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Coordinate transformation parameters in Nepal by using neural network and SVD methods

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Abstract: The present study computes B-W extension model (extended Bursa-Wolf model) coordinate transformation parameters from World Geodetic System 1984 (WGS-84) to the Everest datum namely Everest (1830) and Everest (1956) using records of coordinate measurements from Global Positioning System (GPS) observable across Nepal region. Synthetic or modeled coordinates were determined by using the Artificial Neural Network (ANN) and Singular Value Decomposition (SVD) methods. We studied 9-transformation parameters with the help of the ANN technique and validated the outcomes with the SVD method. The comparative analysis of the ANN, as well as SVD methods, was done with the observed output following one way ANOVA test. The analysis showed that the null hypothesis for both datums were acceptable and suggesting all models statistically significantly equivalent to each other. The outcomes from this study would complement a relatively better understanding of the techniques for coordinate transformation and precise coordinate assignment while assimilating data sets from different resources.

Keywords: Coordinate Transformation, Everest datum, Neural Network, SVD

1 Introduction

The geocentric datum Everest (1830) and Everest (1956) are the official Indian continent coordinate systems and have been implemented for more than 150 years. These datums played an important role in the geodetic studies of the Indian continent. Generally, the 7-parameter (one scale factor, three rotations, and three translations) transformation model was employed to compute the transformation parameters. However, the number of transformation parameters can be increased for better accuracy in positioning. For example, 3 different scale factors may be computed instead of one scale factor. There were various approaches used to coordinate transformation parameters in different local datum like Artificial Neural Network (ANN) (Tierra et al, 2008), Procrustes approach (Awange et al, 2008) and least square method (Ansari et al, 2017a, 2018) etc. ANN is a computing system contains the number of neurons interrelated with the links of variable synaptic weights. The weighted input information is received by each neuron unit by a factor which indicates the strength of the synaptic relation to generating an output. This output is then forwarded as a new input to an added neuron by adapting new weights (Ziggah et al, 2016). The main objective of the study was to build an ANN forecasting model that can compute the transformation parameters for the Everest datums. We used the Back Propagation Artificial Neural Network (BPANN) for converting coordinates from WGS-84 to Everest datum. A feed-forward network with 10 neurons was created and trained on that given data. Except for BPANN, another technique known as Singular Value Decomposition (SVD) method for the purpose of validation and simplicity for readers was also applied in the study. Here, we used BPANN method for the 22 GPS stations located all over Nepal (Fig. 1) and tried to compute the coordinate transformation parameters from WGS-84 to Everest datum. These GPS data were available for the public at the website of Caltech Tectonics Observatory as well as UNAVCO. The GPS observation data in rinex formats have been downloaded from UNAVCO website (ftp://data-out.unavco.org/pub/rinex/) and processed on a daily basis by using GAMIT-GLOBK processing software (Herring et al, 2010). The IGS sites namely LCK3 (Lucknow) from India, LHAZ (Lhasa) from Tibet and one permanent GPS site TIMP from Bhutan have been used to link between regional and global solutions.

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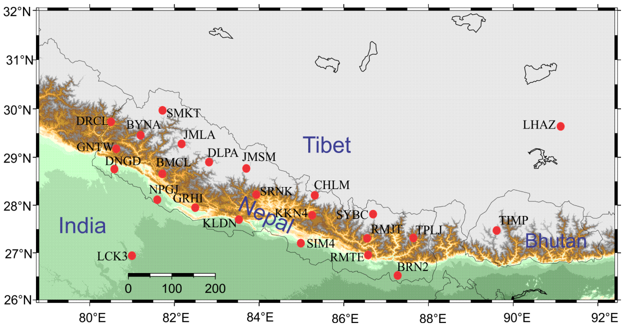

Figure 1: Location of GPS sites in WGS-84 coordinate system

2 Definition of the Problem

Let us consider in 7-parameter transformation model (from WGS-84 to Everest datums) s is scale factor, R_x, R_y, and R_z are three rotations and T_x, T_y and T_z are three translations parameters. Then the Bursa-Wolf model from Everest datum to WGS-84 can be written in the simple form (Bursa 1962):

