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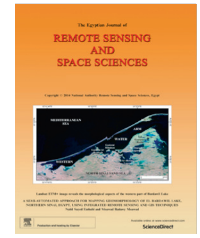

RESEARCH PAPER

Hydrological inferences from watershed analysis for water resource management using remote sensing and GIS techniques

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Abstract The present study highlights the importance of Digital Elevation Model (DEM) and satellite images for assessment of drainage and extraction of their relative parameters for the Orr watershed Ashok Nagar district, M.P., India. Hydrological parameters such as drainage analysis, topographic parameters and land use pattern were evaluated and interpreted for watershed management of the area.

Hydrological module of ARC GIS software was utilized for calculation and delineation of the watershed and morphometric analysis of the watershed using SRTM DEM. The stream order of watershed ranges from first to sixth order showing dendritic type drainage network which is a sign of the homogeneity in texture and lack of structural control of the watershed. The drainage density in the area has been found to be low to medium which indicates that the area possesses highly permeable soils and low relief. The bifurcation ratio varies from 4.74 to 5 and the elongation ratio is 0.58 which reveals that the basin belongs to the elongated shaped basin category. The mean R_b of the entire basin is 4.62 which indicates that the drainage pattern is not much influenced by geological structures. Land use map of the watershed was generated from latest available multispectral satellite data and whole watershed covers under agricultural land, settlement, fallow land, forest, mining areas and water body.

The present study reveals that SRTM DEM based hydrological evaluation at watershed scale is more applied and precise compared to other available techniques.

1. Introduction

Presently high inhabitant's expansion, fast urbanization and climate change along with the irregular frequency and intensity of rainfall make appropriate water management and storage plans difficult. Therefore, there is an urgent need for the evaluation of water resources because they play a primary role in the sustainability of livelihood and regional economics

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throughout the world. It is the primary safeguard against drought and plays a central role in food security at local and national as well as global levels. The ever-growing population and urbanization is leading to over-utilization of the resources, thus exerting pressure on the limited civic amenities, which are on the brink of collapse (Singh et al., 2013; Jha et al., 2007).

Quantitative morphometric analysis of watershed can provide information about the hydrological nature of the rocks exposed within the watershed. A drainage map of basin provides a reliable index of permeability of rocks and their relationship between rock type, structures and their hydrological status. Watershed characterization and management requires detail information for topography, drainage network, water divide, channel length, geomorphologic and geological setup of the area for proper watershed management and implementation plan for water conservation measures (Sreedevi et al., 2013).

Remote sensing data, along with increased resolution from satellite platforms, makes these technologies appear poised to make a better impact on land resource management initiatives involved in monitoring LULC mapping and change detection at varying spatial ranges in semi-arid regions is undergoing severe stresses due to the combined effects of growing population and climate change. (Singh et al., 2012).

Surface hydrological indications are one of the promising scientific tools for assessment and management of water resources. Drainage morphometric analyses are a prerequisite for selection of water recharge site, watershed modeling, runoff modeling, watershed delineation, groundwater prospect mapping and geotechnical investigation. (Magesh et al., 2011; Thomas et al., 2012). The drainage network analysis is generally performed to understand the prevailing geological variation, topographic information and structural set of a basin and their interrelationship. Remote sensing and GIS based drainage basin evaluation has been carried out by number of researchers for different terrains and it is proved to be a very scientific tool for generation of precise and updated information for characterization of drainage basin parameters (Grohmann, 2004; Korkalainen et al., 2007; Hlaing et al., 2008; Javed et al., 2009; Pankaj and Kumar, 2009).

Previously drainage morphometric parameters were extracted from topographical maps or field surveys. Drainage parameter extractions from last two decades are more popular from digital topographical information which is called as digital elevation models (DEM), which is more fast, precise, updated and inexpressive way of watershed analysis (Moore et al., 1991; Maathuis, 2006).

One of the most recent near global elevation data sets recorded during the 11 day Shuttle Radar Topographic Mission is based on a C-band interferometric radar configuration. This information, representing the radar reflective surface (which may be vegetation, man-made features or bare earth), was collected in 2000 (Maathuis, 2006).

Digital elevation models (DEMs), such as from the Shuttle Radar Topography Mission (SRTM), or the ASTER GDEM product (USGS, Denver, Colorado, USA), have been used to extract different geomorphological parameters of drainage basins, including drainage networks, catchment divides, slope gradient and aspect, and upstream flow contributing areas (e.g. Mark, 1984; Tarboton, 1997). GIS based watershed evaluation using Shuttle Radar Topographic Mission (SRTM) data have given a precise, fast, and an inexpensive way for analyzing hydrological systems (Farr and Kobrick, 2000; Grohmann et al., 2007; Panhalkar, 2014).

Recently Bastawesy et al. (2013) utilized remote sensing data and digital elevation models to extract the catchment hydrological parameters to delineate storage areas for the Uganda Equatorial Lakes region. They concluded that digital elevation models (DEMs) are a very accurate tool for morphometrical parameter evaluation and watershed delineation for watershed management.

In addition, low-intensity and erratic monsoons create further shortages of surface-water supply. As a result, the demand for groundwater resources has increased tremendously from year to year, causing a drastic decline of groundwater levels. Over-exploitation of groundwater has led to the drying up of the aquifer zones in several parts of the country. It is, therefore, essential to increase the recharge of the basin for the water management program at watershed level (Ellis and Revitt, 2010; Rao, 2008; Eyquem, 2007).

The present study comes under the semi-arid region and received maximum recharge through rainfall and the area urgently required integrated watershed based morphometric analysis to understand the physiographic status of the area. The hydrological analysis of watershed and their morphometric evaluation of Orr watershed, Ashok Nagar, District of Madhya Pradesh were carried out for water resource management through the use of SRTM DEM, satellite images and GIS analysis. The main aim of present the work is to investigate and identify various drainage parameters to understand the geometry of the watershed for the conservation and management of water resources in a sustainable manner. The result observed in present work can be the scientific data base for further detailed hydrological investigation and finds out the alternative solutions for water harvesting in the study area through the construction of various suitable structures (Check dam, Storage tanks, Recharge shaft) based on observed calculations.

2. Study area

The study area Orr watershed lies between geographic latitudes 24°10′ and 24°50′ N and longitudes 77°40′ and 78°05′ E from 154 m to 541 m average from mean sea level (AMSL) with an area of about 996 km^2 (Fig. 1). Ashok Nagar, is a newly constructed district of Madhya Pradesh and located on the northern part of Madhya Pradesh between Sindh and the Betwa rivers. The area comes under the northern part of Malwa plateau and Bundelkhand plateau.

