DETERMINATION OF OPTIMAL SITE LOCATION FOR CONTINUOUSLY OPERATED REFERENCE STATION (CORS) AND IT’S VALIDATION WITH CORS STATION QUALITY INDEX (CSQI)

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Key words: CORS, CSQI, GNSS, NRTK, PDOP, Cycle Slip, Multipath, SRTM, DEM.

Summary

NRTK GPS positioning uses raw measurements gathered from a network of Continuously Operating Reference Stations (CORS) in order to generate more reliable error models that can mitigate the distance dependent errors within the area covered by the CORS. The positioning of permanent GNSS station in a CORS network is highly restrained. Selection of optimal location on ground is crucial for network quality and further dissemination of optimal correction to rover in field. A CORS Station Quality Index (CSQI) is proposed as an explicit indicator of the quality of location for CORS on ground. By incorporating the proposed approach, and quality of location for a CORS base station can be judged and relative weightage to each CORS station could be assigned for network solution. The results suggest that a set of data quality parameters when used in combination can effectively select stations with high-quality GNSS data with more weightage that improve the performance of Network Real Time Kinematics (NRTK). The number of geodetic applications utilize the GNSS relative positioning capabilities offered by the CORS network (Snay & Soler, 2008) .

1. Introduction

i. Poor GNSS Data Quality

Despite the best efforts to locate a CORS at best possible location, some compromises have to be made in view of surrounding structures, multipath sources and vegetation. Hence, we can say that some stations are always located in unfriendly environment (e.g. next to solar panel, in a bush or in between two super structures). Because signal loss and attenuation are induced by obstacles, such as metal plates and branches, raw GPS measurements from these stations are corrupted and consequently may produce erroneous estimates of instantaneous position. The identification of these sub-optimal sites and providing them less weightage in network solution is of utmost importance in order to avoid transmission of error to the complete network and reducing its effect on the correction determination and transmission to rover.

ii. Satellite Visibility Determination

Satellite visibility at the CORS site is an important criterion for selecting an ideal site. Mutual satellite visibility between the CORS base and rover is a governing factor in determination of positional accuracy. While selecting the ideal CORS site it's important to ensure the maximum satellite visibility. In reality the actual satellite visibility is highly affected by the terrain variation. In this study the adaptive line of sight (LOS) (Han & Li, 2010) analysis approach is adopted for determining satellite visibility based on actual terrain variation. In this approach digital elevation data (e.g., DEM) is used and the radial profile originated from a probable CORS site is analyzed in order to determine the maximum obstruction angle. These angles are then used as the visibility criteria above which a satellite will be identified as being visible to the receiver at CORS site.

By taking into consideration the actual terrain variation, satellite visibility can be more realistically determined. The success of this analytical technique primarily relies on the quality of DEM used.

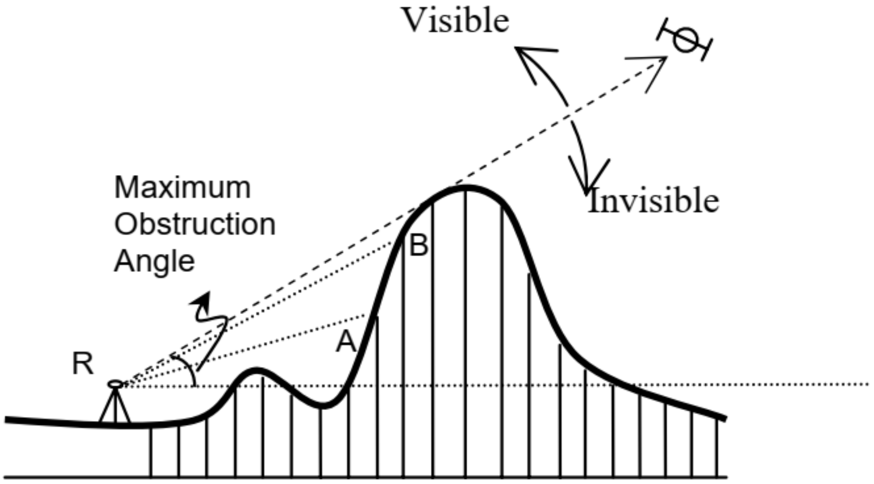

Figure 1: Determining maximum obstruction angle based on terrain variation.

