Effect of DEM data resolution on low relief region sub-watershed boundaries delineating using of SWAT model and DEM derived from CARTOSAT-1 (IRS-P5), SRTM and ASTER

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Abstract: Watersheds are natural integrators of hydrological, biological, and geological processes and as such require an integrated approach to data analysis and modeling, which usually starts delineating accurately a polygon vector layer of watershed boundaries as input. In that way, Garrah sub-watershed in Shahjahanpur district of U.P., India, had been isolated with the objective of evaluate the accuracy of sub-watershed boundaries derived from three different sources: One was delineated by 2.6 m resolution CARTOSAT-1 DEM (IRS-P5) and other two were derived from a 30 m ASTER DEM and a 90 m SRTM DEM, using the Soil and Water Assessment Tool (SWAT) model. In this analysis we found that the accuracy of CARTOSAT-1 DEM is so best for accurate delineation of a sub-watershed in the management of the watershed, and the coarse spatial resolution SRTM DEM (90 m) performed much better and significantly than the high spatial resolution ASTER DEM (30 m) it's cause of the errors in the ASTER DEM, map algebra was used to define where the "Fill" tool had filled the sinks finding that the errors in the stream network occurred where some especially large fills had occurred. Not only the visual interpretation of the produces figures indicate the SRTM DEM delineated sub-watershed as relatively more accurate from ASTER DEM delineated sub-watershed boundaries, also statistics for the SRTM DEM elevation turned in significantly higher than that of the ASTER DEM. Overall SRTM DEMs offer more precise elevations while, ASTER DEMs offer more details. Therefore, the accuracy of the sub-watershed delineation depends on the first place on the accuracy of the DEM.

Keywords: ASTER, CARTOSAT-1, DEM, GIS, SRTM and SWAT

INTRODUCTION

Watershed-based natural resource management in plains regions is gaining interest and acceptance with government and community organizations (Estrada and Posner, 2000). Hydrological research in watersheds of developing countries is a relatively new field, therefore, hydrologic and erosion data are necessary for the development of mathematical watershed models that can simulate and evaluate existing and proposed management scenarios.

Delineation of a sub-watershed plays a vital role in the management of watershed as it forms a nucleus around which the efforts like land use, land change, soil types, geology and river flows are analyzed and conclusions are drawn by the management. The field data are collected rapidly and are processed promptly with the help of remote sensing and graphic information system technologies.

The use of Digital Elevation Models (DEMs) for the purposes of automated sub-watershed and stream delineation has increased dramatically in recent years (Marks *et al.,* 1984; Maidment, 1999). The traditional manual methods of sub-watershed delineation are now rapidly being replaced by automated approaches with the advancements in software algorithms for quick and efficient processing. This gives advantages like reliability, reproducibility, cost saving, results within the context of digital domain which can easily be linked to other meaningful data sets for the watershed under study, over the traditional approaches (Baker and Weller, 2006). The aim of the study was to determine whether the use of SWAT software technologies with remotely sensed data regressed with a digital elevation model could produce results that are comparable to the area that has undergone significant delineation.

A sub-watershed: The area which contributes all the water to a particular stream cross-section of topography is defined as the watershed. (Jenson and Domingue, 1988; Rawat *et al.,* 2013). The flow pathway, rates of movement, magnitude and quality of stream flow is controlled by the characteristics like climate, geology, soils, topography, land use and land cover within the watershed as the processes that determine the behavior of water in the land phase of the hydrological cycle, operates at the watershed level. A sub-watershed is a smaller watershed within
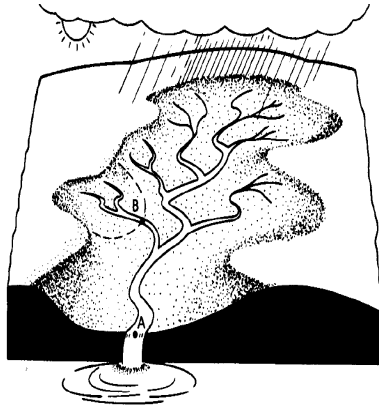
Fig.1. *Ideal sub-watershed with micro sub-watershed (B) and outlet point (A).*

watershed which holds the properties of a watershed. An ideal sub-watershed can be understood by fig. 1.

Digital elevation Data: Digital elevation models (DEMs) provide good terrain representations and are commonly used in watershed modeling. These have been generated throughout the world with the development of Geographic Information Systems (GISs). These are used to derive the flow networks and can automatically generate the watershed boundaries for given outlet point with GIS technologies. Hence, hydrologically DEM of the land area of interest is an essential component to watershed delineation. CARTOSAT-1, SRTM and ASTER are the three types of DEMs used in the current study.