The climate of the study area is characterized by a hot summer and general dryness except during the southwestern monsoon. The period from middle of June to September is the southwestern monsoon season. October and November forms the post monsoon or transition period. The district receives the maximum rainfall during the southwest monsoon period i.e. June–September. About 92.2% of the annual rain fall predicates during the monsoon season. Only 7.8% of the annual rain fall takes place between October and May. Thus surplus water for ground water recharge is available during the period from June to May is the driest month of the year. Normal maximum temperature during the month of May is 42.3 °C and minimum during January month is 6 °C.

Geologically the area is represented by Deccan trap basalts of Malwa group, Vindhyan sandstone and alluvium and groundwater in this group occurs under phreatic conditions.

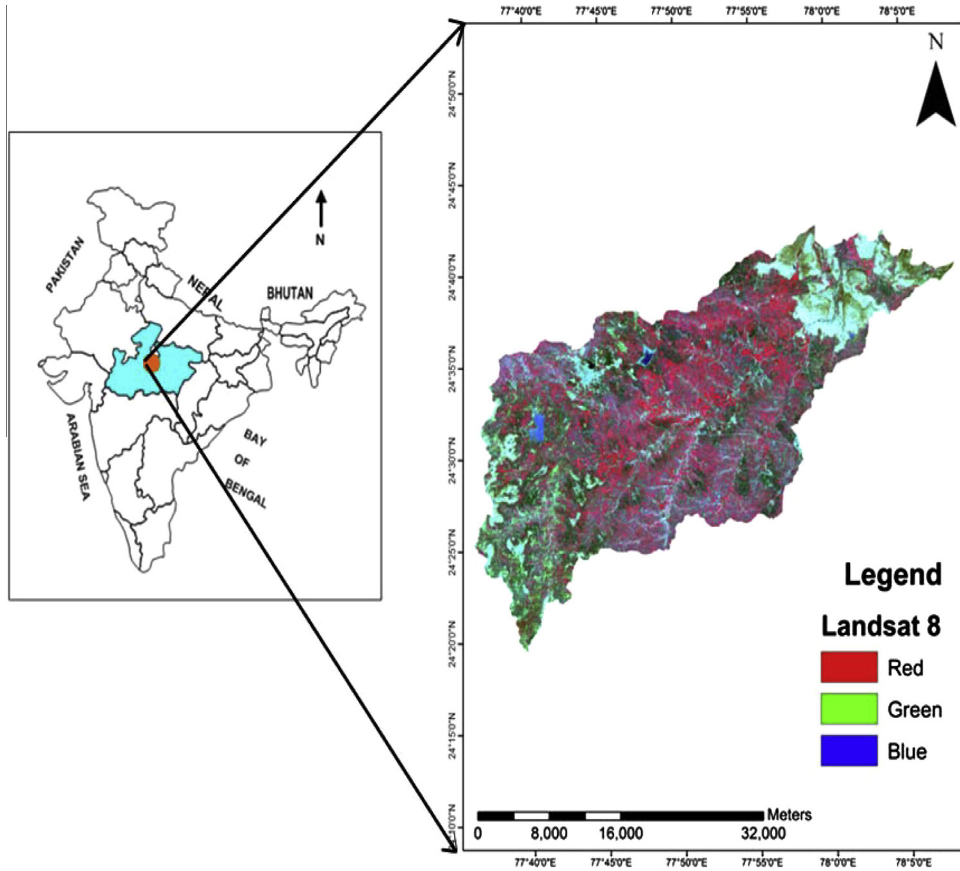

Figure 1 Location map of the Orr watershed, M.P., India.

The rocks of the area are hard and compact, but at some places and at different depths it is fractured and jointed which make potential aquifers at deeper levels. The ground water occurs under semi confined to confined conditions and is being exploited through bore wells. Geomorphologically the area exhibits low lying plateau of extrusive origin with rocky terrain with alluvial deposits along the river sides. Major soil of the watershed comes under three hydrological groups such as clayey soil which is associated with stone of moderately shallow depth and occurring in well-drained moderately sloping plateau affected by severe erosion, well-drained loamy soils associated with stone on gently sloping plateau affected by severe erosion and third group is moderately deep soil developed over gentle slope and they are well drained.

3. Database preparation, methodology and delineation of drainage map

Assessment of drainage pattern and their quantitative analysis provides background information about the hydrological conditions and nature of rock formation exposed within the watershed. Morphometric analysis of a basin provides an indication about permeability, storage capacity of the rocks and gives an indication of the yield of the basin.

In the present paper an integrated use of multispectral satellite data, digital elevation model (DEM) and survey of India topographical sheets were utilized for generation of database and extraction of various drainage parameters. Details of data used are shown in Table 1. The following procedure was followed for watershed analysis.

a. The SOI toposheets were geometrically rectified and georeferenced by taking ground control points (GCPs) by using UTM projection and WGS 84 datum. Further, all geocoded toposheets were mosaic using Erdas Imagine 9.1 image processing software.
b. Catchment area of the Orr watershed delineated from SRTM DEM and Survey of India topographical sheets of the study area by using data preparation option of Erdas Imagine Software by making AOI (Area of Interest) of the basin and same AOI was used to cut the satellite Image of the study area.

Table 1 Data used in the present work.

Type of data/software	Details of data	Sources
Survey of India , toposheets	Toposheet nos. scale: 1:50,000 54H/10,11,14.14 and 54L/2	Survey of India (SOI), Dehradun, India
Landsat 8 satellite imagery	Path/row: 145/43 dated 16/12/2013	https://landsat.usgs.gov
SRTM DEM	3-ARC (90 m) , 2000	USGS website

Table 2 Methodology adopted for computations of morphometric parameters.

S. No.	Parameters	Formulae	References
1	Stream order (U)	Hierarchical rank	Strahler (1964)
2	Stream length (L_u)	Length of the stream	Horton (1945)
3	Mean stream length (L_{sm})	$L_{sm} = L_u/N_u$	Strahler (1964)
4	Stream length ratio (R_L)	$R_L = L_u/(L_u - 1)$	Horton (1945)
5	Bifurcation ration (R_b)	$(R_b) = Nu/Nu + 1$	Schumm (1956)
6	Mean bifurcation ratio (R_{bm})	R_{bm} = average of bifurcation ratios of all order	Strahler (1957)
7	Drainage density (D_d)	$D_d = L_u/A$	Horton (1945)
8	Drainage texture (T)	$T = D_d \times F_s$	Smith (1950)
9	Stream frequency (F_s)	$F_s = N_u/A$	Horton (1945)
10	Elongation ratio (R_e)	$R_e = D/L$	Schumm (1956)
11	Circularity ratio (R_c)	$R_c = 4\pi A/P^2$	Strahler (1964)
12	Form factor (F_f)	$F_f = A/L^2$	Horton (1945)
13	Relief	$R = H - h$	Hadley and Schumm (1961)
14	Relief ratio	$R_r = R/L$	Schumm (1963)

c. Landsat 8 Satellite (December, 2013) Image utilized to generate the land use/land cover map and updation of drainage map of the basin.
d. Digital Elevation Model (DEM) of the catchment was extracted from Shuttle Radar Topographic Mission (SRTM) data obtained during February 2000 with resolution of 90 m (downloaded from the US Geological Survey website). The SRTM DEM was utilized to prepare topographic, slope and delineation of drainage map of the basin Using Spatial Analyst tool of ARC GIS 10.
e. All the extracted parameters from satellite images and SRTM DEM such as the number and lengths of streams of each different order; drainage area, basin perimeter and total basin length, and width were calculated using ARC GIS software, drainage density, drainage frequency, shape, form factor, circulatory ratio, and elongation ratio, etc., were calculated from these parameters. The methodologies adopted for the computation of morphometric parameters are given in Table 2.