iii. Validation from the DEM

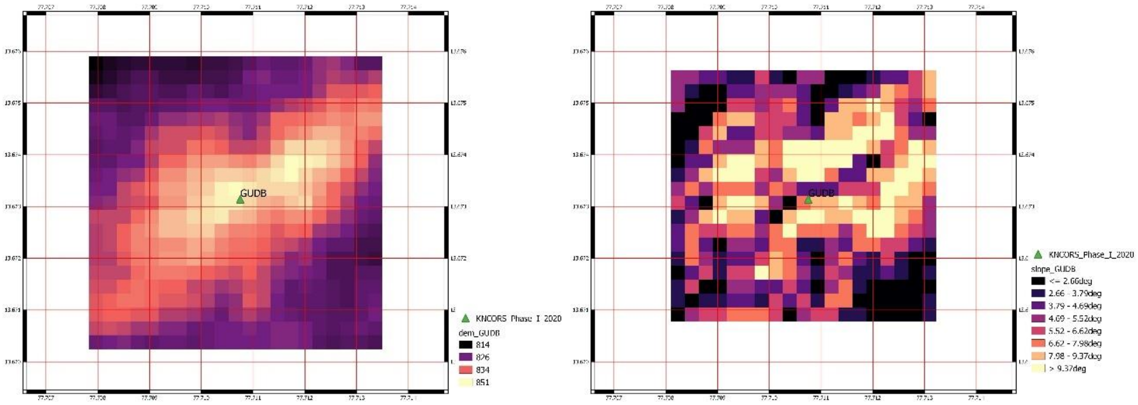

Figure 2: Obstruction angle is minimized for CORS GUDB, which is validated using the DEM on the left and slope on right.

The actual terrain variation is very important site selection criteria. Which will govern the quality of data acquisition at the respective CORS site. It's better to place the CORS at relatively higher ground that will result into smaller slope. At the planning stage open-source available DEM dataset could be used. However, for important project work the temporary base station site should be selected using a detailed DEM dataset. The above depicted representation of CORS GUDB is based on the NASA SRTM Digital Elevation 30 m *(Farr, Rosen, & others, 2007)* dataset available at Google earth engine *(Google Earth Engine, 2021)*.

2. GNSS Data Quality Measurement Algorithm

An approach for determination of GNSS data quality is selected, which is based on GNSS data pre-processing technique and augmenting it with the TEQC algorithm (Estey & Meertens, 1999). The purpose of following this approach is to take quality of GNSS data information into account in a non-arbitrary way.

i. The percentage of observations (% obs) analysis

The percentage of observations (% obs) does not just reflect the availability and integrity of the data but also points towards the stability of the receiver signals. This is an important indicator to measure the quality of data.

$$P = \frac{N_1}{N_0} \times 100$$

Where, P is the percentage of observations (% obs), N_1represents the number of observations received and N_0 represents the number of satellite observations that can be received.

ii. Cycle Slips

A cycle slip is a discontinuity in a receiver's phase lock on a satellite's signal. A power loss, a very low signal-to-noise ratio, a failure of the receiver software, a malfunctioning satellite oscillator can cause a cycle slip. It can also be caused by severe ionospheric conditions. However most common cause is the obstructions such as buildings, trees, etc., that are so solid that they prevent the satellite signal from being tracked by the receiver. Under such circumstances, when the satellite reappears, the tracking resumes.

A cycle slip causes the critical component for successful carrier phase positioning, a resolved integer cycle ambiguity, N, to become instantly unknown again. In other words, lock is lost. When that happens, correct positioning requires that N be re-established. The cycle slips estimated using TEQC software is termed as IOnospheric Delay (IOD) cycle slips. The carrier -phase measurements have lower multipath and receiver noise errors than the code. Hence, the dual frequency code derived estimate of ionospheric error I_P is noisier than the carrier I_φ derived estimate (Kim , Seo, & Lee , 2014).