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{Everest} = \begin{bmatrix} T_x \\ T_y \\ T_z \end{bmatrix} + s \begin{bmatrix} 1 & R_z & -R_y \\ -R_z & 1 & R_x \\ R_y & -R_x & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{WGS84} \tag{1}$$

Here we used 9-parameter (three scale factors, three rotations, and three translations) transformation model and named it B-W extension model. If we take three different scale factors (s_x, s_y, and s_z) in X, Y and Z directions respectively then the Eq. (1) can be written like this:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{Everest} = \begin{bmatrix} T_x \\ T_y \\ T_z \end{bmatrix} + \begin{bmatrix} s_x & 0 & 0 \\ 0 & s_y & 0 \\ 0 & 0 & s_z \end{bmatrix} \begin{bmatrix} 1 & R_z & -R_y \\ -R_z & 1 & R_x \\ R_y & -R_x & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{WGS84} \tag{2}$$

The Eq. (2) showed the form of the B-W extension model.

2.1 BPANN Approach

The BPANN is a multi-layer feed forward approach which works according to error back propagation algorithm. BPANN is able to learn the appropriate internal representations and allow learning any arbitrary mapping of input to output (Rumelhart et al, 1986; Jiang et al, 2008). If we consider x_1, $x_2 \ldots, x_i$ are input nodes, y_1, $y_2 \ldots, y_j$ are the hidden layer nodes and z_1, $z_2 \ldots, z_k$ are the output nodes then a simple BPANN architecture can be given like Fig. 2. In the figure the red circles showed input layer nodes, blue circles indicate hidden layer nodes and green circles are the symbols of output layer nodes.

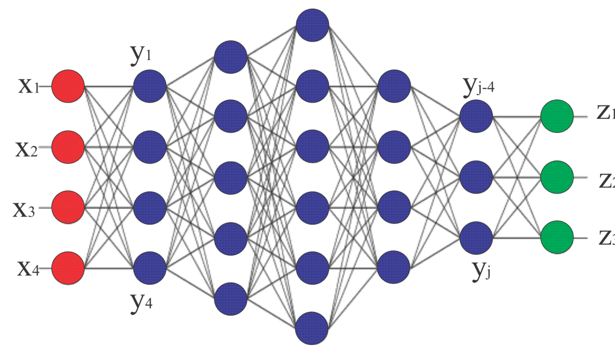

Figure 2: Structure of artificial neural network (ANN)

The computational formula for hidden layer nodes can be expressed as follows:

$$y_j = f\left(\sum_i v_{ij} x_i - \tau_j\right) \tag{3}$$

Where v_{ij} is the weight value of the network between input nodes and hidden layer nodes with threshold value τ_j for the hidden layer nodes. Similarly, if we have w_{ij} weight values of the network between hidden layer nodes and output nodes with threshold value τ_k for the output nodes. The computational formula for output nodes can be given by:

$$z_k = f\left(\sum_i w_{jk} y_j - \tau_k\right) \tag{4}$$

Let us consider ζ_k is the expected values for output nodes then the error (E) in output nodes will be given by:

$$E = \frac{1}{2} \sum_k (\zeta_k - z_k)^2 \tag{5}$$

Putting the value of z_k and then y_j in Eq. (5)

$$E = \tfrac{1}{2} \sum_k \left(\zeta_k - f\left(\sum_i w_{jk} y_j - \tau_k\right)\right)^2 \quad \text{and then}$$

$$E = \frac{1}{2} \sum_k \left(\zeta_k - f\left(\sum_i w_{jk} f\left(\sum_i v_{ij} x_i - \tau_j\right) - \tau_k\right)\right)^2 \tag{6}$$

The training process keeps on continuation by regulating the output weight towards the input until the functional error attains an acceptable value.