4. Result and discussion

Assessment of watershed using quantitative morphometric analysis can provide information about the hydrological nature of the rocks exposed within the watershed. A drainage map of a basin provides a reliable index of permeability of the rocks and gives an indication of the yield of the basin.

The DEM has been obtained with a pixel size of 90 m and furthermore, it has been used to calculate slope and aspect maps of the watershed. The development of drainage networks depends on geology, precipitation apart from exogenic and endogenic forces of the area. Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) data were used for preparing slope, aspect maps and morphometric analysis of the watershed. Linear, areal and relief aspects of the watershed were evaluated in GIS environment using Arc GIS software. Recent development in geospatial technology, the assessment of drainage basin has been more accurate and precise for morphometric parameter evaluation with better accuracy. Satellite data and GIS have been successfully utilized to generate data on the spatial deviations in drainage characteristics thus providing an insight into hydrologic conditions necessary for developing watershed management strategies (Das and Mukherjee, 2005).

Hydrogeological observations, integrated with drainage analysis, provide useful clues regarding broad relationships among the geological framework of the basin. Therefore, the results reveal different levels of agreement using morphometric analysis, which were supposed to be different from one region to another. Factors controlling groundwater storage are different in space and time, and the majority of these factors depend on the following parameters: (1) rainfall availability as the source of water; (2) drainage characteristics have a role in the distribution of runoff and indicate an infiltration scheme and it governs the behavior of water flow on terrain surface vertically and horizontally; (3) rock type for which the lithologic character governs the flow and storage management; (4) slope is another influencing factor, and it controls water flow energy, which plays a role in facilitating water flow in the basin. The morphometric analysis can be achieved through measurements of linear, areal and relief aspects of basin.

Quantitative analysis of Orr watershed has been carried out to evaluate the drainage characteristics using GIS software for calculation and topology building of different morphometric parameters. Important Linear and Arial parameters and their characteristic were calculated such as basin area, perimeter , basin length , bifurcation ratio (R_b), drainage density (D_d), stream frequency (F_s) circulatory ratio (R_c), elongation ratios (R_e) etc. The drainage patterns of the watershed are dendritic with sixth order streams. The details of various morphometric parameter and law used in the present work are shown in Table 2.

4.1. Stream number (Nu) and stream orders

The Orr watershed encompasses a dendritic drainage pattern which indicates homogenous subsurface strata of the study area. In the present study the stream ordering has been ranked based on a method proposed (Strahler, 1964) from the digitized streams from top sheets and satellite images. The order wise stream numbers and their linear characteristics are shown in Table 3. The drainage pattern analysis of the Orr river basin indicated that the area is having a lake of structural tectonic control. Maximum number of stream was found in the first

Table 3 Linear aspect of the Orr watershed.

Stream order (w)	No. of streams (N_u)	Bifurcation ratio (R_{bF})	Mean bifurcation ratio (R_{bm})	Total length of streams (km)	Mean length of streams (km)	Length ratio (R_L)
I	2062		4.62	1162.43	0.809	4.29
II	435	4.74		492.88		
III	91	4.78		231.96		
IV	19	4.79		142.31		
V	5	3.8		30.96		
VI	1	5		54.23		
Total	2613		Total	2114.77		

order and as the stream order increases with a decrease in stream number. The drainage map with stream order of the Orr river basin is shown in Fig. 2.

The stream order of the basin varies from 1st to 6th orders stream. Stream ordering of the Orr river basin was computed using ARC GIS software by applying the law proposed by Horton, 1945. It is found that the total length of streams segment is maximum in first order streams and decreases as the stream order increases. This change in stream orders may indicate flowing of streams from high altitude and lithological variations. The Total length of streams in the Orr river basin is about 2114.77 km. The mean stream length (L_{sm}) and their

