Journal of Applied Engineering, Technology and Management (JAETM)

Evaluating the Positional Stability Status of the Druk CORSNet: A Preliminary Study

Indra Bahadur Chhetri[1*], Dechen Tshomo[2], Dawa Tshering[3], and Thinley Namgay[4]

[1,4]*Department of Civil Engineering and Surveying, Jigme Namgyel Engineering College, Royal University of Bhutan*
[2]*Druk Green Power Corporation Limited, Thimphu, Bhutan*
[3]*A-Star Engineering Consultancy, Samtse, Bhutan*
[*]*Corresponding author: Indra Bahadur Chhetri, indrachhetri.jnec@rub.edu.bt*

Published: June 2024

DOI: https://doi.org/10.54417/jaetm.v4i1.119

Abstract

The continuously operating reference station (CORS) that provides a Global Navigation Satellite System (GNSS) enables precise location and elevation data for various applications, such as site selection for important engineering projects and hazard analysis. Similarly, the most common applications of the CORS network, in Bhutan, are for engineering, cadastral, geodetic, and topographical surveys. In this regard, consistency and dependability of data from the CORS station are crucial. Moreover, the ability of such applications heavily depends on precise and reliable data from the CORS network. However, Bhutan has limited studies conducted on the stability of the CORS station besides their initial testing during its installation since its establishment except for Thimphu station. Therefore, this study aims to determine the positional and elevation variations of seven CORS stations that are operational in Bhutan between the years 2016 and 2022. Identifying and quantifying various geodetic occurrences is feasible by examining the time series of positional analysis. The analysis of elevation variation focuses on changes in orthometric elevations throughout the CORS network. In our study, all the available GNSS CORS data are processed, and the displacement in elevation and position is computed and compared. The analysis consists of a simple method (mean value subtracted) of the monthly time series data, which is computed and compared. Further, the absolute maximum change in position of the stations was computed as 6.36 cm, 4.24 cm, and 5.49 cm for easting, northing, and elevation components, respectively. The findings highlight that the proposed method of determining the variation in elevation and location of the CORS stations is fairly practical and within the CORS differential accuracy range of 1 to 10 cm. The findings from this study will help the user community guide them in using the CORS network wisely across Bhutan. Similarly, the result of this study will be a relevant source of information for organisations such as the National Land Commission Secretariat (NLCS) to augment the system in the future.

Keywords— DRUK CORSNet, Receiver Independent Exchange Format (RINEX), Stability analysis, Trimble Business Center (TBC)

1 Introduction

The Continuously Operating Reference Station (CORS) network is a Global Navigation Satellite System (GNSS) receiver system that provides high-precision positioning data [1]. It has been widely used as a geodetic method of choice for investigating a wide range of geophysical phenomena, such as the motion of the Earth's tectonic plates and the study of global, regional, and local motions and deformations. CORS stations are typically installed at permanent locations. They continuously collect data, which can be accessed and used by various users for various applications, including surveying, mapping, site selection for important engineering projects, mining surveying, precision agriculture studies, and geophysical and geodynamic studies. Moreover, a superconducting gravimeter (SG) and a global positioning system (GPS) receiver were placed to track signals about local environmental influences, global and regional processes, and ground deformation [2], [3]. At the regional level, GNSS-based geodynamic projects were developed, specifically for tectonic investigations such as those conducted in the California region [4], the Mediterranean region [4], Japan [5], and Southwest Anatolia, Turkey [6]. Also, GNSS is regarded as being crucial to the earth sciences. Meteorologists use it for weather forecasting and global climate research [7]. In the CORS network, observation has become increasingly important and convenient in recent years due to its high precision, 24-hour availability, operability under all weather conditions, and automation [8]. In comparison to "stand-alone" GNSS, which can have a precision of up to metres, CORS offers free access to extremely accurate (centimetre-level) positions in the National Spatial Reference System (NSRS) using GNSS and its accompanying technologies like OPUS (Online Positioning User Service). However, to fully leverage the potential of CORS data, it is important to understand the factors that can affect its accuracy and stability [9]. It is highly preferred that CORSNet station antennas be structurally fixed to the exposed bedrock [9]. This is mainly because no station in the network can be regarded as having excellent stability when the CORSNet station antennas are mounted on building rooftops [8]. Since most of the station's antennas established before 2016 were mounted on the rooftops of buildings, understanding the critical issues associated with the suitability, geological stability, data quality, precision, and reliability of the CORSNet solution is significantly important. More importantly, there are little to no studies conducted to monitor their behaviour using the time series of daily positions except for Thimphu station since its installation [10]. Therefore, assessing the stability and dynamic behaviour of reference stations in a CORS network is felt important to evaluate the stability of the stations or position variations.