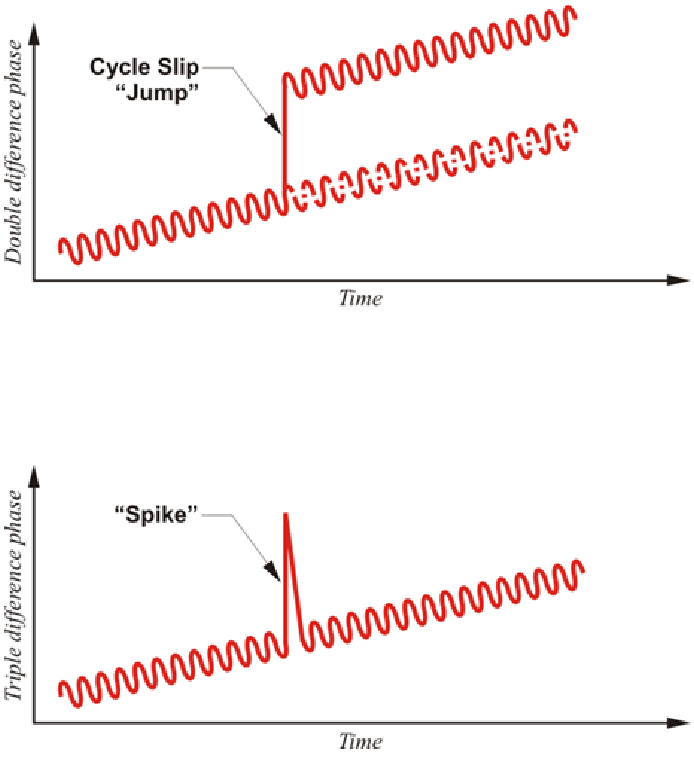

Figure 3: Cycle slip representation in double difference phase and triple difference phase (source: GPS for Land Surveyors)

iii. Multipath, mp_{12}& mp_{21}

Multipath effect is caused due to reflected satellite signals, which will result into satellite lock loss in extreme cases. The multipath will cause the loss of accuracy. In the analysis of GNSS data quality indicators, multipath can not only directly reflect the environmental quality around the station, but also is one of the important indicators of GNSS observation data quality (Xiao, et al., 2020). The multipath effect is divided into two categories pseudorange multipath effect and carrier phase multipath effect. Due to the small value of carrier phase multipath effect, it is customary to use pseudorange multipath effect to reflect the quality of observation data.

The pseudorange multipath effect can be obtained by combining pseudorange and carrier phase observations respectively. The formula for calculating the multipath effect of L_1 and L_2 carriers is as follows:

$$mp_{12} = P_1 - \left[1 + \frac{2}{\alpha - 1}\right]\varphi_1 + \left[\frac{2}{\alpha - 1}\right]\varphi_2$$

$$mp_{21} = P_2 - \left[\frac{2\alpha}{\alpha - 1}\right]\varphi_1 + \left[\frac{2\alpha}{\alpha - 1} - 1\right]\varphi_2$$

where, P_1 is the pseudorange observations on the L_1 band, $P_2$is the pseudorange observations on the L_2 band, φ_1 is the L_1 carrier phase observation, φ_2 is the L_2carrier phase observation, α is the L_1, L_2 two-band frequency and the square of the ratio.

iv. TEQC Algorithm

The TEQC (Translate, Edit, Quality Check, Coordinate) software is freely available tool used to check data quality of GNSS data in the RINEX format. This freeware program developed by the University NAVSTAR Consortium (UNAVCO) facility in Boulder (CO, USA) provides data quality information about the receiver clock slips, receiver cycle slips, multipath, receiver SNR, and other useful parameters and tracking statistics. We adopted some parts of TEQC algorithms to develop a comprehensive quality indicator for CORS site location. The quality indicators include:

1. The percentage of observations (% obs),
2. The RMS of multipath on L1 and L2 code measurements (i.e. mp12, mp21), and
3. The number of IOD cycle slips (at elevation >10^0)

The percentage of observations is the ratio of “possible observations” to “complete observations,” where “possible observations” indicate the total number of possible observation epochs in a given time window, and “complete observations” are the number of epochs that actually observed code and carrier-phase data.

Some of the other parameters namely the signal to noise ratio for L_1 and L_2 are receiver dependent. However, these parameters could also be incorporated in the analysis if the base signature of the all the receivers comprising the network are available. A suitable weighting methodology may be devised thereafter.