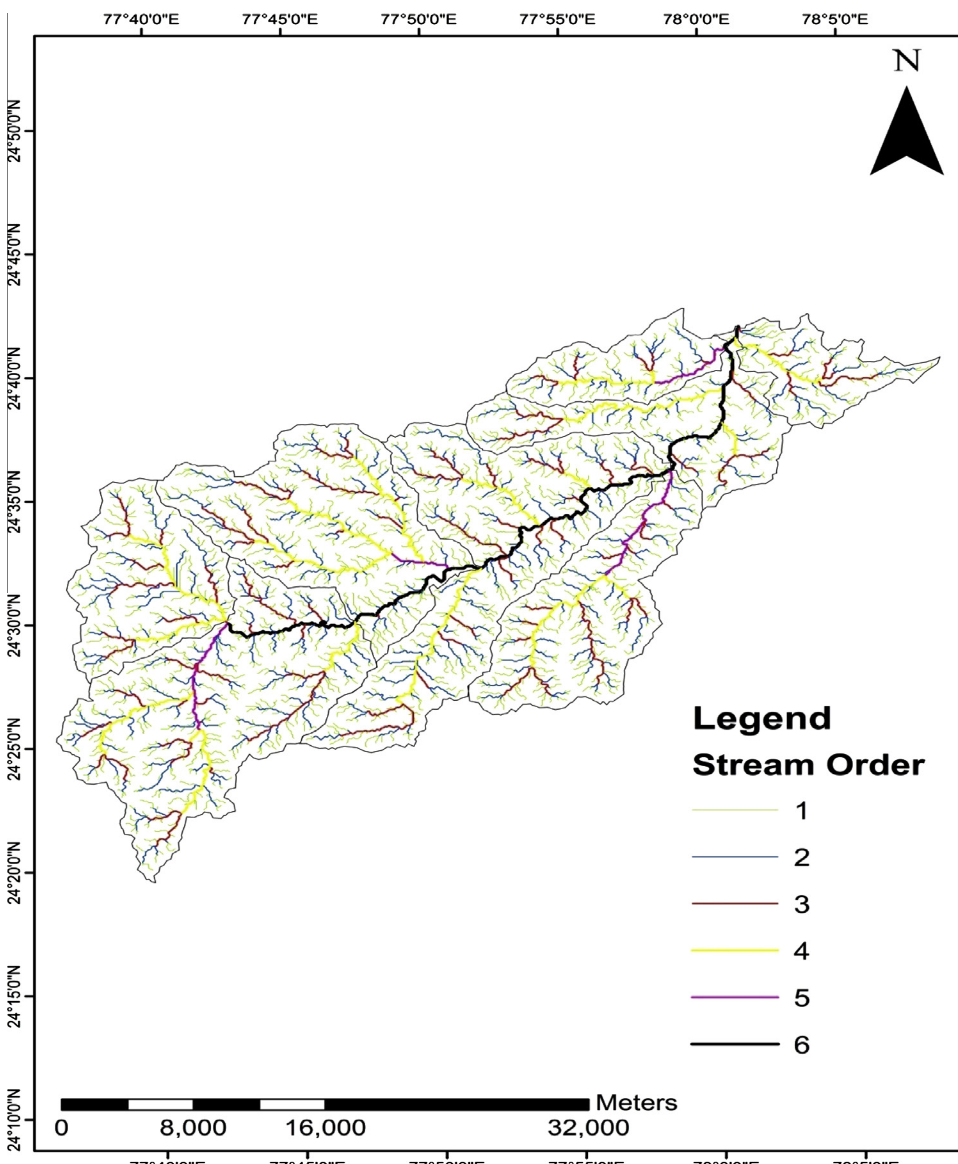

Figure 2 Drainage map with stream order of the Orr watershed, M.P., India.

ratio have been also calculated in GIS Environment (Table 3). The understanding of streams in a drainage system constitutes the drainage pattern, which in turn replicates mainly structural/lithologic controls of the underlying rocks. The study area possesses dendritic drainage patterns, despite stream lengths and other hydrological properties. They are generally characterized by a treelike branching system, which indicates the homogenous and uniformity.

4.2. Stream length (L_u), mean stream length (L_{sm}) and stream length ratio (R_L)

The stream length, Mean stream length and stream length ratio were computed using GIS on the basis of the law proposed by Horton, 1945, for the Orr river basin. Generally, the total length of stream segments decreases as the stream order increases (Table 3). Stream length and their ratio is very important parameter to scan the hydrological characteristics of the river basin because they permeability of the rock formations in a basin. It also indicates if there is a major change in the hydrological characteristics of the underlying rock surfaces with the basin (Singh et al., 2013). The relationship between the bifurcation ratio and the stream length ratio is determined by hydrogeologic, physiographic and geological characteristics. The values of total length, mean length and length ratio of different stream orders of the Orr river basin are shown in Table 3.

4.3. Bifurcation ratio (R_b)

The term bifurcation ratio (R_b) may be defined as ratio of the number of stream segments of a given order to the number of segments of the next higher. Bifurcation ratio values of Orr river basin ranging between 3 and 5 are considered to be characteristics of the basin, which have experience minimum structural disturbances (Strahler, 1964) .The, mean bifurcation ratio of the basin is observed as 4.62. This indicates that the drainage pattern of the basin has not been affected by structural disturbances and the observed R_b is not the same from one order to its next order. These irregularities depend upon the geological and lithological development of the watershed (Table 3).

4.4. Drainage density (D_d) and drainage texture (T)

Horton (1932) has introduced drainage density as an expression to indicate the closeness of spacing of channels. It is a measure of the total length of the stream segment of all orders per unit area and controlled by the Slope gradient and relative relief of the basin. The drainage density of the study area has been calculated and the value is 2.12 (Table 4). Smith (1950) has classified drainage density into five different textures. The Drainage density less than 2 indicates very coarse, between 2 and 4 is related to coarse, between 4 and 6 is moderate, between 6 and 8 is fine and greater than 8 is very fine drainage texture. It is observed that, if the drainage texture is 13.34 it indicates the presence of highly resistant permeable material with low relief. The variation in the value of drainage texture (T) depends upon a number of natural factors such as climate, rainfall, vegetation, rock, soil type and their infiltration capacity and relief of the basin. The relation between geology and hydrological analysis of watershed in semi arid regions has low drainage density and generally results in the areas of highly resistant or permeable subsoil material, dense vegetation and low relief. High drainage density is the resultant of weak or impermeable sub surface material, thin vegetation and mountainous relief. The low drainage density of the watershed reveals that they are composed of permeable subsurface material, good vegetation cover, and low relief which results in more infiltration capacity in the watershed.

4.5. Stream frequency (F_s)

Stream frequency (F_s) or channel frequency is the total number of stream segments of all orders per unit area Horton (1932). F_s values indicate a positive correlation with the drainage density of the basin suggesting that an increase in stream population occurs with respect to increase in drainage density. An observed stream frequency (F_s) of 2.70 for the basin exhibits a positive correlation with the drainage density value of the area indicating an increase in stream population with respect to increase in drainage density (Table 4).

4.6. Elongation ratio (R_e)

Elongation ratio (R_e) is the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin (Schumm, 1956). The values of R_e generally vary from 0.6 to 1.0 over a wide variety of climatic and geologic conditions. Values close to 1.0 are typical of regions of very low relief, whereas values in the range 0.6–0.8 are usually associated with high relief and steep ground slope (Strahler, 1964). These values can be grouped into three categories namely (a) circular (>0.9), (b) oval (0.9–0.8), (c) elongated (<0.7). The elongation ratio of the basin is 0.58, which suggests that the basin belongs to the elongated shape basin and low relief (Table 4).

4.7. Circularity ratio (R_c)

Miller (1953) defined dimensionless circularity ratio (R_c) as ratio of basin area to the area of circle having the same perimeter as the basin. R_c is influenced by the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin. A circularity ratio of the basin is 0.33 which indicates strongly elongated and highly permeable homogenous geologic materials. The observed circularity ratio

Table 4 Areal aspect of the Orr watershed.

Basin area (km^2)	Perimeter (km)	Length (km)	Form factor	Elongation ratio (R_e)	Circularity ratio (R_c)	Drainage density (km)	Stream frequency	Drainage texture
996.66	195.78	60.93	0.268	0.58	0.33	2.12	2.70	13.34

Table 5 Relief characteristics of the Orr watershed.

Height of basin mouth (z) m	Maximum height of the basin (Z) m	Total basin relief (H) m	Relief ratio
387	541	154	2.52

of the basin indicates that the basin is elongated in shape, has low discharge of runoff and highly permeable subsoil conditions (Table 4).

4.8. Form factor (F_f)

According to Horton (1932), form factor (F_f) may be defined as the ratio of the basin area to square of the basin length. The form factor indicates the flow intensity of a basin for a defined area. The form factor value should always be less than 0.7854. The smaller the value of the form factor, the more elongated will be the basin. Basins with high-form factors experience larger peak flows of shorter duration, whereas elongated basin with low-form factors experience lower peak flows of longer duration. The observed form factor value of the basin is 0.264 suggesting that the shape of the basin is elongated (Table 4).The elongated basin with low form factor indicates that the basin will have a flatter peak of flow for longer duration.