2 Druk CORSNet

Bhutan is a small Himalayan nation located in South Asia, known for its stunning mountain landscapes, unique culture, and commitment to environmental sustainability. The country has recently invested in developing its geospatial infrastructure, including establishing a network of ground-based GNSS stations and transferring station antennas mounted on rooftops to ground-based stations. With technical support from the Swedish Survey, the CORS was originally launched in 2004, and the only CORS station was subsequently installed in Thimphu. Six more stations were subsequently installed across Bhutan in 2016 with the technical assistance of a geodesist from Portugal [11]. Bhutan currently has 13 permanent and continuously operating GNSS base stations called DRUK CORSNet across the country, fully equipped for real-time kinematic (RTK) corrections via Networked Transport of Radio Technical Commission for Maritime Services (RTCM) via Internet Protocol (NTRIP) to end users. Here, RTK corrections are the information sent by the base station to the Rover, so the Rover can calculate its position at the centimetre level. The language or protocol used to send this information is called RTCM [12]. The National Land Commission Secretariat (NLCS) manages its operation and provides CORS services in the country. The primary purpose of the DRUK CORSNet is for cadastral, topographical, mining, engineering, and other sectors of surveying, according to the users' current profiles. Table 1 lists the chronological developments of the DRUK CORSNet stations as of August 1, 2023, and their current status. The stations are geographically well-distributed to provide nationwide coverage. The nominal design spacing of DRUK CORSNet is approximately 40 km, but in remote areas, the separations can range over 80 km (see Figure 2) [9].

Table 1: Station Information

Station ID	Location Name	Hierarchy	Date of operation	Current Status
BUMT00BTN	Jakar - Bhutan	Tier3	01/09/2010	Online
KANG00BTN	Kanglung - Bhutan	Tier3	01/09/2010	Online
PHUN00BTN	Phuentsholing - Bhutan	Tier3	01/09/2010	Online
THIM00BTN	Thimphu - Bhutan	Tier3	20/12/2010	Online
GELE00BTN	Bhurgaon - Bhutan	Tier2	2016	Offline
TSGG00BTN	Trashigang - Bhutan	Tier2	2020	Offline
WNGD00BTN	Chilo - Bhutan	Tier2	10/02/2021	Online
DGPL00BTN	Dagana - Bhutan	Tier2	01/06/2021	Online
DTNG00BTN	Deothang - Bhutan	Tier2	28/09/2021	Online
LHUN00BTN	Lhuntse - Bhutan	Tier2	26/05/2022	Offline
HAAC00BTN	Ha - Bhutan	Tier2	11/10/2022	Online
SPGT00BTN	Sarpang - Bhutan	Tier2	15/11/2022	Online
SIPS00BTN	Peljorling - Bhutan	Tier2	17/03/2023	Online

Tier 1 and 2 antenna monuments are to be structurally fixed to sound bedrock. Reinforced concrete pillars over a site with exposed bedrock are preferred for Tier 1 and Tier 2 CORS. A monument height of between 1.2 and 1.7 metres is preferred to minimise the effect of multipath off-ground surfaces [9]. Ground-based Tier 3 CORS use pillars or deep-drilled braced monuments. Stainless steel (preferred) or galvanised mild steel is recommended for Tier 3 CORS mounted on buildings, posts, or mast and brace monuments.

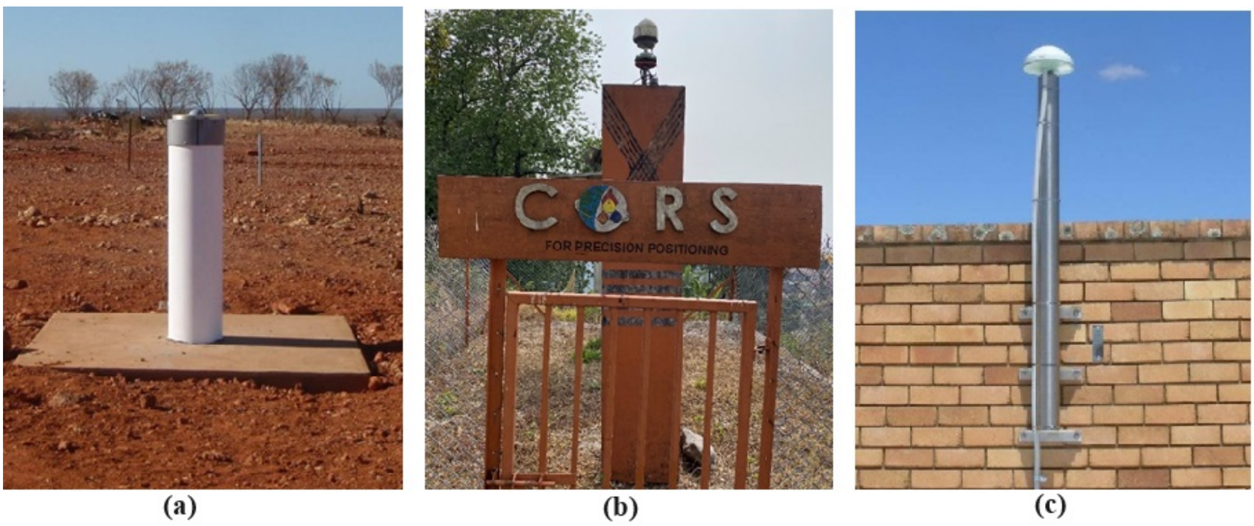


Figure 1: CORS monuments: (a) Tier 1 concrete pillar, (b) Tier 2 concrete pillar from Deothang CORS (DTNG), and (c) Tier 3 wall monument.

