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Generation and validation of cartosat-1 DEM for northern Aravali range of hillocks, Rajasthan, India

Digital Elevation Model (DEM) is a spatial representation of any area or surface in the form of three dimensions (x,y,z) represent the height of the individual points (pixels) of the surface along with x and y rectangular coordinates.DEM is widely used to extract the information from many areas like subsidence/deformation monitoring, updating and preparation of drainage pattern, hydrology and water resource management etc. The selection of DEM (on the basis of accuracy) plays an important role while using it for any particular application. In some application area accuracy of DEM is not a matter of great concern. However, in some application, accuracy of DEM plays a very vital role to derive the required result.. In this study, area of interest belongs to a mineral rich zone, coming under the Khetri copper belt, a part of Northern Aravali range of hillocks in India. This particular belt is predominant with mining activities since late 1960's. Keeping in view of deformation studies in such area using conventional DInSAR technique, accuracy of DEM (normal baseline > 200 m), should be in higher side to eliminate the local topographic phase completely. Keeping in view of above background, DEMs (relative and absolute) were generated from high resolution Cartosat-1 stereo pair dataset (IRS) using GCPs, without GCPs and GCPs collected with the help of Google Earth. RMS error obtained from different techniques were compared along with SRTM DEM (3 arc second).Vertical accuracy in terms of RMS error has been found in the order of 2.54m, 10.10m, 37.97m and 76.66m for Carosat-1 DEM (GCP collected from GNSS), SRTM, Cartosat-1DEM (without GCP) and Cartosat-1 DEM (GCP collected from Google Earth) respectively.

Validation of high accuracy DEM has been demonstrated in DInSAR processing (using ALOS-PALSARSLC dataset) to eliminate topographical phase of the study area.

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1.0 Introduction

Digital model of elevation of earth surface along with latitude, longitude/Easting(x), Northing (y) may be defined as DEM. DEM can be classified further as DSM and DTM. It plays an important role for assessing and monitoring the land surface subsidence/deformation along with much other application like updating and preparation of drainage pattern, hydrology and water resource management etc. In the planning and construction work also DEMs can have a vital role. Linear constructions like roads, railway tracks, oil and gas pipelines, bridges and electric power lines may be planned without having to send surveyors onsite.[1]

When modern aerial photography and satellite remote sensing started to provide continuous surface information by means of optical cameras, radar or laser beams, for example, and the derivation of terrain elevation was made possible by stereoscopy and interferometry, topography gained whole new meaning in spatial studies. Our ability to perceive and analyze the physical, biological, chemical and cultural character of the earth's surface has, since, been greatly expanded[1]. In 1986, launching of first of SPOT series satellite commenced the possibility of using stereo images taken from the satellite for generation of Digital Elevation Model. On May 5, 2005 Cartosat-1 satellite sensor was launched by ISRO (Indian Space Research Organization), mainly indented to open the research possibility in the cartographic applications. Having 2.5 meter of resolution with 30 km of swath cover, satellite has 617.99 km nominal altitude of which orbital repeat cycle is of 116 days. It provides the real time stereo data along its track, facilitated with two panchromatic camera, looking aft (A) and looking fore (F) with a tilt of -5 degree and +26 degree respectively[2]. The major advantage of Cartosat-1 stereo data is; instead of delivering the interior and exterior orientation parameters and other properties related to physical sensor, one can proceed to satellite photogrammetric processes [3], along with the Rational Polynomial Coefficients (RPCs) and generate Digital Elevation Model (DEM) [4]. The name Rational Polynomial derives from the fact that the model is expressed as the ratio of two cubic polynomial expressions [5]. Pandey P. [6] has discussed in detail about RPC.