3. Numerical Validation

i. Observation (Set 1)

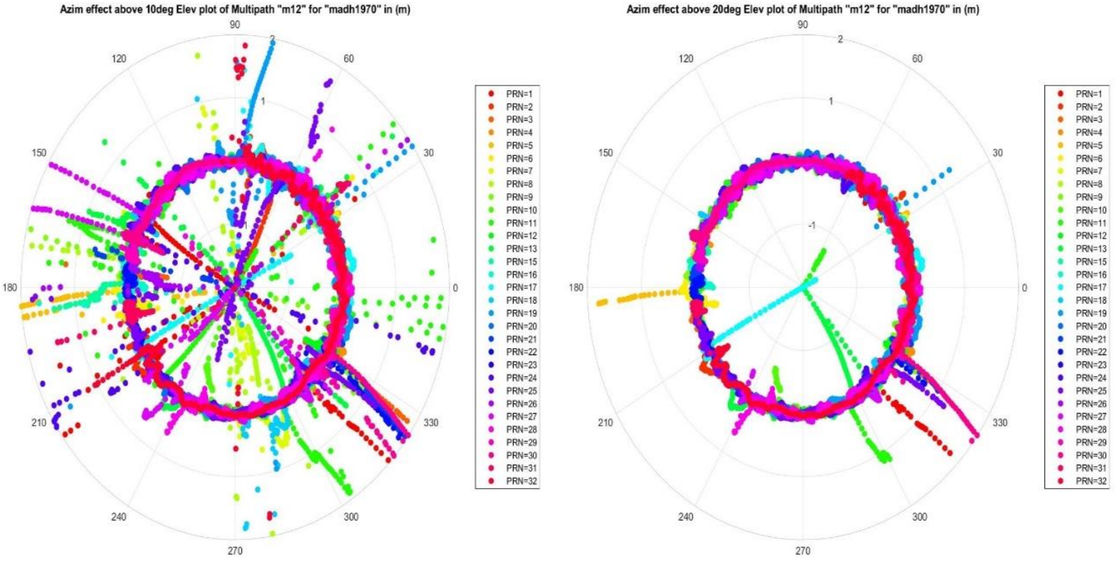

Figure 4: Plot of Azimuth vs. Multipath (m12) for Julian Day 197 at site MADH for all the GPS SVs above 10 and 20 degree elevation respectively.

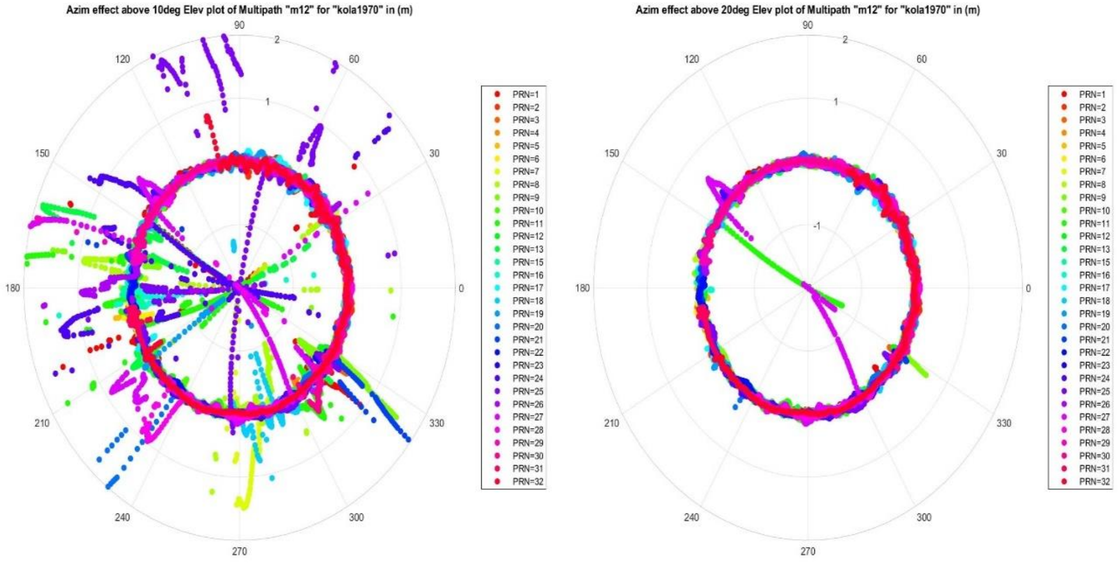

Figure 5: Plot of Azimuth vs. Multipath (m12) for Julian Day 197 at site KOLA for all the GPS SVs above 10 and 20 degree elevation respectively.