CARTOSAT-1(IRS-P5): The Indian Space Research Organization (ISRO) launched the Cartosat-1 satellite on May 05, 2005. The satellite was primarily designed for topographic mapping and has two panchromatic Charge Coupled Device (CCD) sensors, both with a spatial resolution of 2.6 m. i) the Fore camera, pointing +26 degrees with respect to the nadir, and ii) the Aft camera, pointing -5 degrees with respect to the nadir. These sensors can either acquire along-track stereo images with a 27.5 km swath and a base to height ratio (B/H) of 0.6 or mono images with a combined swath of 55 km.

Shuttle Radar Topography Mission (SRTM): Raw radar echoes are easily available in several resolutions of 1 arc second for US and 3 arc seconds for the world which were used to develop SRTM datasets into DEMs. The SRTM is projected into a geographic coordinate system (GCS) with the WGS84 horizontal datum and the EGM96 vertical datum.

"Research" and "Finished" grade SRTM data are available in NASA and National Geography Agency (NGA) respectively. 1 and 3 arc-seconds spatial resolutions were used to produce DEMs. These are available on internet as well. These datasets were described as high quality DEM (Rabus *et al.,* 2003) besides the fact that problems like voids and unexpected negative values were found in its processing (Luedeling *et al.,* 2007; Grohmann, 2006).

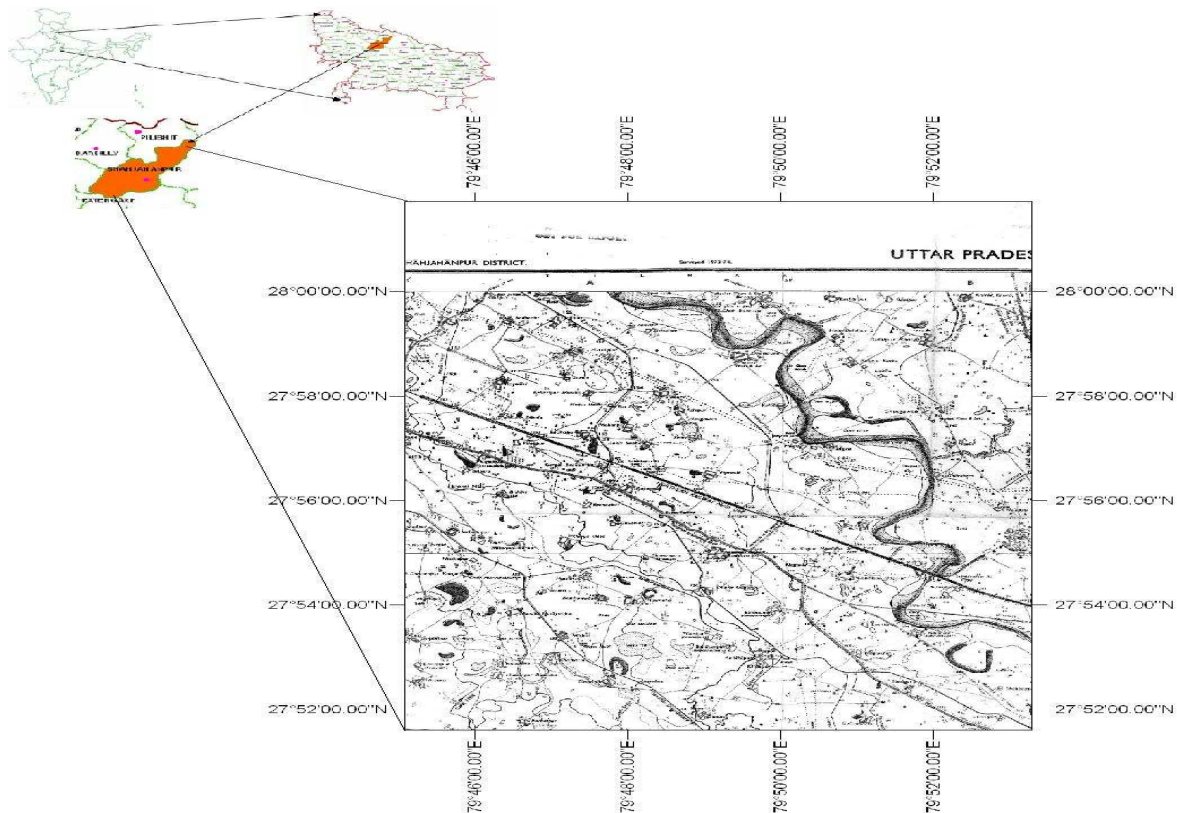**Advanced spaceborne thermal emission and reflection radiometer (ASTER):** An advanced

