Accuracy of the Molodensky Transformation Parameters used in Exploration and Production Industry for Transformation between Everest and WGS84 Datums*

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Abstract

A common problem faced by most countries is the estimation of precise transformation parameters between their national geodetic datum, and the World Geodetic System 1984 (WGS84) global datum, used by the Global Positioning System (GPS). There can be considerable difference in positions of the local ellipsoidal datum and the global datum, sometimes up to several hundred meters. So a country like Pakistan may require many transformation parameters for accurate transformation of coordinates from the local datum to the global one and vice-versa.

In Pakistan, there are many transformation parameter sets that are available for Everest and GPS datum. Different parameter sets are being used for transformation of GPS acquired coordinates to local Everest datum and vice versa. Map users and makers are facing many problems due to this non-standardization of the transformation parameters.

This study is focused to evaluate the accuracy of the currently used transformation parameters in the region and to determine the zone wise transformation parameters for Pakistan. All the available transformation parameters from different sources are used to transform the positions of common known points from WGS84 datum to Everest datum. Transformed Everest coordinates are then compared with the original Everest coordinates. Finally, the difference between transformed and original coordinates was calculated and evaluated. On the basis of this difference, different zones and their corresponding best-fit transformation parameters has been established.

This study will ultimately provide standardization and ease for future mapping and will help to reference all previously acquired exploration data to its true Earth location.

Introduction

Positions used for spatial data (latitude and longitude, also expressed as a grid coordinates) are the realization of a reference surface known as the geodetic datum. The datum usually consists of one or more origin stations and a best fitting model of the Earth (an ellipsoid). Positions in terms of the locally adopted datum are propagated through the country, with varying degrees of accuracy, by survey networks. In the past, datums were generally based on one or more astronomically determined positions and the best model of the Earth for the local area. However, with modern technology, such as the Global Positioning System (GPS), global datums are now readily accessible.

The Global Positioning System (GPS) became the most reliable method for providing geodetic control for all mapping, scientific and engineering purpose. Therefore, it can be considered as the most reliable worldwide coordinate system.

The combination of terrestrial and GPS networks has become very essential to benefit from the great accuracy of the GPS positioning system, especially in remote areas. This combination is usually performed through the determination of a set of transformation parameters between the national and the GPS coordinate systems. In the absence of distortions in geodetic networks, independent determination of the coordinates of common stations on another datum should yield identical values of the transformation parameters. However, the actual situation is more complicated. Distortions exist in the national geodetic datum due to many reasons such as (Abdel Motaal, 1994):

- The entire network is not adjusted simultaneously.

- Neglecting the effect of the geoid when reducing the observations to the ellipsoid.

- Astronomical observations are not corrected for polar motion and plumb line curvature.

The geodetic network established in 1830 by the Survey of India, headed by Sir George Everest, is still in use for all surveying and mapping purposes in Pakistan. Nowadays, GPS is in common use so we are often in need of transformation parameters from Everest to WGS84 and vice versa. There have been no standard transformation parameters for conversion of coordinates between these two datums. Every company is using its own transformation parameters. In this way, errors of up to tens or hundreds of meters can result. This error has been estimated and analyzed in different zones of the country. The zones and best parameters for each zone have been determined.

Everest 1830 Datum

The Everest Ellipsoid has been used for Pakistan and several adjacent countries for mapping activities. Named after Sir George Everest, the ellipsoid was derived in 1830 and since then it has been used as the basis for all types of control surveys. Sir George Everest paid careful attention to the measurement of bases and astronomical latitudes and longitudes were measured throughout the arc of the meridian especially at Kalianpur, where many observation were made (Cook, 1990). Dimensions of Everest ellipsoid and its orientation at origin were carried out one by one a number of times. Semi major axis (a), flattening (f) and North-South component of Deflection of Vertical (Meridonal) was defined by Everest in 1840, whereas the East-West (Prime-Vertical) component was defined by Walker in 1878. Though the Everest ellipsoid has been the best fitting mathematical surface for Pakistan and adjacent countries, it cannot be extended too far from the origin and hence its applications are rather limited. For this reason the Indian Datum is probably the least satisfactory of the major datums (DMA Technical Report, 1983).

WGS84 Datum

The World Geodetic System 1984 (WGS84) is used by the U.S. Department of Defense for GPS and is suitable for charting and navigation. The International Terrestrial Reference Frame (ITRF) is based on many GPS, Satellite Laser Ranging (SLR), and Very Long Baseline Interferometry (VLBI) stations worldwide and is recommended by the International Association of Geodesy and PCGIAP for regional datums and scientific applications (Working Group 1 Resolution of 1999).

Transforming Positions

The difference between positions in terms of an individual local datum and positions in terms of a global datum may be of the order of several hundred meters, and may vary considerably even for a single local datum. If the local survey network has variable quality or does not have a continuous landmass, a country may effectively have a number of local datums, requiring a number of different transformations to the global datum.

With the increasing exchange of geographic information locally and globally, positions need to be available in terms of both local and global datums. The process of mathematically converting positions from one datum to the other is known as transformation.

There are a number of ways to mathematically transform positions from one datum to another, but they all require "common points". Common points (Figure 6) are surveyed points that have known positions in terms of both the local and the global datum. The achievable accuracy of the datum transformation will be determined by the number, distribution and accuracy of these common points and the transformation technique adopted. Generally speaking, the greater the accuracy required, the more common points are needed.

The common points chosen should be a good sample of the true relationship between the local and global datums. If the local survey network was entirely consistent and regular and was merely offset from the global datum, a single common point would be sufficient to determine this block shift. However, this is a highly unlikely scenario and the more irregular the local survey network, the more common points will be required. A good understanding of the local datum and survey framework is required before a datum transformation can be produced.

