



Elevation Contours Generation, Analysis and Water Scarcity Regions Extraction using DEM

Dr. Deshmukh Nilesh Kailasrao
School of Computational Sciences,
Swami Ramanand Teerth Marathwada University,
Nanded (Maharashtra), India.
nileshkd@yahoo.com

Abstract: A digital elevation model (DEM) is a digital representation of a terrain's surface commonly for a planet (including Earth), moon, or asteroid created from terrain elevation data. Using the Synthetic Aperture Radar (SAR) interferometry to produce the first near-global high resolution digital elevation model (DEM) of the Earth, SRTM has created an unparalleled set of global elevations that is freely available for modelling, aping and environmental applications. The global availability (about 80% of the Earth surface, covering land masses between 60°N and 56°S) makes it the most widely-used set of baseline elevation information for a wide-range of applications and this development has been identified by professionals in the geo-information arena as a significant landmark that will tremendously revolutionize medium-scale topographic mapping. The near-global SRTM digital elevation model (DEM) product was processed and compiled at a resolution of 90m by the Consultative Group for International Agriculture Research Consortium for Spatial Information (CGIAR-CSI) and hosted on a Web portal for free public access and download.

In this research paper, the processes of generating contour lines using different elevation data file formats are presented. The elevation file formats, namely, DEM, HGT and IMG are used to represent terrain features like contouring, vertical profiling, hill shading, hypsometric tinting, etc. The errors of particular contour lines have been studied, removed and validated by using APContours.

Keywords: terrain mapping; topographic map; IMG elevation; HGT elevation; APContours; water body extraction

I. INTRODUCTION

A digital elevation model (DEM) is a digital representation of a terrain's surface commonly for a planet (including Earth), moon, or asteroid created from terrain elevation data. Using the Synthetic Aperture Radar (SAR) interferometry to produce the first near-global high resolution digital elevation model (DEM) of the Earth, SRTM has created an unparalleled set of global elevations that is freely available for modelling, aping and environmental applications [1]. The global availability (about 80% of the Earth surface, covering land masses between 60°N and 56°S) makes it the most widely-used set of baseline elevation information for a wide-range of applications and this development has been identified by professionals in the geo-information arena as a significant landmark that will tremendously revolutionize medium-scale topographic mapping. The near-global SRTM digital elevation model (DEM) product was processed and compiled at a resolution of 90m by the Consultative Group for International Agriculture Research Consortium for Spatial Information (CGIAR-CSI) and hosted on a Web portal for free public access and download.

In terrain mapping, there are so many ways to measure and estimate the terrain measurements, like contouring, vertical profiling, hill shading, hypsometric tinting, perspective view, etc. Here, in this research paper, contouring techniques are used to generate the contours for the different digital elevation data like DEM, HGT, IMG etc. The elevation data is captured in dem, hgt and img formats of the same projected area and the contour is generated using the existing techniques and applications. The exact differences, errors of elevation (contour) intervals, slopes and heights are analyzed and recovered for finding water bodies and water scarcity regions.

Contouring is the most common method for terrain mapping. Contour line connects points of equal elevation, the contour interval represents the vertical distance between contour lines, and the base contour is the contour from which contouring starts. Contour lines are lines drawn on a map connecting points of equal elevation. The contour line represented by the shoreline separates areas that have elevations above sea level from those that have elevations below sea level. We refer to contour lines in terms of their elevation above or below sea level. In this example, the shoreline would be the zero contour line (it could be 0 ft., 0 m, or something else depending on the units we were using for elevation). Contour lines are useful, because they allow us to show the shape of the land surface (topography) on a map. Suppose a DEM has elevation readings from 362 to 750 meters. If the base contour is set to 400 and the contour interval at 100, then contouring would create the contour lines of 400, 500, 600 and so. Contour lines can be drawn for any elevation, but to simplify things only lines for certain elevations are drawn on a topographic map [2]. These elevations are chosen to be evenly spaced vertically. This vertical spacing is referred to as the contour interval. For example, if the maps use a 10 ft contour interval, each contour lines are a multiple of 10 ft.(i.e. 0, 10, 20, 30, etc). Other common intervals seen on topographic maps are 20 ft (0, 20, 40, 60, etc), 40 ft (0, 40, 80, 120, etc), 80 ft (0, 80, 160, 220, etc), and 100ft (0, 100, 200, 300, etc). The contour interval chosen for a map depends on the topography in the mapped area. In areas with high relief, the contour interval is usually larger to prevent the map from having too many contour lines, which would make the map difficult to read.

The contour interval is constant for each map. It will be noted on the margin of the map. One can also determine the

contour interval by looking at how many contour lines are between labeled contours. Unlike the simple topographic map, the real topographic maps have many contour lines. It is not possible to label the elevation of each contour line. To make the map easier to read, every fifth contour line vertically is an index contour. Index contours are shown by darker lines on the map. These are the contours lines that are usually labeled [3].

