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Role of GPS / GNSS Surveys in Satellite triangulation for photogrammetric processing using Cartosat-1 datasets and its impact on the photogrammetric products generation cycle

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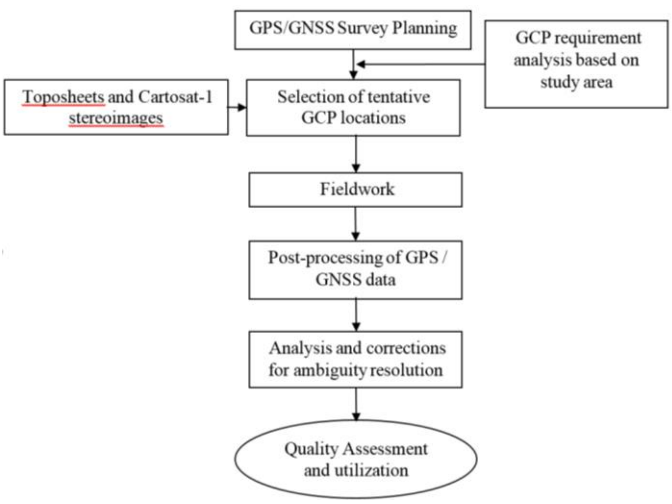
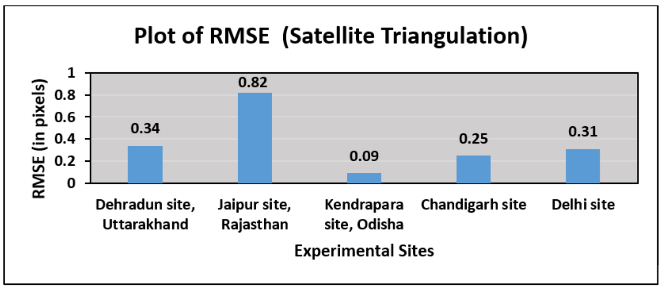
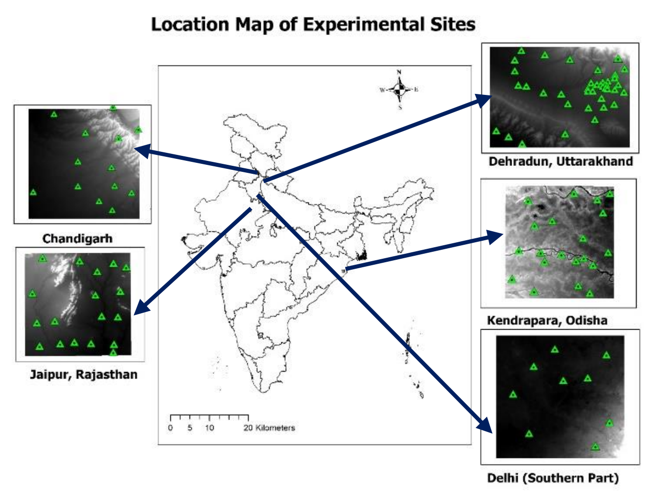
Graphical Abstract





Abstract.
Map-making is an inherent cognitive capability of human beings to fulfill their basic needs and desire to explore. This art usually referred to as Cartography, has moved a long way from markings on the trees and cave stones as well as directions through celestial bodies using heuristics to today's latest applications based on geodesy and web cartography running in real-time. The global satellite-based navigation systems, which came into being in 1995 with their full operational capability, revolutionized the parallel developments in the satellite imaging technology. The NAVigation Satellite Timing And Ranging Global Positioning System (NAVSTAR GPS) from the United States of America and the Globalnaya navigatsionnaya sputnikovaya sistema (GLObal NAvigation Satellite System, GLONASS) from RUSSIA aided their military users and on availability to the cartographic community changed the way of surveying and mapping in different countries. The photogrammetric processing required for cartography purposes, topographic mapping, and photogrammetric product generation need high accuracy in both horizontal (planimetric) and vertical directions. The presented study covers various experimental sites in India at Dehradun site, Uttarakhand; Jaipur site, Rajasthan; Kendrapara site, Odisha; Chandigarh site, and Delhi site where the Differential GPS (DGPS) surveys in the static mode were carried out using Leica 500 series GPS, Trimble Net R9, and Trimble R7 Global Navigation Satellite System (GNSS) geodetic