4.9. Relief (R) and Relief ratio of the Basin

The elevation difference between the highest and lowest points on the valley floor of a basin is known as the total relief of that basin. The relief ratio (R_h) of maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line is termed as relief ratio (Schumm, 1956). It measures the overall steepness of a drainage basin and is an indicator of the intensity of the erosion processes

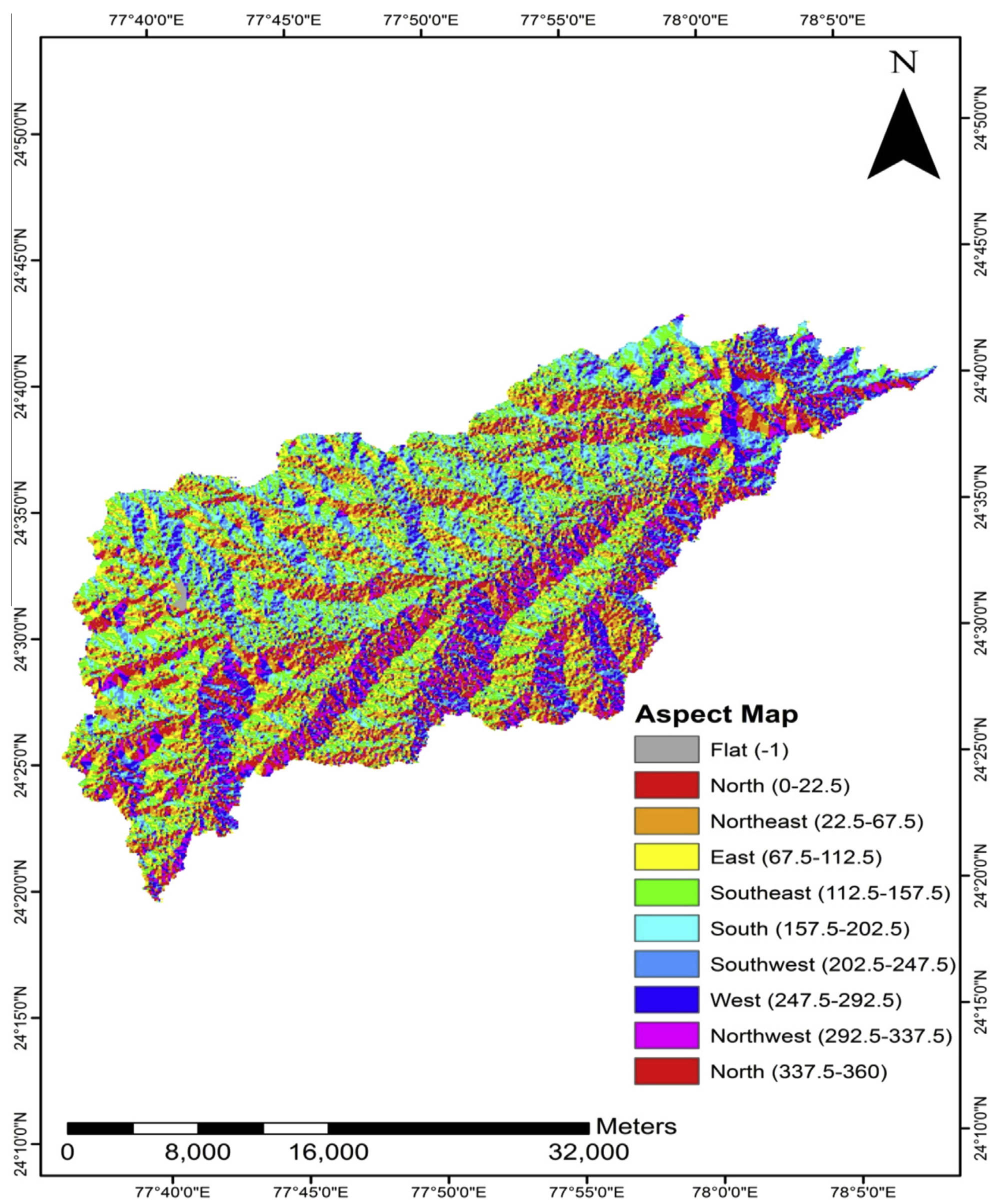

Figure 3 Aspect map of the Orr watershed, M.P., India.

operation on the slope of the basin. In the present study the R_h value of the basin is 2.52 which shows that the major portion of the basin is having gentle slope (Table 5).

4.10. Aspect map

Aspect map generally refers to the direction to which a mountain slope faces. The aspect map is a very important parameter to understand impact of sun on local climate of the area. Generally west facing slope showing the hottest time of day in the afternoon and in most cases a west-facing slope will be warmer than sheltered an east-facing slope. Aspect map has major effects on the distribution of vegetation type of area. The aspect map derived from SRTM DEM represents the compass direction of the aspect. 0_ is true north; a 90_ aspect is to the east (Fig. 3). The Orr watershed shows east-facing slopes and therefore, these slopes have higher moisture content and higher vegetation compared to west facing slope.

4.11. Slope map

Slope is the measure of change in surface value over distance and can be expressed in degrees or as a percentage. In a raster format, the Digital Elevation Model (DEM) is a grid where each cell is a value referenced to a common datum. For extraction of elevation from remote sensing dedicated software packages are required but most GIS packages have routines for point or contour line interpolation. Any two points on the grid will be sufficient to ascertain a slope. Once the slopes have been calculated, then the maximum difference can be found and the gradient can be determined (Burrough and McDonnell, 1998; Maathuis, 2006; Jha et al. 2007).