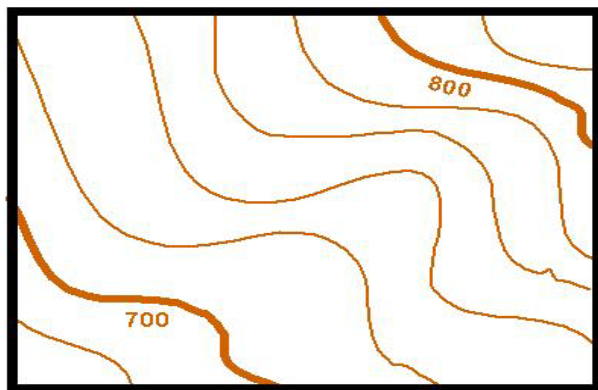


Figure 1. Section of a topographic map.

The example Figure 1 illustrates a section of a topographic map. The lines are the contour lines. The thin lines are the normal contours, while the thick lines are the index contours. The elevations are only marked on the thick lines.

Because we only have a piece of the topographic map, we can not look at the margin to find the contour interval. But since we know the elevation of the two index contours, we can calculate the interval ourselves. The difference in elevation between the two index contours ($800 - 700$) is 100. We cross five lines as we go from the 700 line to the 800 line (note we don't include the line we start on but we do include the line we finish on). Therefore, we divide the elevation difference (100) by the number of lines (5). We will get the contour interval. In this case, it is 20. We can check ourselves by counting up by 20 for each contour from the 700 line. We should reach 800 when we cross the 800 line.

The units of the contour lines can be found in the margin of the map. Most topographic maps in India use feet for elevation, but we use meters.

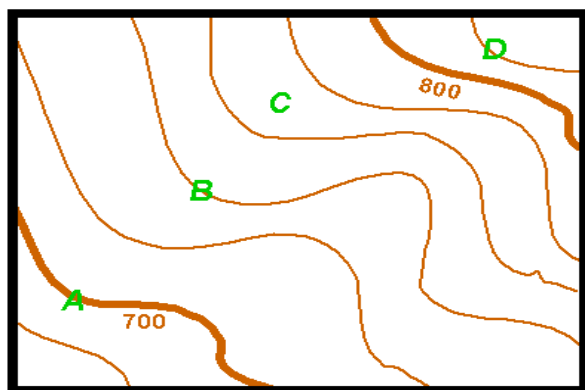


Figure 2. Estimated elevations of contour lines.

Once we know how to determine the elevation of the unmarked contour lines, we are able to determine or at least estimate the elevation of any point on the map. For example,

in the Figure 2, we estimate the elevation of the points marked with letters A, B, C and D.

Point A = 700

Just follow along the index contour from point A until you find a marked elevation. On real maps this may not be easy. One may have to follow the index contour a long distance to find a label.

Point B = 740

This contour line is not labeled. But we can see that it is between the 700 and 800 contour line. From the above, we know the contour interval is 20, so if we count up two contour lines i.e. 40 from 700, we reach 740.

Point C = 770

Point C is not directly on a contour line. But by counting up from 700 we can see that it lies between the 760 and 780 contour lines. Because it is in the middle of the two, we can estimate its elevation as 770.

Point D = 820

Point D is outside the interval between the two measured contours. Because the contour under point D is not an index contour, it can not be the 800 contour, so it must be 820, if interval is 20.

II. DATA, MATERIAL AND METHODS

A. Source Data:

The contouring techniques are used to generate the contours from different digital elevation data models like DEM, HGT, IMG which are collected online from USGS, SRTM and CGIAR-CSI sites. One topographic map sheet at the scale of 1/50,000 covering the chosen study site was selected for use as a reference for analyzing the SRTM elevation data. The map sheet was digitized into different layers as part of the input data sets within the framework. The maps are based on the UTM projection (Zone 43) on WGS 1984 Ellipsoid and had a contour interval of 25 feet.

B. Materials:

Six major software packages were employed for the processing of the data and the visualization and analysis of the results. These included the ArcInfo, open-source Integrated Land and Water Information System (ILWIS 3.4), Global Mapper 11.0, Quantum GIS (QGIS) 1.6, Natural Resource Data Base (NRDB 2.7) and Microsoft Excel.

C. Methodology:

Quantitative statistical and geostatistical tests were performed on the two spatial data sources for different terrain configurations and contexts to determine their suitability for topographical mapping in different scenarios. In particular, this study consisted of:

- measuring the vertical accuracy of the DEM derived from the 1:50,000 topographic map and that of the 90-m resolution CGIAR-CSI SRTM digital elevation data against higher precision GPS measurements within the same site;
- interpolating digital elevation models from an existing topographic map covering the same area and comparing measurements from the two sources;
- implementing a processing strategy to minimize errors emanating from contour interpolation using SRTM data as a base.

- d. contour lines generation using APcontours with 25 meters interval
- e. extraction of water bodies from DEM.
- f. finding which villages fall under critical water scarcity regions of the study site.