Obtaining Common Points

Ideally, global datum positions should be determined for the local datum origin points and the local survey network recomputed in terms of the global datum. Different locations could be used for the global positions, provided they were accurately connected to the survey network. After the re-computation, every point in the survey network would be a "common point" and, provided the new positions for the origin points were of suitable quality, would probably also give an improved survey network in terms of the global datum.

A re-computation of the survey network in terms of the global datum assumes that all the original observations are available, but this may not be the case. An alternative strategy would be to obtain sample common points at suitable existing survey network sites. These sites should be chosen to represent the characteristics of the network, so where the survey network is consistent only a few would be required, but where it is inconsistent many more would be required. Of course any isolated areas (e.g. unconnected islands) would need their own set of common points. These common points are then used to determine a transformation model for the other points in the survey network and the many derived spatial data sets that depend on the local datum but are not directly connected to the survey network.

It is wise to obtain far more than the minimum number of common points. The redundant points will give a much better idea of the consistency of the survey network and the derived transformation parameters.

A number of the redundant common points ("check points") can be reserved from the initial transformation modeling and later can be used as an independent check of the quality of the transformation process by comparing actual and transformed positions. If the difference between the actual and transformed positions (residuals) is not acceptable, then (i) the derivation of the transformation process can be repeated using a different selection of common points, or (ii) more common points can be obtained, or (iii) a different transformation method can be used.

Transformation Method

There are many ways of modeling the transformation between two datums, but those in common use are the Molodensky"s, 7-Parameters and Surface Fitting methods.

Molodensky"s Formulae are commonly used in handheld GPS receivers and Geographic Information Systems (GIS). The formulae are simple, assuming that the transformation between the local and global datums can be represented by 5 parameters: a shift at the origin (the Earth"s center of mass) along the Earth-centered Cartesian coordinate axes (DX, DY, DZ), and the difference between the local and global ellipsoids (semi-major axis and flattening). The origin shifts can be determined by averaging of the same differences at each of the common points, and the difference in ellipsoids is a simple subtraction of the ellipsoid parameters.

The Molodensky Model (Figure 1) simply applies a three-dimensional origin shift, with little regard for any scale changes or rotations. Therefore, it is coarse but also extremely simple to implement. The Cartesian coordinates from the initial datum are simply added to the origin shift, and then converted to curvilinear coordinates on the new datum.

The United States Department of Defense WGS84 Technical report provides Molodensky parameters to transform between many local datums and WGS84. However, the data on which these parameters are based may be very limited and the parameters may have limited accuracy. Although it depends on the data used, the best accuracy that could be expected from this method would be perhaps 5 meters.

Method of Study

The Molodensky Model was used in this study, where the origin shifts were taken from the 25 selected three transformation parameters, one by one, used in the Exploration and Production Industry. These parameters were taken from different sources. Twenty-five different Molodensky Transformation parameter sets and 30 common points, well distributed in the country, were used in this study. The coordinates of these common points were transformed from one datum to another using Molodensky Transformation parameters. All 25 options of Transformation parameters were used to transform 20 common points from one datum to another. Transformed coordinates were compared with original coordinates and the difference was calculated and projected on the graph. The results were analyzed and six different zones and their best-fit corresponding parameters were selected. Ten unused common points (check points) were transformed using the obtained 3 parameters to check their accuracy. On the basis of primarily obtained results and their analysis, three instead of six zones were identified.

Results and Discussion

In the case of terrestrial geodetic horizontal networks (networks established by classical, terrestrial-based measurement techniques, e.g. Everest 1830), the accuracy of geodetic (ellipsoidal) heights „h" may be significantly lower than accuracy of the other two coordinates „Latitude" and „Longitude", and that height is missing altogether. In this study, ellipsoidal height was considered in transformation but it was neglected in comparison due to unavailability of Everest ellipsoidal height. WGS84 coordinates were transformed to Everest coordinates by using selected transformation parameters in order to avoid errors due to missing Everest ellipsoidal height.

Molodensky Transformation Parameters will usually be satisfactory as long as the area for which the transformations are to be used is small. As the area increases, the effect of the unknown rotation or scale change will become significant and lead to distortion. The 3-Parameters transformation implicitly assumes that there are no rotations and no scale change between the two systems. If rotation or a scale change does exist, these effects are being accommodated by these three parameters. So the 3-Parameters method has lower accuracy than the 7-Parameters and Surface Fitting methods.

From the very beginning of this study it was suspected that a single set of transformation parameters for the entire country may not give the level of accuracy required for topographic applications and E & P requirements due to inconsistency and irregularity in the Indian triangulation network. However, to form a definite opinion, initially the model was applied to all 20 points, but 30% of the points were kept reserved for checking the quality of selected transformation parameters. The strategy did not work and it give larger positional errors in transformed and original coordinates.

Care should be taken when using 3-Parameter transformations to not extrapolate far outside the area of common points used to derive the transformation. Ideally, the transformation should be used for points within the area defined by the common points. To minimize extrapolation, first six (Figure 6) and then three (Figure 7) zones were developed for Pakistan.

The transformation parameters, used zone-wise, have brought out a significant improvement in accuracy of transformed coordinates. For most of the stations the transformation accuracy was improved to the level of +/-5 m, which is well within permissible limit on 1:50,000 scale and would serve the purpose of converting existing topographic maps to WGS-84 maps.

In order to minimize errors in transformed coordinates resulting due to non-homogeneity of Everest coordinates, it was decided to produce separate parameter sets for sub-regions. The entire region covered by GPS observations was divided into 6 Zones (Figure 6) to meet the requirement of consistency in the GT (Grand Triangulation) coordinates.