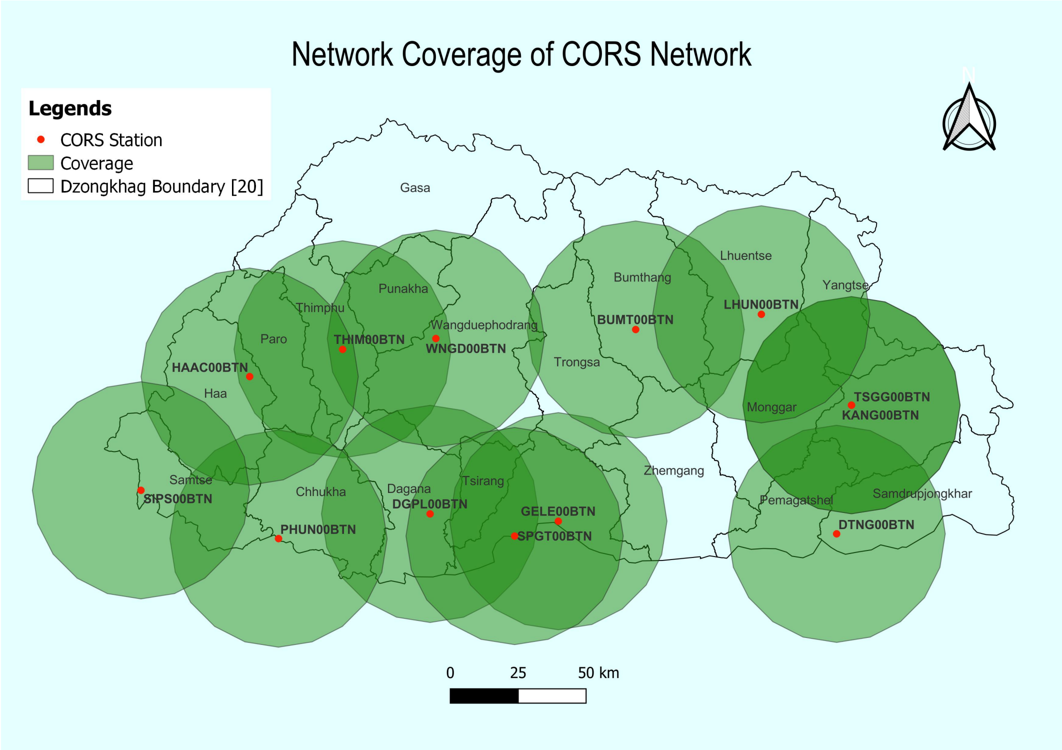


Figure 2: The network coverage of the DRUK CORSNet Stations as of August 1, 2023

3 Methodology

3.1 Data Collection

The data from 7 out of 13 DRUK CORSNet stations between the years 2016 and 2022 was used for the study. This is mainly because of the unavailability (offline status) of data during the study period or stations being non-functional for longer durations during the study periods. Additionally, stations that were established after May 2022 were also excluded from the study. The study maintained the availability of a minimum of two years of continuous data for consistency in the data between the years for all the stations. The available data used during the time of this study are highlighted in Table 2.

Table 2: Data Availability Status

Station ID	Data availability status
BUMT00BTN	2016 - 2022
KANG00BTN	2016 - 2022 (2018 unavailable)
PHUN00BTN	2016 - 2022 (2019 and 2020 unavailable)
THIM00BTN	2016 - 2022
GELE00BTN	2016, 2021 and 2022 (2017, 2018, 2019, and 2020 unavailable)
DGPL00BTN	2020 - 2022
DTNG00BTN	2021 - 2022

In the data collection phase, the data obtained is from 7 stations out of 13 stations, since only the data for the 7 stations was available. Data were downloaded for all the available CORS data for the years 2016–2022, ensuring a substantial dataset for our analysis from the Miranet.net website

[13]. In addition, the precise ephemeris data from Earth Data provided detailed information on satellite positions and clock corrections for the corresponding years (2016–2022), ensuring precise calculations and reliable results during the analysis [14]. Furthermore, in addition to the CORS and ephemeris data, the latest reference coordinate data from the National Land Commission Secretariat (NLCS) in Bhutan was also obtained. The reference coordinate data acquired from NLCS served as known and reliable positions. These reference coordinates allowed us to validate and assess the accuracy of the positioning results, ensuring reliability and integrity during the analysis.