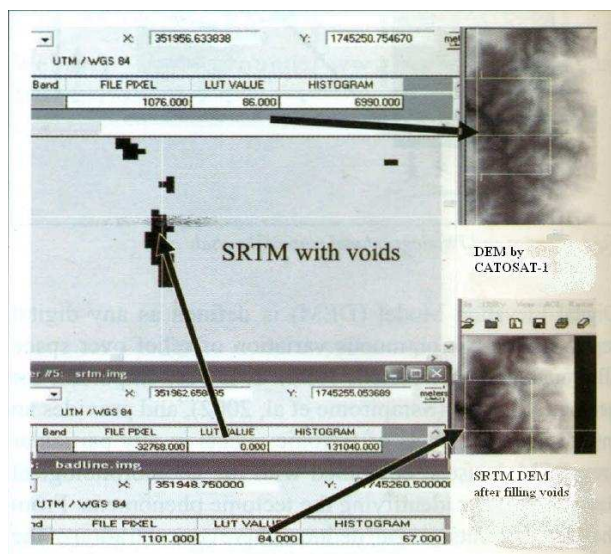**Fig. 2.** *Location and physiographical map of the study area.*

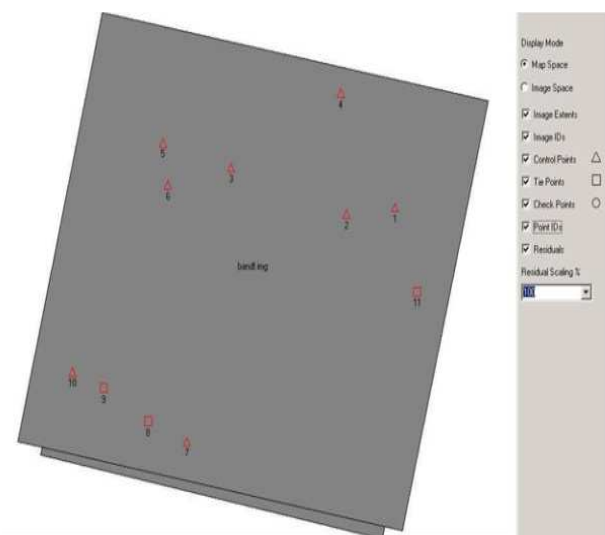**Fig.3.** *SRTM DEM filling voids in ENVI atmosphere.*

Fig. 4. *Ground control points and tie points' location on the stereo model.*

multi-spectral imager called Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) was launched on board NASA's Terra spacecraft in December, 1999 which covers wide visible to thermal infrared spectral region with 14 bands of high spatial, spectral and radiometric. Based on the wavelength, the spatial resolution can be categorised into 3groups: VNIR (visible and near-infrared) - 15 meter, SWIR (short wave infrared) - 30 meter, TIR (thermal infrared) - 90 meter.

Study area: Garrah sub-watershed (study area) in District Shahjahanpur is situated in southeast of Rohilkhand Division. Geographically, it is situated at 27.35° N Latitude and 79.37° E longitude (Fig. 2). The Geographical area of Shahjahanpur is 4575 Km² and Garrah sub-watershed area 0.043802 Km². Agriculture and agriculture based allied activities are play main role in Garrah sub-watershed. Ramganga, Garrah and Gomti are the main rivers flowing through the district Kathana, Jhukma and Mensiare are the tributaries of
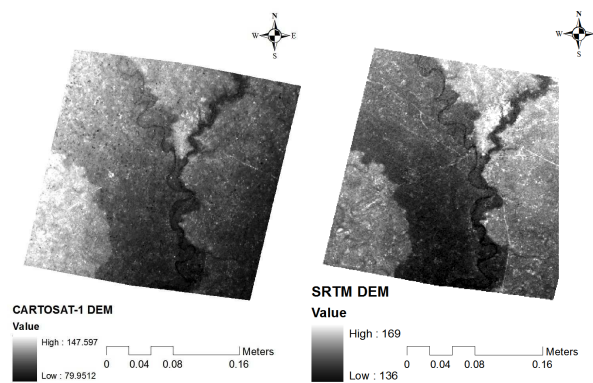

Fig. 5. *CARTOSAT-1 DEM.*   **Fig. 6.** *SRTM DEM.*

Gomti river. Khannaut, Suketa and Kai are the tributaries of Garrah river. Jalalabad Tehsil is mostly affected by flood during monsoon season.

