India's new map policy – Utility of civil users

Jayanta Kumar Ghosh[1],* and Abhishek Dubey[2]

[1]Department of Civil Engineering, Indian Institute of Technology Roorkee, Roorkee 247 667, India
[2]RMG, Covansys, SDF Buildings, MEPZ, Chennai 600 004, India

With the implementation of India's new map policy (NMP), the user community is looking towards a transformation of spatial database (from Everest-1830 ellipsoid polyconic projection system to WGS-1984 ellipsoid, UTM projection system). Different transformation parameters are available from different sources, which provide different spatial positions for the same location and thus generate confusion among users. Further, mismatch in the two data leads to error in the registration of existing topographic maps with new maps. This study aims at finding out the impact of the different readily available transformation parameters on the spatial location and to determine the extent to which the existing database can be used along with the new series maps without losing accuracy. Results show that there are some geographic regions in India whose topographic database can be used without the need for transformation and within the acceptable positional accuracy requirements, depending on the scale of topographic maps.

Keywords: Civil users, geodetic datum, national map policy, positional accuracy.

WITH the objective of unrestricted production, maintenance and dissemination of spatial data, a new map policy (NMP)[1] has been declared by the National Topographic Database of the Survey of India (SOI). This is an outcome of the consistent demand from several quarters, including the GIS industry to consider the topographic database as a national asset and to make it available without much restriction. Keeping in view the national security objectives, two series of maps have been proposed in the policy, namely defence series map (DSM) to cater to defence and national security requirements, and open series map (OSM) for common civilian use.

The open series maps (OSMs) will be produced in UTM projection system on WGS-1984 datum[2]. WGS-1984 is a conventional terrestrial system (CTS) with earth-centred, earth-fixed coordinate system (ECEF). It is a geocentric ellipsoid established by the US Department of Defense, with its origin or geometric centre at the earth's centre of mass. The WGS-1984 series maps will be openly made available to civil users, in both paper and digital form.

The geodetic datum facilitates the mapping of an area by mathematical representation of complex and irregular earth surface. Presently, the SOI topographic database is based on the Everest-1830 ellipsoid as its geodetic datum along with the polyconic projection system. For India and adjacent countries (except China), Everest-1830 ellipsoid is used as reference datum. Everest-1830 is a topocentric reference surface with its origin at Kalyanpur, Madhya Pradesh[3] (lat. 24°07'11.26"N and long. 77°39'17.57"E).

Definition of problem

Since the new map policy proposes the conversion of reference datum and projection system of the existing database with the introduction of OSMs, the following questions arise: How much difference in spatial information will the proposed changes in topographic database lead to? And since the availability of the new map series will take time, can the currently available topographic database in polyconic projection and Everest datum be used without losing accuracy and to what extent?
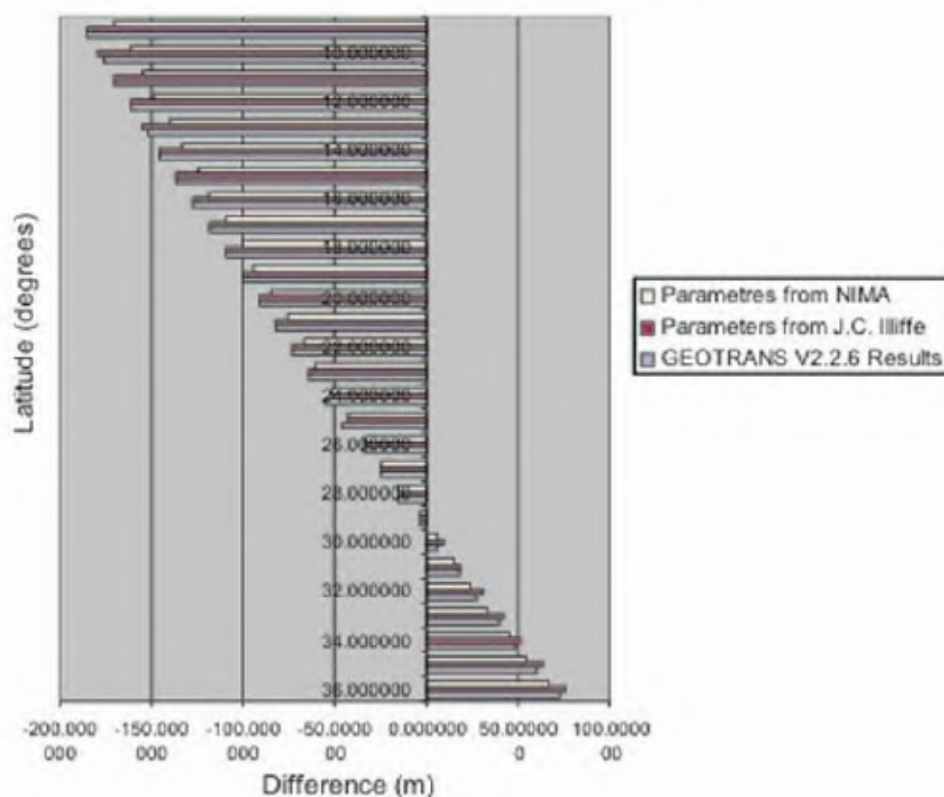
It is possible to theoretically define infinite datum for a large area. But to avoid complexity and to ensure compatibility at the national, regional and global level, the geodetic infrastructure should be founded on a uniform and single layer of well-defined datum.