The data sets employed in this study are chosen from disparate sources based on different formats, coordinate systems and projections. The first step in the exploitation of the data sets was therefore the transformation of all the data sets into a common system. Since the CGIAR-CSI SRTM 90m digital elevation data sets were in LatLon WGS84 system, the topographic map layers (contours and rivers) and the GPS elevation data in UTM Clarke 1880 system were transformed into the LatLon WGS84 system using tools available in ILWIS 3.4 software. The QGIS 1.6 is used to process DEMs and polygonize them to find the waterbodies/lakes of the study site for finding water scarcity zones. In MATLAB, we processed the raster map (JPG) of DEM to extract the river basins. Finally, all the processed data are imported into our local spatial data base to find out the villages which fall under the critical water scarcity zones.

III. READING HGT, IMG ELEVATION DATA AND CONTOURING

A. Contouring from HGT Elevation Data:

The elevation data in hgt, img and dem formats are captured from USGS(United States Geological Survey) and SRTM (Shuttle Radar Topographic Mission) sites for the region of Latur district (study site) in Maharashtra (INDIA) using Universal Transverse Mercator projection 18N076E Long/Lat with minimum 362 to maximum 700 meters of height, which is shown in Figure 3. These images are used for experimentation and validation of elevation data models.

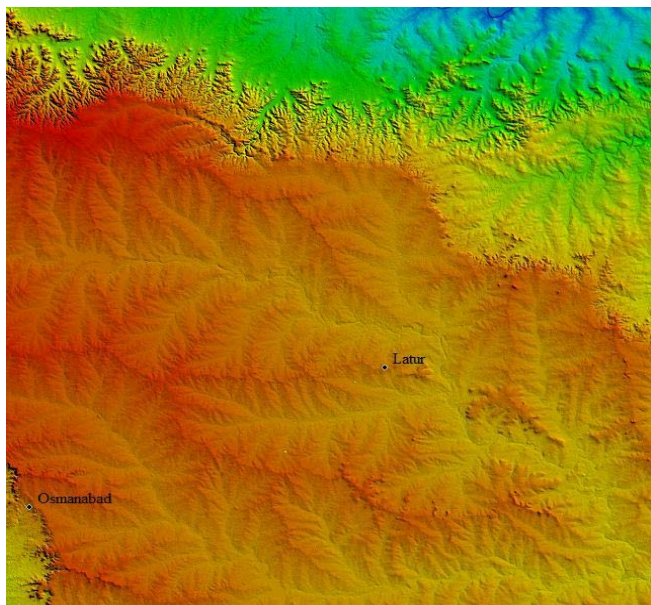


Figure 3. Elevation model of Latur region. (Courtesy USGS-SRTM)

The arrangement and pattern of contour lines reflect the topography. For example, contour lines are closely spaced in steep terrain and are curved in the upstream direction along a stream (Figure 4). With some training and experience in reading contour lines, we can visualize and even judge the accuracy of the terrain as simulated by the digital data.

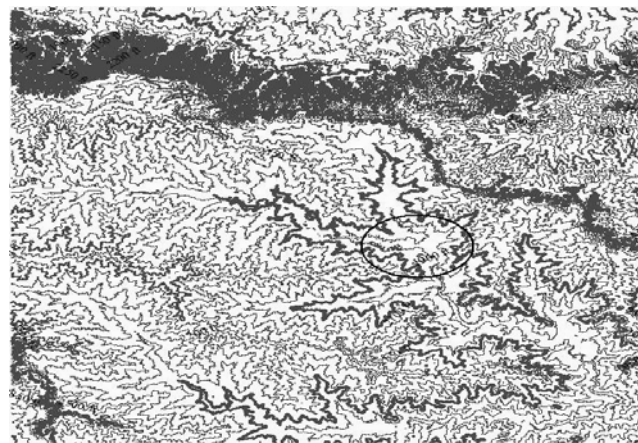


Figure 4. A contour line map with 50mtr interval using .hgt.

The Figure 4 is an automatic contour map which is generated using Global Mapper 10.0 with the elevation reading 362 to 750 meters. The base contour generation is set to 400 with 50 meter contour interval.

Automated contouring follows two basic steps, namely, (i) detecting a contour line that intersects a raster cell or a triangle, (ii) drawing the contour line through the raster cell or triangle.

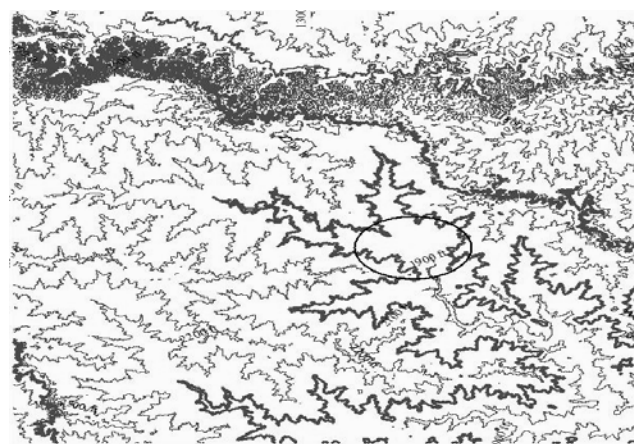


Figure 5. A contour map with 100 mtr interval using .hgt.