2.2 SVD method

In linear algebra, the SVD is a factorization of a real or complex matrix. Suppose G is an $m{\times}n$ order real or complex matrix having factorization in the form of $U\sum V^T$, where U is an m×m orthogonal matrix, Σ is an m×n diagonal matrix and V is an $n{\times}n$ orthogonal matrix. Since we need to estimate the transformation parameter of the Eq. (2), we can modify in the following form:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{Everest} = \begin{bmatrix} 1 & 0 & 0 & X & 0 & 0 & 0 & -Z & Y \\ 0 & 1 & 0 & 0 & Y & 0 & Z & 0 & -X \\ 0 & 0 & 1 & 0 & 0 & Z & -Y & X & 0 \end{bmatrix}_{WGS84} \begin{bmatrix} T_x \\ T_y \\ T_z \\ s_x \\ s_y \\ s_z \\ R_x \\ R_y \\ R_z \end{bmatrix} \tag{7}$$

Suppose the number of GPS sites is p having coordinate (x_1, y_1, z_1), $(x_2, y_2, z_2) \ldots (x_p, y_p, z_p)$ then, in general, the Eq. (7) will be given by like this:

$$\begin{bmatrix} x_1 \\ y_1 \\ z_1 \\ : \\ : \\ : \\ x_p \\ y_p \\ z_p \end{bmatrix}_{Everest} = \begin{bmatrix} 1 & 0 & 0 & x_1 & 0 & 0 & 0 & -z_1 & y_1 \\ 0 & 1 & 0 & 0 & y_1 & 0 & z_1 & 0 & -x_1 \\ 0 & 0 & 1 & 0 & 0 & z_1 & -y_1 & x_1 & 0 \\ : & :: & :: & :: & :: & :: & :: & :: & : \\ : & :: & :: & :: & :: & :: & :: & :: & : \\ : & :: & :: & :: & :: & :: & :: & :: & : \\ 1 & 0 & 0 & x_p & 0 & 0 & 0 & -z_p & x_p \\ 0 & 1 & 0 & 0 & y_p & 0 & z_p & 0 & -x_p \\ 0 & 0 & 1 & 0 & 0 & z_p & -y_p & x_p & 0 \end{bmatrix}_{WGS84} \begin{bmatrix} T_x \\ T_y \\ T_z \\ s_x \\ s_y \\ s_z \\ R_x \\ R_y \\ R_z \end{bmatrix} \tag{8}$$

For simplicity the Eq. (8) can be written like this:

$$[d] = [G][n] \tag{9}$$

Let us consider for the general purpose the number of the unknown parameters are n and number of the equations are m (here $m{=}3p$) then we will start by considering the linear problem ($d = Gn$)

Since G is m×n order matrix then its SVD factor U, $\sum$, and V can be written like this:

$$U = \begin{bmatrix} u_{11} & u_{12} & .. & u_{1m} \\ u_{21} & u_{22} & .. & u_{2m} \\ : & : & :: & : \\ u_{m1} & u_{m2} & .. & u_{mm} \end{bmatrix}_{m\times m}; \quad \Sigma = \begin{bmatrix} \sigma_{11} & 0 & .. & 0 \\ 0 & \sigma_{22} & .. & 0 \\ : & : & \sigma_{nn} & : \\ 0 & 0 & .. & 0 \end{bmatrix}_{m\times n}; \quad V = \begin{bmatrix} v_{11} & v_{12} & .. & v_{1n} \\ v_{21} & v_{22} & .. & v_{2n} \\ : & : & :: & : \\ v_{n1} & v_{n2} & .. & v_{nn} \end{bmatrix}_{n\times n} \tag{10}$$

