A detailed review has been carried out on prioritization of sub-watershed based on morphometric analysis, Saaty’s Analytic Hierarchy Process (SAHP) and Fuzzy Analytic Hierarchy Process (FAHP) using erosion hazard parameters. Work carried out by various researcher are summarized under following headings.

I. GIS database
II. Soil erosion and sediment yield
III. Morphometric parameters and their analysis for prioritization
IV. Prioritization using Saaty’s analytical hierarchical process (SAHP)
V. Prioritization based on Fuzzy analytical hierarchical process (FAHP)
VI. Development of catchment area treatment plan.

2.1 GIS database

Bruce et al. (1993) used the Geographic Information Systems (GIS) for digital presentation of watershed characteristics. They summarizes past efforts and current trends for preparation of topographic map of watershed using digital elevation models and GIS to perform hydrologic analyses with remotely sensed data. They concluded that GIS application is useful for floodplain hydrology, erosion prediction, water quality prediction/control, and drainage utility implementations.

Fortin et al. (2001) discussed the preparation of the watershed database from remotely sensed and geographic information system (GIS) for hydrological modelling.

Garbrecht et al. (2001) worked on increasing proliferation of spatial data, geographic information systems (GIS), and models for hydrologic applications provide many new investigation opportunities but also present a number of challenges
for the uninitiated water resources practitioner. It provides an integrated overview of the multiple facets of data-GIS-modeling issues and a source of background information for selection and application of GIS in watershed modeling. His work addresses selected spatial data issues, data structures and projections, data sources, and information on data resolution and uncertainties. Spatial data that are covered include digital elevation data, stream and drainage data, soil data, digital orthophoto data, remotely sensed data, and radar precipitation data. The focus is on data and issues that are common to many data-GIS modeling applications.

Tim and Mallavaram (2003) have reported that Geographic Information Systems (GIS) technology played critical roles in all aspects of watershed management like assessing watershed conditions through modeling, impacts of human activities on water quality and to visualizing impacts of alternative management scenarios. He found that researchers, resource planners and policy makers are realizing the power of GIS and its unique ability to enhance watershed management.

Chen et al. (2004) analyzed the established geographic information system (GIS) database, which consists of the digital elevation model map, the land use map, the soils map, and the Landsat Thematic Map images, along with information on soil depths and soil properties, which is used in WEHY model for the Shiobara-Dam watershed and configured.

2.2 Soil erosion and sediment yield

Sidhu et al. (1998) prioritized upper Machkund watershed covering an area of 16,111 ha. by remote sensing and GIS techniques. Based on secondary and tertiary drainage pattern the watershed areas were subdivided into 8 sub-watersheds. By using 'union' module of GIS, hydro-geomorphology, land use, land cover and slope maps were combined to generate erosion intensity and composite maps. Watershed was prioritized by following the sedimentation yield index (SYI) approach.

Jain and Kothyari (2000) estimated soil erosion and sediment yield using GIS of the Nagwa and Karso catchments of Bihar, India. The soil erosion of each pixel was calculated using the Universal Soil Loss Equation (USLE) by carefully
determining its various parameters. The Earth Resources Data Analysis System (ERDAS) image Processor was used for the digital analysis of satellite data to deriving the land cover and soli characteristics of the catchments. Further, these databases were used in GIS and the catchments were discretized into hydrologically homogeneous grid cells to capture the catchment heterogeneity. The cells thus formed were then differentiated into cells of overland flow regions and cells of channel flow regions based on the magnitude of their flow accumulation areas. The concept of sediment delivery ratio (SDR) was used for determination of total sediment yield of each catchment during isolated storm events.

**Khan et al. (2001)** used Remote Sensing and GIS for watershed prioritization. Guhiya Basin, (Area 1614 km$^2$) was studied for priority to undertake soil and water conservation measures. Using the terrain information derived from geoded satellite data and 1:50000 scale topographic maps, 68 watershed were assessed on the basis of their erosivity and sediment yield index values. Thematic maps, land use and land cover and slope were digitized using ARC/INFO on the basis of sediment yield index values.