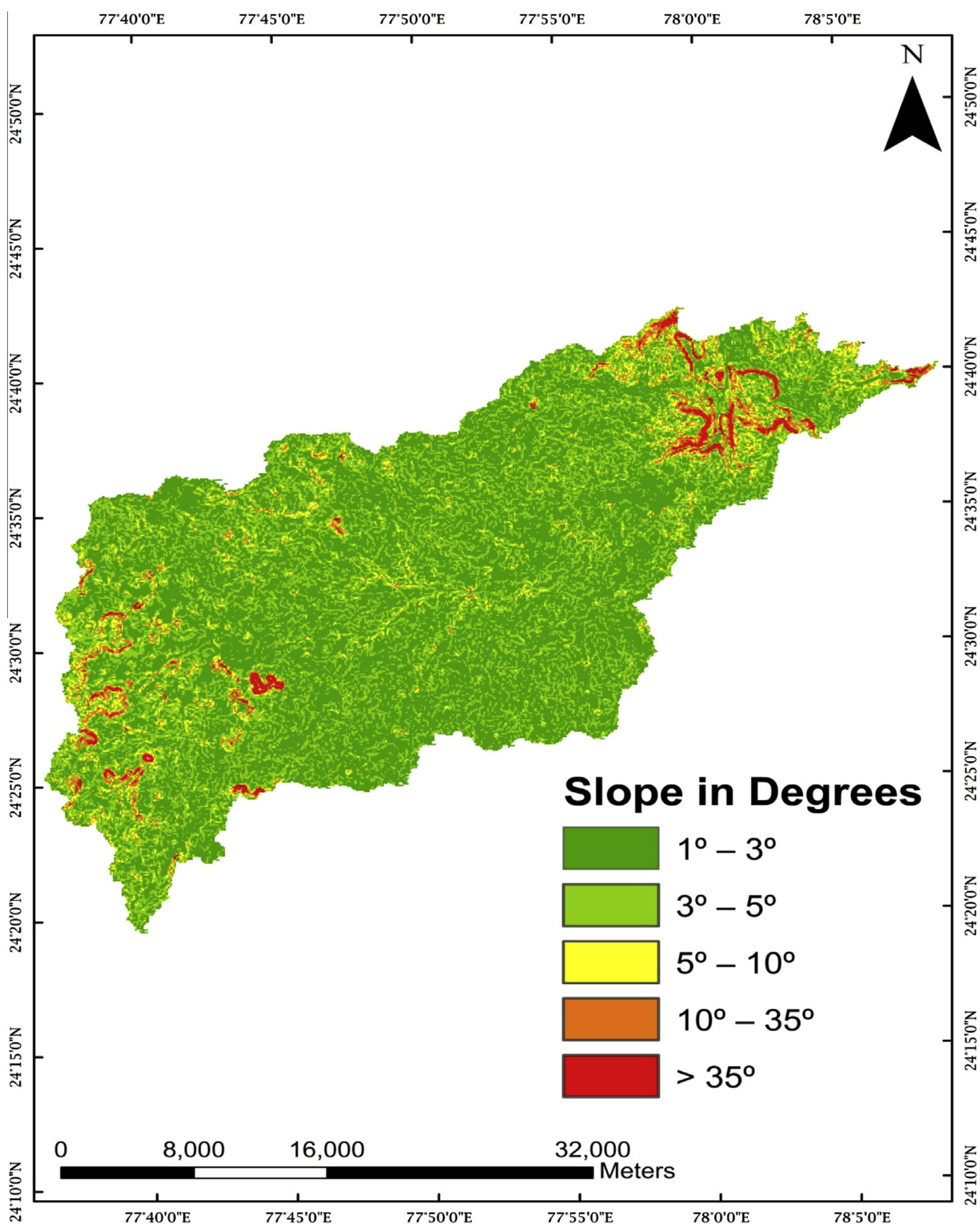

Figure 4 Slope map of the Orr watershed, M.P., India.

In the present paper topographical elevation map for the study area was developed by Digital Elevation Model (DEM) extracted from the Shuttle Radar Topography Mission (SRTM) data. For this, the DEM was subjected to two directional gradient filters (one in *x*-direction and another in *y*-direction).The resultant maps were used to generate a slope map of the study area using ARCGIS Spatial Analyst tools.

The highest topographic elevations (551 m and lowest 387 AMSL) exist in the western and northwestern portions of the area which induces highest runoff and hence less possibility of rainfall infiltration. The slope map of the study area has grouped in five classes in degrees viz. 1–3° (Gentle) , 3–5° (Moderate) , 5–10° (Steep) , 10–35° (Very Steep) and > 35° (Very Very Steep) (Fig. 4).

It is observed that the most of the area of Orr river basin comes under gentle and moderate slope which indicates almost flat topography of the area. Gentle slopes were designated in the ''excellent'' category for groundwater management as the nearly flat terrain is the most favorable for infiltration. Moderate slopes also come under good zone due to slightly undulating topography which gives maximum percolation or partial runoff. The steep class and having a high surface runoff with a negligible amount of infiltration are marked under good zone for construction of stop dams etc. Slope is a critical parameter which directly controls runoff and infiltration of any terrain. Runoff in higher slope regions causes less infiltration. This factor significantly controls the development of aquifers.

4.12. Land use/land cover mapping

Land use and land cover pattern changes are most important factors for assessment of groundwater water conditions of any area. Water resources are under severe pressure due to land use practices and climate change. Land use pattern changes and their estimation describe the utilization of land resource by manmade activities particularly agriculture and

