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REVIEW ARTICLE

A comparative analysis of different DEM interpolation methods

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IDW

Abstract Visualization of geospatial entities generally entails Digital Elevation Models (DEMs) that are interpolated to establish three dimensional co-ordinates for the entire terrain. The accuracy of generated terrain model depends on the interpolation mechanism adopted and hence it is needed to investigate the comparative performance of different approaches in this context. General interpolation techniques namely Inverse Distance Weighted, kriging, ANUDEM, Nearest Neighbor, and Spline approaches have been compared. Differential ground field survey has been conducted to generate reference DEM as well as specific set of test points for comparative evaluation. We have also investigated the suitability of Shuttle Radar Topographic Mapper Digital Elevation Mapper for Indian terrain by comparing it with the Survey of India (SOI) Digital Elevation Model (DEM). Contours were generated at different intervals for comparative analysis and found SRTM as more suitable. The terrain sensitivity of various methods has also been analyzed with reference to the study area.

Contents

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1. Introduction

Remote sensing techniques are being effectively used as a tool for decision making in various fields because of their spatial analysis and display capabilities. The utility of decision making processes is significantly improved using 3D geographical models as they facilitate effective visualization. Digital Elevation Models (DEMs) are the generally adopted data structures for storing topographic information and are usually interpolated to establish the values for entire terrain points. DEM is an array representation of squared cells (pixels) with an elevation value associated to each pixel (Manuel, 2004). DEMs can be obtained from contour lines, topographic maps, field surveys, photogrammetry techniques, radar interferometry, and laser altimetry (Manuel, 2004). Different interpolation methods applied over the same data sources may result in different results and hence it is required to evaluate the comparative suitability of these techniques.

Interpolation techniques are based on the principles of spatial autocorrelation, which assumes that closer points are more similar compared to farther ones. The literature reveals a great deal of interpolation methods which are generally classified as local and global approaches. Local methods predict the value of an unknown point based on the values of neighborhood pixels. Prominent local methods found in the literature include Inverse Distance Weighting (IDW), local polynomial, Nearest Neighbor (NN), and Radial Basis Functions (RBFs). On the other hand, global interpolation methods such as polynomial interpolation functions use all the available sample points to generate predictions for a particular point. These methods facilitate to evaluate and remove global variations caused by physical trends in the data (Burrough and McDonnell, 1998).

Kriging is a geo statistical interpolation method that utilizes variogram which depends on the spatial distribution of data rather than on actual values. Kriging weights are derived using a data-driven weighting function to reduce the bias toward input values, and it provides the best interpolation when good variogram models are available. The IDW approach is a local deterministic interpolation technique that calculates the value as a distance-weighted average of sampled points in a defined neighborhood (Burrough and McDonnell, 1998). It considers that points closer to the query location will have more influence, and weights the sample points with inverse of their distance from the required point.

Nearest Neighbor interpolation finds the closest subset of input samples to a query point and applies weights to them based on proportionate areas (Sibson, 1981). It is a local deterministic method and interpolated heights are guaranteed to be

Table 1 Data resource description.

S. no.	Image used	Resolution (m)	Satellite	Area	Date of procurement
1	PAN	2.5	IRS-P5 (Cartosat-1)	Bhopal	November 2012
2	LISS-IV	5.8	IRS P6	Bhopal	September 2012
3	Google Earth	0.15 (Highest)		MANIT	–
4	SOI DEM	As per 1:50,000 scale topo sheet	–	Bhopal	November 2012
5	SRTM DEM	3-ARC	Shuttle Radar	Bhopal	August 2012