Topography: The major part of the Garrah sub-watershed resembles the upland plains of the Ganga valley. The continuity of plains is interrupted only by valleys predominated by numerous streams and water courses. All small and medium sized rivers flow in a South Easterly direction, indicating the general slope of the district. It is not easy to determine the exact extent of this slope from the recorded heights, although there are fairly large number of permanent station of the survey of India department (datums), but they are usually placed on places of eminences; well above the surrounding tracks. Thus the pillar at Kusrak is 184.71 m above mean sea level (MSL) at its base whereas, the bench mark at Katra, less than 3 km distant is only about 158.80 m MSL. Other stations are Sultanpur (177.08 m) Piparia (174.35 m), in the north of tehsil Powaywn; Karai (170.38 m) near Khutar; Dhaka (151.49 m) near Jalalabad and Goendi, (150.26 m) in the South-West corner. The maximum height of the ground level is approximately 166.11 m on the North-West border, not far from Khudaganj.

MATERIALS AND METHODS

In this study, DEM was generated from CARTOSAT-1, ASTER and from SRTM data. Most of the SRTM data contains voids (cells with no elevation value) (Hall *et al.,* 2005; Luedeling *et al.,* 2007), thus appearing as black colour on the DEM image (Fig. 3).

These voids occur in various regions: water surface, area where the surface materials are in very law reflectance. They also occur in areas with very rough slopes. The voids have therefore, limited the utilization of the DEM generated from SRTM.

Remote sensing-derived DEM dataset used

Dataset from CARTOSAT-1: CARTOSAT-1 is a global mission. The normal life of the mission is planned to be five years. CARTOSAT-1 data for Fore and Aft scenes of west part of Shahjahanpur district, dated 2nd October 2008 were used.

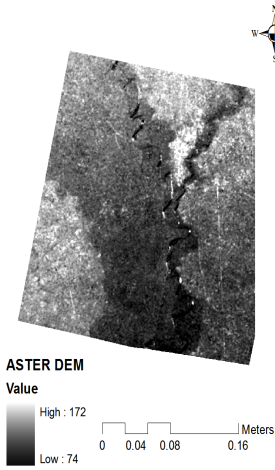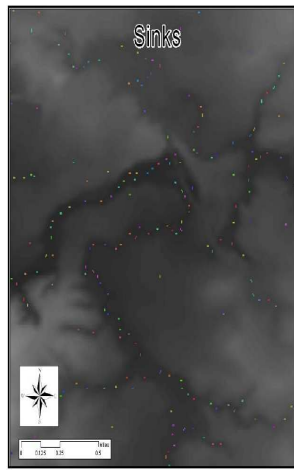**Dataset from SRTM:** The free ware SRTM data was obtained from http://srtm.usgs.gov/ and ftp://

Fig.7. *ASTER DEM.*

Fig.8. Sinks over *SRTM DEM Data Set.*

Fig. 12. *Map of Garra sub-watershed, CARTOSAT-1 DEM dependent boundary.*
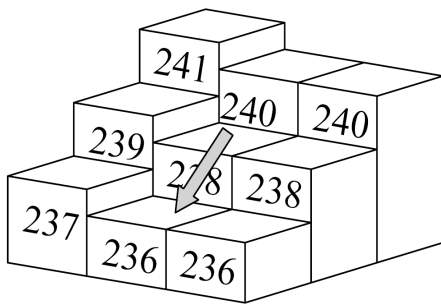
Fig. 9. *Theoretical eight-cell neighborhood (numbers indicate elevation of) cell .*

Fig. 13. *Map of Garra sub-watershed, ASTER DEM dependent boundary.*

Fig.10. *Computed slopes between center cell and each of the surrounding eight cells. Water follows the largest negative (downward) slope to the south.*