receivers. The horizontal and vertical precisions achieved in the post-processing of these collected GPS survey datasets i.e., ground control points (GCPs) using DGPS / DGNSS mode range from 2mm - 6mm majorly. The root mean square error (RMSE) attained for the satellite triangulation is better than a pixel resulting in the photogrammetric generation of significantly more accurate digital elevation models (DEM) as compared to the DEMs based on rational polynomial coefficients (RPC) alone and further improved orthoimages for the study sites using Cartosat-1 stereo pairs.

Keywords: *Photogrammetry, Cartography, Satellite navigation, RPCs, GCPs, DEM, orthoimages*

Introduction

Satellite-based navigation systems have redefined the methods of surveying with its unique unassailable advantages specifically for its no requirement of intervisibility or a clear line of sight (LoS) between any two consecutive surveyed points. This specific advantage of it makes it different from all other types of surveying equipment like theodolite, tacheometer, leveling, electronic digital measurement (EDM) instruments, and total station, which require clear LoS between the successive surveyed points in a traverse survey. The second major advantage lies in its geodetic observations concerning the global datum WGS84, which specifically helps in the surveys of large experimental sites and makes it possible to have a high relative or absolute accuracy all over the globe depending on the methods of processing the GNSS data.

Cartosat-1 stereo data is found good for the preparation of topographic database at 1:25000 scale and is suitable for mapping of certain features at 1:10000 scale [1], [2]. GNSS data is being used by researchers for applications such as assessment of DEM accuracies [3]–[6], computation of terrain attributes / morphometric parameters [7]–[11], mapping of groundwater using gravity anomaly [12], [13], flood monitoring and vulnerability assessment [14], [15]and DEM fusion [16]–[19]. IRNSS is also augmenting the GNSS constellations in the Indian and neighbouring region further improving the ionospheric corrections and providing improved position [20]–[24]. Jin et al determined the regional quasi-geoid EGM2008 Earth gravitational model, with 70 GPS/leveling points and a DEM using the Molodensky theory [25]. GNSS observations followed by total electron content (TEC) analysis have revealed that the low TEC followed by a couple of high TEC values correlate well with the seismic events in the Himalayan region [26]. The objectives of this work include the study of the precision achieved in the GPS / GNSS processing, followed by satellite triangulation of stereopairs with an aimed RMSE of less than a pixel and generation of photogrammetric products (DEMs and orthoimages). Finally, the conclusions drawn from this study are presented in the last section.

Study area and Material

The experimental sites for the study were selected in India at five locations with varying topographic characteristics. Cartosat-1 stereo pairs are used in this experiment procured from National Remote Sensing Centre (NRSC), Hyderabad. The first site is at Dehradun city, Uttarakhand, and includes its surrounding region, which is a highly undulating terrain, and it includes a large area covered by forest and agricultural land. Dehradun is the capital city of Uttarakhand state, India. The second site is the capital city of Rajasthan, i.e. Jaipur city which is commonly known as Pink city. Jaipur site has majorly an urban area having agricultural activity around it with a moderate slope. The third site is relatively a plain agricultural area, which is a part of the Kendrapara district in Odisha (earlier known as Orissa). Chandigarh city is a highly planned union territory with a large urban region and is the fourth experimental site. The Chandigarh dataset includes parts of Punjab and Himachal Pradesh also. The fifth site includes the portion of South Delhi, which is a part of the Capital of India. The ground control points (GCPs) collected in DGPS mode were used for satellite triangulation of the experimental sites. Table 1, gives the details of the toposheets (Scale 1:50,000) used for carrying out the fieldwork during DGPS surveys at the experimental sites.