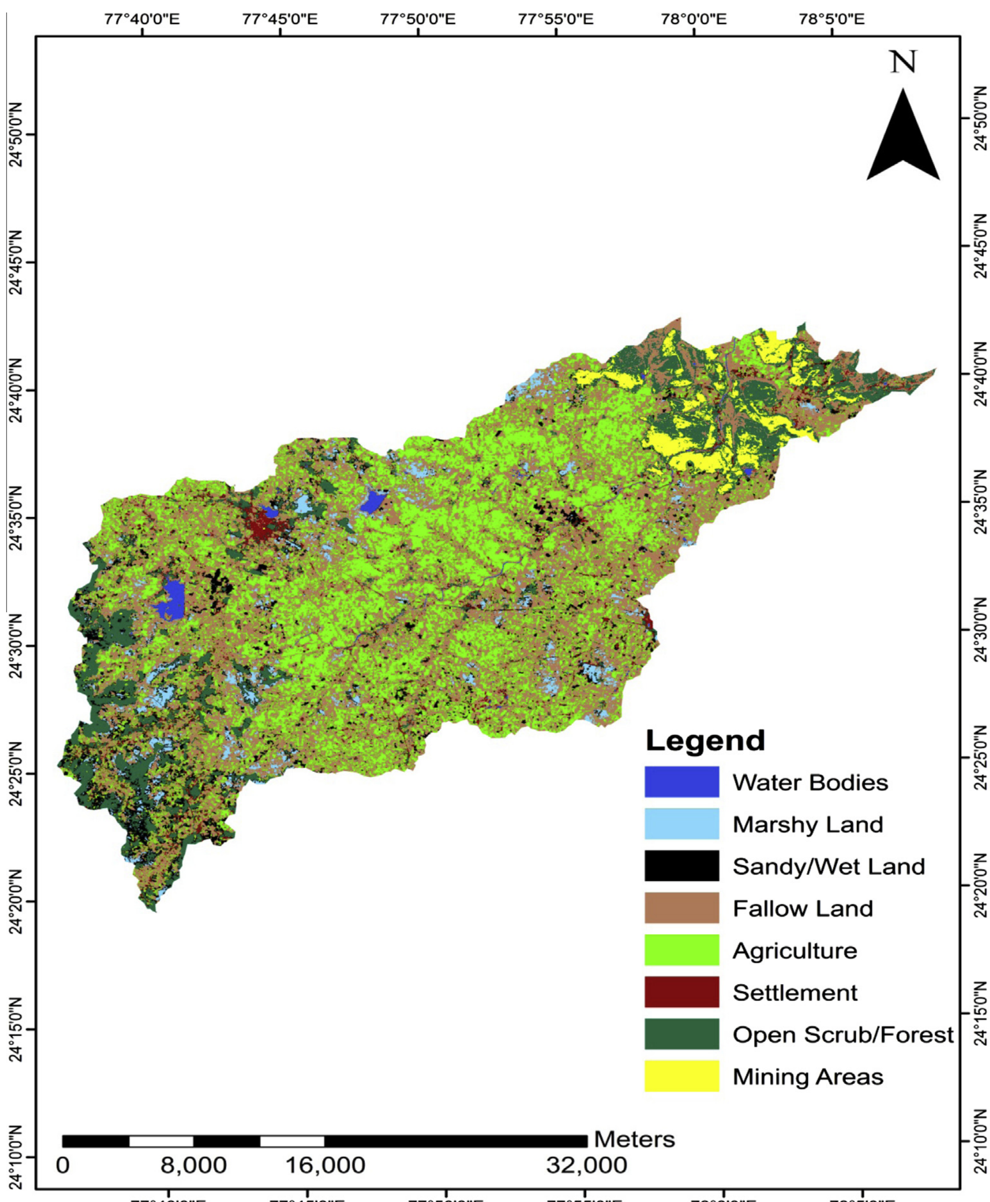

Figure 5 Land use/land cover map of the Orr watershed, M.P., India.

Table 6 Land use/land cover of the watershed.

S. No.	Land use category	Area (sq. km)	Percentage (%)
1	Water bodies	7.20	0.72
2	Marshy land	33.89	3.40
3	Sandy/wet land	45.19	4.53
4	Fallow land	430.55	43.20
5	Agriculture	305.92	30.70
6	Settlement	35.29	3.54
7	Open scrub/forest	108.06	10.84
8	Mining areas	30.69	3.07
	Total	996.66	100

urbanization (YanYun et al., 2014; Singh et al., 2012). Hydrological inferences from land use pattern can help understand the changing scenario of water demand from different activities such as Agricultural requirement, domestic needs, industrialization and its can also used to understand the infiltration, recharge and runoff rate of the watershed. Land use pattern changes become an important component in hydrological monitoring and natural resources management (Rawat et al., 2013; Sylla et al.2012).

Analyses of land use changes for hydrologic processes are major needs for the future (Turner et al., 2003), which includes: changes in water demands from changing land use practices, such as irrigation and urbanization; changes in water supply from altered hydrological processes of infiltration, groundwater recharge and runoff. Land use maps and their role is a very important parameter to understand the hydrological conditions of the watershed and their management is discussed by number of researchers (Wagner et al., 2013; Singh et al., 2013).

In the present paper, supervised classification scheme was performed to assess the land use pattern and their spatial variation from recent freely available satellite data of Lasndsat-8 December, 2013 which have 30 m spatial resolution.

A standard approach was applied for classification of the satellite image using Erdas Imagine 9.1 software starting from defining of the training sites, extraction of signatures from the image and then classification was performed. Finally, Maximum Likelihood Classification (MLC) the classification methods were applied. Field survey was also performed to finalize the land use/land cover map of the watershed by using GPS receiver for verification of doubtful classes. Common land use categories were identified with reference to their water requirement i.e., Agricultural land, settlement, fallow land, forest, wet/ marshy land, mining areas and water body (Fig. 5). Assessment of land use pattern of the watershed reveals that most part of the area comes under agricultural and fallow land which indirectly supports the future for watershed development and management (Table 6).

4.13. Hydrological interferences from morphometric analysis

Morphometric analysis of watershed based on remote sensing and satellite derived Digital Elevation Model (DEM) are most important data for proper hydrological investigation of any terrain which indirectly support hydrogeological status of the watershed. The quantitative analysis of morphometric parameters is found to be of immense utility in watershed delineation, soil and water conservation and their management. The morphometric analysis carried out in the Orr watershed shows that the basin has low relief and elongated shape. Artificial recharge and runoff harvesting in the area for groundwater development management are selected based on small-scale topographic maps. Drainage analysis makes a positive contribution through the advantage of remote sensing and GIS-based tool in selecting artificial recharge sites. These analyzed drainage parameters provide comparative indices of the permeability of rock surfaces in various parts of a drainage basin. If these information are integrated with the other hydrological characteristics of the drainage basin, the strategy of siting recharge and water-harvesting measures provides better groundwater development and management plan.

The drainage pattern in the present watershed is dendritic in nature. This may be due to more or less homogeneous lithology and structural controls. In the study area high drainage density is observed over the hilly terrain with impermeable hard rock substratum, and low drainage density over the highly permeable sub-soils and low relief areas. Low drainage density areas are favorable for identification of groundwater potential zones. Slope plays a very significant role in determining infiltration vs. runoff relation. Infiltration is inversely related to slope i.e. gentler is the slope, higher is infiltration and less is runoff and vice versa.

5. Conclusion and recommendation

The hydrological analysis carried out for the Orr watershed confirms that the watershed is having low relief and elongated shape. Drainage network of the basin exhibits as mainly dendritic type which indicates the homogeneity in texture and lack of structural control and helps understand various terrain parameters such as nature of the bedrock, infiltration capacity, runoff, etc. Lower drainage density and stream frequency indicate high permeability rate of the subsurface formation. The observed parameters reveal recharge-related measures and areas where surface-water augmentation measures can be undertaken for water resource management and soil conservation structures. Large scale watershed analysis using GIS, remote sensing data and Digital elevation Model (DEM) has efficient tools for understanding any terrain parameters such as nature of bedrock, infiltration capacity, surface run off etc., which helps in better understanding the status of land form and their processes, drainage management and evolution of groundwater potential for watershed planning and management. This work will be useful for natural resource management at the micro level of any terrain for sustainable development by planners and decision makers for sustainable watershed development programme.

The results observed in the present work can be used for site suitability analysis of soil and water conservation structures in the area and subsequently, these parameters were integrated with other hydrological information viz., land use/cover, land forms, geology, water level and soil in the GIS domain to arrive at a decision regarding a suitable site for soil and water conservation structures (nala bund, check dam, and percolation tank, recharge shaft, etc.) in the area for groundwater development and management. The study recommended that the watershed needs a hydrogeological and geophysical investigation in future for proper water management and selection of artificial groundwater recharge structures within the study area.

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References

El Bastawesy, M., White, K.H., Gabr, S., 2013. Hydrology and geomorphology of the Upper White Nile Lakes and their relevance for water resources management in the Nile basin. Hydrol. Process. 27, 196–205.

Burrough, P.A., McDonnell, R.A., 1998. Principles of Geographical Information System. Oxford University Press, Oxford, UK, p. 333.

Das, A.K., Mukherjee, S., 2005. Drainage morphometry using satellite data and GIS in Raigad district, Maharashtra. J. Geol. Soc. India 65, 577–586.

Ellis, J.B., Revitt, D.M., 2010. The management of urban surface water drainage in England and Wales. Water Environ. J. 24, 1–8.