Now the minimum norm solution will be given like this:

$$\begin{bmatrix} T_x \\ T_y \\ T_z \\ s_x \\ s_y \\ s_z \\ R_x \\ R_y \\ R_z \end{bmatrix} = \frac{1}{\sigma_{11}} \begin{bmatrix} u_{11} \\ u_{21} \\ : \\ : \\ u_{m1} \end{bmatrix}^T [d] \begin{bmatrix} v_{11} \\ v_{21} \\ : \\ : \\ v_{n1} \end{bmatrix} + \frac{1}{\sigma_{22}} \begin{bmatrix} u_{12} \\ u_{22} \\ : \\ : \\ u_{m2} \end{bmatrix}^T [d] \begin{bmatrix} v_{12} \\ v_{22} \\ : \\ : \\ v_{n2} \end{bmatrix} + \ldots\ldots. + \frac{1}{\sigma_{nn}} \begin{bmatrix} u_{1n} \\ u_{2n} \\ : \\ : \\ u_{mn} \end{bmatrix}^T [d] \begin{bmatrix} v_{1n} \\ v_{2n} \\ : \\ : \\ v_{nn} \end{bmatrix} \tag{11}$$

The Eq. (11) will be the final solution to the given problem.

3 Computation of Transformation Parameters

The shocking and strong earthquakes occurred in Nepal and the surrounding Himalayan areas in history showed a seismotectonic local feature (Mukul et al, 2014, 2018). Distortions resulting from the crust motion are handled by using numerical methods (Ansari 2014, Ansari et al, 2017b) including transformation parameters. In the 9-parameter transformation includes the determination of three different scale factors for the corresponding coordinate axes (Yetkin and Ansari, 2017). The use of 9-parameter transformation in the computation of transformation parameters between different datum solutions is needed for seismically active countries such as Nepal (Ansari, 2018). The main objective of this study was to address this important issue and to determine 9-transformation parameters using ANN technique and validation with SVD method. The results of the transformation parameter from both methods have been shown in Table 1. The comparison study for both types of methods using ANOVA test has been investigated in the next section. The closeness of measured Cartesian coordinates and predictions based on the training for Everest 1830 and Everest 1956 has been shown in Figs. 3 & 4 respectively. This is notable for Everest (1830) datum the translation parameters in X and Y directions are negative while Z has positive value (Table 1), that means during transformation X and Y coordinate shifted towards opposite while Z in upward direction. The scale factor values almost equal to one which indicated there was no change in scale happens due to the transformation. Now, if we look at the rotation parameters, X and Z have positive values while Y depicted negative value. That means during transformation X and Z axes rotate in a clockwise direction while Y in an anticlockwise direction. Comparison to Y and Z the magnitude of X has a higher value which indicates more rotation effects in X compared to Y and Z axes. Similar explanations can be given for Everest (1956) datum also.

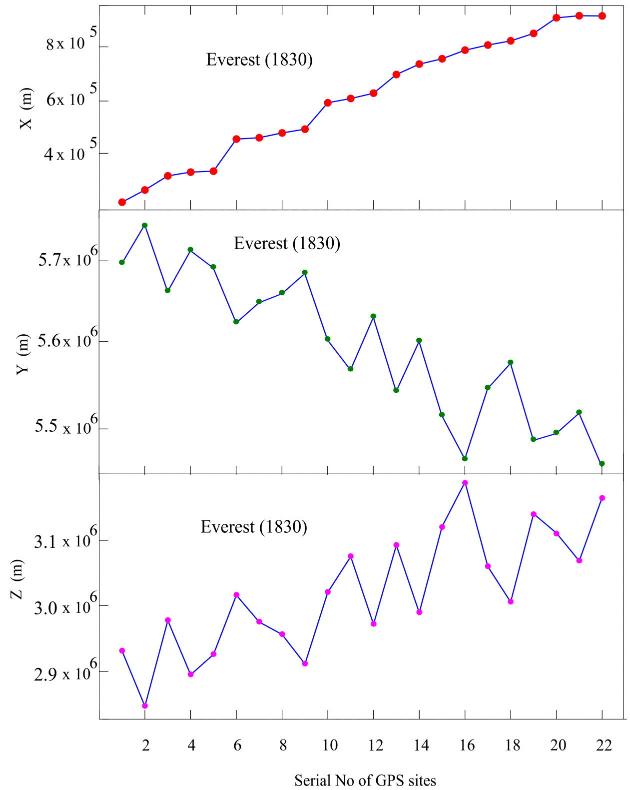

Figure 3: Training data for Everest (1830) datum (in X, Y and Z) coordinates and ANN prediction results