The various levels of positional errors in transformed coordinates with different options has been shown zone-wise in Figure 2. The effect of consistency in Everest coordinates on the accuracy of transformation is clearly visible in Figure 3, Figure 4 and Figure 5. However, the zone-wise transformation parameters devised from this exercise are accurate enough to accomplish the goal of producing WGS-84 series maps on 1:50,000 or smaller scales Everest and WGS-84 datums.

If the local terrestrial network is consistent or well-adjusted within a framework, few points would be sufficient to determine datums (local and global) relationship. However, this is a highly unlikely scenario and may be feasible in countries where the extent of the local network is confined to a smaller region. But in Pakistan and India, where the geodetic network is more irregular and coverage is large, it would be difficult to select the few points to represent the characteristics of the entire network. Even after the division into six parts, only meter level transformation accuracy could be achieved. Therefore, it is highly desirable to readjust the existing network so that every point would represent the actual quality of network. Also, there is need to apply more sophisticated techniques of transformation, such as 7-Parameters or Surface Fitting, which cater for distortion in the local survey network providing improved transformation for derived data sets. Where a sufficient quality data set has been used, transformation with an accuracy of better than 10 cm has been achieved.

Conclusions

Most of the transformation parameters were transforming one of the coordinates accurately but giving error in other coordinates (Figure 2). Some transformation parameters were giving accurate results in one or two zones, but they were not accurate for other zones. If they were applied to that particular zone, accurate transformation could be obtained, but for the entire country it was causing erroneous transformed coordinates.

Initially, six transformation zones were identified (Figure 6). After some analysis and adjustment of transformation parameters, the number of zones was reduced to three (Figure 7). The distortion between original and transformed coordinates is due to:

- Extrapolation of parameter.
- Non-geodetically determined parameters.
- Common points accessibility.

The transformation parameters for northern (Figure 3) zone have lower accuracy due to having the highest mountain ranges of the world in the area. The central (Figure 4) and southern (Figure 5) zones have better accuracy of selected transformation parameters due to the plains terrain of the middle and lower Indus Basin.

An effort should be made to find transformation parameters for the entire country, but its accuracy could be limited. The Molodensky 3-Transformation Parameters Model was used (Figure 8) instead of the Molodensky Transformation Formulae due to better comparative accuracy of the transformation model assessed during this study.

The transformation parameters and zones identified in this study have accuracy as follows:

Zone	Northern	Central	Southern
Transformation Accuracy	+/- 6 m	+/- 5 m	+/- 5 m

There should be some standardization of using transformation parameters by the Government (concerned department) in order to achieve the consistency in all E & P data, and to avoid waste of money, and to accurately georeference exploration data.

References Cited

Abdel Motaal, H., 1994, Comparison of polynomial and similarity transformation based datum-Shift: Geodesique, v. 68, p. 168-172.

Cook, A., 1990, The achievements of Sir George Everest in Geodesy: Survey Review, v. 30, p. 368-374.

DMA Technical Report, December 1983, Geodesy for the Layman, DMA-TR80-003.

El Tokey, M.E., 1993, On the determination of consistent transformation parameters between GPS and the Egyptian geodetic reference systems: (PhD Thesis) Faculty of Engineering, Ain Shams University, Cairo, Egypt.

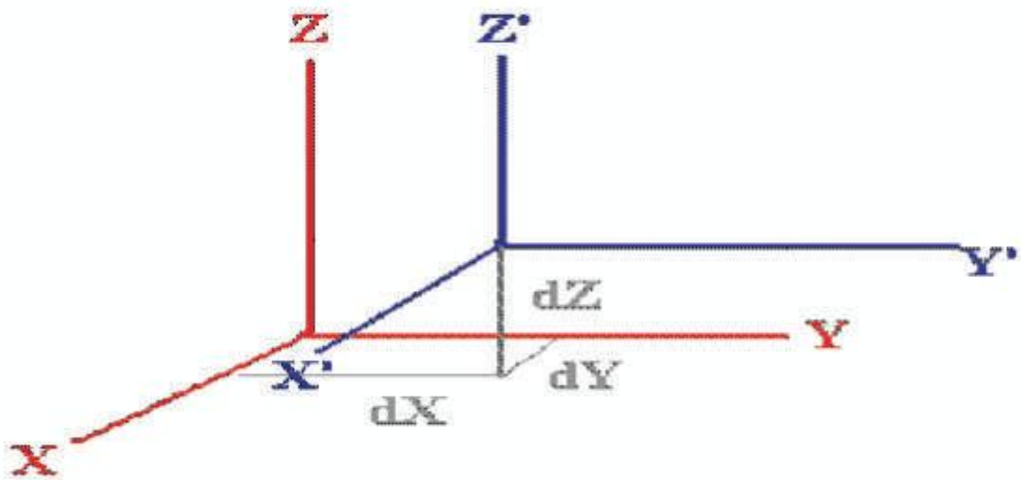
Featherstone, W.E., and P. Vanicek, 1999, The role of coordinate system, coordinates and heights in horizontal datum transformation: The Australian Survey, v. 44/2.

Featherstone, W.E., 1997, A comparison of existing coordinate transformation models and parameters in Australia Cartography: The Australian Survey, v. 26/1, p. 13-26.

Howr, J. Gregrey, 1982, Satellite surveying theory, geodesy, map projection application, equipment and operation, Magavox.

National Imagery and Mapping Agency (NIMA), 2000, Department of Defense World Geodetic System 1984: its definition and relationships with local geodetic systems, 3rd Edition: NIMA Technical Report, Department of Defense, Bethesda, Maryland, 1 volume (various pagings), maps.