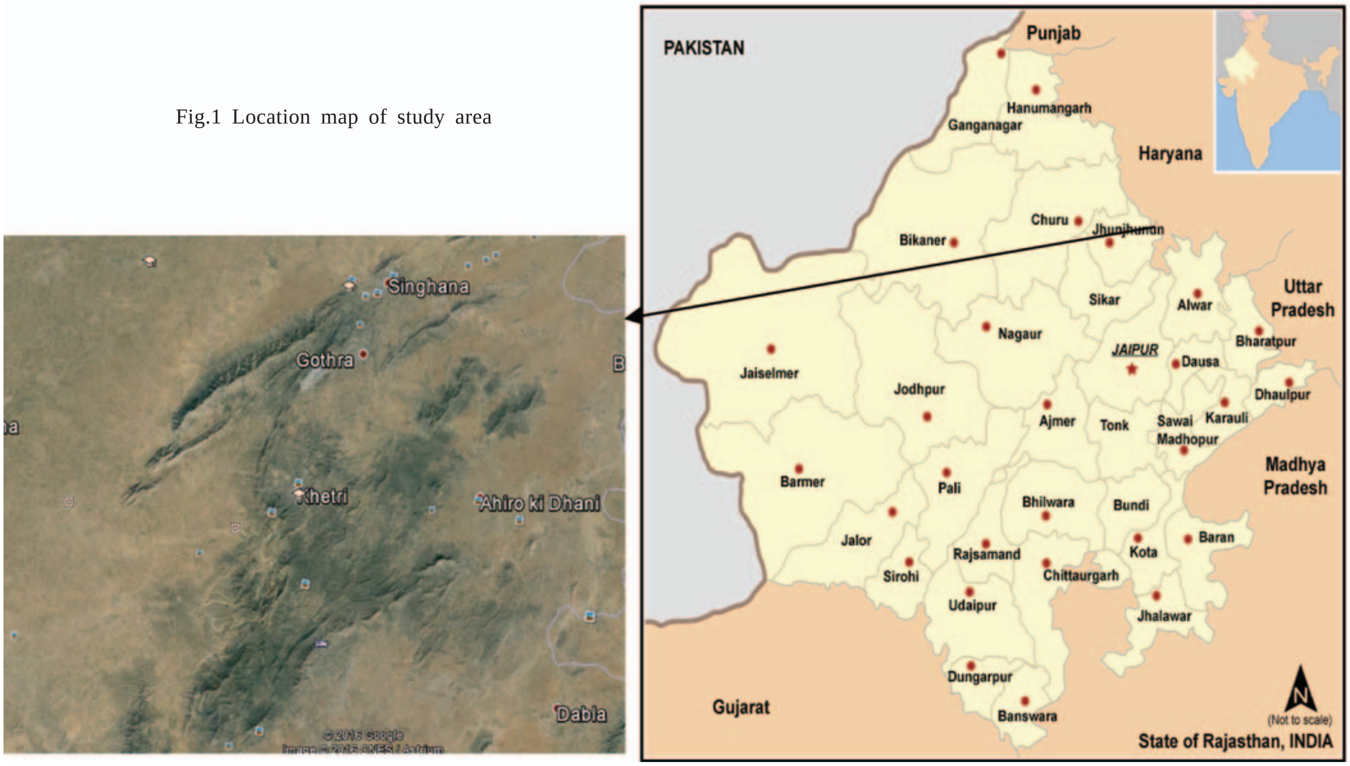

Fig.1 Location map of study area

For identifying land surface subsidence, many techniques have been introduced, for example, geodetic monitoring, airborne laser subsidence measurement system, differential SAR (DInSAR), DGPS, and satellite radar measurements [7]. Keeping in view of deformation studies in hilly terrain, to obtain displacement in order of millimeter level using conventional DInSAR Technique, accuracy of DEM if normal baseline > 200 m,[8] should be in higher side as well as certain sources of error due to decorrelation and residual atmospheric phase to be addressed. However, in present study we have focused on generation and validation of high accuracy DEM using cartosatr-1 stereo pair dataset to eliminate one of the sources of phase (topographic phase) from interferometric phase.