**Jain and Goel (2002)** investigated vulnerability of catchments to erosion for planning soil conservation. Criterion used to determine the susceptibility of catchments to erosion, is the sediment yield of a basin. In India, sediment yield data are generally not collected for smaller sub-catchments and it becomes difficult to identity the most vulnerable areas for erosion that can be treated on a priority basis. An index based approach, based on the surface factors mainly responsible for soil erosion, is suggested in this study. These factors include soil type, vegetation, slope and various catchment properties such as drainage density, form factors, etc. The method is illustrated with a case study of sub-catchments immediately upstream of the Ukai reservoir located on the river Tapi in Gujarat state, India. The area is divided into 16 watersheds and different soil, vegetation, topography and morphology-related parameters are estimated separately for each watershed. Satellite data are used to evaluate the soil and vegetation indices, while a GIS system is used to evaluate the topography and morphology-related indices. The integrated effect of all the parameters is evaluated to find different areas vulnerable to soil erosion.
Singh et al. (2002) carried out study on prioritization of Bata river basin using Remote Sensing techniques. Soil erosion assessment in the study area was done using Morgan et al. (1984) model. By Using this model, it was found that the average annual soil loss in the watershed was 17.22 t/ha. Detailed analysis showed that detachment limited soil erosion is higher in the agricultural & barren land, while transport limited erosion was higher in the forestland.

Suresh et al. (2004) made prioritization of sub-watersheds on the basis of sediment production rate. Further, basic hydrologic information such as peak rate of runoff and annual surface water potential were also assessed for the study watersheds and these are essential requisites for effective watershed management. The 10 sub watersheds of Tarai development project area are selected for the present study. Morphometric parameters pertaining to study area are used in the estimation of sediment production rate. The sediment production rate in the study area, varies between 2.45 to 11.0 ha-m/100 km²/year.

Bhattarai and Dutta (2007) estimated the soil erosion and sediment yield using GIS at of a small watershed of Mun river basin, Thailand. The catchment was spatial disintegrated into homogeneous grid cell to capture the catchment heterogeneity. The gross soil erosion of each cell was calculated using Universal Soil Loss Equation (USLE) by carefully determining its various parameters. The concept of sediment delivery ratio was used to route surface erosion from each of the discretized cells to the catchment outlet. The spatial discretization of the catchment and derivation of the physical parameters related to erosion in the cell were performed through GIS techniques.

Erdogan (2007) used USLE/GIS methodology for predicting soil loss from an agricultural watershed known as Kazan watershed, Central Anatolia, Turkey. Rainfall erosivity (R), soil erodibility (K), and cover management factor (C) values of the model were calculated from erosivity map, soil map, and land use map of Turkey respectively. Rainfall erosivity (R) values are site specifically and corrected using DEM and climatic data. The topographical effects on the soil loss were characterized by LS factor evaluated by the flow accumulation tool using DEM and watershed
delineation techniques. From simulated soil loss map of the watershed the magnitude of the soil erosion was estimated in terms of the different soil units and land uses.

Alejandra (2008) calculated soil erosion using RS and GIS in Rio Grande de Arecibo watershed, Puerto. Inputs of the model such as cover factor and conservation practice factor was successfully derived from remotely sensed data. The LS factor map was generated from the slope and aspect map derived from the DEM. The K factor map was prepared from the soil map and K factor values from a Soil Survey of United States and Virgin Islands (1998). Maps covering each parameter R, K, L, S, C and P were integrated to generate a composite map of the study area.

Ismail & Ravichandran (2008) applied RUSLE Model for Soil Erosion Assessment using Remote Sensing and GIS in the Veppanapalll sub watershed of Krishnagiri catchment located in Tamil Nadu, India. The soil erosion was estimated for each of the hillslope units in the study area. The factors considered were intensity of rainfall, type of soil, land use classification by using 5.6 m resolution imaginary and the existing soil conservation practices. Detailed analysis of soil samples were done to assess the texture, structure, permeability and organic matter. A data base was created with all the factors of USLE for all the hillslope units.