The difference between positions in terms of an individual local datum and those in terms of a global datum may be of the order of several hundred metres, and may vary considerably even for a single local datum.
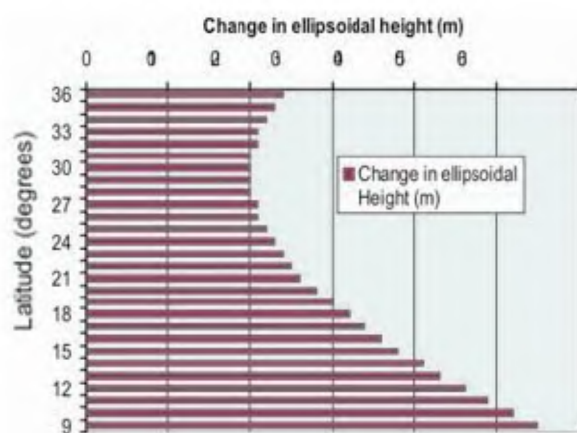
To use the existing maps without introducing any error in the spatial database is to convert the existing maps through datum transformation techniques. Different types of transformation exist like geocentric coordinate transformation, direct transformation and geographic coordinate transformation. Different mathematical models have been developed to establish the relationship between coordinates in two different data, among which the Molodensky–Badekas and Bursa–Wolf models are the most popular[4]. These models require transformation parameters to be developed from the position of known points on local geodetic networks to a uniform regional datum. The simplest transformation to implement involves shifts (translation) to the three geocentric coordinates, with the assumption that the axes of the source and target systems are parallel to each other[5]. For higher accuracies, seven-parameter transformations can be applied (three translational, three rotational and one scale factor), but it is found that consequent errors are generally less than the observational accuracy of the data.

*For correspondence. (e-mail: gjkumfce@iitr.ernet.in)

Datum transformation parameters define a functional relationship between two reference frames. From time to time, due to restrictions placed by the SOI different methods have been used to find the transformation parameters between the Indian reference datum and WGS-1984. So, several values of these parameters are available from different sources, which are creating confusion among the spatial user community. The SOI has already completed the task of determining the transformation parameters for the whole country through GPS observations[4], but these values are not readily available to the user community.

Moreover, due to the availability and ease of using digital form of maps after the introduction of the NMP, it becomes necessary to assess the effect of variations at different scales of maps. With the increasing use of spatial data in digital form, it becomes necessary to integrate all aspects of such a system in terms of datum and accuracy.

Objective

The aim of this study is to find the difference in spatial coordinates of the same position in two reference data (Everest-1830 and WGS-1984) with different sets of transformation parameters (proposed by different organizations) and to estimate the extent up to which the existing topographic maps can be used with OSMs[1].

Methodology

India is a large country. It lies approximately between 68–98°E long. and 8–37°N lat. The country is divided into grids measuring 1° × 1° by the SOI for the purpose of numbering topographic maps on the scale of 1 : 250,000. Coordinates of the corners of this grid covering the whole country have been considered in this study. Transformation is performed between geographic coordinates in Everest-1830 and WGS-1984 using three source sets (types) of transformation parameters: (i) GEOTRANS v2.2.6 software developed and released by the National Imagery and Mapping Agency (NIMA), USA; (ii) transformation parameters based on Molodensky model, and (iii) parameters published by NIMA. The models/assumptions on which transformation parameters are based differ in several ways, including a priori conditions, the type of coordinates used and thus parameter values.