3.2 Data conversion

In the data conversion phase, the CORS data from its original format is converted into a receiver-independent exchange format (RINEX) compatible with Trimble Business Center (TBC), the software used in this study for processing. The original format of the CORS data is not compatible with TBC version 2.00. It should be converted to RINEX to ensure seamless import and utilisation of the data within the software. RINEX is a widely recognised and standardised file format in the GNSS industry that allows for the exchange and interoperability of GNSS data between different software and hardware systems. The conversion process involved using the appropriate RINEX converter or tools capable of transforming the original CORS data files into RINEX format. For this study, RINEX Converter v.4.54 is used [15]. It will enable the CORS data to be converted into a format that TBC can read and interpret accurately, facilitating subsequent data processing tasks [16].

3.3 Input data

The CORS data collected from various stations, which was further converted into RINEX format, is used as a primary input during the processing. In addition, SP3 (standard precise ephemeris) data were also incorporated. SP3 files contain precise satellite ephemeris information, including satellite positions and clock corrections. These files provide essential data for accurately calculating the positions and trajectories of the satellites in the GNSS system.

3.4 Data processing

Figure 3 outlines the detailed process of this investigation using CORSNet measurements for CORS station stability analysis. The major steps include data collection and conversion, data pre-processing, baseline processing, and stability analysis. The data collection and conversion phases for the study are included above under sections 3.1 and 3.2.

3.4.1 Data pre-processing

During the data pre-processing phase, data cleaning and editing, including removing duplicate or missing observations, handling outliers, and ensuring the data was in a consistent format, were undertaken. In GNSS CORS data processing, analysis of the precision and stability of the GNSS network solution was conducted using TBC version 2.00. In TBC processing, the coordinate system setting is very useful to accurately align this data with the appropriate coordinate system to ensure the reliability and consistency of the results. For this, we defined the coordinate parameter of TBC as DRUKREF03/Bhutan National Grid, which is in the WGS1984 datum. Table 3 highlights the coordinate system parameters used for transforming CORS data into the DRUKREF03 coordinate system. In the reference station setting phase, a reliable and geodetically stable reference station with known coordinates is selected. This reference station in TBC will ensure accurate data correction and alignment. The reference station plays a crucial role in differential correction techniques, where it serves as a benchmark for comparing and correcting the CORS data. This process enhances the precision and reliability of the final results by eliminating common errors and discrepancies.

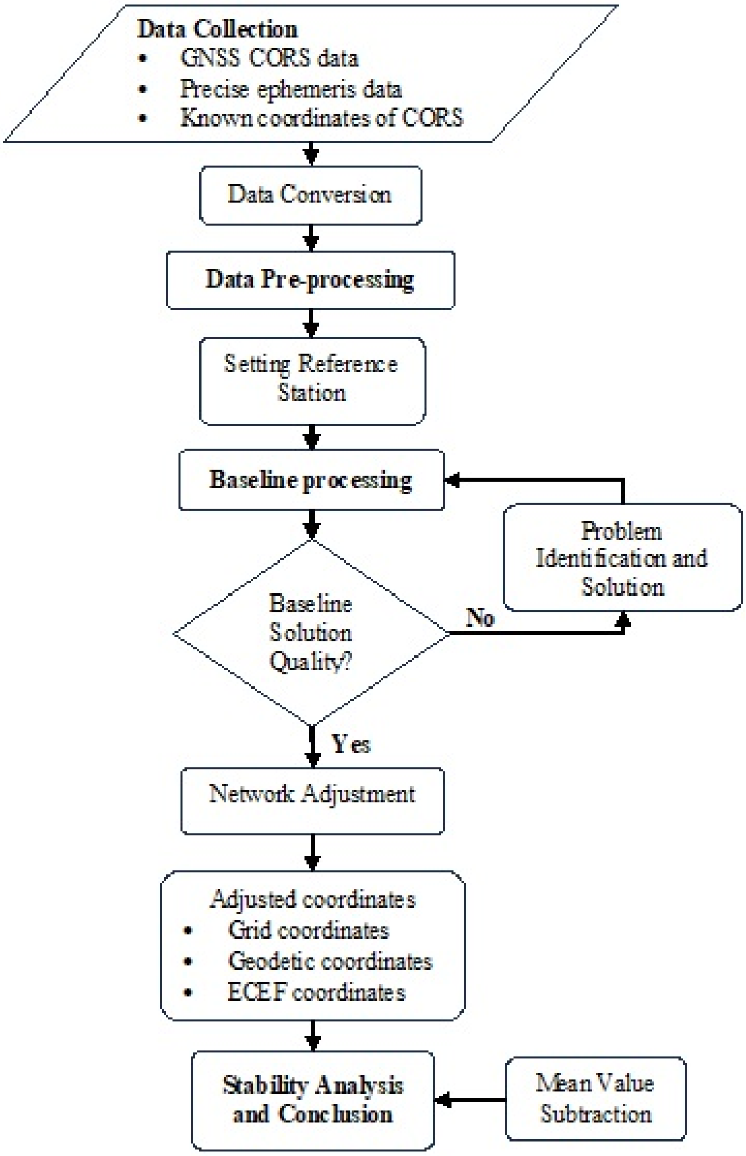


Figure 3: Flowchart of CORSNet data processing and stability analysis

Additionally, the reference station allows for geodetic transformations and facilitates quality control checks throughout the data processing workflow.