Rostamian et al. (2008) estimated runoff and sediment in the Beheshtabad (3860 km²) and Vanak (3198 km²) watersheds of the Northern Karun catchment, Central Iran using Soil and Water Assessment Tool (SWAT). They calibrate of model performance was evaluated by sequential uncertainty fitting (SUFI-2). They found P factor for Beheshtabad stations ranged from 0.31 to 0.86, while those for Vanak stations were between 0.71 and 0.80 and D factor for Beheshtabad ranged from 0.3 to 1.1, and for Vanak it was 0.77- 1.16. These measures indicate a fair model calibration and accounting of uncertainties. The predicted runoff values were quite similar to those for discharge.

Brhane et al. (2009) have worked on Estimation of soil loss using Universal Soil Loss Equation (USLE) for Soil Conservation planning of Medego watershed. An administrative unit of Lalay-maychew district in Tigray region, Northern Ethiopia.
They found that the lowest soil loss estimated on flat plains (< 2% slope) was about 1.59 tons ha\(^{-1}\) y\(^{-1}\), which was less than the minimum tolerable soil loss (2 tons ha\(^{-1}\) y\(^{-1}\)) for the country and highest soil loss from steep slopes (30-50%) was 35.43 tons ha\(^{-1}\) y\(^{-1}\), about twice the maximum tolerable soil loss (18 tons ha\(^{-1}\) y\(^{-1}\)). The average soil loss rate at watershed level is 9.63 tons ha\(^{-1}\) y\(^{-1}\) about half of the maximum tolerable soil loss.

**Joshi and Nagare (2009)** used remote sensing and GIS techniques for land use change detection for the Pravara River Basin in Maharashtra. The basin, which was economically growing fast by converting the fallow lands, badlands and woodlands to agricultural land for the past few decades. IRS (Indian Remote sensing Satellites) 1 C — LISS III, IRS 1 C PAN, IRS P6 — LISS III and IRS 1 D PAN Images were used to generate imageries with resolution matching to the landscape processes of an area. The images of the year 1997, 2000, 2004 and 2007 were analyzed to detect the changes in the land use and land cover in the past ten years. The analysis revealed that there has been 20% increase in the agricultural area over the past ten years

**Jain and Das (2010)** used GIS and Remote Sensing for estimation of sediment yield and identify the soil erosion and deposition prone areas for watershed prioritization in the Upper Damodar Valley in Jharkhand, India. Due to availability of gauged data at multiple locations within watershed area, the watershed was discretized into hydrologically homogeneous grid cells to capture the watershed heterogeneity. The gross soil erosion in each cell was calculated using the Universal Soil Loss Equation (USLE). The parameters of the USLE were evaluated using digital elevation model, soil and land use information on cell basis. The concept of transport limited sediment delivery (TLSD) was formulated and used in ArcGIS for generating the transport capacity maps. An empirical relation was proposed and demonstrated for its usefulness for computation of land vegetation dependent transport capacity factor used in TLSD approach by linking it with normalized difference vegetation index (NDVI) derived from satellite data. Using these maps, the gross soil erosion was
routed to the watershed outlet using hydrological drainage paths, for derivation of transport capacity limited sediment outflow maps.

**Saravanan et al. (2010)** carried out soil erosion mapping using Universal Soil Loss Equation (USLE) for watershed management. They used IRS-IC LISS III satellite imagery and classified by supervise classification technique for preparing the landuse/landcover which estimates cover management factor (C) and the landuse practice factor (P). Using digital elevation model (DEM) as input, the slope length factor (LS) was determined by AML programme. Soil erodibility (K) values were measured for all mapped soil types of the study area. The rainfall erosivity factor (R) was directly computed from rainfall intensities. These USLE factors, with associated attribute data, were digitally encoded in a GIS database and converted into 30 m grid cells. They found amount of soil loss in the basin varies 0.54 to 75.1 t ha\(^{-1}\) yr\(^{-1}\) and the average annual soil loss of the basin has been found out to be 24.74 t ha\(^{-1}\) yr\(^{-1}\). They said, research confirms that remote sensing and GIS provide promising tools for evaluating and mapping soil erosion risk in watershed.