4 Model comparisons using ANOVA Test

ANN and SVD methods comparison analysis have great importance to understand the validity of the study. Here, we have chosen five stations (TPLJ, SYBC, SRNK, BMCL and DRCL) X, Y and Z coordinates from different location of Nepal. We studied the comparative analysis by using one-way analysis of variant (ANOVA) test for the purpose of clear verification. Basically, the ANOVA test was used to decide whether there is any type of statistically significant difference between the means of three or more independent groups. It is assumed that One-way ANOVA test approximates normality, independence and homogeneity of variances. We made three groups of selected stations namely group (a) for the difference between observed WGS-84 to observed Everest datum, group (b) for the difference between observed WGS-84 to ANN modeled Everest datum, and group (c) for the difference between observed WGS-84 to SVD modeled Everest datum (Table 2 & 3). The special form of ANOVA test checks the null hypothesis like this:

$$H_0 : \mu_1 = \mu_2 = ... = \mu_{k-1} = \mu_k$$

Where μ is the mean of the group and k is the total number of groups. However, if the one-way ANOVA test proceeds the statistically significant results, the alternative hypothesis (H_A) is accepted, which indicate that there are at least two groups that are statistically different from each other. To perform the ANOVA test the following parameters are needed:

n_G= Total numbers of variables, n_g=Numbers in each group

$\bar{X}_g$ =mean of each group, $\bar{X}_G$ =Overall grand mean

Within groups mean sum of squares

$$MSS_w = \frac{\sum\limits_{g \in G} (X - \bar{X}_g)^2}{n - k} \quad (12)$$

Table 1: Estimated parameters form WGS-84 to Everest datums

	ANN Approach			SVD Method		
	T_x, T_y, T_z (cm)	s_x, s_y, s_z	R_x, R_y, R_z (degree)	T_x, T_y, T_z (cm)	s_x, s_y, s_z	R_x, R_y, R_z (degree)
Everest (1830)	-5.7395 -13.8593 15.1571	0.9998650267 0.9998647535 0.9998651978	3.83×10^{-6} -0.89×10^{-6} 0.96×10^{-6}	-5.3273 -14.7893 15.6343	0.9998650267 0.9998647535 0.9998651978	2.53×10^{-6} -0.67×10^{-6} 0.60×10^{-6}
Everest (1956)	-5.2962 -13.010 15.1571	0.9998689285 0.9998686757 0.9998690899	3.26×10^{-6} -0.87×10^{-6} 0.74×10^{-6}	-5.1773 -14.3481 15.1571	0.9998689285 0.9998686757 0.9998690899	2.45×10^{-6} -0.64×10^{-6} 0.58×10^{-6}

Table 2: ANOVA test for Everest (1830) datum

station	Group (a)	Group (b)	Group (c)	$(\bar{X}_g\text{-a})^2$	$(\bar{X}_g\text{-b})^2$	$(\bar{X}_g\text{-c})^2$
TPLJ (X)	30.57	42.99	45.26	146329.20	310572.14	311832.90
TPLJ (Y)	764.28	1135.40	1144.07	123327.39	286353.41	292021.35
TPLJ (Z)	395.65	549.66	556.50	304.50	2562.38	2225.95
SYBC (X)	43.68	62.42	64.69	136471.14	289293.38	290510.22
SYBC (Y)	760.43	1129.83	1113.52	120638.13	280423.20	259936.83
SYBC (Z)	401.82	559.09	565.88	127.24	1696.62	1428.84
SRNK (X)	80.14	116.42	118.68	110862.36	234120.50	235225.00
SRNK (Y)	754.30	1120.45	1125.09	116417.44	270576.83	271868.39
SRNK (Z)	407.74	568.08	574.74	28.73	1036.84	837.52
BMCL (X)	108.91	159.07	161.32	92531.56	194666.26	195682.37
BMCL (Y)	747.84	1111.01	1115.63	112050.87	260845.13	262092.80
BMCL (Z)	412.97	576.26	582.80	0.02	576.96	435.97
DRCL (X)	123.42	180.54	182.79	83914.50	176181.67	177148.39
DRCL (Y)	737.60	1095.45	1100.17	105300.25	245193.33	246502.32
DRCL (Z)	427.13	597.58	604.00	196.84	7.29	0.1024
				∑=1148500.17	**∑=**2554105.95	**∑=**2547748.96
n_g	**15**	**15**	**15**			
n_G		**45**		Critical values of F_{crt} for the 0.05 significance level at (2 × 42) column=3.22		
$\bar{X}_g$	**413.10**	**600.28**	**603.68**			
$\bar{X}_G$	**539.02**					
k		**3**				