Table 1: Comparative for observed data (>10 deg) elevation of all the stations (of set 1) on (JD 197)

Station Code	% of Obser-vation (Col 1)	No of IOD or MP cycle slips (at elevation $>10^0$) (Col 2)	RMS mp12 (in m) (Col 3)	RMS mp21 (in m) (Col 4)	Signal to noise ratio for L1 (Col 5) S1	Signal to noise ratio for L2 (Col 6) S2	Observa tion /Slip (o/slps) (Col 7)	Wt_1 Weight of CORS site based on Col 1	Wt_2 Weight of CORS site based on Col 2	Wt_3 Weight of CORS site based on Col 3	Wt_4 Weight of CORS site based on Col 4	CSQI
BANG	90	106	0.327447	0.379752	47.04	46.49	224	0.16667	0.41071	0.98390	1.00000	0.99701
GUDB	97	123	0.458411	0.461198	46.38	45.84	207	0.47368	0.31507	0.28125	0.27688	0.98741
KANK	95	109	0.490078	0.432254	46.75	46.12	231	0.31034	0.38983	0.23984	0.37264	0.98674
KOLA	99	73	0.326603	0.417407	46.61	45.86	359	1.00000	1.00000	1.00000	0.45301	0.99922
MADH	93	188	0.584493	0.535679	46.53	46.03	130	0.23077	0.16667	0.16667	0.16667	0.94758

From the observations stated above its evident that the observed data quality at MADH is inferior compare to KOLA. The study on this line is very essential in order to assign the weight to each observation and selecting degree of control in a network.

Table 2: Standard error derived from network solution (of set 1) at each CORS location

Station	RMS (Northing) (in m) (Col 1)	RMS (Easting) (in m) (Col 2)	RMS (Height) (in m) (Col 3)	Wt_1 Weight of CORS site based on Col 1	Wt_2 Weight of CORS site based on Col 2	Wt_3 Weight of CORS site based on Col 3	Relative weight in CORS network based on spherical error SE
BANG	0.00041	0.00039	0.00127	0.0909	0.1667	0.1558	0.8750
GUDB	0.00039	0.00037	0.00117	1.0000	0.3750	0.4444	0.9933
KANK	0.0004	0.00038	0.00125	0.1667	0.2308	0.1791	0.9311
KOLA	0.00039	0.00036	0.00114	1.0000	1.0000	1.0000	0.9984
MADH	0.00039	0.00039	0.00126	1.0000	0.1667	0.1667	0.9799

ii. Observation (Set 2)