Singh, S.K., 1994, Coordinate transformation between Everest and WGS-84 datums – A parametric approach: Geodetic & Research Branch, Survey of India, Dehradun, India: Web accessed 19 February 2013. http://www.gisdevelopment.net/proceedings/asiangps/2002/gpsdp/trend004pf.htm



$$\begin{pmatrix} X' \\ Y' \\ Z' \end{pmatrix} = \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} + \begin{pmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{pmatrix}$$

Figure 1. Molondesky Datum Transformation Parameters and Model.

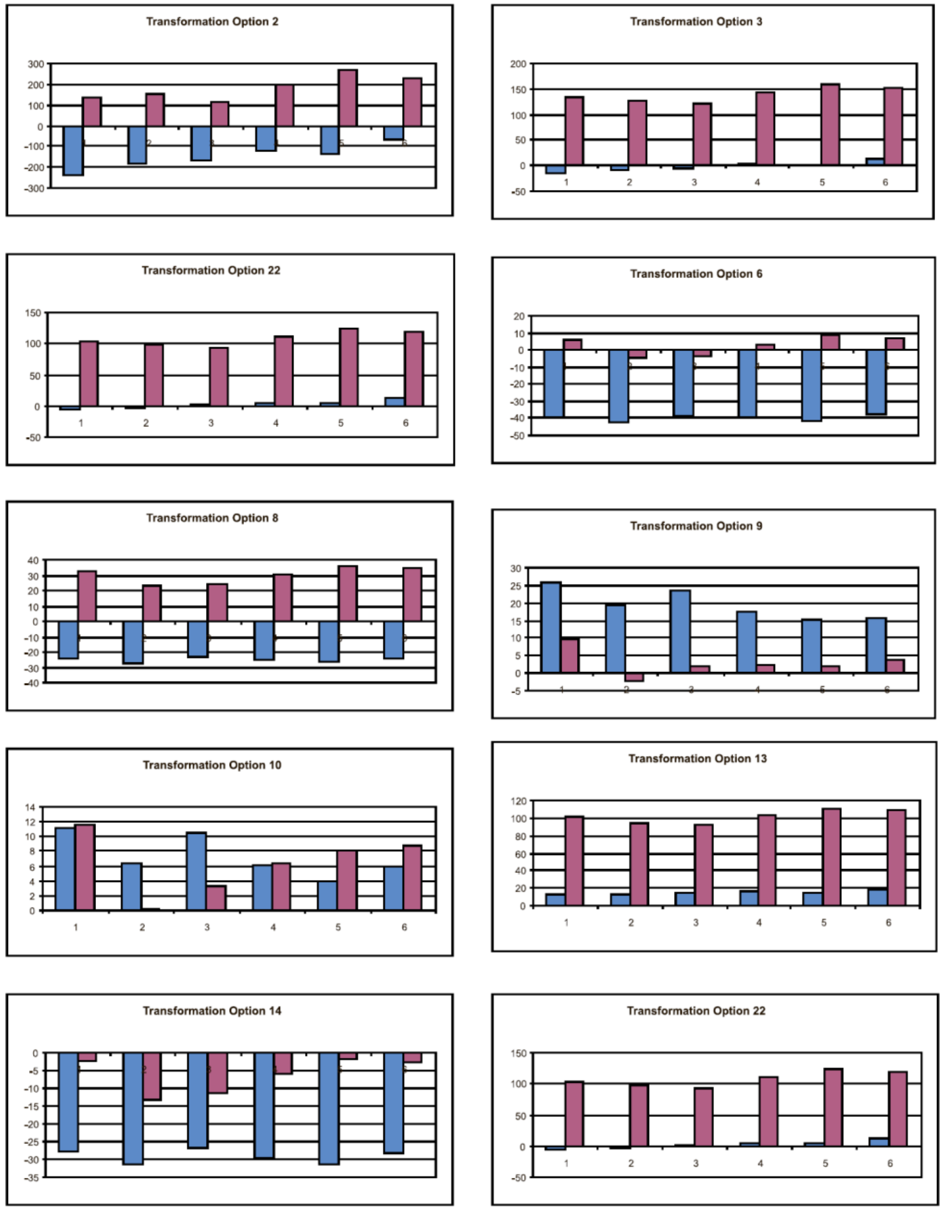


Figure 2. Positional error in horizontal coordinates by comparing original and transformed .