The difference between Figures 4 and 5 are highlighted by showing a circle at 1900 feet elevation. In Figure 4 one can see the lower level contour (interval 50) lines showing the depth of surface area, but in Figure 5, that particular contour lines are not generated due to the highest range of contour interval (i.e 100 meters).

B. Contouring from IMG Elevation Data:

In section II, we have already seen the contours of .hgt (Digital Elevation Model) elevation data file formats. Now we describe image file formats (.img) of elevation data. The .img files with high bandwidth elevation data are some what same like .dem and .hgt file formats, but the actual resolution and clarity is poor than the .dem and .hgt due to the low band width. To differentiate the contour maps obtained by using .hgt formats file and .img satellite imageries, consider map shown in Figure 6.

The Figure 6 uses the same parameters used as in Figure 4 to generate the contour line map of the same projected area. But there are so many differences and errors that we may find out if we compare the Figure 4 with Figure 6.

The circles drawn in Figure 6 are highlighting the major difference between the contour lines of the part of the same

area with same contour interval as in Figure 4. The estimated height of both the contour lines of that area is same, but the contour lines are drawn differently.

The circles in Figure 6 are errors which have occurred due to the insufficient data values available in the .img data formats.

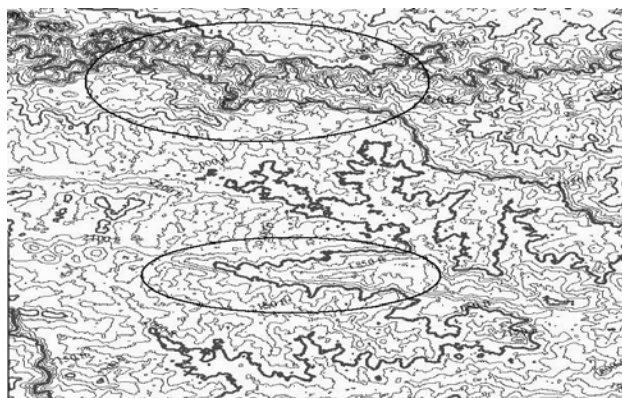


Figure 6. A contour line map with 50 mtr interval using .img

IV. ERROR DETECTION AND FIXING

After contour generation, many undesired line features are included in the overall contour vectors. Typical irregularities include contours without connection on either side, contours representing pure connection elements which do not contribute to a contour line continuation, or contour intersections. These irregularities are detected and eliminated step by step. Error checks have to be run several times, since the correction of one kind of error may induce another kind. Handling of these undesired contour features is focused on identifying and deleting arcs. Arc and node characteristics play the elemental role for the identification, which is based on the Info-Tables of elevation data and coordinate information.

For this purpose, typical topological characteristics for all node and arc classes are defined as shown in Figure 7 (a) and (b):

- Dangle-Arc (DNG) – arc, which is at least on one end not connected to another arc.
- Dead End-Arc (DE) – dangle arc, where the connectivity is not given inside the data set boundaries.
- ArcShares2Polygons-Arc (AS2P) – arc, which contributes to two polygons representing the same elevation.
- Polygon In Contour-Arc (PIC) – longer arc of two arcs forming a polygon, which is at the same time contributing to an unclosed contour line and therefore can cause confusion when it is interpreted.
- Polygon Touch Polygon-Arc (PTP) – longer arc of two arcs forming a polygon, which touches another polygon.
- Connection-Arc (CoA) – arc, which connects two or one polygon with an unclosed contour line and does not contribute to contour line continuation.
- Dead End-Node (DE) – dangle node, where an arc is not connected to another arc inside the data set boundaries.
- Multi Arc Connection-Node (MAC) – node, where more than two arcs are connected.

- Closed Arc-Node (CIA) – node, represented by a closed arc (can be a MAC for one arc, while it represents a CIA for another closed arc at the same time).

These defined arc and node classes are characterized by mutual relationship (topology). They can be identified by expanding, linking and analyzing entries from the associated attribute tables and lists, which are attached to the geometric elements in ArcInfo. Four tables are given: Node Attribute Table (NAT), Arc Attribute Table (AAT), Polygon Attribute Table (PAT), and Polygon Arc List (PAL). As an example, the node and arc classes 'Dead End' are described as follows.

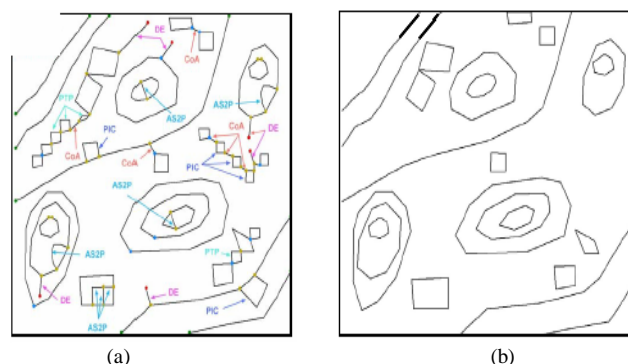


Figure 7. (a) Error detection and fixing: Line scenario with highlighted arc and node classes; (b) Contours after automated solving of undesired features.

