ 2 cm at 23 km and 35 km, respectively. In terms of precision, the baseline length had very little effect on the standard deviation as for all three baselines a standard deviation of ~ 1.8 cm was observed.

5. Conclusion

CORS networks can be applied to provide a new technical idea for large-scale control networks of the country or region and provide real-time dynamic framework for digital city. In addition, CORS can provide higher accuracy, stronger integrated application than conventional techniques. However, in Ethiopia, there is no appropriate design and coverage of CORS network. We implement different factors such as distance, accessibility as well as geometry for designing the CORS network. We proposed and optimal design that includes 228 CORS network locations which covers Ethiopia. We validated the CORS network by the principles of VRS. We selected 8 stations out of the 228 selected stations that form 6 network of triangles. For each triangle, one VRS station inside the network is selected. The RINEX data of the VRS station are generated using software and their precise coordinates are compared with the real measured VRS stations. Our comparison showed a standard deviation of 0.65 cm and 2.7 cm in the horizontal and up directions. Therefore, this CORS network design can be used for different applications with 3D accuracy less than 3 cm.

Declarations

Acknowledgment

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Declaration of Interest Statement

No conflict between authors

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Figures

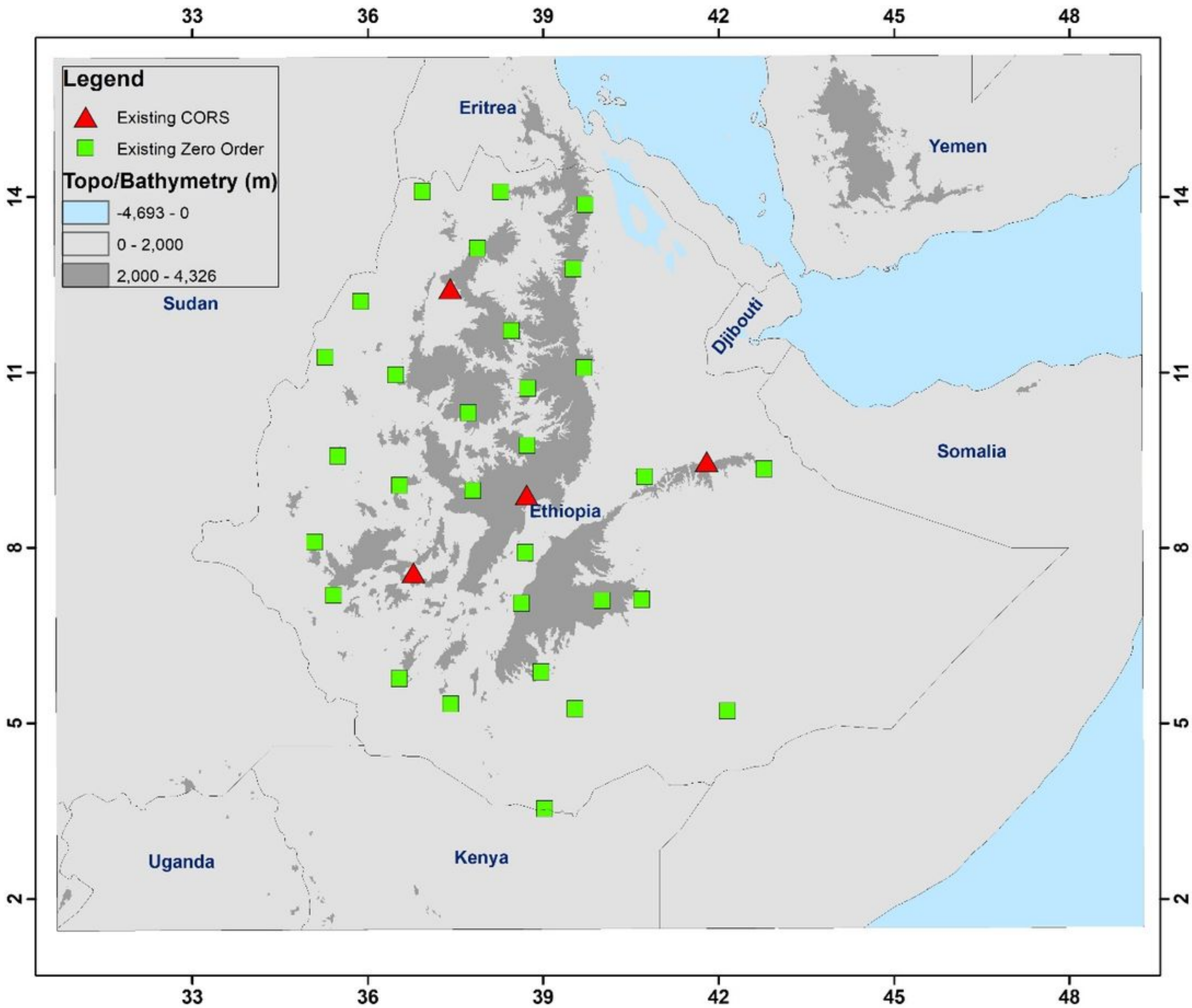

Figure 1

Study area map showing existing geodetic infrastructures in Ethiopia

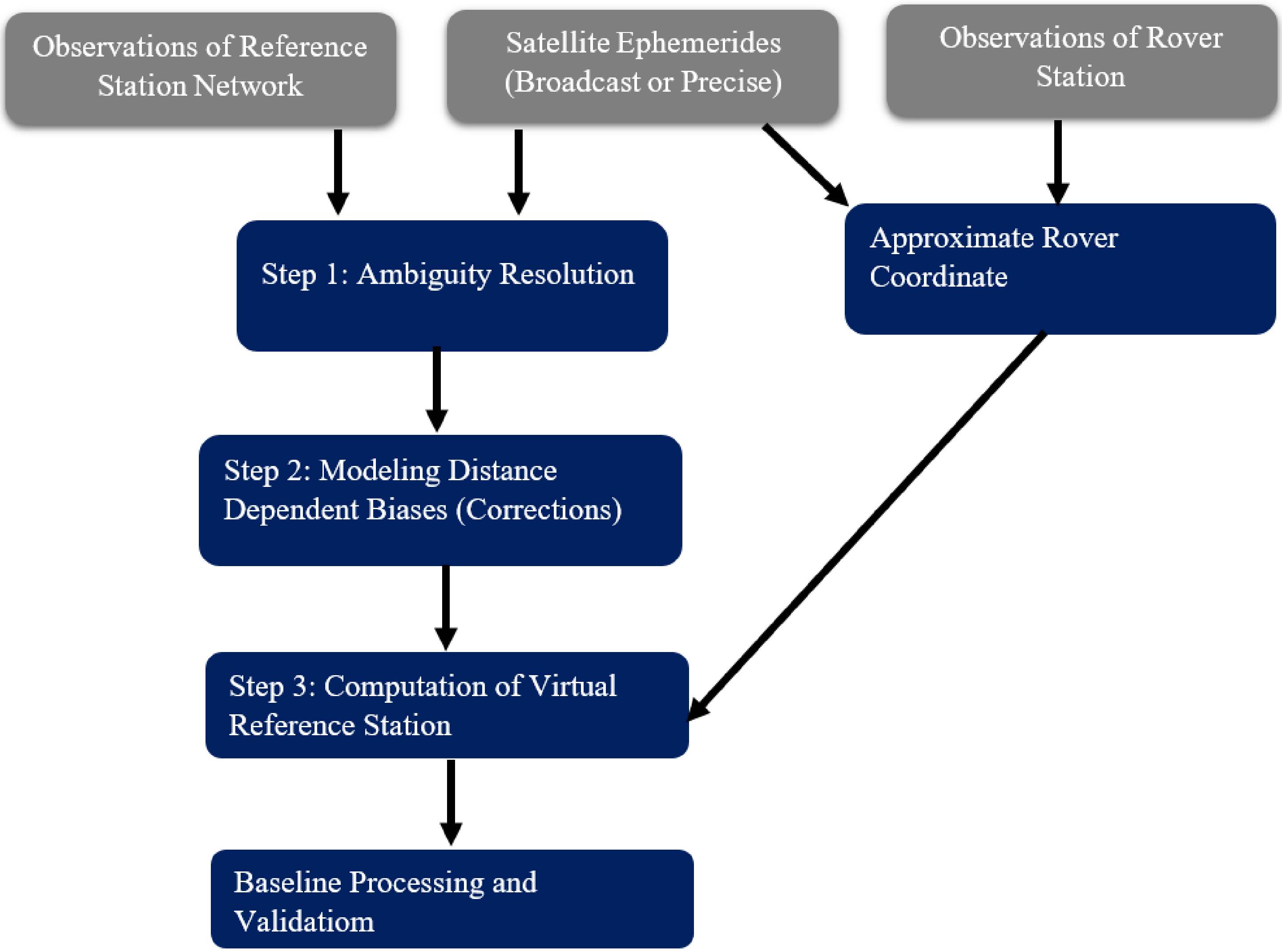

Figure 2

VRS computation steps used in Wav2 Software

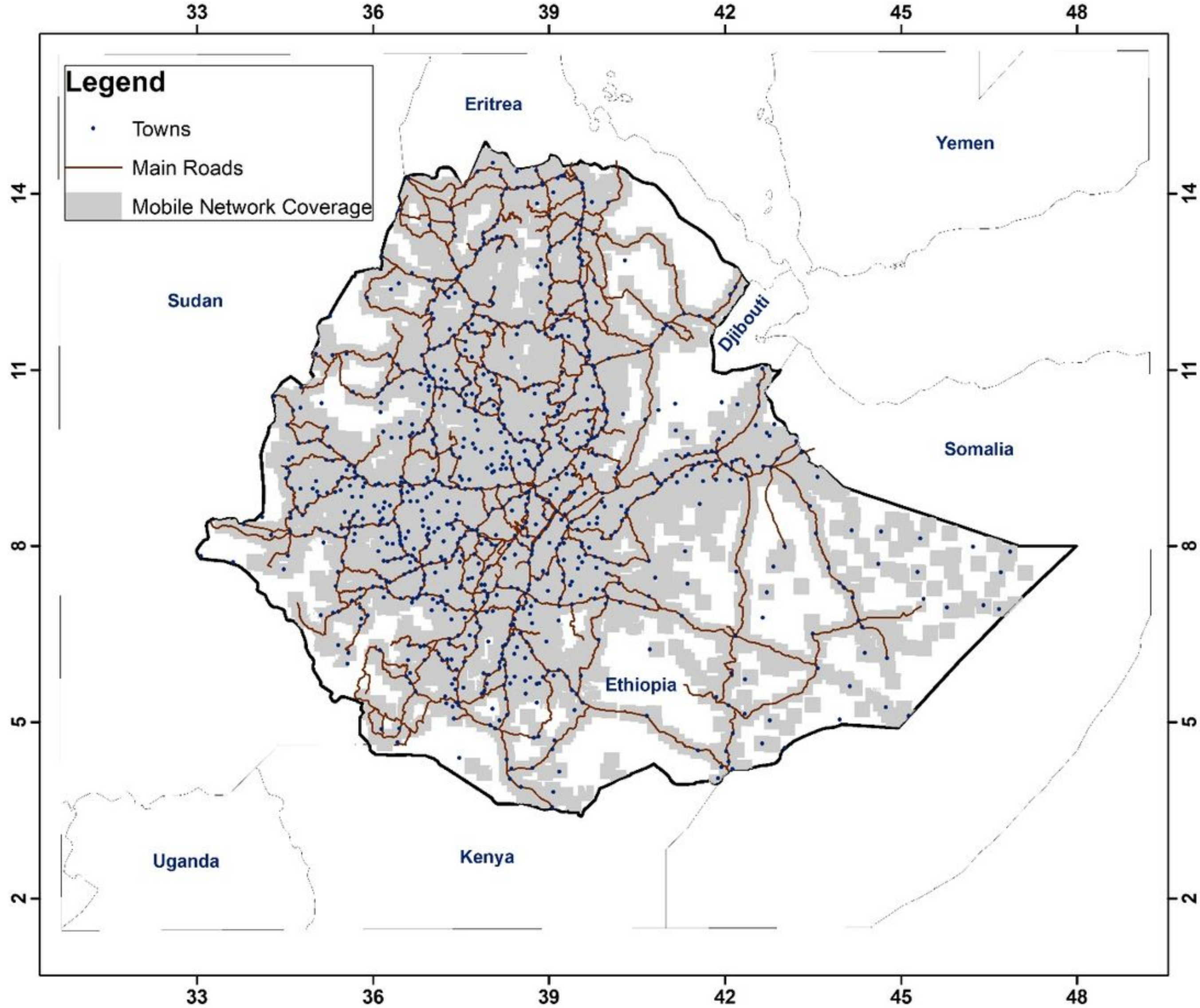

Figure 3

Map of factors considered for selecting CORS network location

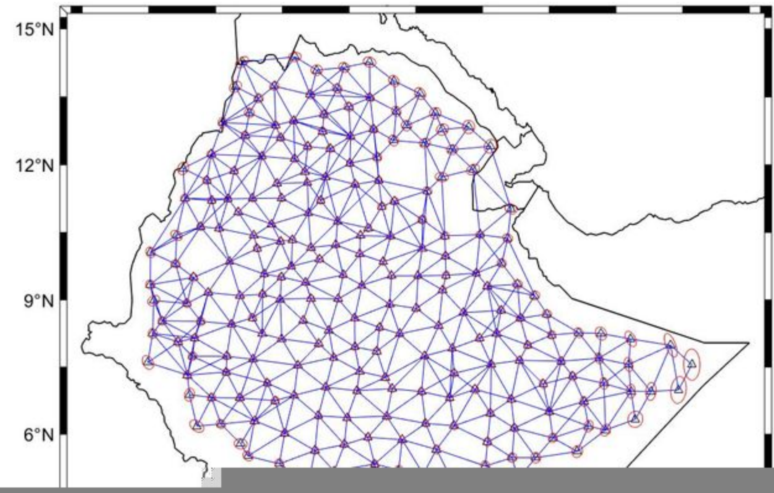

Figure 4

CORS network locations with their error ellipse

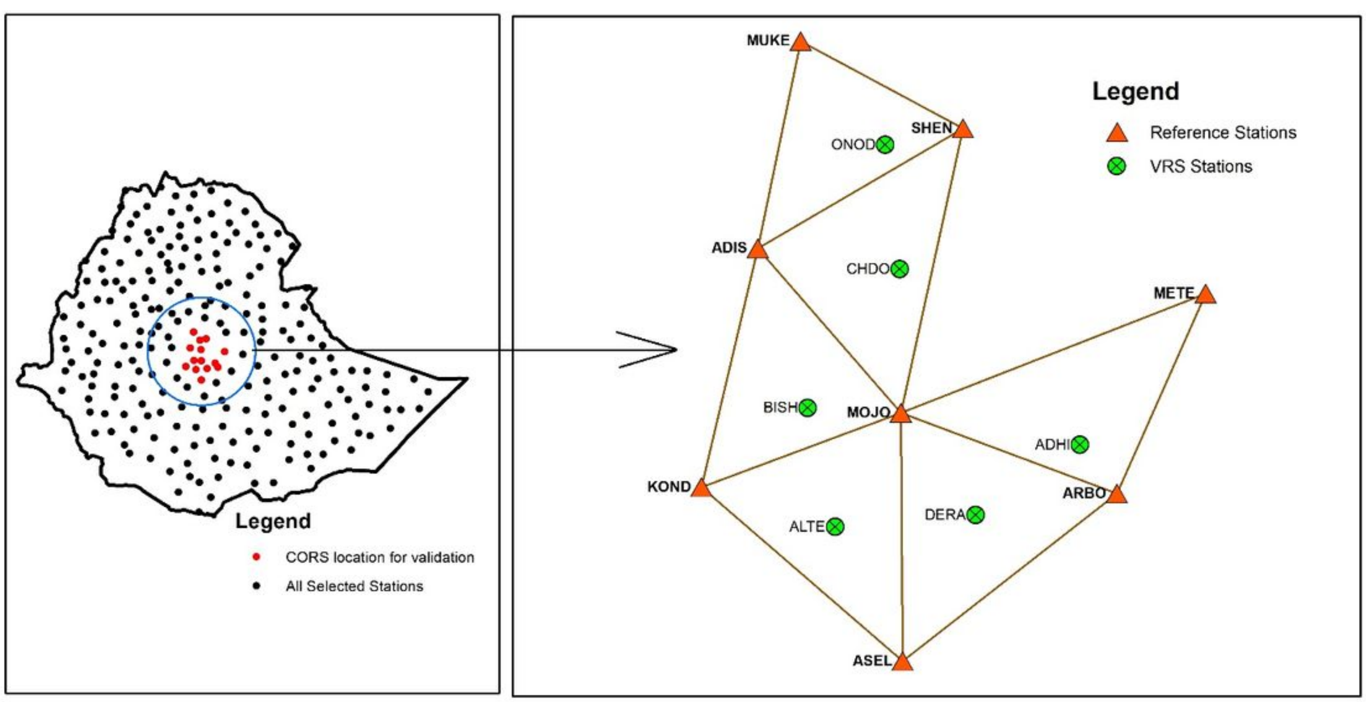

Figure 5

Map of reference and VRS stations used for CORS network validation