National Geospatial Policy: Status of the Indian geodetic data

Ropesh Goyal[1,*] , Onkar Dikshit[1] , Ashutosh Tiwari[1]

[1]National Centre for Geodesy, Indian Institute of Technology Kanpur, India

ORCID - Ropesh Goyal: 0000-0002-2178-3265; Onkar Dikshit: 0000-0003-3213-8218;

*Ropesh Goyal: rupeshg@iitk.ac.in; ropeshgoyal2809@gmail.com

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Dr. Ropesh Goyal: Research Associate-III, National Centre for Geodesy, IIT Kanpur, Kanpur 208016, Uttar Pradesh, India rupeshg@iitk.ac.in

Dr. Onkar Dikshit: Professor, Dept. of Civil Engineering, IITK, and Coordinator, National Centre for Geodesy, IITK, Kanpur 208016, Uttar Pradesh, India onkar@iitk.ac.in

Dr. Ahutosh Tiwari, Research Establsihment Officer, National Centre for Geodesy, IIT Kanpur, Kanpur 208016, Uttar Pradesh, India ashutoshtiwari796@gmail.com

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ABSTRACT

The national geospatial policy has well-communicated the need for sharing the geospatial data with an emphasis that national geospatial data must refer to the geodetic/topographic database of the Survey of India (SoI). SoI has been collecting, processing, archiving, and disseminating geodetic data for over a century. Several stakeholders are using these datasets viz. government, academia, industry, and research, for their respective applications. SoI also updated their database as and when required due to the introduction of sophisticated and precise instruments, and accuracy requirements, or to improve the database scientifically. Although the results or the policies involving the geodetic data are provided in the literature, there is limited discussion on the data itself. This article provides comprehensive information about the geodetic data available to Indian users for various applications. The geodetic data discussed in this article are the horizontal and vertical positioning, gravity, geoid model, and Digital Elevation Models. The article is also a testament to the most commendable efforts of our premier surveying and mapping organization, Survey of India.

Key Words: Geospatial guidelines, geospatial policy, geodetic data, India

INTRODUCTION

National geospatial policy and guidelines broadly delivered that all the topographic databases must be referred to the Survey of India (SoI) database, thereby maintaining the consistency in the geospatial data and avoiding duplication in data collection by several stakeholders[1,2,3]. As such, it is mentioned that SoI shall prepare and update the national topographic database and provide the national geospatial frame. Further, SoI will take necessary measures to simplify procedures for accessing its data by citizens, industry, academia, research, NGOs, and government.

The first two national foundation data asset themes are: 1. Geodetic Reference System (System for uniquely referencing spatial information in space as a set of coordinates (x, y, z) and/or latitude and longitude and height, based on a geodetic horizontal and vertical datum), and 2. Elevation and Depth (Digital elevation models for land, ice, and ocean surface. This includes terrestrial elevation, bathymetry, and shoreline). Further, threshold values for geospatial guidelines have also been provided as 1. On-site spatial accuracy shall be one meter for horizontal or planimetry and three meters for vertical or elevation, and 2. Gravity anomaly shall be 1 milli-gal. There is also a threshold value provided for bathymetric data, but it is not discussed in this article.

From the above recapitulation of a few important aspects of geospatial guidelines and policy, it becomes inevitable to use SoI data by various stakeholders to maintain geospatial data consistency in India. Therefore, the primary requirement is to understand the dataset provided by SoI, which is to be used as a reference dataset for observing further geospatial data and developing geospatial data products. This article provides a detailed discussion of the dataset concerning the first two national foundation data asset themes. These are horizontal positioning, vertical positioning, gravity, geoid model, and digital elevation model (DEM), which we have collectively called geodetic data.

India is the seventh largest country in the world with the most varied topography that comprises the Gangetic plains, desert, Aravalli and Vindhya ranges, plateaus, Eastern and Western ghats, Himalayas, and a long peninsular coastline (Figure 1). The Indian government depends significantly on the use of geospatial technologies in various initiatives and programs like Gati Shakti, Survey of Villages Abadi and Mapping with Improvised Technology in Village Areas (SVAMITVA), Digital India Land Records Modernization Programme (DILRMP), National Hydrology Project (NHP), National Mission for Clean Ganga (NMCG), etc. According to the Geospatial Artha report, the geospatial economy of India may grow up to Rs 63,100 crore by 2025 (ref 4).

Almost all the ministries are looking forward to the geospatial sector for providing improved services to the citizens (e.g., National Centre of Geoinformatics, https://ncog.gov.in/users.html). To aid the government programs, i.e., to develop geospatial products, services, and solutions, Indian academia, research, and industry are also actively participating. Further, academia and research organizations are also involved in scientific studies involving geospatial technologies. The release of the geospatial policy has been a boosting factor to attract industry, academia, research, and government to use geospatial technologies in their respective applications.

However, the whole of the geospatial sector has its basis in geodetic data, which is further based on reference surfaces, commonly known as datums. Similarly, some geodetic products are crucial inputs in various applications, such as the geoid model or DEM. Any user can obtain the horizontal position using a global navigation satellite system (GNSS), gravity using a gravimeter, heights using levelling or GNSS, (global) geoid model from International Centre for Global Earth Models (ICGEM), and DEM from different freely available sources. However, to maintain consistency in the data, which is also the main objective of the new geospatial guidelines and policy, it is important that the data should refer to some national datum.