Between groups mean sum of squares

$$MSS_B = \frac{\sum_{g\in G} n_g(\bar{X}_g - \bar{X}_G)^2}{k-1} \tag{13}$$

F-test statics

$$F_{sta} = \frac{MSS_B}{MSS_W} \tag{14}$$

The degree of freedom within the group and between the groups

$$df_W = n - k \quad and \quad df_B = k - 1$$

Here, we have four groups so the Null Hypothesis is H_0 : $\mu_1 = \mu_2 = \mu_3 = \mu_4$

Alternate Hypothesis is

$$H_1 : \mu_1 \neq \mu_2 \neq \mu_3 \neq \mu_4$$

Now the null Hypothesis H_0 for both Everest (1830) datum and Everest (1956) datums are calculated (see appendix) and they are acceptable.

We compared observed results with ANN approach as well as SVD method by using ANOVA test. The result

Table 3: ANOVA test for Everest (1956) datum

station	Group (a)	Group (b)	Group (c)	$(\bar{X}_g\text{-}a)^2$	$(\bar{X}_g\text{-}b)^2$	$(\bar{X}_g\text{-}c)^2$
TPLJ (X)	29.68	43.85	45.31	137989.97	241434.65	313308.87
TPLJ (Y)	742.18	1136.18	1139.85	116301.46	361164.94	286011.04
TPLJ (Z)	384.21	552.89	557.42	286.96	312.58	2268.62
SYBC (X)	42.42	63.28	64.74	128687.21	222717.92	291934.90
SYBC (Y)	738.45	1130.61	1134.21	113771.29	354501.16	280010.31
SYBC (Z)	390.20	562.30	566.80	119.90	733.87	1463.06
SRNK (X)	77.82	117.26	118.73	104542.29	174682.20	236507.14
SRNK (Y)	732.50	1121.19	1124.88	109792.82	343372.56	270223.23
SRNK (Z)	395.95	571.25	575.64	27.04	1298.88	864.95
BMCL (X)	105.76	159.90	161.38	87255.25	140857.60	196843.07
BMCL (Y)	726.22	111.73	1115.42	105670.50	179335.310	260477.54
BMCL (Z)	401.03	579.40	583.70	0.01	1952.76	455.82
DRCL (X)	119.83	181.36	182.84	79140.94	125209.82	178261.28
DRCL (Y)	716.28	1096.21	1099.96	99306.92	314721.00	244935.91
DRCL (Z)	414.79	600.67	604.89	186.05	4285.01	0.03
				∑=1083078.62	∑=2466580.27	∑=2563565.75
n_g	**15**	**15**	**15**			
n_G		**45**		Critical values of F_{crt} for the 0.05 significance level at (2 × 42) column=3.22		
$\bar{X}_g$	**401.15**	**535.21**	**605.05**			
$\bar{X}_G$	**513.80**					
k		**3**				