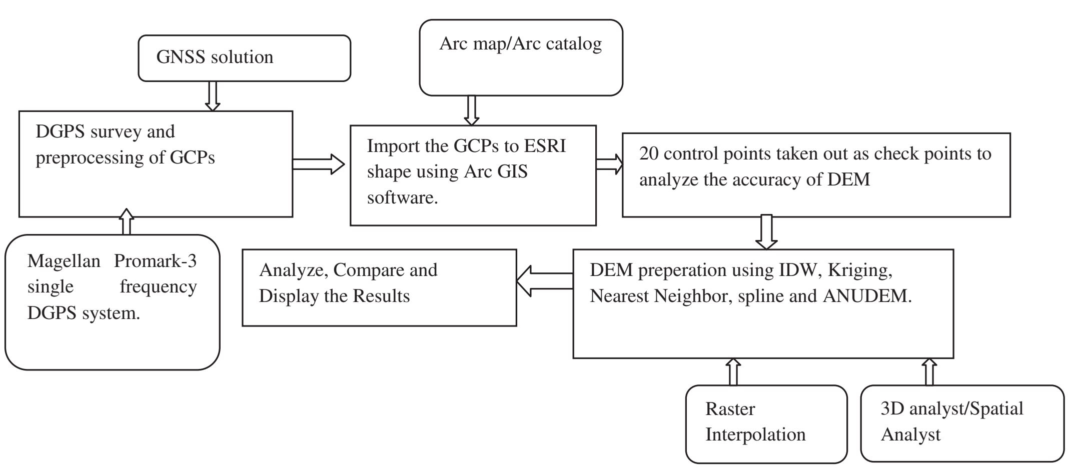


Figure 1 Methodology for comparative analysis of interpolation methods.

Table 2 Ellipsoidal heights at test GCPs from interpolated and DGPS observed values.

Control points ID	Ellipsoidal heights in meter					
	IDW Value	ANUDEM	Nearest neighbor	Spline	Kriging	DGPS observed value
FID-24	474.97	474.89	476.93	476.33	476.02	476.72
FID-81	476.64	476.78	476.72	477.54	476.68	478.54
FID-39	479.42	478.63	479.22	479.37	478.90	477.60
FID-7	476.78	477.30	475.59	475.66	475.83	478.40
FID-11	477.75	477.30	477.78	477.30	477.29	478.24
FID-14	478.06	477.48	478.59	480.76	479.63	479.58
FID-17	479.27	477.85	479.32	480.36	479.44	479.37
FID-71	477.38	476.26	477.18	477.65	477.64	476.68
FID-64	477.39	478.41	478.05	478.18	477.93	477.28
FID-61	479.30	480.06	479.59	477.79	479.03	479.69
FID-56	477.72	478.11	478.40	477.96	478.20	475.72
FID-45	477.93	478.93	477.57	477.36	477.43	477.97
FID-39	479.450	478.32	479.22	479.123	478.75	477.60
FID-91	473.11	471.95	473.94	474.50	474.18	475.83
FID-87	473.02	471.95	473.56	473.25	473.39	476.42
FID-30	474.32	474.83	473.67	471.40	472.58	473.19
FID-28	473.80	475.57	473.41	473.32	473.47	471.82
FID-89	473.14	471.95	472.31	472.33	472.22	469.89
FID-95	471.08	471.95	471.27	471.15	471.11	472.14
FID-34	477.07	478.01	477.90	477.14	477.43	477.82

Table 3 RMSE values with reference to terrain variation.

Type of test GCPs used	RMSE values				
	IDW	ANUDEM	NN	Spline	Kriging
Mild slope areas	0.93	0.87	0.72	0.91	0.70
Steep slope area	1.45	1.82	1.34	1.37	1.31
Combined slope area	1.73	2.02	1.53	1.62	1.49

within the range of the samples used. It does not produce peaks, pits, ridges or valleys that are not already present in the input samples and adapts locally to the structure of the input data. It does not require input from the user and works equally well for regularly as well as irregularly distributed data (Watson, 1992). The Spline interpolation approach uses mathematical function to minimize the surface curvature and produces a smooth surface that exactly fits the input points. The ANUDEM method uses an interpolation technique specifically designed to create a surface that more closely represents a natural drainage surface and preserves both ridgelines as well as stream networks (Hutchinson, 1989).