In India, SoI has been instrumental in collecting and providing most of the geodetic data and products to all the stakeholders. SoI have defined Indian geodetic datums with the available data and methods, but given the present-day accuracy and application requirements, the geodetic datums need to be re-defined. For example, DILRMP or SVAMITVA program, if executed without a static horizontal datum, observations may have to be repeated after a few years (15-20 years). It is because the coordinates obtained in the WGS84 datum (and not in a national datum) will change with time, primarily due to the dynamicity of the tectonic plates. Therefore, such projects must be referred to as a static horizontal datum instead of a dynamic datum (e.g., WGS84). The proposed strategy for the redefinition of the geodetic datums is not covered in this article but will be discussed in another article dedicated to a way forward for establishing the Indian Geodetic Reference Frame (InGReF), i.e., re-defining the Indian geodetic datums.

It should be noted here that we have two geodetic networks in India, one for horizontal positioning and another for vertical, i.e., there were very limited benchmarks/GCPs where both the horizontal coordinates and the levelling heights were available. Recently, SoI has taken up a massive task to connect GCPs with levelling networks and take GNSS observations on the levelling benchmarks. This combined information - latitude, longitude, ellipsoidal height, and levelling height, forms an important dataset for various tasks, including validation of geoid and DEMs, and calculating hybrid geoid.

The following sections are dedicated to the five geodetic data/products available for Indian users: horizontal position, vertical position, gravity, geoid, and DEM. First, these are explained briefly, followed by details in the Indian context. The collection, processing, and archival of these datasets involved tremendous and appreciable efforts by SoI. However, the discussions may instigate a few questions that users would like to discuss before procuring/using the SoI geodetic data for referring to their respective geodetic projects in view of geospatial policy.

Horizontal positioning

The horizontal position refers to the two-dimensional positional information required to locate any point on the Earth, disregarding its topographical information. The 2-D coordinates are referred to a mathematical surface of the Earth, known as the reference ellipsoid. It can be either a locally best-fitting ellipsoid, e.g., Everest, or a globally best-fitting ellipsoid, e.g., WGS84. Although there can be a different representation of these coordinates depending on the choice of the coordinate system, most commonly these are provided in the cartesian coordinate system (X, Y) or curvilinear geodetic coordinate system (geodetic latitude and longitude) which are now easily obtained using GNSS. Most location-based services require only 2-D positional information. GNSS also provides height information (known as ellipsoidal height), which is geometric in nature.

Until a few decades back, the horizontal position in India was referenced to the Great Trigonometric Survey (GTS) stations with the Everest ellipsoid. There have been three adjustments known with the GTS stations, i.e., the adjustment of 1880, 1916 (important for Burma), and the readjustment of 1937. The details of all these three adjustments have been provided in Bomford (1939) (ref 5). One must also see de Graff Hunter (1918) for effect on the station positions due to the choice of the local and international spheroid and foot to metre conversion, for India[6]. The different numerical values of the semi-major axis associated with the Everest ellipsoid have also been discussed by Featherstone and Goyal (2022, pp.5) (ref 7).

All the topographic maps have been initially published in the Everest datum. Noting the significance of using the international spheroid, SoI decided, around 2005, to publish a new set of maps from the existing Everest datum to the WGS84 datum. Some transformation parameters are available in technical report of the National Imagery and Mapping Agency (NIMA), which are also being used in different open-source or proprietary software[8]. However, these are based on only seven common stations, so the uncertainties are high. The original transformation from Everest to WGS84 was carried out zone-wise, i.e., there are different transformation parameters for different regions of India. No official transformation parameters or procedure is available to the public. However, SoI provides the transformed coordinates as per user requirements.

As a step toward working with global ellipsoid, SoI planned the 'Creation of National Ground Control Points (GCP) Library for India' to be carried out in three phases[9]. The total number of established GCPs in the first and the second phases are reported to be 292 and 2252, respectively (Figure 2a) (ref 9). Similar information but with a different number of GCPs is also provided in reports by the National Disaster Management Authority and Department of Science and Technology[10,11]. Understandably, the different number of GCPs may be a typographical error, or the number of points may have been added or destroyed with time. However, the number of GCPs becomes important because it is mentioned that the first phase network is adjusted, the solution of which will depend on the number of GCPs. It must be noted here that this adjusted first phase GCP network is also sometimes referred to as the Indian geodetic reference frame, Indian geodetic datum or National Spatial Reference Frame. However, we could not find any information on the processing and adjustment of this network to define the national datum.