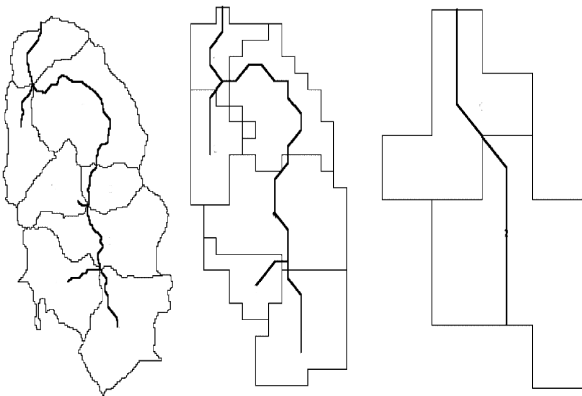

Fig. 14. *Map of Garra sub-watershed, SRTM DEM dependent boundary.*

Fig. 11. *SWAT watershed delineation shown at 2.6 m, 30 m*
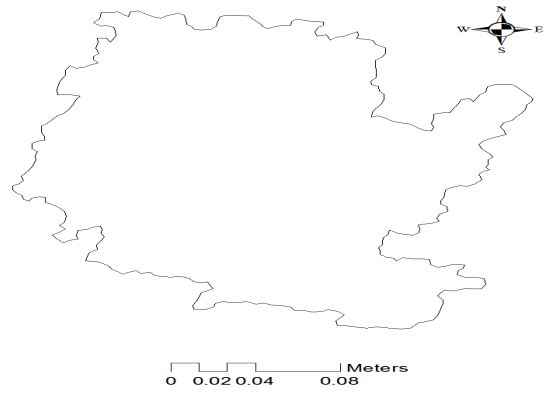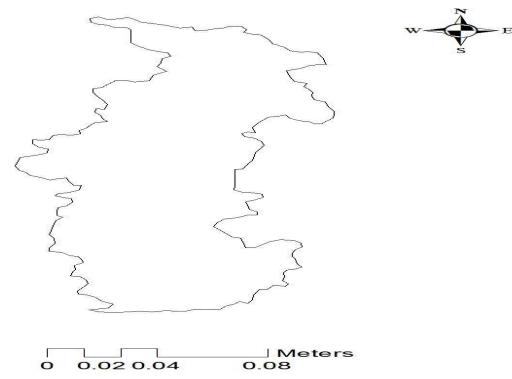
Fig. 15. *Map of Micro sub-watersheds in the Garra sub-watershed, CARTOSAT-1DEM dependent boundary.*

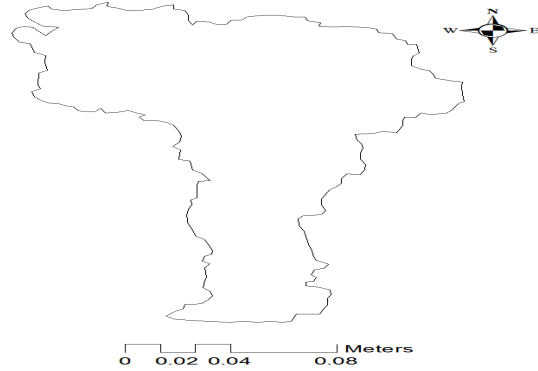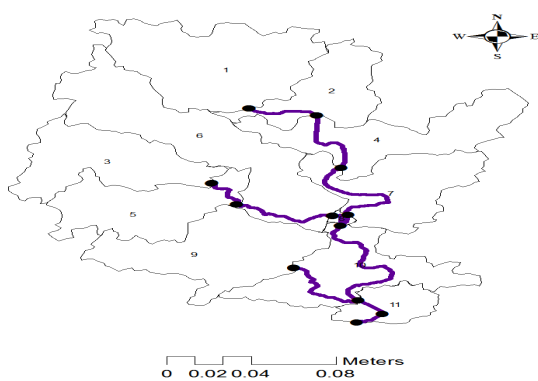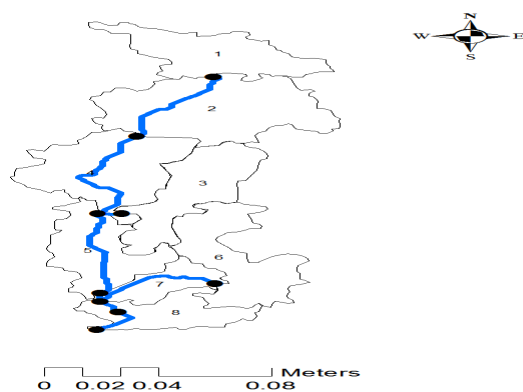**Fig. 16.** *Map of Micro sub-watersheds in the Garra sub-watershed, ASTER DEM dependent boundary.*
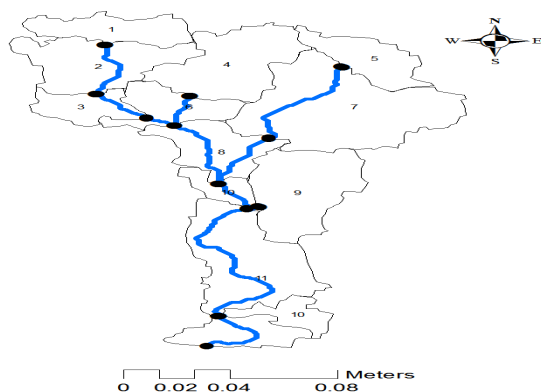

Fig. 17. *Map of Micro sub-watersheds in the Garra sub-watershed, SRTM DEM dependent boundary.*

edcsgs9.cr.usgs.gov/pub/data/srtm/A.Norte/). Downloaded SRTM data contains many voids (gaps) occurring at various positions with the digital value (-140) (Fig. 3). The voids were filled by using the ENVI(ITT Visual Information Solutions) +IDL 4.5, with the bad values (-140) replaced (Bhang and Schwartz, 2008). Comparison of all the elevation values was done with the elevation values of DEM from the digitized contour lines.