Zimmerman et al. (1999) showed that kriging yielded better estimations of altitude than inverse distance weighting (IDW) irrespective of the landform type and sampling pattern. This result is attributed to the ability of kriging to adjust itself to the spatial structure of the data. However, in other studies (Weber and Englund, 1992; Gallichand and Marcotte, 1993; Brus et al., 1996; Declercq, 1996; Aguilar et al., 2005), neighborhood approaches such as IDW or RBFs were found to be as accurate as kriging or even better. The ANUDEM interpolation method is specifically designed for the creation of hydrologically correct terrain surfaces.

In this paper, we evaluate the comparative suitability of different interpolation techniques based on their accuracy and sensitivity to terrain variations. Performance of different interpolation methods namely IDW, ordinary kriging (KRG), ANUDEM, NN and spline has been evaluated with reference to the study area. Generally available DEMs for Indian terrain namely Shuttle Radar Topographic Mapper (SRTM) and Survey of India (SOI) Digital Elevation Models (DEMs) are also evaluated based on the contours generated at different intervals.

2. Data resources

Investigations have been conducted over MANIT campus and surrounding areas of Bhopal city in India; variation of the ter-

Table 4 Comparison of contours.

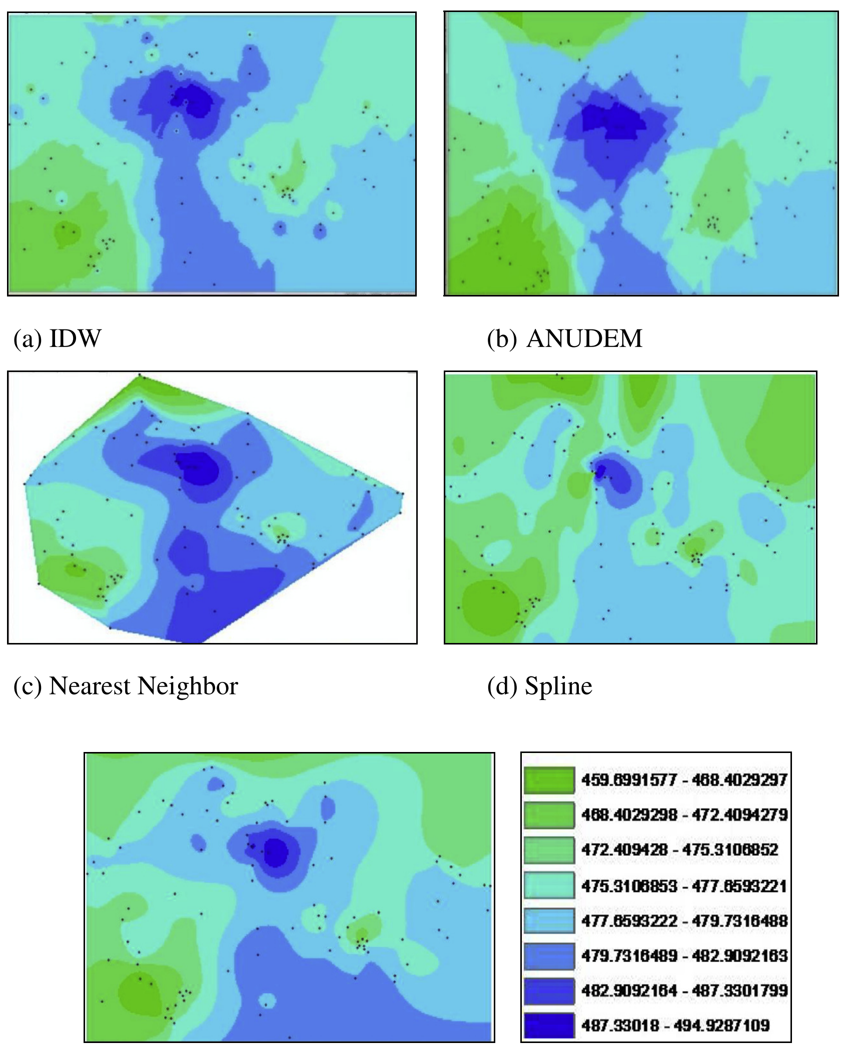
Type DEM used	Number of contours generated			
	1 m Interval	2 m Interval	5 m Interval	10 m Interval
SOI	3303	1637	663	342
SRTM	12,182	11,212	4274	2153