DEMs (relative and absolute) were generated from high resolution Cartosat-1 stereo pair dataset (IRS) using GCPs collected from using GNSS dual frequency 120 channels, without GCPs and GCPs collected with the help of Google Earth. RMS error obtained from different techniques were compared along with SRTM DEM (3 arc second) using test/ check points collected using GNSS dual frequency 120 channel.

Quality of DEM generated using different techniques were validated in DInSAR processing of ALOS PALSAR SLC dataset in terms of elimination of topographic phase associated with interferogram.

2.0 Study area

The research is carried out around the Khetri copper belt, a part of northern Aravali of hillocks, Rajasthan India. The geographical location of study area is (latitude N 28 00' 46" to N 28 05'50" longitude E 75 45' 32" to E 75 49'53"). The area

Table 1: General information of cartosat-1 stereo pair used for DEM generation

Satellite image no.	Satellite ID	Sensor	Generating agency	Path/row	Date of pass	Resolution along	Resolution across
1	Cartosat-1	Pan_fore	NRSC	0518/268	13 June, 2010	2.5 metr	2.5 metr
2	Cartosat-1	Pan_aft	NRSC	0518/268	13 June, 2010	2.5 metr	2.5 metr

Table 2: General information of Alos PalSAR data set used for interferogram generation

Satellite image no.	Satellite ID	Sensor	Generating agency	Date of pass	Resolution along	Resolution across	Nadir off angle
1	Alos	PALSAR	JAXA	22 Jan, 2010	8	3	34.3 degree
2	Alos	PALSAR	JAXA	9 March, 2010	8	3	34.3 degree

falls in the Survey of India Toposheet No. 44/P1, 6. The altitude of the area ranges between 300 to 700 meter above ellipsoidal height. Main hill ranges in area strikes NNE-SSW. The hill ranges contain the host rock of copper mineralization. The western slope of the hill is steep while the eastern slope is relatively gentle. The area covers two main underground mines, where mining has been predominant since late 1960s.

3.0 Dataset used

For DEM generation, Cartosat-1 stereo pair and for validation of DEMs in DinSAR processing, AlOS PALSAR dataset were used. Specifications of utilized dataset are summarized in Tables 1 and 2.