Table 3: Coordinate system properties for DRUKREF03

Field	Parameters
Projection	Transverse Mercator
Central latitude	0°00'00.0000" N
Central longitude	90°00'00.0000" E
False northing (m)	0
False easting (m)	250000
Scale factor	1

3.4.2 Baseline processing

During baseline processing, we compute the vector between two GNSS receivers (baseline) based on the observed data. They are essentially vectors that represent the difference in the position of two GNSS receivers. This step included calculating positional differences, applying atmospheric corrections, and considering other relevant factors required, if any, for accurate baseline processing. Further, the quality and reliability of the computed baseline solutions are evaluated. This involves evaluating parameters such as baseline length, signal-to-noise ratios, and statistical measures of precision and accuracy until acceptance criteria are established.

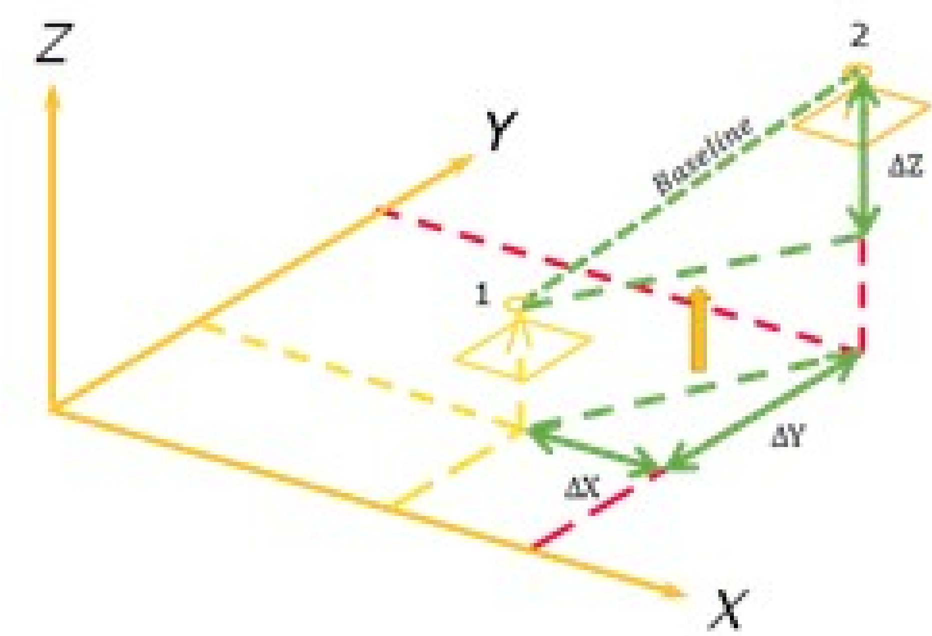


Figure 4: Calculating baselines using Pythagoras' Theorem

Suppose two GNSS receivers are capable of reading the phase observable, one is on mark 1 and one is on mark 2, as shown in Figure 4. To calculate the baseline, it's a simple case of calculating the hypotenuse of two right-angled triangles. Substituting this into Pythagoras' Theorem gives:

$$\text{Hypotenuse}^2 = \Delta X^2 + \Delta Y^2 \quad (1)$$

$$\text{Hypotenuse}^2 = \sqrt{\Delta X^2 + \Delta Y^2} \quad (2)$$

We can now project or push this hypotenuse up to the level of mark 1, and by using the value (the difference between the heights of the marks) in this case, we can make another right-angle triangle. This time, we have:

$$\text{Hypotenuse}^2 = (\sqrt{\Delta X^2 + \Delta Y^2})^2 + \Delta Z^2 \quad (3)$$

$$\text{Hypotenuse}^2 = \sqrt{(\sqrt{\Delta X^2 + \Delta Y^2})^2 + \Delta Z^2} \quad (4)$$

Thus, the baseline between mark 1 and mark 2 can be described by the equation:

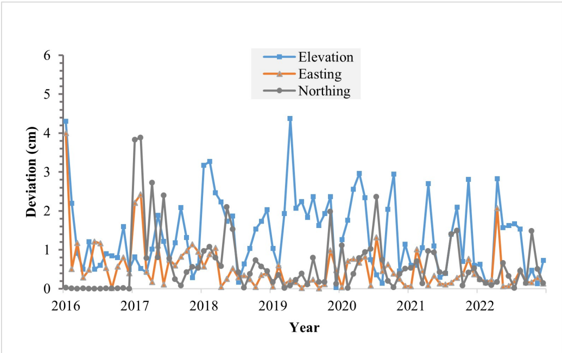
$$\text{Baseline} = (\sqrt{\delta X^2 + \Delta Y^2 + \Delta Z^2} \quad (5)$$