Limited documents on comprehensive information about the GCP library are available in the public domain. Further, those available have mentioned different ITRF solutions (ITRF2005 or ITRF2008) for the GCP library[10,12]. There is also little confusion regarding the choice of a global ellipsoid, i.e., WGS84 or GRS80. The choice of an ellipsoid is important for consistency because we observe that in India WGS84 is utilized for horizontal positioning while calculating gravity anomalies involves GRS80[13,14,15]. Further, 'epoch' is also reported inconsistently. The epoch for which an ITRF solution is given, e.g., ITRF 2008 epoch 2005.0, signifies that the ITRF2008 is realized such that there are null translation parameters, translation rates, scale factor, scale rate, rotation parameters, and rotation rates (with respect to previous ITRF solution, ITRF2005 in case of ITRF2008) at epoch 2005.0. Another way the epoch is used is to refer the coordinates of the desired stations (e.g., national GCP library) to any given date (decimal years) using the plate velocity models. It is important to distinguish because there is some confusion about the horizontal positional data in ITRF2005 epoch 2008.0 or ITRF2008 epoch 2005.0 (ref 10, 12, 14, 16). The GCP data can be procured from SoI. However, in the pre-geospatial guidelines era, no information was shared on the error estimates of the data.

We hope that more details will be made available while procuring the GCP data to maintain the consistency of the heterogeneously collected data (by various stakeholders).

Recently, SoI has also undertaken an enormous and significant task of establishing continuously operating reference stations (CORS) all around India. All the required information on the various services and data available from these CORS network, along with video tutorials, is available in detail at the SoI CORS website (https://www.cors.surveyofindia.gov.in/). The current setup seems more suitable only for Real Time Kinematic (RTK) positioning applications. The information on the operational CORS, installed CORS and under testing, and those under installation is available from the SoI CORS website, which is updated regularly. As of Feb 2023, the CORS network in the sates of Uttar Pradesh, Uttarakhand, Haryana, Punjab, Madhya Pradesh, Maharashtra, and Karnataka is functional (Figure 2b). Once the desired CORS network has been set up, it is envisaged that the data can be checked for repeatability and reliability. Henceforth, the most precise stations must be identified to be included in the stochastically constrained network adjustment, which can be the basis of the redefined Indian Horizontal Datum.

Vertical positioning

Vertical positioning, i.e., the heights, are useful for various applications such as military planning and guidance, infrastructural developments, disaster management and mitigation, etc. However, the term 'height' is not self-explanatory because different heights or height-related terms are available in the geodesy and surveying depending on the vertical reference surface being used, e.g., geoid, quasigeoid, or ellipsoid. The heights referred to the ellipsoid are known as the ellipsoidal height (i.e., the height we obtain using GNSS), which are geometric in nature, i.e., and do not follow the water flow criteria. Hence, ellipsoidal heights are not used in large-scale infrastructure developments. The contours on the topographical maps of SoI are generated using the heights from the levelling network, i.e., the physically meaningful heights, also generally known as heights above mean sea level (MSL) or orthometric heights (although the two are not the same). The benchmarks established during the levelling exercise form the basis of the vertical control of almost all the major infrastructural development projects of the nation.

There are two Indian Vertical Datums (IVD) defined by SoI, one in 1909 and the other in 2018 (ref 14, 19). The former IVD is more commonly known as the Indian Mean Sea Level datum (we call it here IVD1909), and the latter is known as Redefined Indian Vertical datum 2009 (we call it here IVD2009). IVD1909 was based on constraining the mean sea level of nine tidal observatories to zero. Constraining to zero means that the heights of the nine-tide gauge benchmarks (TGBM) were transferred from the respective tidal observatories considering that the MSL estimate at each of these nine observatories is the same, i.e., zero. It should be noted that although the MSL estimate at nine tide observatories was considered to be at the same level, i.e., zero, the Bay of Bengal is, on average, ~320 mm higher than the Arabian Sea[20]. This situation was also observed during levelling for IVD909 but was left unexplored for the future. Such an approach of constraining the level net to the multiple tidal observatories with the same MSL estimate leads to a north-south tilt in the datum, thus causing systematic biases[21]. The spirit levelling heights were transformed to dynamic heights which were further transformed to orthometric heights by applying the orthometric correction. Due to the non-availability of sufficient portable gravimeters, the normal (theoretical) gravity was used with the levelling. Hence, the heights so obtained were normal-orthometric heights[22].

IVD2009 was based on constraining the geopotential at eight tidal observatories to the same value. Constraining to the same value means that the local geopotential value was calculated by taking an average of the geopotential values at eight tidal observatories to decide the geopotential value for IVD2009. It implied that although the average geopotential at eight tidal observatories varied from 62636856.54 m^2s^{-2} to 62636861.80 m^2s^{-2}, the final value for all eight stations was fixed at 62636859.40 m^2s^{-2}. The difference between the final adopted geopotential value and the maximum and minimum values (from eight stations) translates to a difference of approximately 0.29 m and -0.26 m, respectively. In IVD2009, gravity readings were also taken along the levelling lines (Figure 3). Hence, the heights that are referenced to IVD2009 are Helmert's orthometric heights. Levelling heights can also be procured from SoI. However, in the pre-geospatial guidelines era, the values were provided with truncation at the cm level (e.g., 123.45 m), which may now change after the geospatial policy.