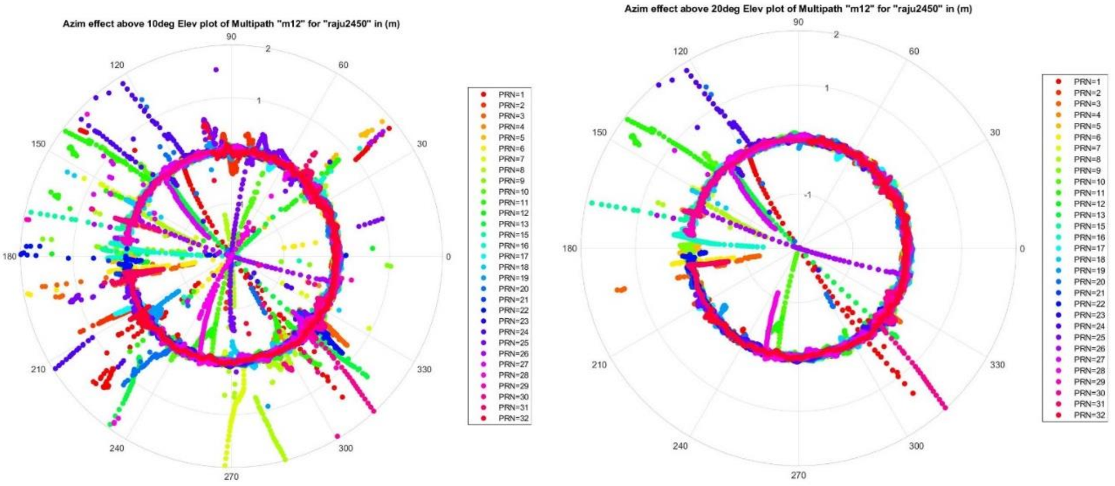

Figure 6: Plot of Azimuth vs. Multipath (m12) for Julian Day 245 at site RAJU for all the GPS SVs above 10 and 20 degree elevation respectively.

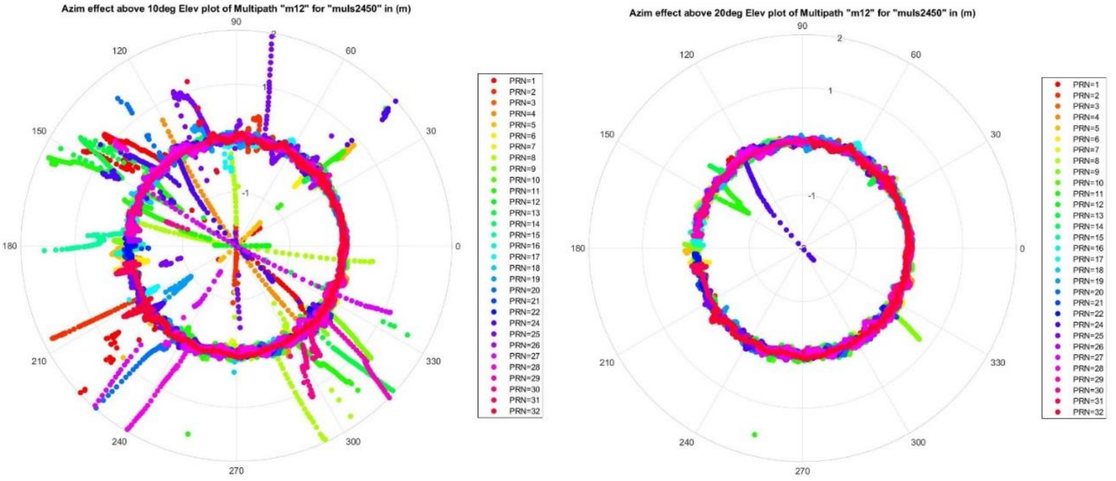

Figure 7: Plot of Azimuth vs. Multipath (m12) for Julian Day 245 at site MULS for all the GPS SVs above 10 and 20 degree elevation respectively.

Table 3: Comparative for observed data (>10 deg) elevation of all the stations (of set 2) on (JD 245)

Station Code	% of Obser-vation (Col 1)	No of IOD or MP cycle slips (at elevation $>10^0$) (Col 2)	RMS mp12 (in m) (Col 3)	RMS mp21 (in m) (Col 4)	Signal to noise ratio for L1 (Col 5) S1	Signal to noise ratio for L2 (Col 6) S2	Observation /Slip (o/slps) (Col 7)	Wt_1 Weight of CORS site based on Col 1	Wt_2 Weight of CORS site based on Col 2	Wt_3 Weight of CORS site based on Col 3	Wt_4 Weight of CORS site based on Col 4	CSQI
DHAN	98	85	0.423	0.438	46.79	46.27	288	0.37500	0.45423	0.33862	0.30091	0.99029
MULC	95	90	0.348	0.365	46.95	46.42	265	0.19355	0.41748	1.00000	0.67577	0.99627
MULS	100	54	0.365	0.346	46.93	46.35	460	1.00000	1.00000	0.69314	1.00000	0.99943
RAJU	94	183	0.54	0.544	46.7	46.24	129	0.16667	0.16667	0.16667	0.16667	0.93750
WADS	98	99	0.45	0.471	46.81	46.22	247	0.37500	0.36441	0.27350	0.24058	0.98504

From the observations stated above its evident that the observed data quality at RAJU is inferior compare to MULS. Similarly, a comparison of derived standard error for the same network is presented below in table 4.