3.5 Stability analysis

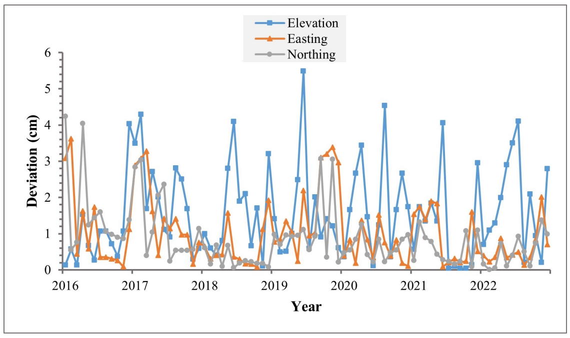
The final adjusted station coordinates (easting, northing, and elevation) then computed in the DRUKREF03 (projected coordinates) were used in the coordinate time series stability analysis of at least 7 CORS stations. However, a few gaps in the data series are due to data acquisition interruptions, mainly in conjunction with other unidentified factors, including weather conditions at the stations. The monthly time series coordinate data of GNSS CORS stations was used. The monthly coordinates, easting, northing, and elevation (mean value subtracted) are computed and analysed.

4 Result and Discussion

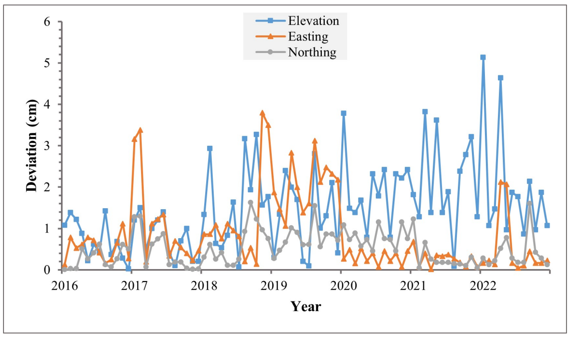
Figures 5 and 6 show each CORS station's observation variation in elevation and horizontal positions (easting and northing). It shows the monthly time series values (mean value subtracted) of each CORS station for the period between January 2016 and December 2022. Figure 5 shows the mean average deviation of monthly repeatability concerning (w.r.t.) monthly averaged solutions for PHUN, KANG, THIMP, and BUMT, while Figure 6 shows the mean average deviation for GELE, DTANG, and DGPL stations. The mean average deviation of monthly repeatability throughout the CORS data set typically ranges from 0.08 mm to 63.58 mm for the easting horizontal component, 0.01 mm to 42.42 mm for the northing horizontal component, and 1.70 mm to 54.92 mm for the vertical component (elevation). In addition, from Figure 6, it was observed that the mean average monthly repeatability for the GELE, DTANG, and DGPL stations shows higher variability in the easting and northing components as compared to the rest of the stations. This is possibly due to the CORS stations being installed quite recently (2021) for DTANG and DGPL stations. The detailed statistical parameters, such as the maximum, minimum, and standard deviations for each station, are highlighted in Table 4. Preliminary results indicate that the DRUK CORSNet enabled differential GNSS positioning for post-processing less than 7 cm for all 7 CORSNet, which is well within a permissible positional accuracy of 1 to 10 cm [9]. Moreover, the Himalayan Mountain range was created by the ongoing tectonic processes that resulted from the collision of the Indian and Eurasian plates and is still being built today. With the help of permanent reference stations (PRS) data, these interior deformations have been precisely predicted to occur at a rate of 0.6 cm per year between the south and central parts of Bhutan as observed by Tashi et al. [10]. This implies 10 cm internal deformation of the DRUKREF03 reference frame since its creation in 2003 showing a close agreement with the estimation made in this study. Thus, the mean average deviation results of monthly repeatability for all CORS stations are considered good and also proof that GNSS CORS data processing via Trimble Business Center software performed fairly well in this study in deriving horizontal and vertical time series coordinates. Our study's alignment with similar past research reflects a concerted effort to build upon existing knowledge in investigating the feasibility of using CORS for deformation monitoring and analysis. The solution of the Victorian regional CORS network showed an average velocity of displacement of 6.8 cm per year [8]. In addition, in Figures 5 and 6, there is also an apparent spike visible at KANG, THIMP, BUMT, GELE, and DTANG stations around the year 2022, this aligns perfectly with the time of cleaning or maintenance (antenna change) of the antenna occurring. However, through the visual inspection, the mean average deviation results did not show a very uniform pattern; it is seen that the vertical variability is more apparent than the horizontal variability over the years, with an increasing trend. One of the reasons for such variations might be due to the antenna's positional stability, as the antenna tracks the GNSS satellites continuously and logs the data into the receiver. To understand the true source of these behaviours, further investigation needs to be carried out at those stations independently. Therefore, the daily time series analysis for the same observation period as in this study will be analysed to check the precision of the coordinates computed for understanding the CORS network behaviour more significantly as a result of this analysis in the future.