4.0 Research methodology

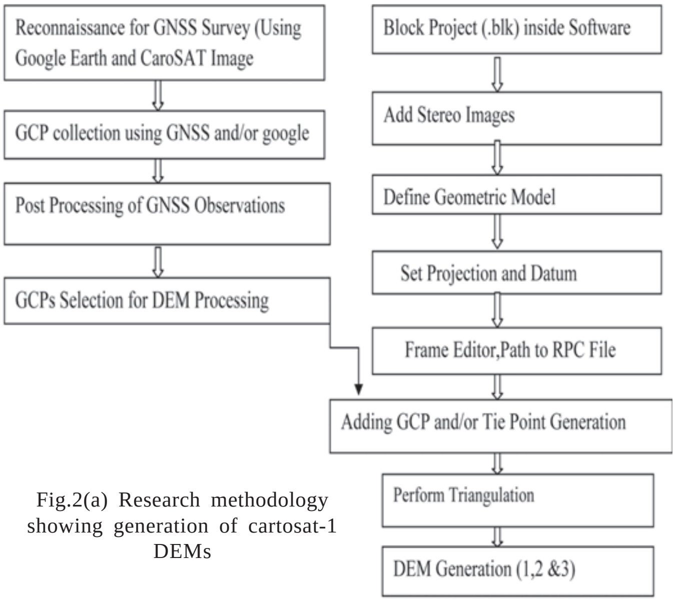

Fig.2(a) Research methodology showing generation of cartosat-1 DEMs

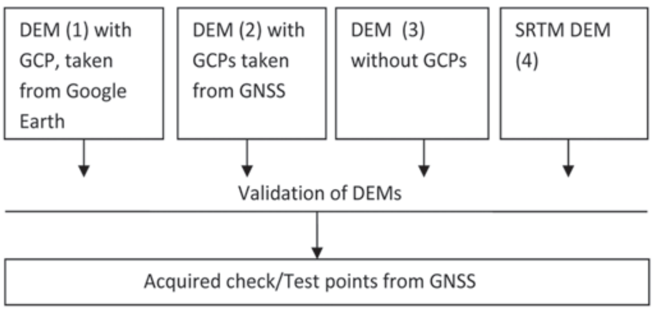

Fig.2(b) Showing methodology for vertical accuracy assessment of different DEMs

5.0 Observations

5.1 Guidelines for GCP collection [9]

- Determination of required number of GCPs: Required no. of GCPs calculated using following equations: Number of ground control points = 10 + (area covered in square kilometers/25) + (2 × number of overlapping scene edges)

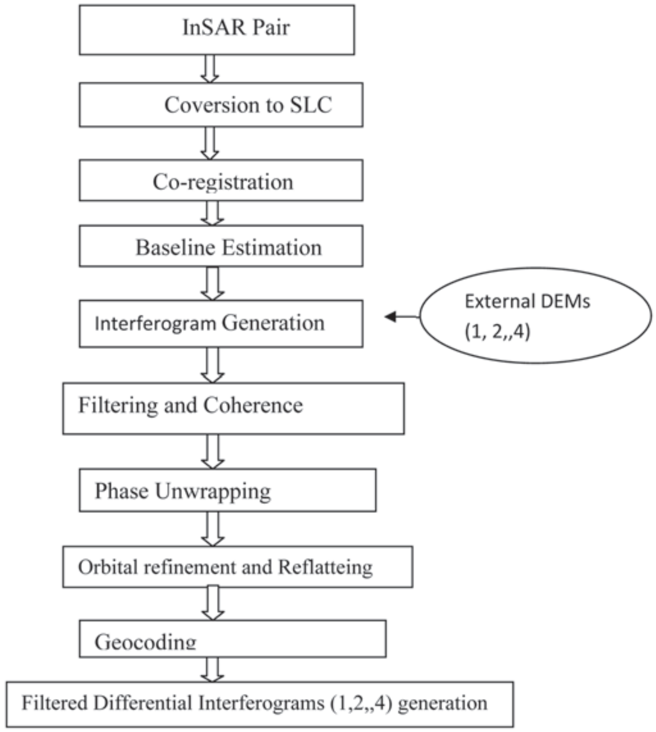

Fig.3 Process Flow of filtered differential interferogram generation of ALOS PALSAR dataset using external DEMs of varied vertical accuracy

- At least two points should be selected per edge (if possible) where various images overlap.
- Features should be chosen that are stationary and unlikely to move.
- Flat features should be chosen when possible as they have no lien in the imagery so their locations can be determined more accurately.
- Features with a high contrast between them and surrounding grounds should be selected as they can be easily and accurately located in imagery.