The topology characteristic of node class Dead End is defined by the 'sum of all incoming and outgoing arcs = 1'. There is either no incoming or outgoing arc associated with the node. For identification in ArcInfo the items 'Arc_per_Node' and 'Status' are added to NAT. The incoming and outgoing arcs in NAT are summed up and the results are written to the item 'Arc_per_node'. Then all nodes with 'final sum = 1' as well as the node coordinates (x, y) inside the data set boundaries are selected. Nodes in the NAT item 'Status' with 'DE' are attributed. The topology of the arc class 'Dead End' is characterized as arcs with a DE-node on one end and no connectivity to another arc. The location of this DE node is inside the data set boundaries. The detection of these arcs is performed by linking the node-IDs from the NAT to the 'FNODE#'-entry and 'TNODE#'-entry of the AAT. Then all arcs with the entry 'DE' in the NAT item 'Status' for at least one node are selected and deleted. After detection and deletion of a class, the nodes left along contours, where there was a connection with a deleted arc, are transformed to vertices during a topology update by joining single arcs, connected on either end to one other arc only.

V. APCONTOURS (APC)

The appearance and the quality of the contour lines depend strongly on the input data. Therefore, a high quality bare earth DTM without artifacts and noise processed with an appropriate grid size is required. The DTM resolution determines the level of surface detail and affects the appearance of the output contours. For example, a large cell size may result in coarse, blocky looking contour lines. Noisy DEMs produce contours of poor quality with a high level of details not representing the characteristics of the terrain. Intermap's core product Digital Terrain Model (DTM) produced with its airborne IFSAR technology

ensures a high quality input dataset. The grid cell size of 5 m as well as high level of horizontal and vertical accuracy allows the selection of very small contour intervals up to 2 feet (depending on the terrain and ground cover) as required for flood maps in flat areas. The seamless overlap of one pixel between adjacent DTM tiles guarantees contour continuation, since the APC process starts in the middle of the marginal pixels.

Contour lines produced by running APC process using Intermap's DTMs are called APContours. The elevation is stored as an attribute for each contour line according to the selected processing interval. The contours do not support breaklines or spot heights. They are free of common artifacts such as isolated or blocky lines (Figure 8) (Schmieder, A. and Huber, R, 2000).

Intersections or Dead Ends exist if the interval is not appropriately selected to the terrain characteristics or manmade objects are contained in the DTM. APContours of different intervals produced independently are identical at the same levels, e.g. contours of 5 m interval are identical with contours of 10 m interval at the same elevation.

APContours have been thoroughly tested using different intervals in feet and meters on more than 50 DTM tiles of NEXTMap USA in Geographic Coordinates and NEXTMap UK in OSGB projection. The tiles cover areas of different topography from flat to very steep terrain and different surface coverage. The tests showed that the APContours characterize the terrain very well in either case. Examples of the statistical results of the comparison of a certain number of arcs and nodes with the height of the input DTM for some NEXTMap USA data are listed. The high agreement between the APContours and the DTM can be noticed.



Figure 8. APContours; Interval: 2 ft

VI. VALIDATION

For appraising the developed process and the resulting contour products, a series of tests were designed and conducted to validate both the APContours process as well as the Intermap's DTM as input. For this purpose, the APC process was run using other DEMs as inputs and commercial contour programs were used to generate contour lines from Intermap's DTM. Furthermore, APContours were compared to contours distributed by other vendors of geo-data. For testing the robustness of the process, the APC process was used to generate contours from different input data like USGS (U.S. Geological Survey) DEM, LIDAR DEM generated from LIDAR point data, OSGB DEM (Ordnance

Survey of Great Britain), and SRTM DEM. The DEMs are available either in Geographic Coordinate System or in UTM projection; the grid size was resampled to 5 m, except for OSGB DEM (10 m). Different contour intervals (between 1 and 10 m) were tested.

The quality of the input DEM largely determines the accuracy of the resulting contours. The comparison of APContours with contours generated from USGS DEM and high sample rate LIDAR data using the same processing parameters shows that APContours and USGS contours look quite similar unlike the LIDAR contours (Figure 9). The LIDAR DEM exhibits much more noise and consequently the contours are rougher and include more errors like intersections. Beside the statistical accuracy, the appearance of the contour lines is very important. To verify this, contours generated from Intermap's DTMs using two different commercial software packages (below called software package 1 and 2) as well as contour products distributed by other companies were compared to APContours. The overall appearance of contours processed using commercial software packages is quite similar compared to APContours, but the contours include some errors. They exhibit isolated small lines and many contour lines with spikes. In addition, the contours of software package 2 show Dead Ends, double lines and the run of the lines is quite blocky (InterMap, 2004).