Gravity

Gravity is the resultant of the mass attraction of the Earth (gravitation) and its rotation (centrifugal). Further, the Earth's mass distribution and its rotation vary in time. Thus, gravity information is essential for various geodetic, geophysical, geodynamic, and oceanographic applications along with orbit determinations[24]. In India, primarily SoI has done appreciable work in the geodetic applications with gravity data while NGRI has undertaken various scientific applications, including some other organizations as well[25]. Concerning this article, for geodetic purposes, precise gravity information can be used to determine positions: horizontal and vertical[26]. Although precise horizontal positions are now obtained using GNSS, gravity information will always be necessary to obtain precise orthometric heights[22].

SoI began absolute gravity measurements in 1865 using brass pendulums. Five hundred and sixty-four pendulum measurements were acquired throughout the country in two separate phases, i.e., 1902-1925 and 1926-1939. After the second world war, gravity surveys were continued for further densification using Frost and Worden gravimeters. A gravity map of India was developed in 1956 at a scale of 1:12,000,000 and a contour interval of 20 mGal (ref 27). This gravity map was constructed using data from around 3000 stations.

The gravity base station for the Indian National Gravity Datum 1963 (INGD63) is situated at Dehradun. The absolute gravity value of this base station in INGD63 is 978064.0 mGal and 978049.09 mGal based on the International Gravity Standardization Net 1971 (IGSN71). Hence, a correction of ~14.9 mGal (which originates from an error at Potsdam) is generally applied to data observed in the INGD63 to obtain the corresponding value in IGSN71.

During the late 1950s to the mid-1970s, other organizations, such as the Geological Survey of India (GSI), collected gravity data. The old and new data were compiled and transformed to a common datum (INGD63) to prepare the gravity map of India with a 10 mGal contour interval[28]. We were unable to obtain any information on how the different data were transformed into the same datum. This map was published in 1975 on a scale of 1:5,000,000.

Later, due to the requirement of updated and comparably precise gravity data, it was decided to revise the gravity map of India using the data collected by SoI, GSI, NGRI, Oil and Natural Gas Corporation

(ONGC), and Oil India Limited (OIL) under various projects[29]. A total of 143,786 gravity data points were observed by these organizations, which were archived at GSI, Hyderabad. However, only 51,356 data points were selected to maintain uniform coverage over the entire India. These points were reprocessed to refer to IGSN71, but the reprocessing steps are not available in the literature. The final output was a revised gravity map series of India (GMSI) 2006 that comprises five sets of gravity anomaly maps, including a free-air anomaly map and a Bouguer anomaly map, both at a 1:2,000,000 scale. These are the latest gravity maps computed/compiled for India.

Recently, SoI has started re-observing gravity data all over India. An absolute gravimeter has been procured, and a few absolute gravity points have been established. The absolute gravity value is transferred from an established absolute gravity benchmark to a benchmark in the region of interest using relative measurement. The absolute gravity at the new benchmark is then used for further densification of absolute gravity points in that region. In a few past years, approximately 31000 gravity points have been already observed by SoI[30]. However, it should be noted that these observed gravity values do not refer to any national gravity datum.

Geoid Model

The geoid is an equipotential surface of the Earth's gravity field that is best approximated by the ocean at rest. All terrestrial geodetic and engineering surveying measurements are made after aligning the instrument's vertical axis orthogonal to an equipotential surface. The geoid, therefore, is the best candidate for a reference surface, especially for heights. Although geoid has numerous scientific applications, including subsurface mass anomaly structures, plate tectonics, earth rotation, oceanic lithosphere, etc., the geoid is also being computed to adopt as a national vertical datum. Canada and New Zealand have already adopted geoid (and quasigeoid, respectively) as the national vertical datum, and the USA is following suit. SoI has also suggested adopting a gravimetric geoid model as the new vertical datum for India[15]. The most useful application of the geoid model is for the surveyors to effortlessly transform the GNSS obtained ellipsoidal heights to orthometric heights. Furthermore, a precise geoid can be used with GNSS as an alternative to tedious, laborious, and costly levelling exercise.

de Graaff Hunter compiled the first geoid map for India in 1922 based on astrogeodetic observations referred to an international spheroid[31]. SoI, in 1951 also provided a geoid map for India[32]. During the 1970s to mid-1980s, a few other gravimetric and astrogeodetic geoid-related studies were conducted in India, with respect to both Everest and GRS67 ellipsoids[33, 34,35,36]

From 2007 onwards, mostly gravimetric geoid-related studies over India were available in the literature[23,37, 38,39,40,41]. A detailed review of these geoid models has been presented in Goyal (2022) (ref 42). It has been discussed that although there are a few Indian gravimetric geoid models available in the public domain (Figure 4), the official and reliable model is still elusive[43]. The efforts so far either include a less meticulous computational framework or data of unknown qualities, both of which resulted in not availability of a precise gravimetric geoid model for India.

SoI is making a laudable attempt at consistent gravity data collection for the whole country while the academic institutions are developing their software and improving methods of geoid computation[42,44,45]. Thus, a collaborative effort of SoI and academic and research organizations is the need of the hour if we need a precise geoid model for India in the near future. SoI has calculated α and β versions of INDGEOID, but limited information on their computation and access to the public is available on either of the two versions.