Table 4: Standard error derived from network solution (of set 2) at each CORS location

Station	RMS (Northing) (in m) (Col 1)	RMS (Easting) (in m) (Col 2)	RMS (Height) (in m) (Col 3)	Wt_1 Weight of CORS site based on Col 1	Wt_2 Weight of CORS site based on Col 2	Wt_3 Weight of CORS site based on Col 3	Relative weight in CORS network based on spherical error SE
DHAN	0.00032	0.00036	0.00111	1.0000	0.1250	0.2222	0.9800
MULC	0.00033	0.00036	0.00112	0.1250	0.1250	0.1860	0.8995
MULS	0.00032	0.00035	0.00107	1.0000	1.0000	1.0000	0.9986
RAJU	0.00033	0.00036	0.00115	0.1250	0.1250	0.1250	0.8750
WADS	0.00032	0.00035	0.00108	1.0000	1.0000	0.5333	0.9977

Table 5:Comparative for observed data (>10 deg) elevation of all the stations (set 1 & 2)

Station Code	% of Obser-vation (Col 1)	No of IOD or MP cycle slips (at elevation $>10^0$) (Col 2)	RMS mp12 (in m) (Col 3)	RMS mp21 (in m) (Col 4)	Signal to noise ratio for L1 (Col 5) S1	Signal to noise ratio for L2 (Col 6) S2	Observation /Slip (o/slps) (Col 7)	Wt_1 Weight of CORS site based on Col 1	Wt_2 Weight of CORS site based on Col 2	Wt_3 Weight of CORS site based on Col 3	Wt_4 Weight of CORS site based on Col 4	CSQI
BANG	90	106	0.327447	0.379752	47.04	46.49	224	0.09091	0.20489	0.96831	0.36973	0.99740
GUDB	97	123	0.458411	0.461198	46.38	45.84	207	0.25000	0.16262	0.16364	0.14667	0.98693
KANK	95	109	0.490078	0.432254	46.75	46.12	231	0.16667	0.19591	0.13626	0.18670	0.98534
KOLA	99	73	0.326603	0.417407	46.61	45.86	359	0.50000	0.41358	1.00000	0.21709	0.99932
MADH	93	188	0.584493	0.535679	46.53	46.03	130	0.12500	0.09091	0.09091	0.09452	0.94839
DHAN	98	85	0.423	0.438	46.79	46.27	288	0.33333	0.30180	0.21106	0.17710	0.99493
MULC	95	90	0.348	0.365	46.95	46.42	265	0.16667	0.27126	0.54654	0.51031	0.99809
MULS	100	54	0.365	0.346	46.93	46.35	460	1.00000	1.00000	0.40179	1.00000	0.99989
RAJU	94	183	0.54	0.544	46.7	46.24	129	0.14286	0.09410	0.10782	0.09091	0.95629
WADS	98	99	0.45	0.471	46.81	46.22	247	0.33333	0.22945	0.17286	0.13674	0.99163

Table 6: Standard error derived from network solution (set 1 & 2) at each CORS location

Station	RMS (Northing) (in m) (Col 1)	RMS (Easting) (in m) (Col 2)	RMS (Height) (in m) (Col 3)	Wt_A Weight of CORS site based on Col 1	Wt_B Weight of CORS site based on Col 2	Wt_C Weight of CORS site based on Col 3	Relative weight in CORS network based on spherical error SE
BANG	0.00041	0.00039	0.00127	0.0816	0.0909	0.0868	0.8750
GUDB	0.00039	0.00037	0.00117	0.1026	0.1667	0.1597	0.9449
KANK	0.00040	0.00038	0.00125	0.0909	0.1176	0.0955	0.9018
KOLA	0.00039	0.00036	0.00114	0.1026	0.2857	0.2135	0.9691
MADH	0.00039	0.00039	0.00126	0.1026	0.0909	0.0909	0.8918
DHAN	0.00032	0.00036	0.00111	1.0000	0.2857	0.3220	0.9961
MULC	0.00033	0.00036	0.00112	0.4444	0.2857	0.2754	0.9910
MULS	0.00032	0.00035	0.00107	1.0000	1.0000	1.0000	0.9995
RAJU	0.00033	0.00036	0.00115	0.4444	0.2857	0.1919	0.9883
WADS	0.00032	0.00035	0.00108	1.0000	1.0000	0.6552	0.9993