Eyquem, J., 2007. Using fluvial geomorphology to inform integrated river basin management. Water Environ. J. 21, 54–60.

Farr, T.G., Kobrick, M., 2000. Shuttle radar topography mission produces a wealth of data. Am. Geophys. Union Eos. 81, 583–585.

Grohmann, C.H., 2004. Morphometric analysis in geographic information systems: applications of free software. Comput. Geosci. 30, 1055–1067.

Grohmann, C.H., Riccomini, C., Alves, F.M., 2007. SRTM-based morphotectonic analysis of the Pocos de Caldas alkaline Massif, southeastern Brazil. Comput. Geosci. 33, 10–19.

Hadley, R.F., Schumm, S.A., 1961. Sediment sources and drainage basin characteristics in upper Cheyenne River Basin. US Geol. Surv. Water-Supply Pap. 1531-B, 198.

Hlaing, T.K., Haruyama, S., Aye, M.M., 2008. Using GIS-based distributed soil loss modeling and morphometric analysis to prioritize watershed for soil conservation in Bago river basin of lower Myanmar. Front Earth Sci. China 2, 465–478.

Horton, R.E., 1932. Drainage basin characteristics. Trans. Amer. Geophys. Union 13, 350–361.

Horton, R.E., 1945. Erosional development of streams and their drainage basins: hydrophysical approach to quantitative morphology. Bull. Geo. Soc. Am. 56, 275–370.

Javed, A., Khanday, M.Y., Ahmed, R., 2009. Prioritization of subwatershed based on morphometric and land use analysis using remote sensing and GIS techniques. J. Indian Soc. Remote Sens. 37, 261–274.

Jha, M.K., Chowdhury, A., Chowdary, V.M., Peiffer, S., 2007. Groundwater management and development by integrated RS and GIS: prospects and constraints. Water Resour. Manage. 21, 427–467.

Korkalainen, T.H.J., Lauren, A.M., Kokkonen, T.S., 2007. A GIS based analysis of catchment properties within a drumlin field. Boreal Environ. Res. 12, 489–500.

Maathuis, B.H.P., 2006. Digital elevation model based hydro-processing. Geocarto Int. 21 (1), 21–26.

Magesh, N., Chandrasekar, N., Soundranayagam, J., 2011. Morphometric evaluation of Papanasam and Manimuthar watersheds, parts of Western Ghats, Tirunelveli district, Tamil Nadu, India: a GIS approach. Environ. Earth Sci. 64, 373–381.

Mark, D.M., 1984. Automatic detection of drainage networks from digital elevation models. Cartographica 21, 168–178.

Miller, V.C., 1953. A Quantitative Geomorphologic Study of Drainage Basin Characteristics in the Clinch Mountain Area, Virginia and Tennessee, Project NR 389042, Tech Rept 3. Columbia University Department of Geology, ONR Geography Branch, New York.

Moore, I.D., Grayson, R.B., Ladson, A.R., 1991. Digital terrain modelling: a review of hydrological, geomorphological and biological applications. Hydrol. Process. 5 (1), 3–30.

Panhalkar, S.S., 2014. Hydrological modeling using SWAT model and geoinformatic techniques. Egypt. J. Remote Sens. Space Sci., doi.org/10.1016/j.ejrs.2014.03.001.

Pankaj, A., Kumar, P., 2009. GIS based morphometric analysis of five major sub-watershed of Song River, Dehradun district, Uttarakhand with special reference to landslide incidences. J. Indian Soc. Remote Sens. 37, 157–166.

Rao, N.S., 2008. A numerical scheme for groundwater development in a watershed basin of basement terrain: a case study from India. Hydrogeol. J. 17, 379–396.

Rawat, J.S., Biswas, V., Kumar, Manish., 2013. Changes in land use/cover using geospatial techniques: A case study of Ramnagar town area, district Nainital, Uttarakhand, India. Egypt. J. Remote Sens. Space Sci. 16, 111–117.

Schumm, S.A., 1956. Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. Geol. Soc. Am. Bull. 67, 597–646.

Schumm, S.A., 1963. Sinuosity of alluvial rivers in the great plains. Bull. Geol. Soc. Am. 74, 1089–1100.

Singh, Prafull, Thakur, J.K., Kumar, S., Singh, U.C., 2012. Assessment of land use/land cover using Geospatial Techniques in a semi arid region of Madhya Pradesh, India. In: Thakur, Singh, Prasad, Gossel (Eds.), Geospatial Techniques for Managing Environmental Resources. Springer and Capital Publication, Heidelberg, Germany, pp. 152–163.

Singh, Prafull., Thakur, J., Singh, U.C., 2013. Morphometric analysis of Morar River Basin, Madhya Pradesh, India, using remote sensing and GIS techniques. Environ. Earth Sci. 68, 1967–1977.

Smith, K.G., 1950. Standards for grading texture of erosional topography. Am. J. Sci. 248, 655–668.

Sreedevi, P.D., Sreekanth, P.D., Khan, H.H., Ahmed, S., 2013. Drainage morphometry and its influence on hydrology in an semi arid region: using SRTM data and GIS. Environ. Earth Sci. 70 (2), 839–848.

Strahler, A.N., 1957. Quantitative analysis of watershed geomorphology. Trans. Am. Geophys. Union 38, 913–920.

Strahler, A.N., 1964. Quantative geomorphology of drainage basins and channel networks. In: Te Chow, Ven. (Ed.), Hand Book of Applied Hydrology. McGraw Hill Book Company, New York.

Sylla, L., Xiong, D., Zhang, H.Y., Bangoura, S.T., 2012. A GIS technology and method to assess environmental problems from land use/cover changes: Conakry, Coyah and Dubreka region case study. Egypt. J. Remote Sens. Space Sci. 15, 31–38.

Tarboton, D.G., 1997. A new method for the determination of flow directions and contributing areas in grid digital elevation models. Water Resour. Res. 33, 309–319.

Thomas, J., Joseph, S., Thrivikramji, K., Abe, G., Kannan, N., 2012. Morphometrical analysis of two tropical mountain river basins of contrasting environmental settings, the southern Western Ghats, India. Environ. Earth Sci. 66 (8), 2353–2366.

Turner, M.G., Pearson, S.M., Bolstad, P., 2003. Effects of land-cover change on spatial pattern of forest communities in the Southern Appalachian Mountains (USA). Landscape Ecol. 18 (5), 449–464.

Wagner, P.D., Kumar, S., Schneider, K., 2013. An assessment of land use change impacts on the water resources of the Mula and Mutha Rivers catchment upstream of Pune, India. Hydrol. Earth Syst. Sci. 17 (6), 2233–2246.

YanYun, N.I.A.N., Xin, L.I., Jian, Z.H.O.U., XiaoLi, H.U., 2014. Impact of land use change on water resource allocation in the middle reaches of the Heihe River Basin in northwestern China. J. Arid Land 6 (3), 273–286.