Digital Elevation Model

Digital Elevation Model (DEM) is a 3D representation of the bare ground (topographic) surface of the Earth, excluding trees and man-made structures. At the same time, a Digital Surface Model (DSM) is a representation of the surface sensed that includes trees and man-made structures. Digital Terrain Model is another terminology that is used synonymously with DEM and DSM. However, in contrast to DEM and DSM, which are raster datasets, DTM is a vector dataset composed of regularly spaced points and natural features such as ridges and break lines. A DTM augments a DEM by including linear features of the bare-earth terrain. The applications of DEM, DSM, and DTM are well documented in the literature[46,47].

It should be noted that most of the freely available global digital height models are generated by processing the remotely sensed images and hence, the primary output is a DSM (e.g., SRTM, ASTER), which is sometimes synonymously used also in those applications that strictly require a DEM, e.g., applications requiring water flow mapping. The Indian CartoDEM is also a DSM and not a DEM. However, the efforts put in by SoI to digitize the contours from the topographic maps will result in the required DEM. The accuracy assessment of different freely available DSMs and DEMs over India has been undertaken by many researchers, yet a consistently precise DEM/DSM is still not available for the country[48,49]. A way forward for generating a high-resolution precise national DEM could be LiDAR mapping and processing (to separate ground and non-ground points) and augmenting it with a precise gravimetric geoid model.

There are two DEMs for India, precisely, one DSM, i.e., CartoDEM, and one DEM that is developed by SoI[50,51]. CartoDEM is derived from stereoscopic imagery from the Cartosat mission and is available in the public domain at a 30 m × 30 m grid resolution. The vertical datum for the CartoDEM is WGS84, i.e., the heights available from CartoDEM are the ellipsoidal heights. The DEM (or DSM) with ellipsoidal heights has limited usage because it does not follow the water flow criterion. All the satellite imagery derived DSM have ellipsoidal heights, but a few of them have been further referenced with respect to a global geoid model (e.g., EGM96) to provide the required physical (orthometric) heights for various applications, e.g., flood mapping and management. The DEMs which are referenced to EGM96 include SRTM and ASTER, both of which are extensively used in India, although they had varied accuracy primarily depending on the topographic landform and ruggedness[49]. CartoDEM as available is still referenced to WGS84, and hence, the user must use EGM96 in comparing it with SRTM or ASTER in the area of interest or with other precise global or regional geoid models for other activities.

SoI (2020) (ref 51) mentioned that they would develop three DEMs: a national DEM of ±10 m accuracy, a high-resolution DEM of ±3-5 m accuracy, and an ultra-high resolution of ±50 cm accuracy. There is some confusion if the mentioned numbers are accuracy (or precision, although both are different) or if they denote the expected resolution of the DEMs. The proposed aim to develop these DEMs is using data from Unmanned Aerial System (UAS) or LiDAR survey integrated with a precise national geoid model.

However, the present DEM that is made available by SoI is generated by digitizing the contours from the topographic maps and is available at 10 m resolution[52]. SoI may have also constructed other resolution DEM, but we are unaware of any of those. The following three points should be noted: 1. the topographic maps were initially developed in the Everest datum and were transformed into the WGS84 datum only after 2005. The transformation parameters were not consistent throughout the country, which resulted in absolute shifting of the coordinates by as large as 300 m, 2. the contour interval ranges from 5-10 m in plain regions to 50-100 m in the undulating mountainous regions, with limited spot heights (it should be noted that contour intervals further vary depending on the terrain type and scale of the map), and 3. the height information used in topographic maps are from IVD1909, i.e., normal-orthometric heights observed more than a century ago (while Helmert's orthometric heights are measured in modernized vertical datum, i.e., IVD2009). Therefore, given these points, the DEM so generated may not provide nationally-consistent precise elevation information because it may only include archaic height information collected mainly along the roads and railways. Moreover, this DEM may also be horizontally shifted due to the non-consistent transformation of coordinates from Everest to WGS84.

In addition to the massive work of digitizing the contours and producing the DEM, SoI is continuously working towards developing a precise DEM to provide an accurate high-resolution topographic representation. Given the many Indian landforms and other conditions, data collection and processing might take considerable time. Till then, the current practice may be continued, but with an aim for re-computation (for any pursued DEM application) once precise DEM is made available. DEM can also be procured from SoI, but they may be based on contours from the topographic maps.

Conclusive statement

According to the new geospatial guidelines, any Indian user can procure geospatial (geodetic) data from the Survey of India (SoI) for their respective applications. Further, all the stakeholders can collect geodetic data of any quality and resolution, but all must refer to the SoI database. Therefore, it is crucial to understand the SoI database. This article briefly explained the geodetic data (horizontal position, vertical position, gravity, geoid model, and digital elevation model) and their availability status in India. The discussions provided may also be used to collect relevant metadata while procuring these data from SoI. Given that geodetic data had been collected for decades under different scenarios, the metadata will be the most critical utility to meet the geospatial guidelines and policy objective, i.e., maintaining consistency and avoiding duplication in geospatial data collection and processing. The discussions also show that though SoI has been undertaking stupendous tasks of geodetic data collection, processing, archival, and dissemination, there is still much to do in terms of defining consistent geodetic datums, which has now also been mentioned in the national geospatial policy.