rain, spread over more than 1000 acres made it optimal for the analyses. Satellite images of Bhopal along with SOI and SRTM DEMs have been used for comparative analysis of various methodologies. Details of the satellite data used for these investigations are summarized in Table 1. The ground truthing information has been collected using Differential Global Positioning System (DGPS) survey conducted over Bhopal during October 2012.

3. Methodology

3.1. Comparative analysis of interpolation methods

Commonly used interpolation approaches have been evaluated with reference to the study area and adopted methodology is summarized in Fig. 1. Differential Global Positioning System (DGPS) survey has been conducted over the study area to collect three-dimensional coordinates of around 1000 samples and test points in WGS-84 datum. Collected raw data have been pre-processed using GNSS software (Trimble Survey Division, 2013) to remove various errors and to calibrate the readings at centimeter level accuracy. The processed data (GCPs) have been imported in the ArcGIS environment (ArcGIS, 2013) and plotted to a shape file. About 680 GCPs were used as sample points to generate the DEM and rest were used as test points to estimate accuracy of interpolation. Raster surface has been generated from reference DEM using different interpolation methods namely IDW, Kriging, NN, ANUDEM and Spline. Accuracies of generated surfaces have been evaluated using 320 reference GCPs as test points. Visual analyses as well as statistical parameters have been adopted for comparative evaluation of the interpolated surfaces. In the visual analysis, DEM generated heights were verified in the ground by field visit using GPS. Mathematical analysis has been done by calculating the deviations of interpolated height values from corresponding observed values in terms of root mean square error (RMSE).



(a) IDW (b) ANUDEM

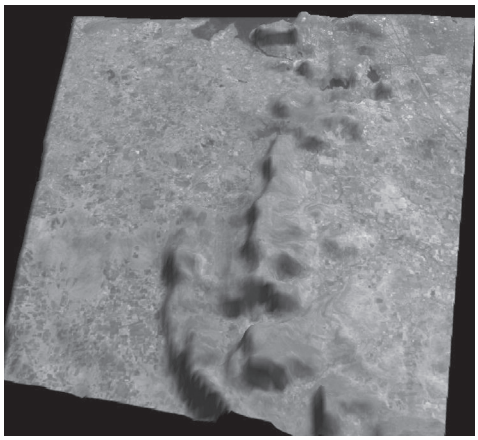
(c) Nearest Neighbor (d) Spline

(e) Kriging (f) Index

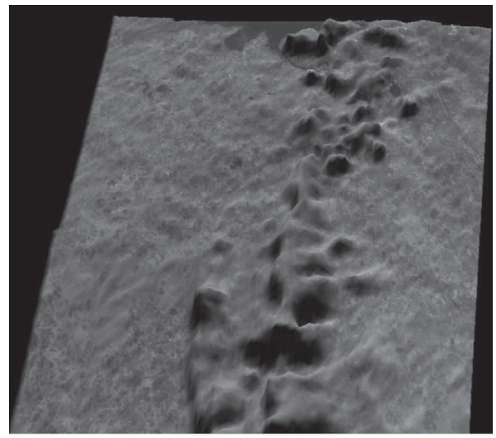
Figure 2 Slope maps generated using different interpolation methods.