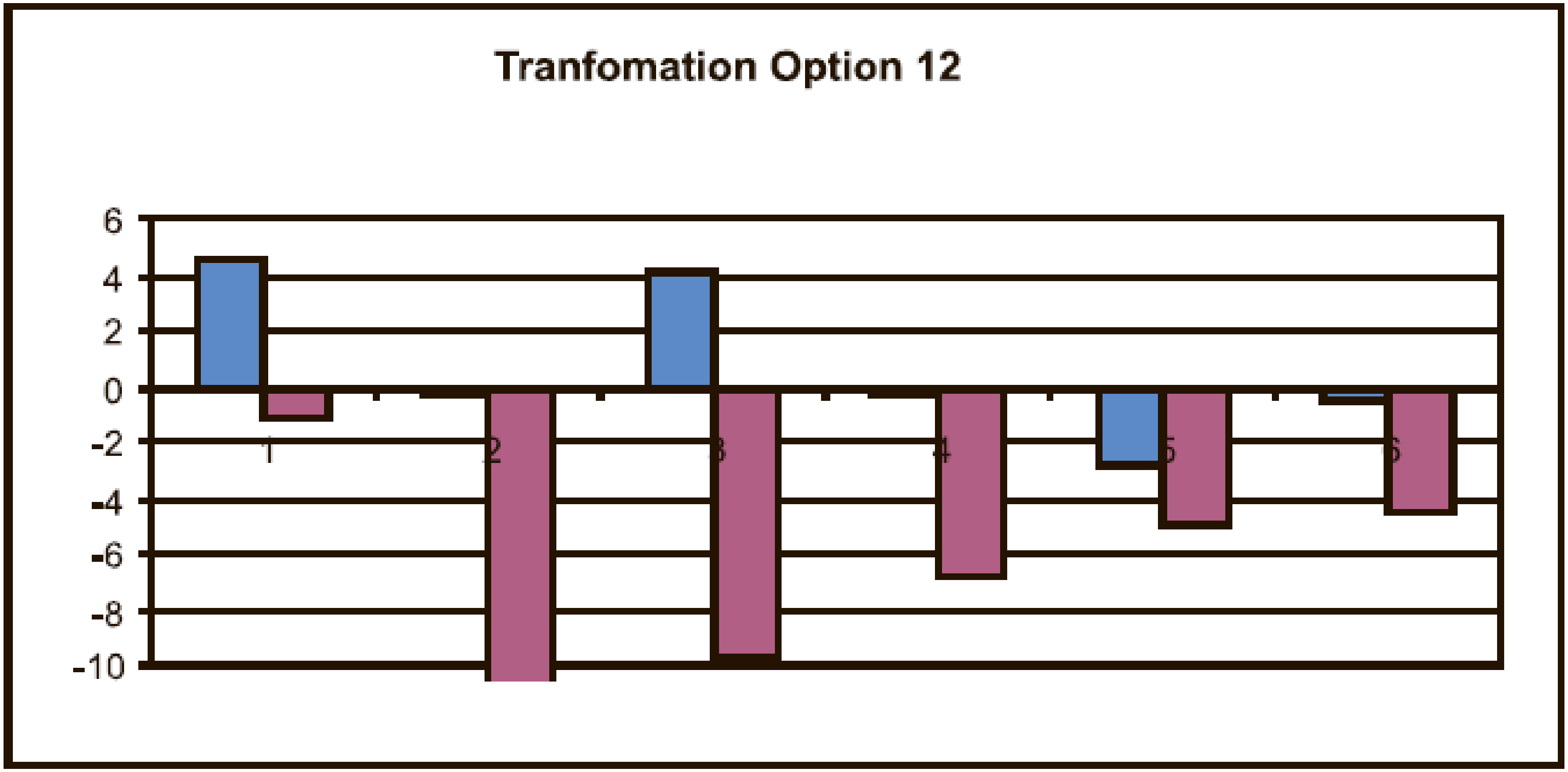


Figure 3. Positional error of transformed coordinates in northern zone.