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Figure Legends

Figure 1: Indian topographical landforms

Figure 2a. GCP library. Source: Singh and Kumar (2019) (ref 17)

Figure 2b. CORS network. Source: SoI (2022) (ref 18)

Figure 3. Levelling net for IVD2009 (red line shows primary netwotk). Source: Singh and Srivastava (2018) (ref 23)

Figure 4. Indian gravimetric geoid model. Source: Goyal (2022) (ref 44)

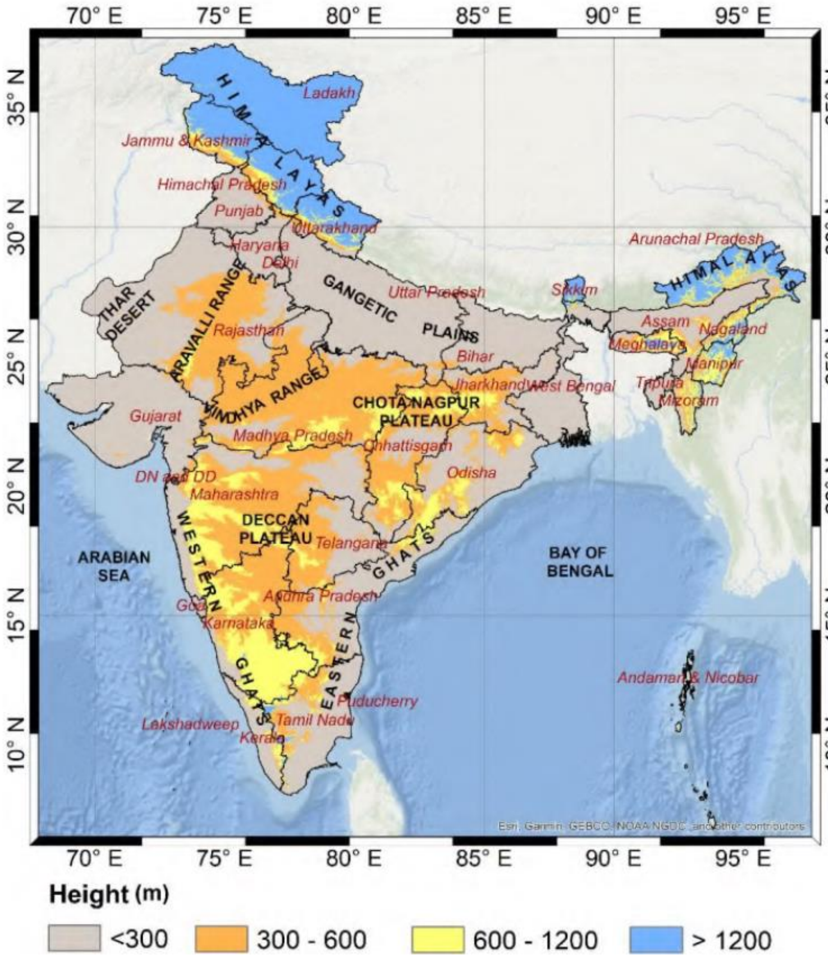


Figure 1: Indian topographical landforms

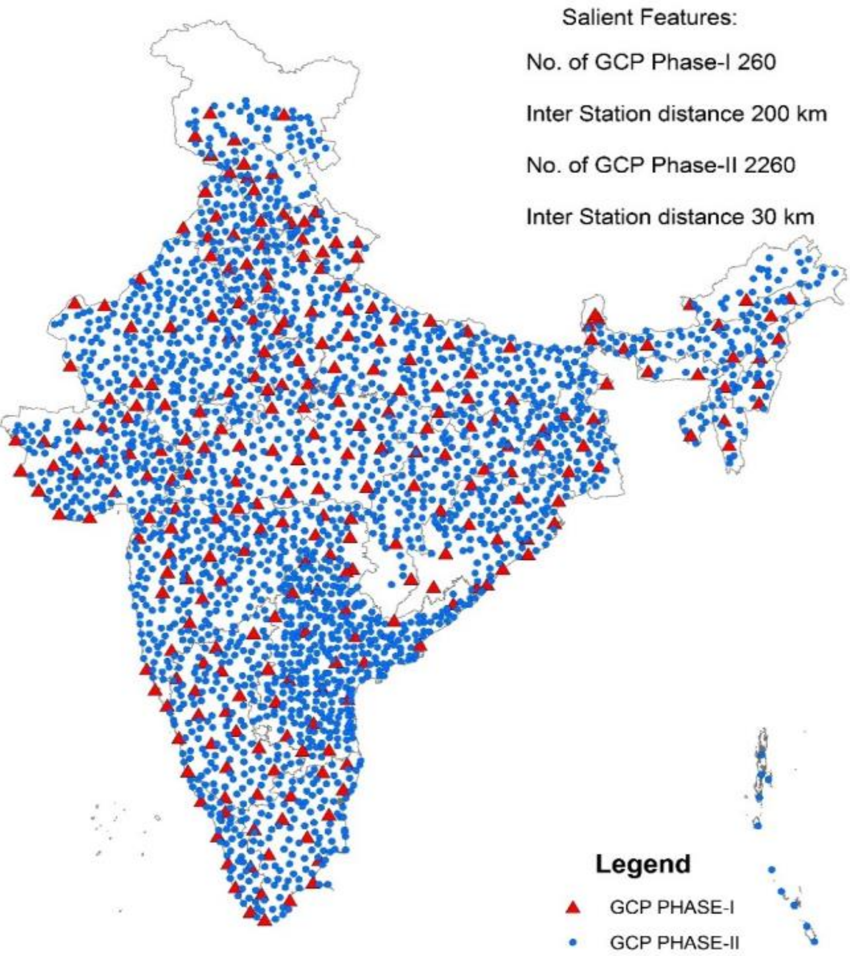


Figure 2a. GCP library. Source: Singh and Kumar (2019) (ref 17)

CORS Network in India

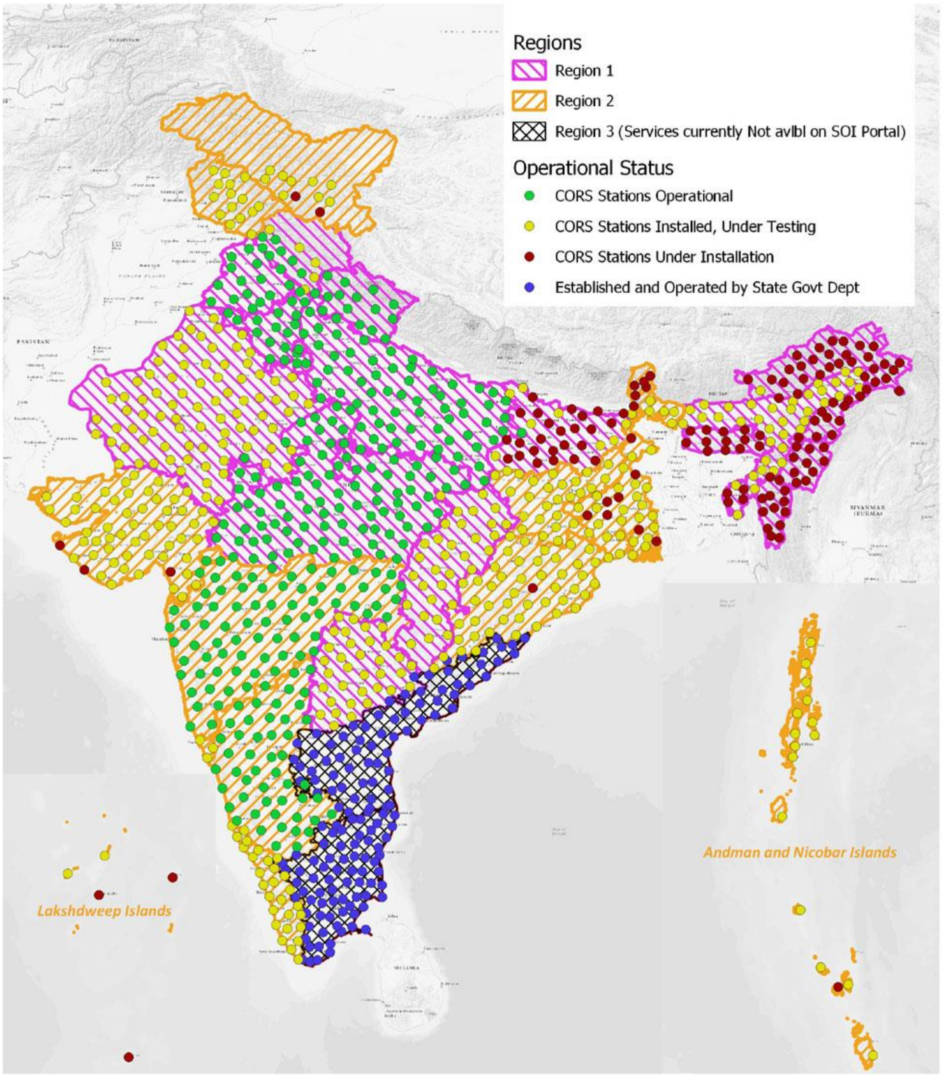
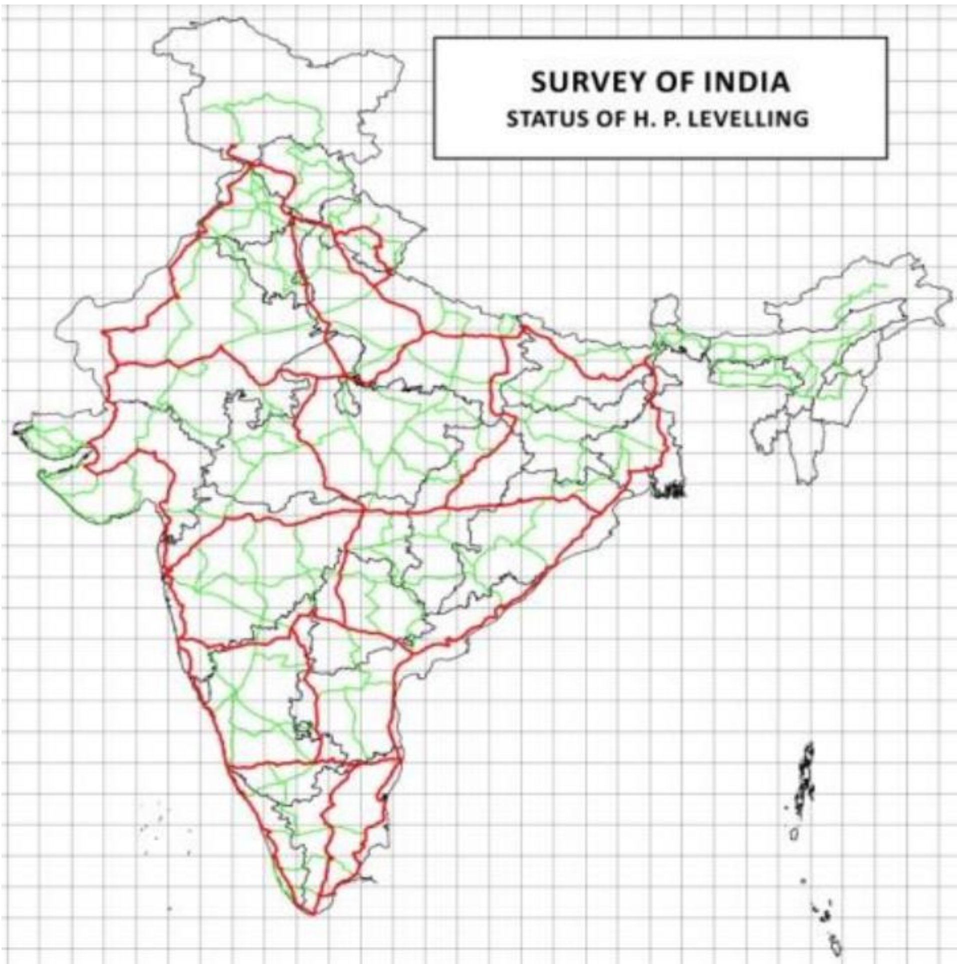