Table 1: SOI Toposheets used for the five Experimental sites

S. No.	Study area	SOI Toposheet nos.
1	Dehradun Site	53J/3, 53J/4, 53F/15, 53F/16
2	Jaipur Site	45N/9, 45N/13
3	Kendrapara site	73L/6, 73L/7
4	Delhi Site	53D/14, 53H/2, 53H/3
5	Chandigarh site	53B/9, 53B/10, 53B/13, 53B/14

Methodology

The methodology for GPS / GNSS survey from planning to quality assessment is described in Figure 1. It is an essential part to control the final accuracy achieved in the process of satellite triangulation (Figure 3), which further controls the photogrammetric product generation cycle.

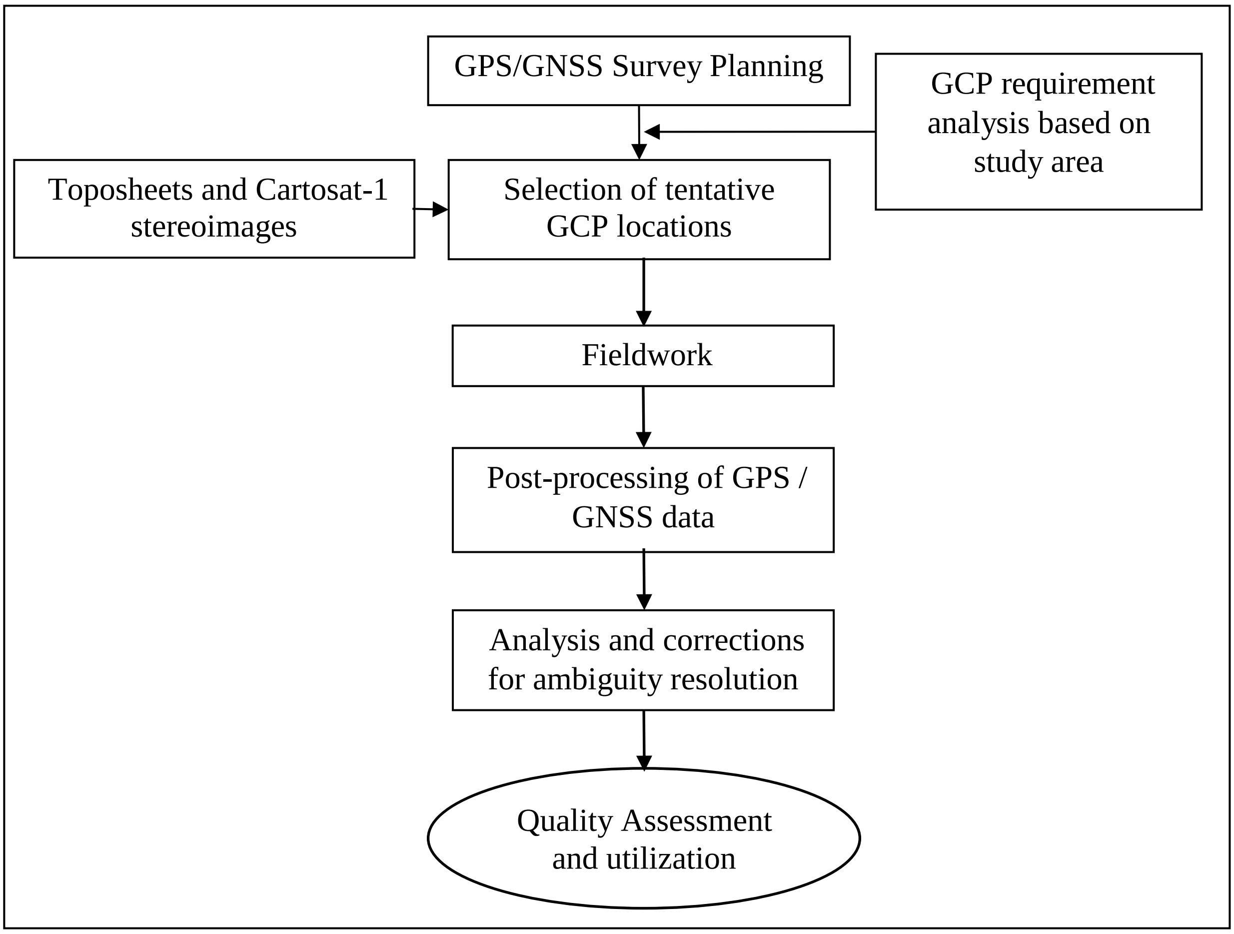


Figure 1: Methodology for Differential GPS / GNSS survey

GPS/GNSS Survey Planning and processing methods

The GNSS Survey Planning first considers the peripheral control and control in the center for generating a stable stereo model. The ground control surveys were conducted in static mode for the collection of GCPs. The location of GCPs is selected first at the von grubber locations and then more number of points are selected in the image to provide a nearly uniform distribution of GCPs (Figure 2) in the stereo pair subjected to local constraints and accessibility (Figure 4). This distribution provides the maximum model space for mapping. The GCPs should be sharply visible in both the images constituting the stereopairs. The duration of observation depends primarily on the baseline lengths to fulfill the criteria of signals received by the basestation and rover from the minimum common four number of satellites. This condition is nowadays met very easily in short duration surveys because of the large number of GPS/GNSS satellites. Secondly, the receivers at rover locations should operate for a time sufficient for receiving the complete almanac data.

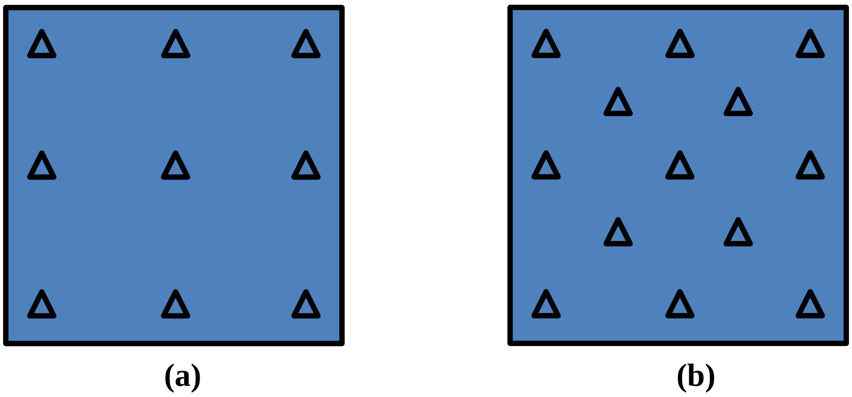