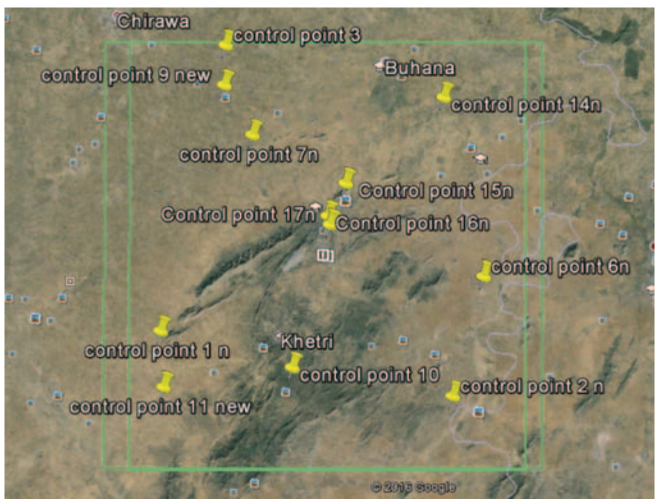

Fig.4(a) Showing selected GCPs with the help of Google earth for DEM generation

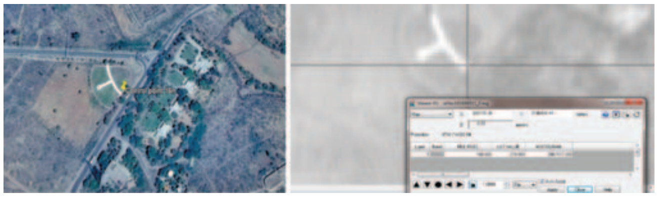

Fig.4(b) Showing one of the GCP selected on cartosat -1 imagery (right) with the help of Google earth (left)

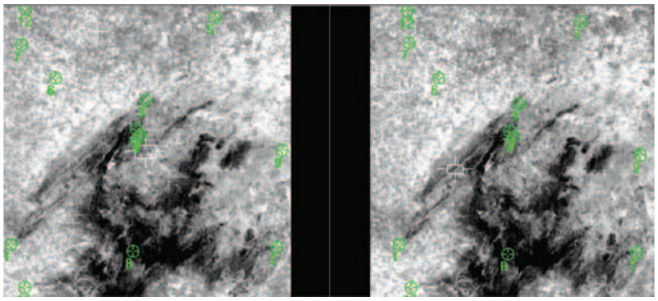

Fig.4(c) Final GCP selection on the stereo pair Aft (left) and fore (right)

- Features for GCPs locations should be selected that are big enough to easily see in but also small enough so that it is easy to pinpoint the exact location down to a single pixel (Fig.3).

5.2 Ellipsoidal Height of the Points Obtained from the Different Sources

5.3 Contribution of residual error (in vertical accuracy) by individual check/test points

5.4 Baseline estimation for SAR dataset used

5.5 Filtered differential interferograms

6.0 Results and discussion

6.1 Accuracy assessment of different DEMs

- Vertical accuracy of different DEMs was assessed with the help of RMS error as shown in Table 3. Test/check points obtained from dual frequency GNSS were taken as reference for RMS error calculation. It was observed that vertical accuracy obtained from Cartosat-1 DEM using

Table 3: Showing variation in ellipsoidal height (GCPs and check/test points) derived from different DEMs w.r.t ellipsoidal height obtained by dual frequency GNSS

Test/check points	Ellipsoidal height derived using dual frequency GNSS	Ellipsoidal height derived from cartosat-1DEM			Ellipsodal height from SRTM
		Using GCPs (collected from Google earth)	Using GCPs (collected from dual frequency GNSS)	Without GCP	
GCP 1N	383.0609	432.199	386.5714	369.909	387.387
GCP 2N	298.6065	342.173	298.6977	258.931	298.806
GCP 3	261.9193	311.295	263.3062	248.773	263.9
GCP 4N	349.6362	399.056	352.735	330.634	347.293
GCP 6N	279.6327	325.778	281.476	248.936	282.654
GCP 7N	278.9202	328.061	281.4909	263.339	278.975
GCP 9 NEW	267.8554	346.362	270.7466	253.164	269.957
GCP 10	405.4046	381.897	407.8438	371.654	409.154
GCP 11 NEW	381.23	432.273	387.737	350.444	381.431
GCP 12N	351.6824	377.254	353.294	337.984	356.065
GCP 13N	263.3897	308.889	266.543	232.457	310.969
GCP 14N	258.5326	303.764	257.9927	232.261	261.562
GCP 15N	490.068	488.295	491.9516	348.333	486.861
GCP 16N	304.2175	351.932	305.8164	283.402	305.932
GCP17 N	297.5204	346.362	300.6261	271.831	299.939
GCP KCM RX	334.7027	381.897	336.626	317.796	340.116
KCC CP T 16N	332.5002	379.938	333.343	298	339.997
KCC CP T15	331.7144	377.254	331.91	300.615	342.991
KCC CP TL	324.478	354.287	322.392	308.623	310.969
MB KCC MB 7	382.1376	433.171	385.614	368.232	385.982
MB KCC MB 14	324.9427	372.737	326.946	287.673	330.97
MB KCC MB 15	342.6887	395.385	344.326	290.427	388.971
MB KCC MB 17	342.0092	336.626	343.748	293.957	353.993
MB KCC MB 18	330.7706	379.18	333.193	329.817	334.026
MB KCC MB11	307.5443	355.302	311.009	279.102	310.938
MB KCC PB 5A	306.3676	354.287	308.419	281.436	341.94
MB KCC PB 5C	299.1531	346.11	301.767	273.999	296.915