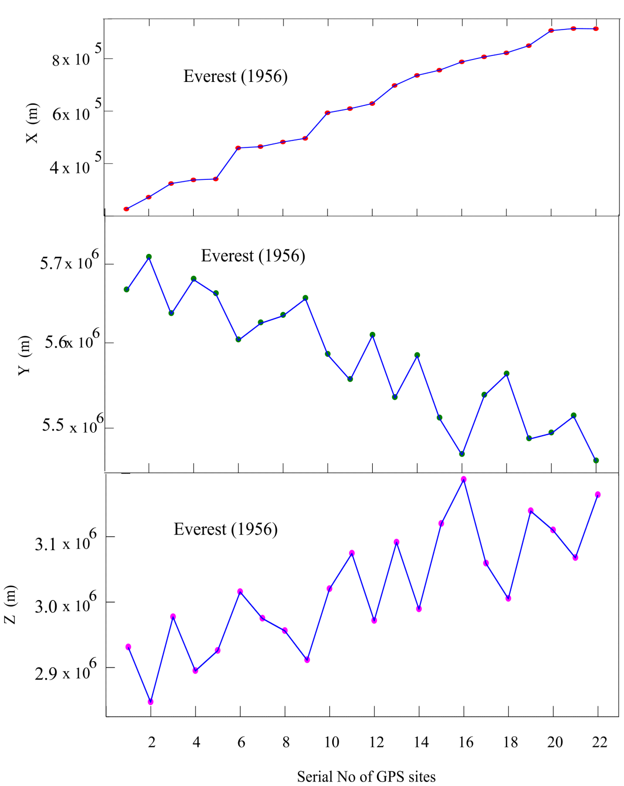

Figure 4: Training data for Everest (1956) datum (in X, Y and Z) coordinates and ANN prediction results

shows that in both models null hypothesis is accepted that means all models are statistically the same.

5 Conclusion

The transformation from WGS-84 coordinate to two Everest datums namely Everest (1830) and Everest (1956) was carried out in the study. We used 9-transformation parameters based on B-W extension model. ANN approach is enough to solve the type of problem but validation and simplicity purpose the SVD method was also applied in the study. The study of comparison results with ANOVA test showed that in both models null hypothesis was accepted that means all models were statistically the same. We believe SVD and ANOVA tests are explained very well and will help to understand the technique of coordinate transformation and its comparison with observed data. Moreover, the GPS data having a dense network across the Nepal region may yield further developments in the study of crustal deformation.

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A Appendix

Everest (1830) datum

$$MSS_w = \frac{1148500.17 + 2554105.95 + 2547748.96}{45-3} = 148817.98$$

$$MSS_B = \frac{n_1(\bar{X}_{ga} - \bar{X}_G)^2 + n_2(\bar{X}_{gb} - \bar{X}_G)^2 + n_3(\bar{X}_{gc} - \bar{X}_G)^2}{k-1}$$

$$MSS_B = \frac{15(413.10-539.02)^2 + 15(600.28-539.02)^2 + 15(603.68-539.02)^2}{3-1}$$

$$MSS_B = 178423.32$$

Now $Fsta = \frac{MSS_w}{MSS_B} = 0.834$

$$df_w = n - k = 45 - 3 = 42$$
$$and \quad df_B = k - 1 = 3 - 1 = 2$$

Critical values of F_{crt} for the 0.05 significance level at (2 ×42) column = 3.22

Since $F_{sta} < F_{crt}$

The null H_0 Hypothesis is accepted for Everest (1830) datum.

Everest (1956) datum

$$MSS_w = \frac{1083078.62+2466580.27+2563565.75}{45-3} = 145552.968$$

$$MSS_B = \frac{n_1(\bar{X}_{ga} - \bar{X}_G)^2 + n_2(\bar{X}_{gb} - \bar{X}_G)^2 + n_3(\bar{X}_{gc} - \bar{X}_G)^2}{k-1}$$

$$MSS_B = \frac{15(401.15-513.80)^2 + 15(535.21-513.80)^2 + 15(605.05-513.80)^2}{3-1}$$

$$MSS_B = 161054.74$$

Now $Fsta = \frac{MSS_w}{MSS_B} = 0.904$

$$df_w = n - k = 45 - 3 = 42$$
$$and \quad df_B = k - 1 = 3 - 1 = 2$$

Critical values of $F_{crt}$for the 0.05 significance level at (2 ×42) column = 3.22

Since $F_{sta} < F_{crt}$

The null H_0 Hypothesis is accepted for Everest (1956) datum.

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