3.2. Comparative analysis of SRTM and SOI DEM

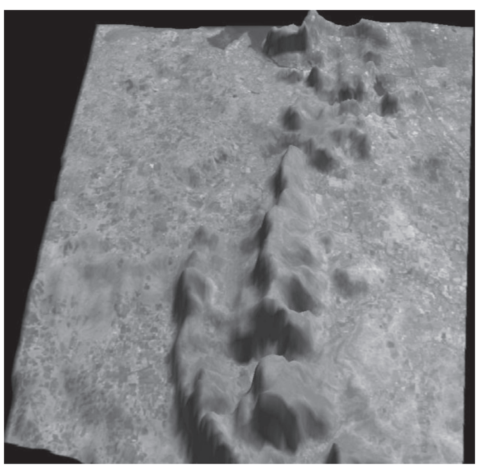
Comparative suitability of SRTM and SOI DEMs has been analyzed with reference to the generation of contours. Contours of the study areas have been digitized from SOI Topo sheet No. 55E7 and 55E8 and contour heights were recorded in the attribute table. SOI DEM has been generated from corresponding contours using the Kriging interpolation technique in the ArcGIS environment. Contours with interval 10 m, 5 m, 2 m and 1 m were generated from SRTM as well as SOI DEM using ArcGIS 3D analyst extension. Comparative analysis has been done with reference to the nature and number of contours generated from DEMs. Further, visual analysis has been conducted based on the 3D view generated



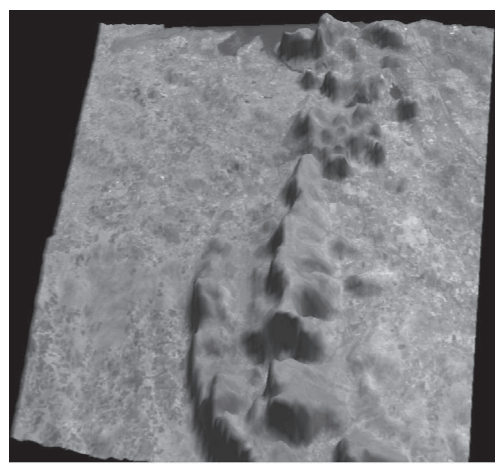
(a) SOI-55E8 DEM draped with exaggeration 10



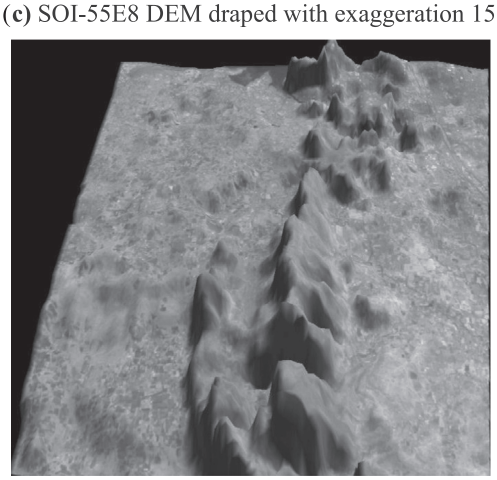
(b) SRTM DEM draped with exaggeration 10



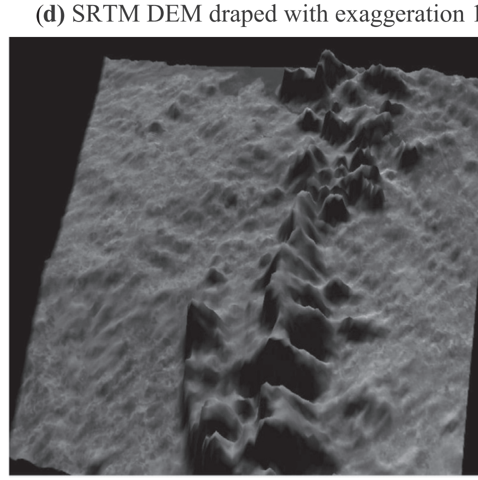
(**c**) SOI-55E8 DEM draped with exaggeration 15



(d) SRTM DEM draped with exaggeration 15



(e) SOI-55E8 DEM draped with exaggeration 20.