In order to study the effect of variation of latitude and longitude on the difference between the two systems, one of the parameters is kept constant and the other varied, and vice versa. Also, the difference in height in two different ellipsoids has been studied.

Linear equivalent of arcsecond

From Figure 1, the angle between the normal PD at P and the equatorial axis CO is called the geodetic latitude φ.

Angle COP is the geocentric latitude. The radius of curvature[6] at any point P is given by:

$$M = a(1 - e^2)/(1 - e^2 \sin^2 \varphi)^{3/2}.$$

The radius of curvature in the direction perpendicular to the direction of the meridian is $N = PD$.

$$N = \frac{a}{(1 - e^2 \sin^2 \varphi)^{1/2}}.$$

With radius of curvature dependent on the latitude, the value of distance equivalent to 1 arcsec will change accordingly.

Results

It is found that along a N–S direction, i.e. if the longitude is kept constant and latitude varied, the value of coordinate in Everest datum is more than WGS-1984 datum in the north and lower in the south. At long. 77.0°E, the difference in values between two data varies from 2.4″ (74.2 m; at lat. 36.0°) to −6.1″ (−188.624 m; at lat. 8.0°) having no variation, i.e. 0″ somewhere between lat. 29.0° and 30.0°. Magnitude of difference obtained is as follows:

(1) Difference along the meridian (keeping longitude constant) varies from 2.4″ or 74.46 m (at lat. 36.0°N and long. 77.0°E) to −6.1″ or −189.24 m (at lat. 8.0°N and long. 77.0°E; Figure 2).

(2) At latitude near 28°N, the difference in coordinates changes sign which shows that in the northern region the Everest-1830 datum has higher coordinate values and in the southern region it becomes negative (Figure 2).

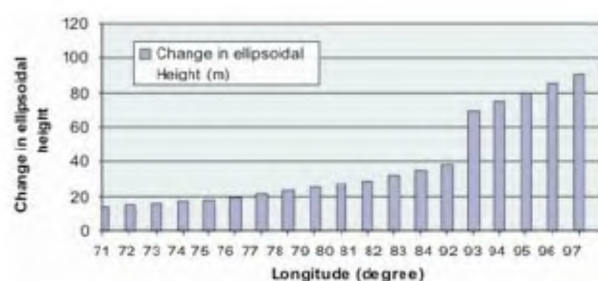**Figure 1.** Ellipsoidal parameters.

Figure 2. Graph showing variation in coordinates (along long. 77.0°E) for different transformation sets.

Figure 3. Graph showing variation in ellipsoidal height with varying latitude at longitude 77°00′00″E.

Figure 4. Graph showing variation in ellipsoidal height with varying longitude (along lat. 27°00′00″N).

(3) In the case of difference in ellipsoidal heights between two data, the variation is found to be 24–55 m along the meridian (at long. 77.0°E; Figure 3).

(4) The same has been found to vary from 14 to 96 m along the parallel (at lat. 27°00′00″N; Figure 4).

(5) Difference along parallel (lat. 27°00′00″N) varies from 0.6″ or 18.61 m (long. 70.0°E) to 12.9″ (long. 96.0°E; Figure 5).

(6) Maximum difference is found to be 12.9″ (398.99 m) in the northeastern region along the parallel 27°N (Figure 5).

Discussion

The effect of these variations in the accuracy in spatial databases will depend on the scale and purpose of the maps.