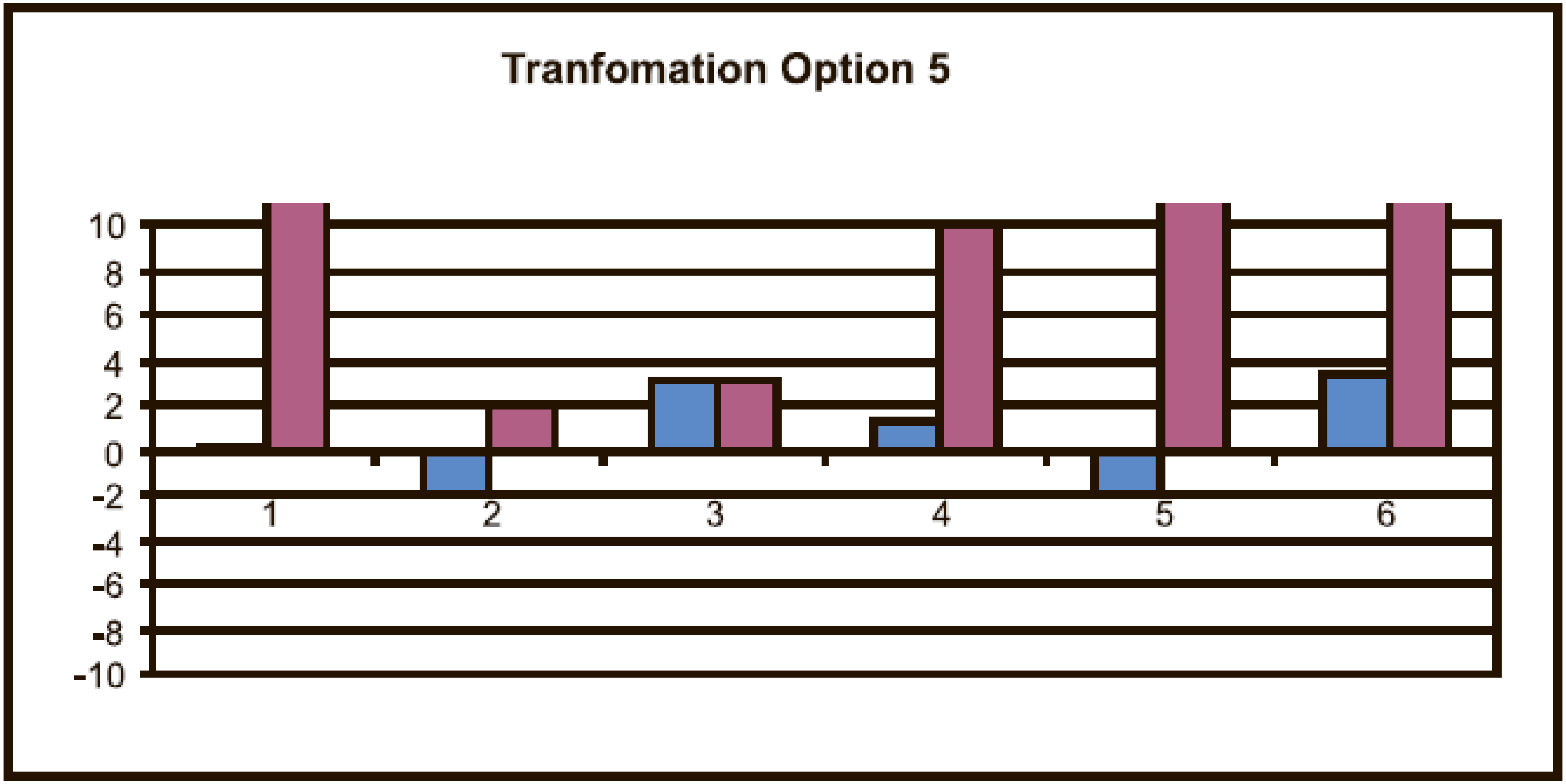


Figure 4. Positional error of transformed coordinates in central zone.

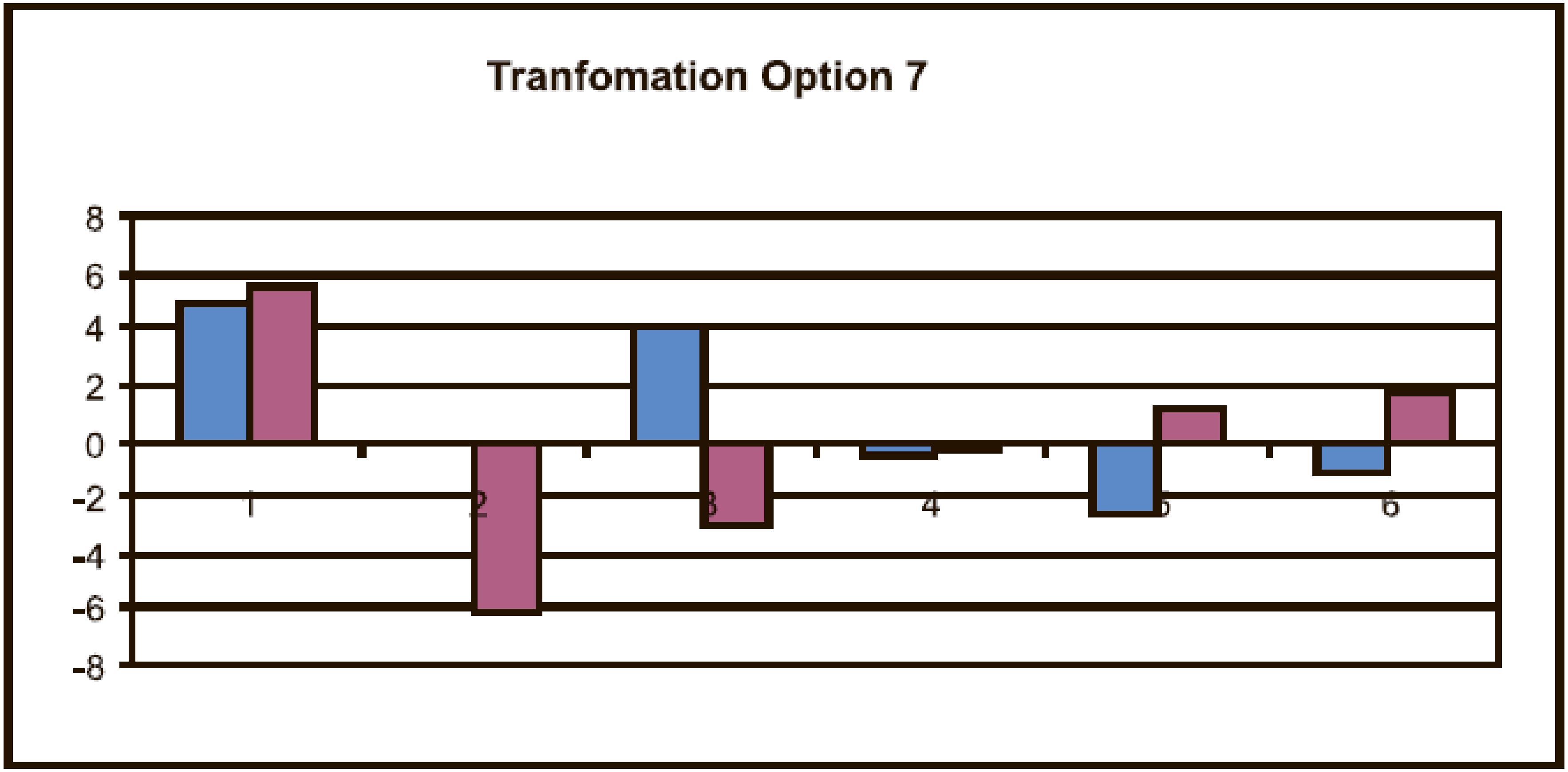


Figure 5. Positional error of transformed coordinates in southern zone.