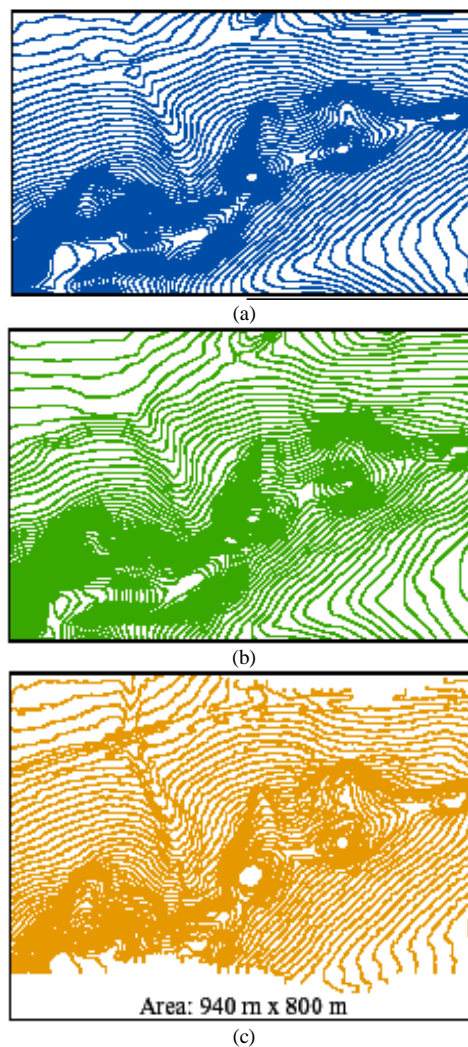


Figure 9. Comparison: (a) APContours (blue), (b) contours generated from USGS DEM (green), and (c) from LIDAR DEM (orange); Interval: 1 m

As already mentioned, contour line continuation between separate generated tiles is very important. In Figure 6, the results of the different software solutions are depicted. The APContours show seamless continuation on tile edges.

Software package 1 generates interrupted contours and the contours generated using software package 2 show non fitting contour overlaps. For comparison of APContours with other commercial contour data products, the contours distributed by two different vendors of geo-data (following called vendor 1 and 2) were used. In the following example, the contours distributed by vendor 1 (interval: 5 m) cover a very flat coastal area. In the underlying OSGB DEM (grid size: 10 mtr), many man-made structures can be identified.

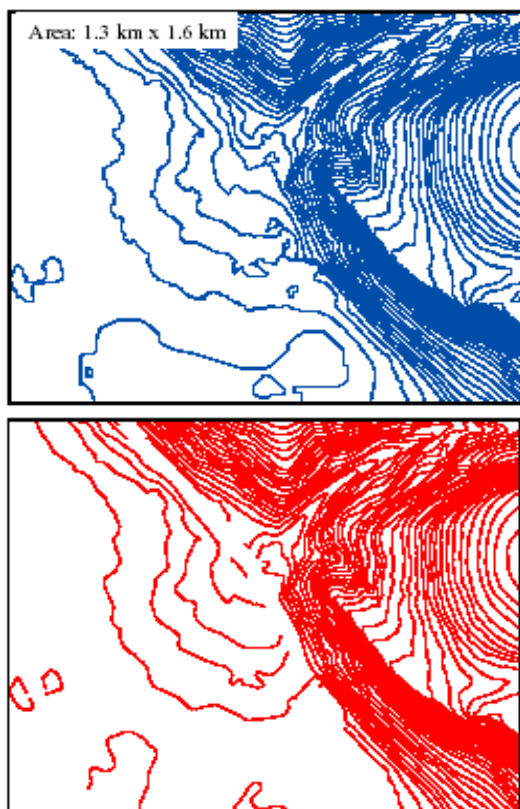


Figure 10. Contour line continuity: APContours (blue) and vendor 1 contours (red);

In general, the contours look smooth and appealing, but the continuity is not guaranteed. At some places, the lines are interrupted, whereas the APContours show continuous lines (Figure 10). In some areas, The APContours appear blockier than the vendor 1 contours. The vendor 1 seems to generalize the contours stronger. That explains the worse result of the vendor 1 contours in the accuracy check.