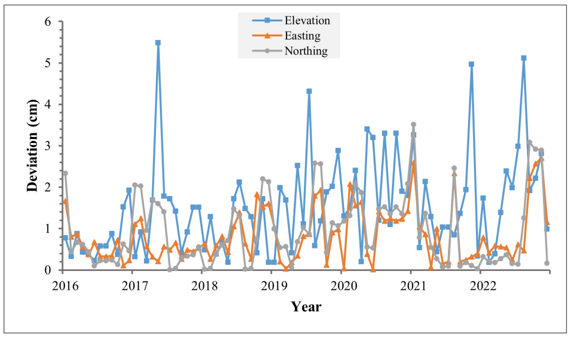
(a)



(b)

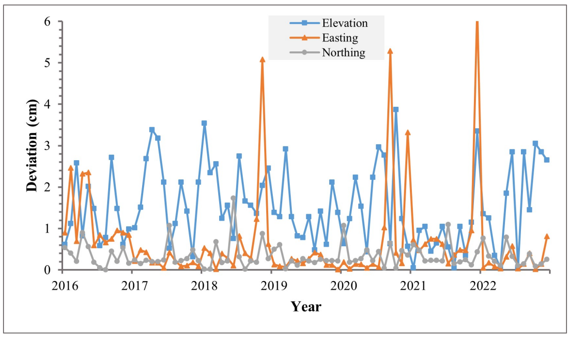


(c)

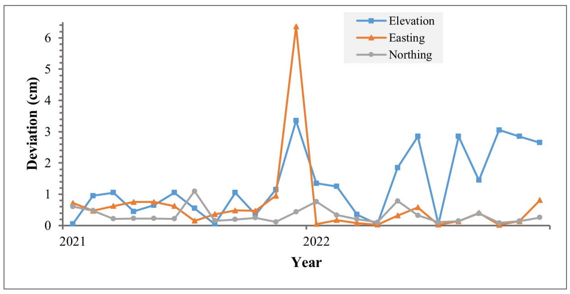


(d)

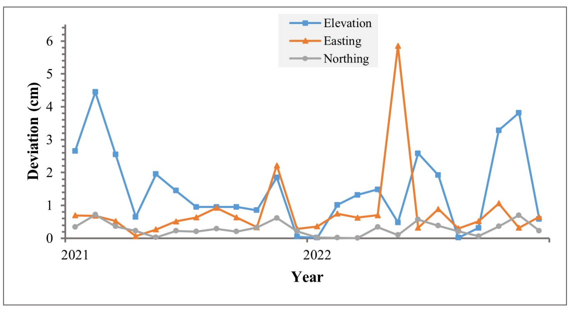
Figure 5: Monthly repeatability w.r.t monthly averaged solutions for (a) PHUN, (b) KANG, (c) THIMP, and (d) BUMT stations



(a)



(b)



(c)

Figure 6: Monthly repeatability w.r.t monthly averaged solutions for (a) GELE, (b) DTANG, and (c) DGPL stations

Table 4: Basic statistical parameters in cm/year over the DRUK CORSNet Stations for horizontal and vertical time series coordinates derived using TBC

Station ID	Easting (cm)			Northing (cm)			Elevation (cm)		
	Max.	Min.	SD	Max.	Min.	SD	Max.	Min.	SD
PHUN	3.995	0.008	0.614	3.880	0.001	0.782	4.366	0.034	0.961
KANG	3.617	0.077	0.928	4.242	0.009	0.851	5.492	0.043	1.266
THIM	3.799	0.012	0.917	1.625	0.003	0.410	5.133	0.021	1.062
BUMT	2.705	0.014	0.652	3.512	0.007	0.866	5.483	0.183	1.165
GELE	6.358	0.009	1.112	1.734	0.002	0.290	3.867	0.050	0.949
DTNG	6.358	0.019	1.250	1.096	0.086	0.255	3.350	0.050	1.078
DGPL	5.851	0.065	1.145	0.717	0.008	0.206	4.450	0.017	1.206