Figure 2b. CORS network. Source: SoI (2022) (ref 18)



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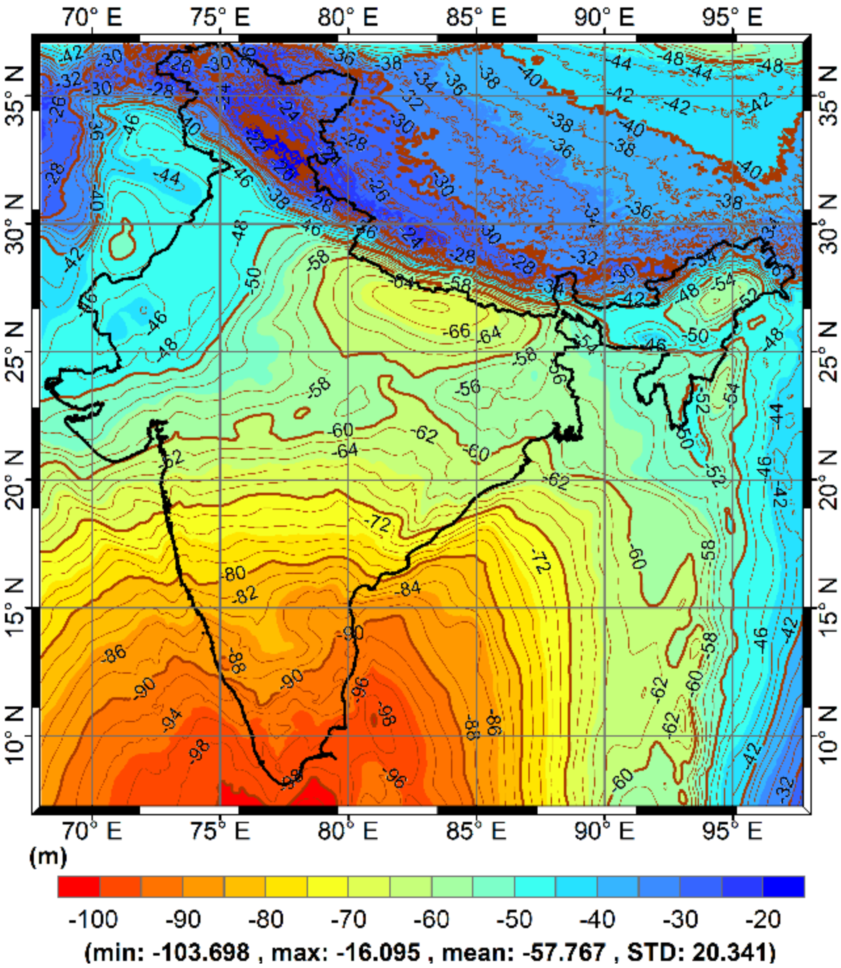

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