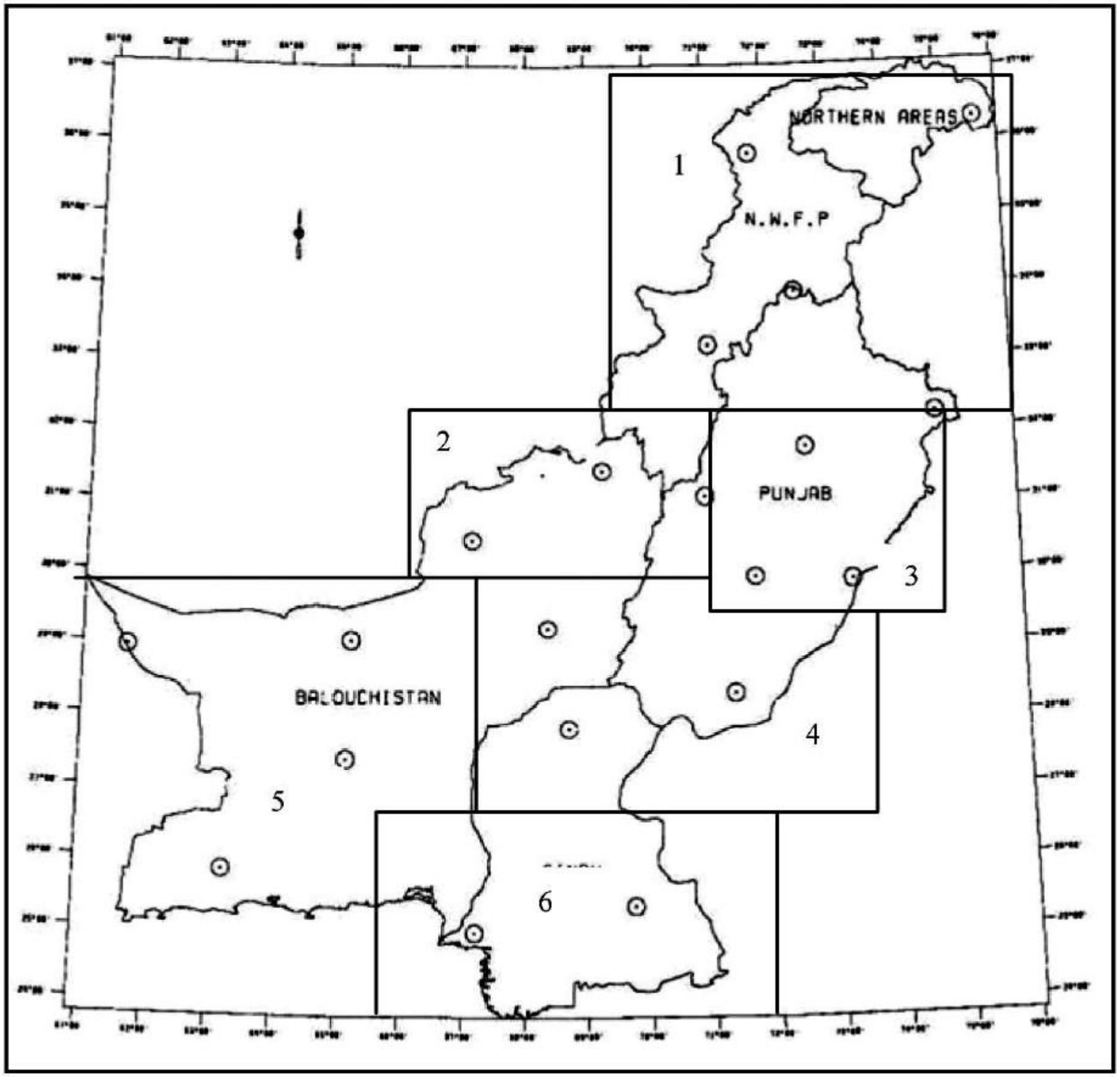


Figure 6. Common points and six transformation zones initially identified.