Dataset from ASTER: Here, an ASTER DEM of a resolution of 30 m was taken on October 02, 2009 (http://www.gdem.aster.ersdac.or.jp. Freely available) covering the entire Shahjahanpur district of Uttar Pradesh, India was acquired.

Generation of DEM from CARTOSAT-1 data: Transformation between the image space and object space is represented by application of Rational Functions (RFs) in photogrammetry and remote sensing whenever the rigorous model is made unavailable intentionally or unintentionally. With the release of high resolution images, this is gaining more attention among the users with only RF coefficients (Egels and Kasser, 1998; DeVencia *et al.,* 2007; Gianinetto, 2008; Gianinetto and Fassi, 2008). Eleven GCPs were used for evaluating the CARTOSAT-1 data of Shahjahanpur to refine the orbital parameters of Fore and Aft scenes. Geodetic Single Frequency GPS was used in Relative mode to assemble the GCPs of this area. Fig. 4 shows that eight ground points were used as GCPs and three points on the ground were used as Tie points while generating the stereo model.

Triangulation was used to refine the exterior orientation parameters by the eight GCPs. As shown in fig. 5, DEMs were generated after triangulation. The known points on the ground were used as GCPs along with tie points to evaluate the DEM generated using CARTOSAT-1 stereo data of Shahjahanpur area (Gianinetto, 2008; Gianinetto and Fassi, 2008; Krishna *et al.,* 2008).

DEM from SRTM: A digital elevation model (DEM) (Table 1) used for this study area (Fig. 6) with resolution of 90 meter of SRTM available on http://srtm.csi.cgiar.org/

DEM from ASTER: A digital elevation model (DEM) used for Garra sub-watershed (Fig. 7) with resolution of 30 meter of ASTER available on http://www.gdem.aster.ersdac.or.jp/

Software used for analysis: The main software used for compiling and analyzing the data, is ArgGIS 9.2 (ESRI) and SWAT. ArgGIS-9.2 has a very good GIS operation capability and SWAT model is specially built for ArgGIS 9.2. With the added advantage of SWAT extension, ArgGIS 9.2 is well suited for the present study.

The SWAT model was developed and maintained by the U.S. Department of Agriculture (USDA) Agricultural Research Service or ARS (Arnold *et al.,* 1998), which incorporates features of several ARS models. Moreover, it is a direct outgrowth of the simulator for Water Resources in Rural Basins (SWRRB) model and Routing Outputs to Outlet (ROTO) model (Arnold *et al.,* 1995). Additionally, there are some specific models viz. Chemicals, Runoff, and Erosion from Agricul-

Table 1: Metadata of Satellite data set for study area.

Data	Original projection	Original resolution	Satellite/ Source	Description of original format	Purpose
SRTM DEM	Lat/Long	90 x 90 m	NASA Shuttle Mission	One tiles covering study area	Sub-watershed and Micro-sub watershed delineation
ASTER DEM	Lat/Long	30 x 30 m	NASA Terra Satellite	One tiles covering study area	Sub-watershed and Micro sub- watershed delineation
CARTOSAT-1 DEM	Lat/Long	2.6 x 2.6 m	ISRO Satellite	Row and Path	Sub-Watershed and Micro -sub watershed delineation

Table 2. Responses of input DEM resolutions on SWAT model predictions at varying DEM resolutions on delineated sub-watershed properties.

DEM resolution	SW area (KM^2)	Number of MSW	SW length (Km)	Elevation ranges for MSW
90 x 90 m	0.0218	11	0.947	157 m–149 m
30 x 30 m	0.0175	8	0.933	134 m–145 m
2.6 x 2.6 m	0.0438	11	1.347	112.67 m–98.42 m

MSW: Micro sub-Watershed and SW: sub-Watershed.

Table 3. Responses of input DEM resolutions on SWAT model predictions at varying DEM resolutions on delineated micro sub-watershed properties.