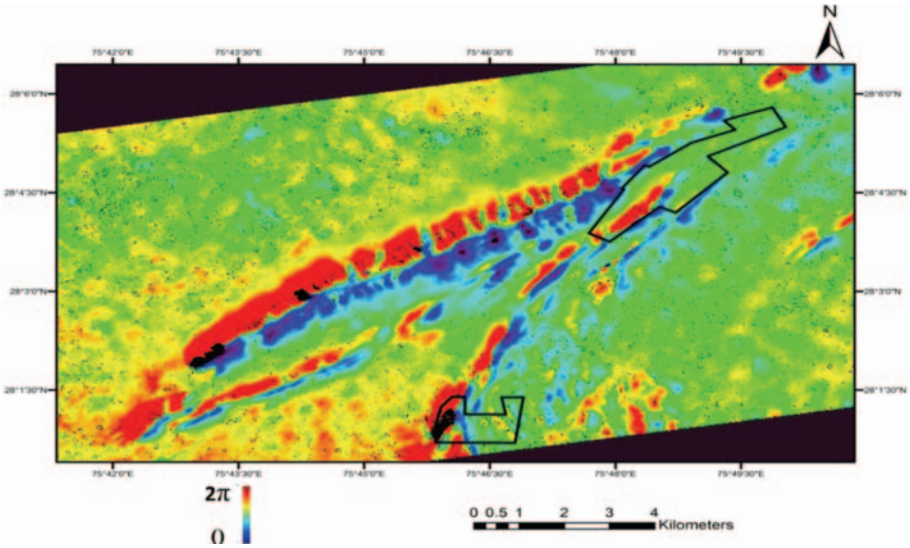

Fig.5(a) Filtered differential interferogram (after orbital refinement) using cartosat-1 DEM (GCPs collected from Google earth); arrows are indicating the presence of topographic phase in the interferogram