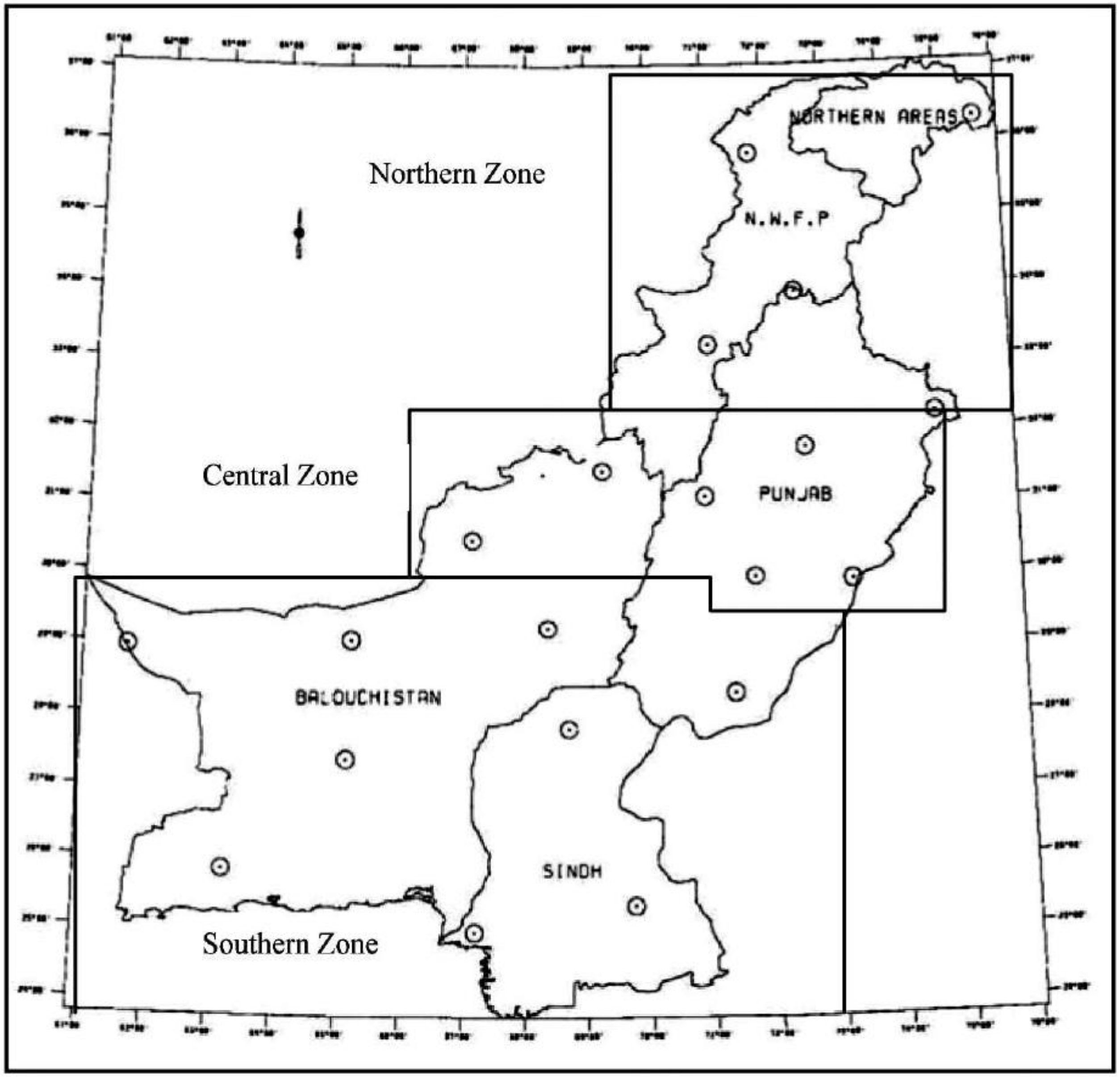


Figure 7. Three Molodensky transformation zones for Pakistan after analysis and adjustment.

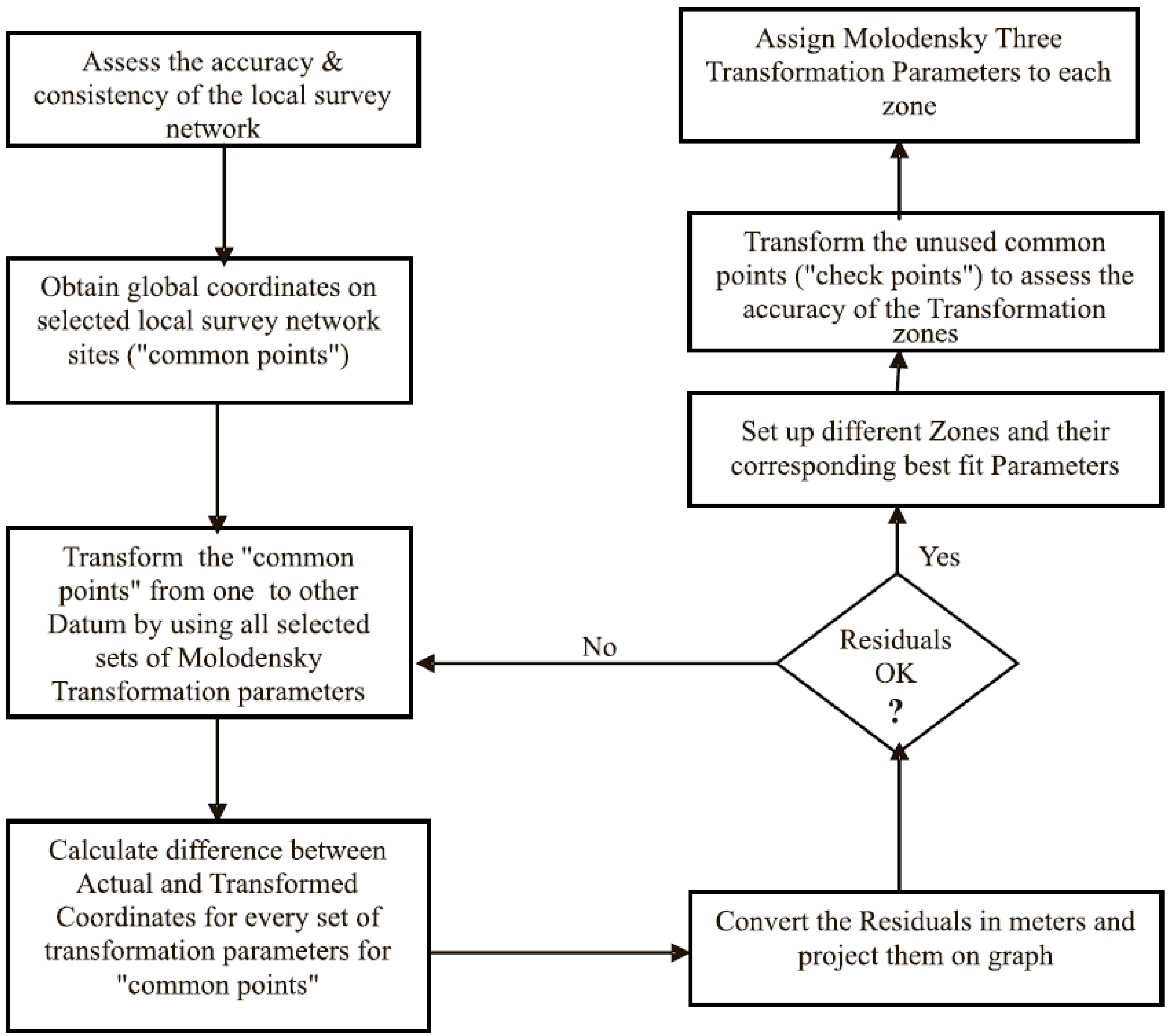


Figure 8. Flowchart of general transformation procedure, using Molodensky 3-Transformation Paramenters method.