S M W W No	CARTOSAT-1			SRTM			ASTER		
	Area of MSW (km^2)	MSW Length (km)	Elevation Max Ranges for MSW (m)	Area of MSW (km^2)	MSW Length (km)	Elevation Max Ranges for MSW (m)	Area of MSW (km^2)	MSW Length (km)	Elevation Max Ranges for MSW (m)
1	0.006464	0.420059	112.67	0.001148	0.184834	154	0.002097	0.279184	140
2	0.002943	0.337659	107.69	0.002055	0.246046	149	0.003727	0.316407	145
3	0.004263	0.392487	112.19	0.000838	0.148365	150	0.002188	0.300011	137
4	0.004392	0.4705	111.92	0.002305	0.248039	158	0.002879	0.291767	141
5	0.003917	0.403708	108.33	0.001182	0.185596	150	0.00201	0.288199	138
6	0.007198	0.589794	108.28	0.001094	0.1903	150	0.002311	0.348273	135
7	0.003937	0.36445	101.44	0.004311	0.328223	157	0.000892	0.162966	134
8	0.000111	0.044572	98.42	0.00141	0.199125	140	0.001355	0.235349	134
9	0.005122	0.414725	102.91	0.002382	0.228652	151	Nil	Nil	Nill
10	0.004087	0.420175	100.36	0.001091	0.283784	150	Nil	Nil	Nill
11	0.001354	0.171661	98.72	0.003903	0.438868	152	Nil	Nil	Nill

MSW: Micro sub-Watershed.

tural Management Systems (CREAMS) model that contributed significantly to the development of SWAT (Knisel, 1980).

Basics of automated sub-watershed delineation from different sources DEMs: Sub-watershed boundaries were derived from the DEMs using SWAT model automated procedures with the Sub-watershed Delineator. 2.6 m, 30 m and 90 m resolution DEM data (Table 1) was used to extract the boundary of sub-watershed and the process was composed of main three steps.

The first step is to fill the depression (Sink) in DEM (Fig. 8). Depression refers to a cell whose elevation value was lower than that of any of its neighbor cells. This phenomenon occurs when the breadth of valley is less than the grid size and the low value of valley decreases the average value of the cell. Since depression usually occurs in upper stream, it is necessary to fill the depression before determining the flow direction. The second step is to determine the direction of flow from every cell in the grid. This function takes a grid surface as input and generates a grid output that shows the direction of flow out of each cell (Figs. 9 and 10). There are eight valid output directions, relating to the eight adjacent cells into which flow could travel. Former elevation values of

each cell is substituted by one number among 1, 2, 4, 8, 16, 32, 64, 128 for potential flow direction of east, southeast, south, southwest, west, northwest, north, and northeast. Thus a new digital grid with flow direction is recorded, which is called as flow direction grid. The last step is 'flow accumulation', which calculated accumulating flow as the accumulated weight of all cells flowing into each down slope cell in the output grid (Fig. 10) (Lindsay, 2008) If no value was assigned to the grid, a value of one was applied to each cell, and the value of cells in the output grid would be the number of cells that flowed into each cell.

All the commands were completed in SWAT environment and the ensuing boundary map was obtained as fig. 11.

RESULTS AND DISCUSSION

The sub-watershed (Figs. 12 to 14) and micro sub-watersheds (Figs.15 to 17) boundary was computed with an automated procedure using digital data (DEM) and represents an estimate of the sub-watershed and micro sub-watersheds boundary determined with the best available Digital Elevation Model (DEM)-analysis SWAT model.

The effect of input DEM data resolution on delineated sub-watershed area, number of micro sub-watersheds
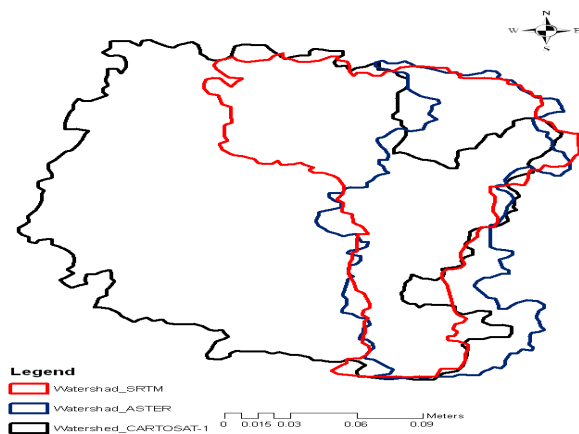
Fig. 18. *CARTOSAT-1, ASTER and SRTM DEMs dependent sub-watershed boundaries comparison.*
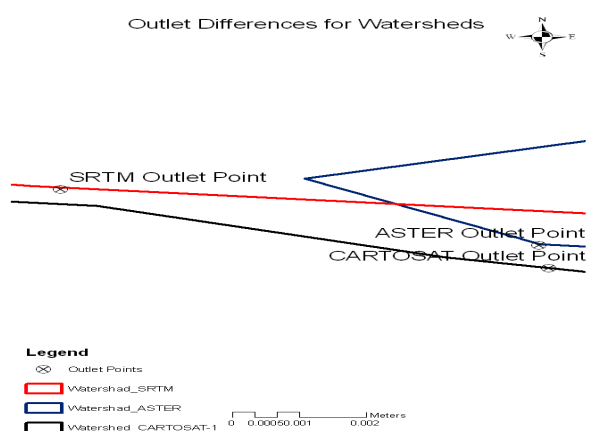

Fig. 19. *CARTOSAT-1, ASTER and SRTM DEMs dependent sub-watershed outlet comparison.*

Table 4. Effect of different resolution DEM on SWAT model for predictions of outlet (at different elevation) of sub-watershed .