Figure 2: Depicts ideally planned scheme for distribution of GCPs for conducting GNSS survey (a) plan indicates von-Grubber location and (b) plan represents further

The basestation or known location is mostly not available from any previously conducted surveys, and thus these are computed by the processing of the base station GPS / GNSS data, with respect to the IGS stations or by independent single point positioning (SPP) at the experimental sites. Once, the coordinates of the basestation are computed, the rover station datasets are processed with respect to the base station in DGPS / DGNSS processing mode using Leica Ski-pro or Trimble business center (TBC) softwares. The frequent cycle slip durations and high DOP value duration of GPS / GNSS data, are to be excluded during the post-processing. Both Leica and Trimble GNSS data processing softwares provide a very user-friendly graphical user interface (GUI) for identification, selection, and exclusion of such datasets for specific durations. This exclusion is especially executed for the GCPs with unresolved ambiguities and has been done in a step-by-step iterative process by the selection of datasets identified by satellite vehicle (SV) number observing the impact on the processing.

The DGPS / DGNSS survey usually takes a couple of days to a few weeks depending on the area of experimental sites. When the surveys are done using two geodetic receivers the coverage of GCP locations for observations can be planned more flexibly due to radial baselines only. However, when three or more geodetic receivers are used, the practice of occupying the last point (GCP) of the previous day, as the first GCP point for the starting new survey day is followed to maintain a triangular pattern of generating baselines. The observations were always taken for sufficient duration to get a good dataset with four minimum satellites between operating geodetic receivers, further assisting in error adjustments during the post-processing.