VII. ELEVATION ANALYSIS AND WATER BODY EXTRACTION

Topography is basic to many earth surface processes and thus finds applications in ecology, hydrology, security, agriculture, climatology, geology, pedology, geomorphology and a host of other domains and constitutes the basis for explaining processes and predicting them through the process of modelling. The tremendous role of topographic mapping in national development continues to receive recognition by national, state and local governments the world over. The importance of topographic mapping as a national project is therefore growing and accurate topographic maps as its

major products are considered as indispensable components of national geospatial data infrastructure. In countries with developed and stable economies, a clearly articulated road map is usually made for regular, fresh topographic mapping using current data and the state-of-the-art mapping technologies. In less-developed countries, however, the problem of poverty and inadequate technical capacities in the area of geo-information production and management culminate in the inability of such countries to carry out fresh topographical mapping at regular time intervals using expensive but accurate topographical mapping techniques. For such countries, an alternative and cost-effective strategy over the years has been topographical map revision using existing topographical maps, satellite imageries and other readily available spatial data sources. Unfortunately, the process of extracting topographical information (contours) from existing topographical maps and integrating same in a new digital topographical map, often at a larger scale, is usually a lengthy and time-consuming process due to differences in map units and contour intervals between the existing base maps and the new map. Moreover, most of the topographical map sheets to be used as base maps for a revision exercise are either missing or, where they exist, are very old and suffer from severe distortion. A recent development representing a tremendous forward leap in remote sensing technology that will significantly eliminate some of the lacunae associated with topographic map revision from existing topographical maps is the launching of the Shuttle Radar Topography Mission (SRTM) in February, 2000.

A. Land elevation contours of study site:

The SRTM (Shuttled Radar Topographic Mission) DEM of our study site (Latur district) is processed and generated the elevation contour lines/area using APContours with 25 meter interval. The areas of specific heights, mean elevation, standard deviation of area and standard deviation of elevation are computed and shown in APPENDIX IV, and the area of specific height is shown in Table 1. The generated vector maps of elevation contour lines/area of Latur district is shown in Figure 11.

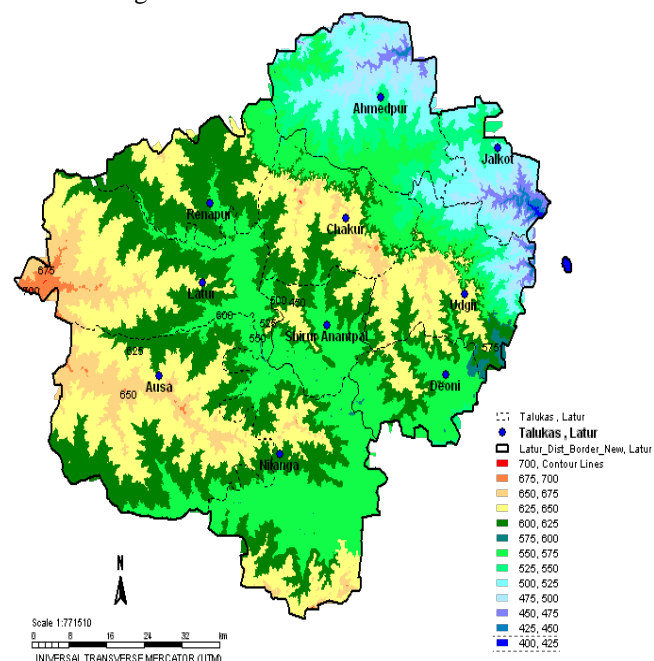


Figure 11. Elevation contours of Latur district.

Table I. Elevations and their covered area

ID	Elevation (Mtr)	Area (Ha)
1	415	315
2	425	2127
3	450	8068
4	475	26511
5	500	49710
6	525	47635
7	550	179404
8	575	5962
9	600	182758
10	625	170194
11	650	46997
12	675	5333
13	700	83

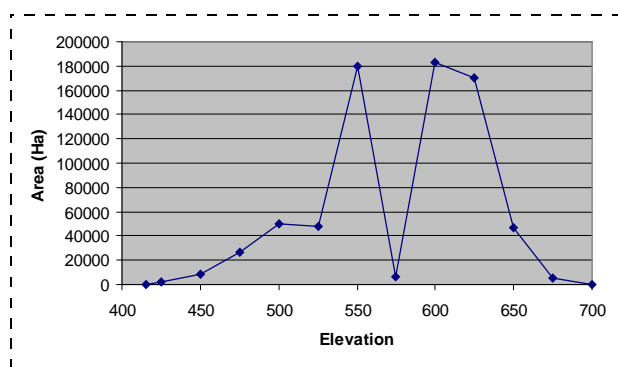


Figure 12. Covered elevation area of Latur district

B. Water body Extraction from DEM:

The slope map was derived using the DEM. The Quantum GIS package is used to extract the reservoirs or lakes of the study area using polygonization. The polygonization utility creates vector polygons for all connected regions of pixels in the raster sharing a common pixel value. Each polygon is created with an attribute indicating the pixel value of that polygon. A raster mask may also be provided to determine which pixels are eligible for processing. The utility will create the output vector data source if it does not already exist, defaulting to GML format [4]. The extracted water bodies are compared with hydrological topo sheet map for accuracy assessment. The slope map is shown in Figure 13, and the extracted water bodies for reservoirs/lakes of Latur district is shown in Figure 14.