Results obtained can be discussed from different aspects. As a user, the prime requirement will be accuracy of spa-
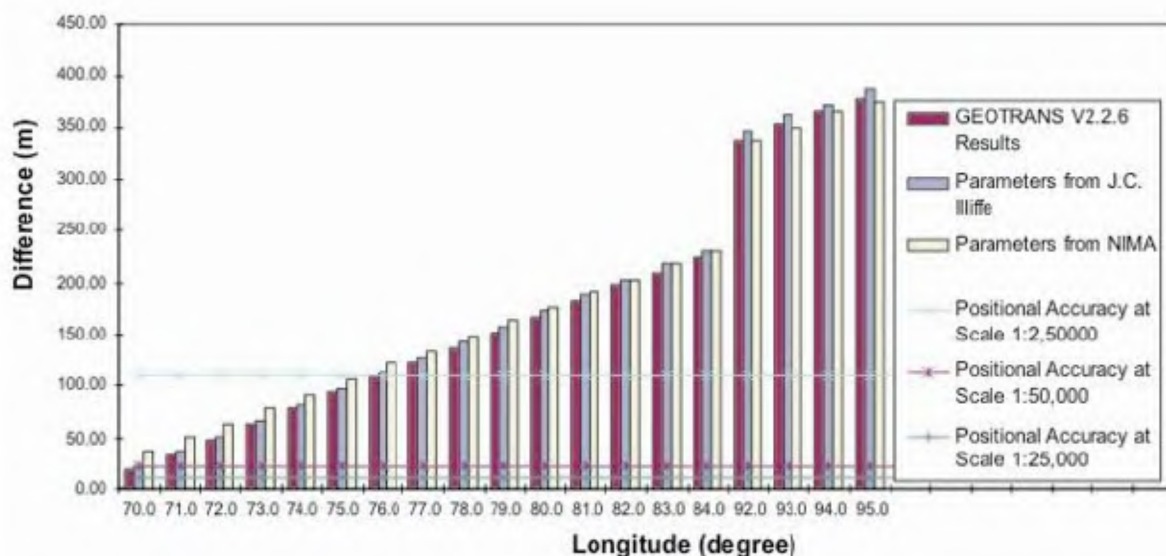
Figure 5. Graph showing variation in coordinates (along lat. 27°N) using different transformation sets. Positional accuracy limit is overlaid on the graph.

Table 1. Positional accuracy at different scales

Map scale	Positional accuracy (m)
1 : 1,000,000	438
1 : 250,000	109.5
1 : 50,000	21.9
1 : 25,000	10.95
1 : 10,000	4.38

tial database. It may be noted that the results of transformation with different parameters differ from each other. These issues are discussed here.

Positional accuracy at different scales

Change in scale of map leads to changing positional accuracy requirements. The SOI provides topographical maps in the following scales: 1 : 1,000,000, 1 : 250,000, 1 : 50,000, 1 : 25,000, 1 : 10,000.

Positional accuracy describes the accuracy in the position of features (ISO Standard 15046-13). It relates to the coordinate values for geographic objects and depends on the absolute and relative positions, termed as absolute accuracy and relative accuracy respectively.

Considering the fact that the error starts accumulating from the plotting process, the following accuracy limits can be defined:

(i)   Plotting accuracy = 0.25 mm
(ii) Accuracy while georeferencing data = 0.2 mm
(iii) Digitizing accuracy = 0.3 mm.

RMS value of the resulting positional accuracy can be calculated as:

$$[(0.25)^2 + (0.2)^2 + (0.3)^2]^{1/2} = 0.438 \text{ mm.}$$

The accuracy limits of different scale maps with this value are given in Table 1.

At constant longitude (along the meridian 77°E), maximum difference is found to be 6.1″ or nearly 189 m (Figure 2). Thus using Table 1 and Figure 2, it can be concluded that the region which varies from lat. 17° to 36° can be tolerated in GIS and remote sensing studies, and the OSMs can be used without loss of accuracy on a scale of 1 : 250,000.

Positional accuracy for different scales is included in the graphs plotted (to show variation in the coordinate difference). This shows regions whose topographic maps (of different scales) can be used in spatial databases without transformation and also how much accuracy loss they will cause. Considering Figure 5, at the scale of 1 : 250,000 the area varying from long. 70°00′00″ to 76°00′00″ at 27° lat. lies below the accuracy limits. Hence topographic maps of this area can be used in the existing datum (Everest-1830) without transforming it to another geodetic datum (WGS-84).

Similarly, at scale 1 : 50,000 the area varying from long. 70°00′00″ to 71°00′00″ at 27° lat. lies below the accuracy limits.

Difference between the datum from long. 70°00′00″ to 76°00′00″ (at 27° lat.) varies from 0.6 to 3.6 arcsec. At the scale of 1 : 250,000, maximum difference between the datum lies well below the positional accuracy obtainable