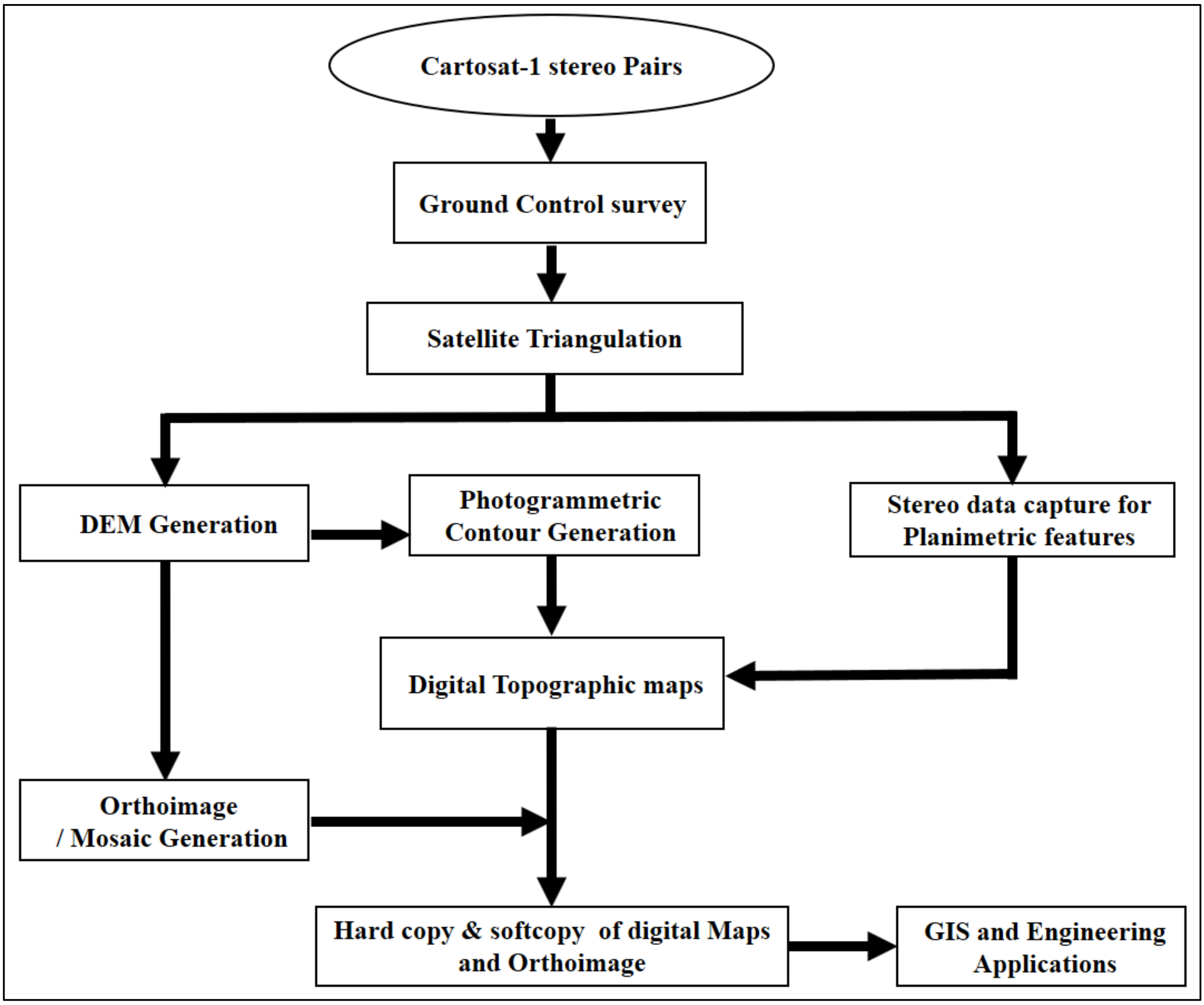


Figure 3: Methodology for Photogrammetric procedure

Results and Discussion

The horizontal and vertical precisions are mostly in the range of 2mm - 6mm on post-processing of the collected GPS survey datasets in DGPS / DGNSS mode. The RMSE on processing the DGPS data and baselines are typically ranging between 3-7mm for observations with sufficient duration. However, as experimented for less observation duration at GCP locations the RMSE can reach an order of decimeter or more, even on the ambiguity resolution. Table 2, depicts the RMSE values achieved for the satellite triangulation carried out for the five experimental sites and having a value of less than a pixel at each of the sites. The DEMs were generated from the stereopairs after the acceptance of satellite triangulation results in the Leica photogrammetric suite (LPS) software (version 2018). The best results are obtained for the plain site at Kendrapara for the satellite triangulation, followed by Chandigarh site, Delhi site, and Dehradun site. The highest RMSE is observed at Jaipur site with a value of 0.82. This high value can be attributed to the initial parameters for the Cartosat-1 sensor, which were further improved resulting in improved RPCs and better block adjustments. The accuracy of the DEMs can be assessed using the checkpoints collected during the ground control surveys. The accuracy of DEM and orthoimage can be assessed using checkpoints, which will depend on the accuracy of processed GCPs and accuracy of satellite triangulation besides the other factors like topography and contrast of images constituting stereopairs [17].

The ground relief is removed in the generation of orthoimages providing the uniform scale in the orthoimage. However, object relief needs the digitization of the top and bottom of features such as buildings for removal of object relief and generate a product referred to as, “true orthoimage”. These GCPs can also provide a means for assessing the accuracy of open source DEM and fused DEM products [27].