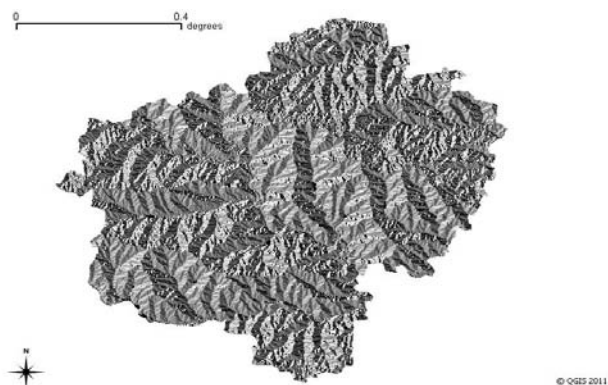


Figure 13. Slope map of Latur district

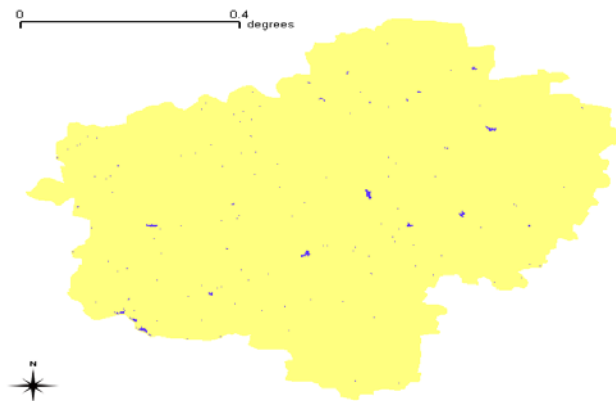


Figure 14. Hydrological map (reservoirs/lakes) of Latur district

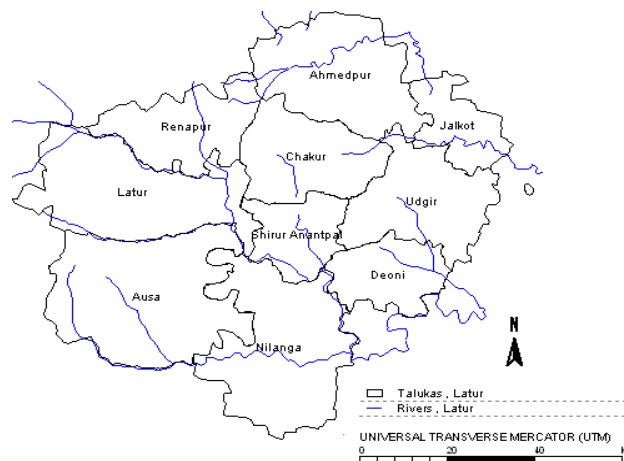


Figure 15. River map of Latur district

The location and flow of each individual river in the district is shown in Figure 15. Regarding water bodies (rivers/reservoirs) of Latur district.

VIII. WATER SCARCITY REGIONS

Taking all the above processes, the elevation maps, slope map, reservoir map, river map, and villages near to water bodies are imported into spatial data base of Latur district. By examining the villages' locations and processed results in the spatial database, the Figure 16 is drawn and it shows the locations of density of water scarcity regions.

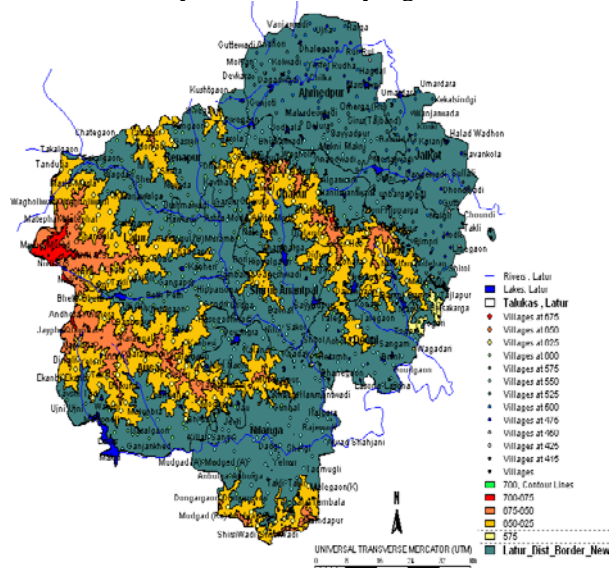


Figure 16. Water scarcity map of Latur district.

The Figure 16 shows the levels of critical regions of water scarcity. The yellow colored polygon used to showcase normal water scarcity regions, the orange color polygon visualized for medium water scarcity regions and the red color polygon shows the critical water scarcity region in Latur district.

IX. CONCLUSION

In this research paper, we have discussed the determination and estimation of contour lines using linear interpolation. The optimal selection from different digital elevation data file formats for contour generation, comparative study on generated contour lines and their errors, calculations and analysis plays very important role for a particular projected area are proposed. This research paper also deals with different methods for analysis of elevation contour lines, water body (reservoirs and lakes) extractions from digital elevation models, and finding critical zones of water scarcity in our study area are proposed. The outcome of this research paper will helps for planning and monitoring of water conservation, water resources department, ground water management, and water for agricultural use etc.

X. ACKNOWLEDGMENT

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