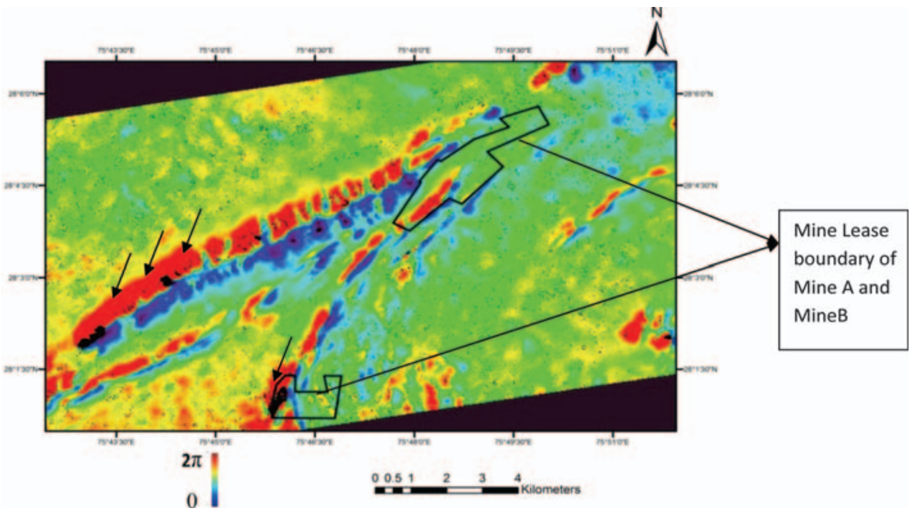

Fig.5(b) Filtered differential interferogram (after orbital refinement) using SRTM DEM; same case as above interferogram (presence of topographic phase)

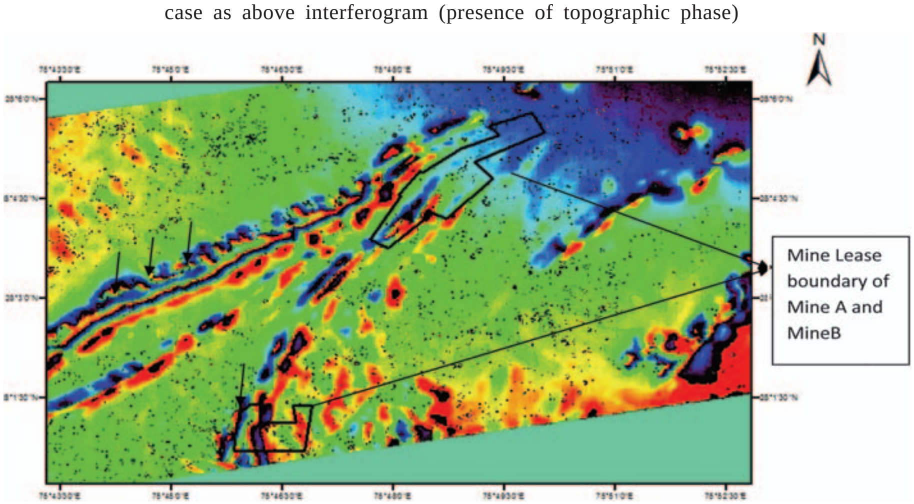

Fig.5(c) Filtered differential interferogram (after orbital refinement) using cartosat-1 DEM (GCPs collected from dual frequency GNSS); arrows indicate smoothening in topographic phase can be observed

GCPs (collected from dual frequency GNSS), SRTM, Cartosat-1 DEM without GCP and Cartosat-1 DEM using GCPs (collected from Google Earth) in the range of 2.54 m, 10.10m, 37.97m and 76.66m respectively. It has been observed from the result that vertical accuracy obtained from Cartosat-1 DEM using GCPs (collected from dual frequency GNSS) has improved significantly in comparison with DEMs from other sources as shown in Table 3 for the study area.

- As shown in Table 4, the normal baseline of the SAR pair was in the range of 500m, which is quite significant to resolve the topographic height of the study area. Therefore to eliminate the topographic phase significantly, attempt has been taken to generate high accuracy DEM. From Fig.5(c), it has been observed that topographic phase of the area eliminated up to some extent by simulation of Cartosat-1 DEM using GCPs collected from dual frequency GNSS as compared to other sources of DEM. Topographic phase could not be eliminated completely due to the accuracy of Cartosat-1 DEM using GCPs collected from dual frequency GNSS may be affected by non-coverage of whole variation of topography of the study area because of unidentifiable features on hilly area w.r.t imagery, there is no exact guideline for accuracy level of DEM with respect to the normal baseline. However, to eliminate topographic phase completely for normal baseline in the order of 500m, even more accurate DEM would require.
- As per literature review, condition for the standard DInSAR technique normal baseline should be less than 200m (8). Attempt has been taken to address the deformation phenomena in the study area by using archive data available keeping in view of preliminary investigation.