4.1 Conclusion

The results show that DRUK CORSNet stations have not experienced a major positional displacement. The precision of both the horizontal and vertical absolute coordinates of all the stations is well below 7 cm. It is evident that there was no recorded Earth's surface deformation due to natural disasters (earthquakes, landslides, etc.), including human activities such as mining, in the vicinity of the DRUK CORSNet Station as far as each CORS station is concerned. This preliminary study concluded that the method is feasible and effective in providing acceptable insight into deriving horizontal and vertical time series coordinates for understanding the stability of the CORS stations. The horizontal positions of the stations may significantly benefit scientific work, such as understanding horizontal land motion trends in Bhutan. It can be inferred that the CORS are not notably affected by local geological features and that the stations are relatively stable. However, further investigation is required considering the limitations of this study and considering more CORSNet data covering a larger chronological span. Therefore, we would like to improve the result and undertake further investigation in the future, considering the following:

- Derive the coordinates using other session lengths (daily or hourly), which will enable a better understanding of the precision and stability of CORSNet for high-precision deformation monitoring and analysis.
- Since there was also the presence of missing data in the dataset, which was not adequately addressed in this study, we will see the possibility of incorporating missing data from the nearby International GNSS Service (IGS) stations, formally the International GPS Service.
- Include all 13 CORS stations in the study that are capable of providing stable, reliable, accurate, and continuous data coverage across Bhutan.

Acknowledgement

The project team would like to acknowledge Mr. Kinzang Thinley, Specialist II, Department of Surveying and Mapping, National Land Commission Secretariat (NLCS), Bhutan, for his valuable guidance during data processing. Also, we are grateful to NLCS for providing login access to the DRUK CORSNet. Nevertheless, we are grateful to the anonymous reviewers for their recommendations to improve our manuscript.

References

[1] A. H. Md Din, M. N. Md Reba, K. M. Omar, S. Ses, and A. S. Ab Latip, "Monitoring vertical land motion in Malaysia using Global Positioning System (GPS)," ACRS 2015 - 36th Asian Conf. Remote Sens. Foster. Resilient Growth Asia, Proc., 2015.

[2] S. Zerbini et al., "Height and gravity variations by continuous GPS, gravity and environmental parameter observations in the Southern Po Plain, near Bologna, Italy," Earth Planet. Sci. Lett., vol. 192, no. 3, pp. 267–279, 2001, doi: 10.1016/S0012-821X(01)00445-9.

[3] S. Zerbini, M. Negusini, C. Romagnoli, F. Domenichini, B. Richter, and D. Simon, "Multi-parameter continuous observations to detect ground deformation and to study environmental variability impacts," Glob. Planet. Change, vol. 34, no. 1–2, pp. 37–58, 2002, doi: 10.1016/S0921-8181(02)00105-4.

[4] S. Larsen and R. Reilinger, "GPS Measurements of Strain Across the Imperial Valley, Accumulation California: 1986-1989," 1989.

[5] K. L. Feigl et al., "Space geodetic measurement of crustal deformation in central and southern California, 1984-1992," J. Geophys. Res., vol. 98, no. B12, pp. 1984–1992, 1993, doi: 10.1029/93jb02405.

[6] S. Erdoğan, M. Şahin, I. Tiryakioğlu, E. Gülal, and A. K. Telli, "GPS velocity and strain rate fields in Southwest Anatolia from repeated GPS measurements," Sensors, vol. 9, no. 3, pp. 2017–2034, 2009, doi: 10.3390/s90302017.

[7] V. L. Stevens, R. De Risi, R. Le Roux-Mallouf, D. Drukpa, and G. Hetényi, "Seismic hazard and risk in Bhutan," Nat. Hazards, vol. 104, no. 3, pp. 2339–2367, 2020, doi: 10.1007/s11069-020-04275-3.

[8] K. Zhang, Y. Jian, G. Liu, F. Wu, and R. Deakin, "Deformation Monitoring and Analysis Using Victorian Regional CORS Data," J. Glob. Position. Syst., vol. 4, no. 1&2, pp. 129–138, 2005, doi: 10.5081/jgps.4.1.129.

[9] N. L. Commission, "Continuously Operating Reference Stations Establishment by National Land Commission Secretariat," 2023.

[10] T. Tashi, T. Namgay, and D. Pelzang, "DrukRef21 – Defining the Reference Frame of Bhutan in a Deforming Region," in FIG Congress 2022, no. September 2022, pp. 11–15.

[11] National Land Commission Secretariat, "Manual for DRUK CORSNet," 2021.

[12] C. Rizos and S. Han, "Reference station network-based RTK systems-concepts and progress," Wuhan Univ. J. Nat. Sci., vol. 8, no. 2, pp. 566–574, 2003, doi: 10.1007/BF02899820.

[13] MIRASpaco, "MiraNet - GNSS Data Management Platform." https://miranet.druknet.net/ (accessed Apr. 08, 2024).

[14] National Aeronautics and Space Administration (NASA), "Earthdata | Earthdata." https://www.earthdata.nasa.gov/ (accessed Apr. 08, 2024).

[15] W. Gurtner and L. Estey, "RINEX The Receiver Independant Exchange Format," IGS Workshop 2012, vol. 104. pp. 1–74, 2007.

[16] Trimble, "Trimble Business Center User Guide." p. 519, 2008.