Table 2. Coefficients of regression models and their RMS and standard errors

Transformation sets	a_1	a_2	a_3	RMS error	Standard error
NIMA	−42.9082	−0.1281	0.7341	0.9768	0.000102
GEOTRANS	−34.3715	−0.8676	0.8632	0.96932	0.000122
Lliffe	−00.7087	−0.8355	0.4062	0.96950	0.000125
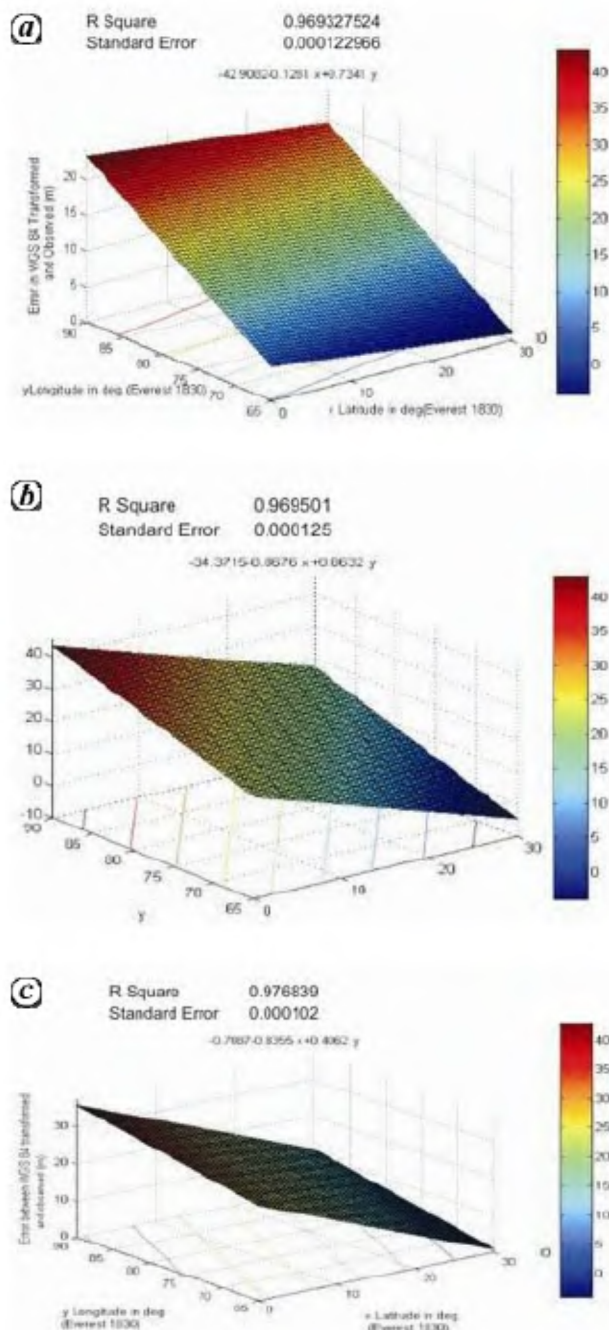
Figure 6. Error surface generated using transformation parameters: *a*, published by NIMA; *b*, GEOTRANS; *c*, Lliffe[4].

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Different transformation parameters

Results show that the difference among different methods (transformation parameters) used is found to be maximum 0.6″, which is well within the tolerance limit of the 1 : 50,000 map (from the positional accuracy requirements, Table 1).

Error surface generation

In order to obtain the error between WGS-84 transformed and WGS-84 observed coordinates at any point with known Everest-1830 geodetic coordinates, the error surface is generated. The utility of the surface model lies in the fact that if the error exceeds the positional accuracy requirements, users can safely reject any further check for difference in datum.

A regression model has been generated from observed and transformed coordinates in WGS-84 using different transformation parameters available[7]. Considering the Everest-1830 coordinates as independent variables and the error between the transformed and observed values of coordinates in WGS-84 coordinates as the dependent variable, a regression model has been developed.

$$\text{Error } (m) = a_1 + a_2 \times \text{latitude} + a_3 \times \text{longitude}.$$

Parameters a_1, a_2, a_3 are determined as shown in Table 2. A test has been performed to find the feasibility of the models (Figure 6 *a–c*). It shows that the maximum error lies below 2.5σ (standard deviation of the testing coordinates) for all the three models created using different transformation parameters.

Conclusion

Depending on the scale and purpose of the work, transformation from one datum to another can be avoided

without losing accuracy in the database. Geographical locations where the use of both geodetic data is possible without losing the positional accuracy requirements can be identified, making the work of the user simpler. Existing maps for the northeastern region are required to be transformed before using them as a source for any spatial database in WGS-1984 datum, since maximum variation is found to be 12.9″ in this region. This shows the requirement for establishing well-defined transformation parameters and estimation of coordinates in both data by the observation method.

Difference in ellipsoidal height at the same latitudes and longitudes varies from 24 to 55 m, which is significant and needs further consideration. The present study has been performed on a grid size of $1° \times 1°$; using a finer grid can refine the results.

The results obtained are calculated for the whole country considering uniform transformation parameters. The results may vary pertaining to the non-uniformity in geography of the country as a whole, if zone-wise transformation parameters are calculated.

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