(f) SRTM DEM draped with exaggeration 20.

Figure 3 3D surfaces generated from SOI & SRTM DEM at different exaggeration levels.

from the two DEMs. Satellite images were draped over the DEMs using Virtual GIS viewer in ERDAS and were analyzed at different exaggeration levels.

4. Results and discussion

4.1. Comparative analysis of interpolation methods

We have investigated the comparative performance of different interpolation techniques with reference to various terrain contexts. Visual comparisons as well as mathematical analyses have been conducted. Visual comparison of slope map generated using different interpolation techniques is presented in Fig. 2.

DGPS survey data revealed that the kriging approach performed accurately in average cases when compared to others. Interpolated heights at different test points (points having coordinates from DGPS survey) have been also compared for the five different methods and results are summarized in Table 2.

Table 2 reveals that different approaches produce varied results over the same points. Interpolated height values for different methods at each test point have been plotted. Deviations of interpolated height values from the actual values (DGPS observed) at each test point give a better understanding about the performance of each method and reveals a better performance of the kriging approach.

In order to investigate the sensitivity of interpolation methods to the nature of terrain, the test GCPs were divided into two zones namely mild slope and steep slope areas. Average RMSE values of the test points have been also calculated with reference to terrain variations and are summarized in Table 3. IDW and Kriging have been found to adjust themselves to the terrain variations when compared to other methods. ANUDEM has been found to yield a better performance for ridges as well as stream areas.

The investigations have shown that interpolation results vary with variation in a spatial structure and terrain nature of input data. As far as our data are concerned, we have more samples at slope areas than at plane areas. Kriging and NN were found to perform well in these contexts and can be adopted for geomorphologically smooth and small areas. In stream and ridge line areas, the ANUDEM method has shown lowest RMSE value. The NN method has shown nearly optimal values over smooth surfaces, i.e. second lowest. This trend in RMSE values of Kriging has continued even for steep slope areas as well as for areas covering both steep and mild slopes. IDW and NN methods have been found to be good for interpolation of geo-morphologically smooth areas. Kriging methods take into consideration autocorrelation structures of elevations in order to define optimal weights. The method requires a skilled user with geo-statistical knowledge. Spline-based methods fit a minimum-curvature surface through the input points, and ensure preservation of trend in the sample data along with rapid changes in gradient or slope.

4.2. Comparative analysis of SRTM and SOI DEM

We have investigated the accuracy of DEMs namely SRTM and SOI with reference to contour extraction. Contours have been generated using 3D analyst extension of Arc GIS software and outcomes of these investigations are tabulated in Table 4.

From the table, it is evident that the contours generated from SOI DEM are sparse while that from SRTM are comparatively denser. Therefore we can conclude that SOI DEM is having very poor data quality compared to SRTM.

The suitability of DEMs has also been evaluated based on the comparative visualization of 3D models generated from these DEMs at different exaggeration levels as given in Fig. 3.

Visual comparison also reveals that SRTM is performing better than the SOI DEMs. Reason behind the poor performance of the SOI DEM may be attributed to its construction from 1:50,000 scale topographic maps. Open source SRTM data are giving more reliability and accuracy than the SOI DEM due to the usage of radar technology.

5. Conclusion

The generated DEMs are found to be sensitive to height interpolation methods as well as the terrain nature. Investigations revealed that the Kriging method performs better when compared to other contemporary methods in most contexts. DEM generated from the DGPS data was found to be better than the DEM available from SOI or SRTM data. Number of contours extracted from SRTM DEM was found to be better than that from SOI DEM, which may be attributed to the better accuracy of SRTM data source. Kriging has been found to adapt itself to terrain variations while ANUDEM is found preferable for streams and ridge lines.

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