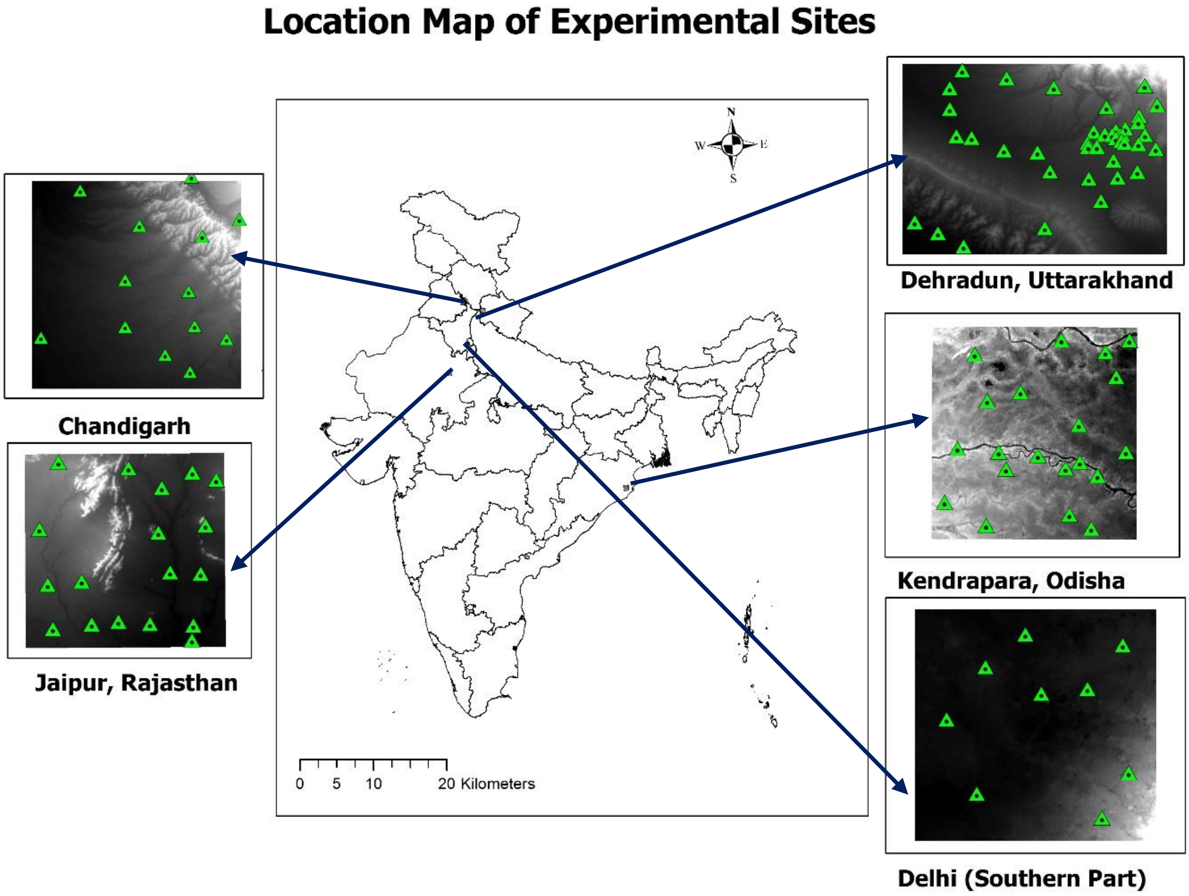


Figure 4: Location map depicting DEMs of experimental sites with overlaid GCPs collected using Differential GPS survey

Table 2: depicts the RMSE values for satellite triangulation at experimental sites

S.No.	Study Area	Date of Pass	RMSE (Satellite Triangulation, in pixels)
1.	Dehradun site, Uttarakhand	05-02-2006	0.34
2.	Jaipur site, Rajasthan	18-05-2005	0.82
3.	Kendrapara site, Odisha	19-02-2006	0.09
4.	Chandigarh site	17-04-2009	0.25
5.	Delhi site	10-08-2009	0.31

It was observed further during the experimentations that in cases, the GPS datasets are processed for less observation time in the range of 10 -30 minutes, the ambiguity remains unresolved for few points with even shorter baselines. At times, these observations can be resolved through iterative attempts by excluding the satellites (partially or completely) having high DOP and observations with frequent cycle slips. However, this method will be a hit and trial adjustment. Moreover, for longer baselines, these may not assist and the position may remain unresolved. The precision attained at such locations or observation points is also not satisfactory yielding precision of the order of 30-50mm raising the flag on the resolved values in the processed reports. In the case of the short duration GNSS observations, the observations may still give satisfactory results due to a higher number of satellites from the different groups of constellations (NAVSTAR GPS, GLONASS, Beidou, Galileo) providing good geometry and thus better DOP. User can also use scientific GNSS data processing softwares such as Bernese, GipsyX, GIPSY-OASIS (GNSS-Inferred Positioning System and Orbit Analysis Simulation Software) and GAMIT ("GNSS at MIT") /GLOBK ("Global Kalman filter") for further improved processing of GNSS datasets for varied land/ocean-based and in-air / in-space applications (http://www.bernese.unibe.ch/; https://www.unavco.org/software/data-processing/postprocessing/gipsy/gipsy.html).

Conclusion

The obtained results showed that the selection of satellite, followed by exclusion or inclusion of specific duration of GNSS observations assists in resolving the ambiguity in the post-processing of GNSS data. It is also worth noting that the observation time is an important parameter for generating accurate results from the processing of GPS / GNSS surveys in differential mode. The results of the experiments confirmed that the DGPS / DGNSS method could achieve sub-pixel-level accuracy for the satellite triangulation of Cartosat-1 stereopairs as observed for all the five experimental study sites. While working on various datasets and handling the systems ranging from Leica 300 series to Trimble NetR9 in campaign mode or continuously operating reference stations (CORS), it is observed that a proper standard operating procedure for GNSS surveys provide ample opportunity for accurate results for any operational or research project.

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