TABLE 4: RESIDUAL ERROR CONTRIBUTION OF DIFFERENT CHECK/TEST POINTS IN DEM MODELS

Test/check ponits	Residual error (meter)			
	Using GCPs (collected from Google earth)	Using GCPs (collected from dual frequency GNSS)	Without GCP	SRTM
GCP 1N	49.1381	3.5105	-13.1519	4.3261
GCP 2N	43.5665	0.0912	-39.6755	0.1995
GCP 3	49.3747	1.3869	-13.1463	1.9807
GCP 4N	49.4198	3.0900	-19.0022	-2.3432
GCP 6N	46.1453	1.8433	-30.6887	3.0213
GCP 7N	49.1408	2.5707	-15.5812	0.0548
GCP 9 NEW	78.5066	2.8912	-14.6914	2.1016
GCP 10	-23.5076	2.4392	-33.7506	3.7494
GCP 11 NEW	51.043	6.5070	-30.786	0.201
GCP 12N	25.5716	1.6116	-13.6984	4.3826
GCP 13N	45.4993	0.1263	-30.9327	3.027
GCP 14N	45.2314	-0.5399	-26.2716	3.0294
GCP 15N	-1.773	1.8836	-141.735	-3.207
GCP 16N	47.7145	1.5989	-20.8155	1.7145
GCP17 N	48.8416	3.1057	-25.6894	2.4186
GCP KCM RX	47.1943	1.9233	-16.9067	3.49
KCC CP T 16N	47.4378	0.8428	-34.5002	7.4968
KCC CP T15	45.5396	0.1956	-31.0994	11.276
KCC CP TL	29.809	-2.086	-15.855	-13.509
MB KCC MB 7	51.0331	3.4764	-13.9056	3.8444
MB KCC MB 14	47.7943	2.0033	-37.2697	6.0273
MB KCC MB 15	52.6963	1.6373	-52.2617	46.2823
MB KCC MB 17	-5.3832	1.7388	-48.0522	11.9838
MB KCC MB 18	48.4094	2.4224	-0.9536	3.2554
MB KCC MB11	47.7577	3.4647	-28.4423	3.3937
MB KCC PB 5A	47.9194	2.0514	-24.9316	2.0514
MB KCC PB 5C	46.9569	2.6139	-25.1621	-2.2381

TABLE 5: SHOWING RMSE (M) IN TERMS OF VERTICAL ACCURACY OF DIFFERENT DEMS

	DEM	RMSE (m) in terms of vertical accuracy
1	Cartosat-1 DEM using GCPs (collected from dual frequency GNSS)	2.54
2	SRTM	10.10
3	Cartosat-1 DEM without GCP	37.96
4	Cartosat-1 DEM using GCPs (collected from Google earth)	76.66

TABLE 6: SHOWING BASELINE OF SAR DATASET (1-2) USED FOR FILTERED DIFFERENTIAL INTERFEROGRAM GENERATION

SAR pair	Normal baseline (m)	Temporal baseline (days)	Range shift (pixel)	Azimuth shift (pixel)	Doppler shift difference (Hz)
1-2	518.477	46	53.407	27.671	-14.809

7.0 Conclusions and suggestions

- Vertical accuracy of Cartosat-1 DEM without GCP (using RCP) is even better than Cartosat-1 DEM using GCPs collected from Google Earth.
- Attempts should be taken further to prepare more accurate DEM using high resolution optical stereo pair dataset of other sensors.
- Accuracy of receiver for collecting GCPs plays a vital role to increase the accuracy of DEM.
- Guidelines for GCP collection also plays a vital role to increase the accuracy of DEM.
- As per literature review, condition for the standard DinSAR technique, normal baseline should be less than 200m (8). Since, it was the preliminary investigation in terms of deformation studies of the area, study was limited on available archive data

- It is suggested that in conventional DInSAR technique for displacement mapping, normal baseline should be kept less than 200 m [8] to eliminate the topographic phase completely and to avoid the complexity of high accurate DEM generation.

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