Elevation of outlet from different DEM	Elevation (m)
Elevation of outlet point of sub-watershed from SRTM-DEM	142
Elevation of outlet point of sub-watershed from ASTER-DEM	131
Elevation of outlet point of sub-watershed from CARTOSAT-1-DEM	94.72

0.0218 Km^2 (49.77169 % of CARTOSAT-1 based sub-watershed area), and the ASTER-based sub-watershed area is 0.0175 Km^2 (39.95434 % of CARTOSAT-1 based sub-watershed area). The numbers of micro sub-watersheds were also affected by the DEM resolution, possibly due to differences in sub-watershed and stream network delineation by the SWAT model. Table 3 shows that number of micro sub-watersheds within the sub-watershed increased for 2.6 x 2.6 m and 90 x 90 m decreased for 30 x 30 m DEM resolution because ASTER DEMs could be generated without GCPs so Microwave based SRTM data provide better alternatives for associated topographical applications because usually ASTER DEM is based on several images, named as stacks (Hasan *et al.,* 2011). In this analysis we also found that outlet point of Garra watershed have put different elevation for Different DEMs, and minimum, maximum outlet elevation value is 94.72 m, 142 m found from CARTOSAT-1, SRTM DEM respectively (Table 3), but distances of outlet point from SRTM DEM based boundaries to CARTOSAT-1 based boundaries is 7.63 m while 0.65 m (Fig. 19, Table 4) distances found from CARTOSAT-1 to ASTER because outlet point of sub-watershed always will be effective due to sum of total input of sub-watershed finally out come from this point so this point can be easily dedicated from any resolution data of DEM.

Conclusion

The results of our effort indicated evaluatation of sub-watershed delineation on DEMs of different source. The accuracy of the sub-watershed delineation is highly dependent on the accuracy and good quality of the Digital Elevation Model available. ASTER data have several advantages, including low cost, high spatial resolution, good correlation over vegetated areas. Its disadvantages include mainly the potential masking by clouds and ASTER DEMs generated without GCPs. There have been other topographic datasets however, elevation models produced from SRTM data will be the highest resolution datasets ever produced for Earth's land surface. This clearly gives SRTM and edge over the existing global elevation data due to the increase in spatial resolution and vertical accuracy. SRTM DEMs, when fused with other types of satellite derived data such as ASTER, leads to improved resolution results but not much improve to

is shown in table 2. If we consider the 2.6 x 2.6 m DEM data to give the best estimate of the sub-watershed properties, table 2 shows that all other DEM resolutions resulted in different sub-watershed delineation, sub-watershed area and number of sub-watershads (Figs. 14 to 17, Table 3). The effect was most significant for 90 x 90 m and 30 x 30 m resolution, where the area of sub-watershed estimated was 49.77 % and 39.95 %, respectively with respect to CAROSAT-1 derived sub-watershed area. The SWAT delineated sub-watershed boundary, micro sub-watersheds and major stream network for three DEM resolutions are shown in fig. 14 to 17. The sub-watershed and major stream network representation became increasingly less accurate with decrease in DEM resolution.

Visually, there are much differences between the CARTOSAT-1 DEM based boundaries delineated and the SRTM DEM and ASTER DEM based boundaries (Fig. 18), while the ASTER DEM and SRTM DEM based boundary are some close to each other at right hand side only because right hand side stream is clearly shows in each DEMs. The area of the sub-watershed delineated from CARTOSAT-1 is 0.0438 Km^2, while the SRTM-based sub-watershed area is

topographic results. The input DEM data resolution affected SWAT model results as the total area of delineated sub-watershed, predicted stream network and sub-watershed were affected by it. It was found that the choice of input DEM data resolution for the SWAT model depends on the output of interest. Efforts must be applied to collect and input DEM data at finer resolutions to minimize the uncertainties in the model predictions as the use of the SWAT model in making sub-watershed response predictions are expected to increase in future. This work is only the first step in providing a Geographic Information System (GIS) framework for primary level study of Garrah Sub-watershed. This study demonstrates that developing an accurate sub-watershed analysis for various uses with a minimum amount of time, effort and cost can certainly be achieved by using remotely sensed data and available software.

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