4. CSQI derivation and its validation

Expressions for calculation of weights:

i. Expression of weight calculation for parameter *i* where lesser value is better e.g. No of IOD or MP cycle slips, RMS mp12, RMS mp21, RMS Northing, RMS Easting and RMS Height etc.

$$Wt\_ik = 1 - \frac{1}{\left[\left(1 + \frac{[Obs_{ik} - min(Obs_i)] \times N}{[\max(Obs_i) - \min(Obs_i)]}\right)\right]}$$

ii. Expression of weight calculation for parameter *j* where higher value is better e.g. % of observation.

$$Wt\_jk = 1 - \frac{1}{\left[\left(1 + \frac{\left[max\left(Obs_j\right) - Obs_{jk}\right] \times N}{\max\left(Obs_j\right) - \min\left(Obs_j\right)}\right)\right]}$$

where,

$Wt_{ik} = weight\ of\ k^{th}\ observation\ of\ parameter\ i$

$Obs_{ik} =\ k^{th}\ observation\ of\ parameter\ i$

$min(Obs_i) = minimum\ of\ all\ observation\ for\ parameter\ i$

$\max(Obs_i) = maximum\ of\ all\ observation\ for\ parameter\ i$

$N = Total\ number\ of\ observation$

$Wt\_jk = weight\ of\ k^{th}\ observation\ of\ parameter\ j$

$Obs_{jk} =\ k^{th}\ observation\ of\ parameter\ j$

$min\left(Obs_j\right) = minimum\ of\ all\ observation\ for\ parameter\ j$

$\max\left(Obs_j\right) = maximum\ of\ all\ observation\ for\ parameter\ j$

$$Wt\_SE = 1 - \frac{1}{\left[\left(1 + \frac{Wt\_\mathrm{A}}{Min\ Wt\_\mathrm{A}}\right) \times \left(1 + \frac{Wt\_\mathrm{B}}{Min\ Wt\_\mathrm{B}}\right) \times \left(1 + \frac{Wt\_\mathrm{C}}{Min\ Wt\_\mathrm{C}}\right)\right]}$$

$$CSQI = 1 - \frac{1}{\left[\left(1 + \frac{Wt\_1}{Min\ Wt\_1}\right) \times \left(1 + \frac{Wt\_2}{Min\ Wt\_2}\right) \times \left(1 + \frac{Wt\_3}{Min\ Wt\_3}\right) \times \left(1 + \frac{Wt\_4}{Min\ Wt\_4}\right)\right]}$$

5. Base station coordinates

The coordinates of the base station were determined in ITRF 2008 at the L_1 Antenna Phase Centre (APC) on WGS84 datum, which was realized by the simultaneous observation of IGS stations and the coordinates were determined using Bernese 5.2 using minimum constrained network solution strategy.

6. Conclusion

The CORS Station Quality Index, CSQI derived in this paper is an indicator of CORS relative strength in the network under study. It’s evident from the numerical validations presented above that for the observation (set 1), CSQI derived for stations in table 1 validate their relative standard errors in the network comprising stations of set 1 represented in table 2. Similarly, for observation (set 2), CSQI derived for stations in table 3 validate their relative standard errors in the network comprising stations of set 2 represented in table 4. CSQI derived for the combined network also validates the relative standard errors of individual CORS in the resulting network depicted in table 5 and 6 respectively.

Recent advances in the field of GNSS surveying have resulted in the adoption of CORS network for the purpose of Network Real Time Kinematics (NRTK) positioning in fields of both engineering and scientific research. However, the positional accuracy derived from the CORS network is dependent upon the individual CORS site and the CSQI discussed in this paper is a quantitative measure of this. CSQI values can be used as primary evidence when deciding upon an optimal CORS site location. Consequently, any CORS network can be better designed or modified, resulting in a quality CORS site selection in a more cost- effective manner. CSQI could further be used as a tool for defining the priority of individual CORS among a large network for devising a weighting or control strategy.

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BIOGRAPHICAL NOTES

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