**Pal and Samanta (2011)** estimated soil loss using remote sensing and geographic Information system techniques in the Keliaghai River basin, Purbe & Peschim Medinipur District, West Bangal, India. Different parameters, namely the rainfall and runoff factor (R), soil erodibility factor (K), slope length and steepness factor (LS), crop management factor (C) and conservation practice factor (P), that are the mandatory inputs to RUSLE, had been either derived from remote sensing data or through conventional data collection systems. The rainfall and runoff factor (R) was calculated from monthly and annual rainfall data, soil erodibility factor (K) was estimated by soil map of the region, steepness factor (LS) was calculated by Digital Elevation Model (DEM), crop management factor (C) and conservation practice factor (P) using RS techniques (with use of Normalized Difference Vegetation Index) by land use/land cover map, respectively. The experiential study resulted with Soil loss is very high in the river basin area, calculated as 1927779 tons/year using RUBLE model.
Sakthivel et al. (2011) used Remote Sensing and GIS for Soil Erosion Prone areas Assessment in Kalrayan hills, Part of Eastern Ghats, Tamil Nadu, India. The geocoded digital data of IRS P6 LISS — Ill (Path 101-Row 65 of 2001) and Survey of India toposheets (1971) were used for preparation of various thematic maps such as drainage, lineament, geomorphology, land use/land cover and slope maps. After assigning the weightage to each parameters they were over layed and integrated to each other and various soil erosion prone areas were demarcated.

Lin-jing QIU et al. (2012) tested the feasibility of SWAT on runoff and sediment load simulation in the Zhifanggou watershed located in hilly-gullied region of China. Daily runoff and sediment event data from 1998-2008 were used in this study; data from 1998-2003 were used for calibration and 2004-2008 for validation. The evaluation statistics for the daily runoff simulation showed that the model results were acceptable, but the model underestimated the runoff for high-flow events. For sediment load simulation, the SWAT performed well in capturing the trend of sediment load, while the model tended to underestimate sediment load during both the calibration and validation periods. The disparity between observed and simulated data most likely resulted from limitations of the existing SCS-CN and MUSLE methods in the model. The study indicated that the modification of SWAT components is needed to take rainfall intensity and its duration into account to enhance the model performance on peak flow and sediment load simulation during heavy rainfall season.

Pal et al. (2012) worked on morphometric and hydrological analysis and mapping of Watut watershed of Morobe province of Papua New Guinea, using remote sensing and GIS techniques. They analyzes six morphometric parameters namely absolute relief, relative relief, dissection index, average slope, drainage density and ruggedness index, for better understanding of hydrologic processes in a watershed. The advanced application of Remote Sensing (RS) and Geographic Information System (GIS) techniques have lead to estimation of surface runoff and soil loss based on different parameters. Topographical map and Landsat Enhanced Thematic Mapper Plus (ETM+) satellite image are used for morphometric analysis. Land use/land cover, hydrologic soil characteristics, rainfall, curve number (CN) are used for surface runoff assessment using Soil Conservation Service (SCS) model. USLE (Universal Soil Loss
Equation) model was used for soil loss estimation. The result indicates an average of 68.23% of total rainfall flowing out as surface runoff with a 12.16 tons/ha/year of eroded soil from the watershed. Wall to wall (pixel wise) spatial mapping for the entire watershed is carried out using these results. They observed that the integrated approach of SCS and USLE model with RS and GIS technologies have great potential for modeling of different hydrological parameters and producing risk maps in any watershed region.

Praveen and Kumar (2012) conducted a study on integrated approach of Universal Soil Loss Equation (USLE) and Geographical Information System (GIS) for Soil Loss Risk Assessment in Upper South Koel Basin, Jharkhand. The soil erosion rate was determined as a function of land topography, soil texture, land use/land cover, rainfall erosivity, and crop management practice in the watershed using the Universal Soil Loss Equation (for Indian conditions), remote sensing imagery, and GIS techniques. The rainfall erosivity R-factor of USLE was found as 546 MJ mm/ha/hr/yr and the soil erodibility K-factor varied from 0.23 – 0.37, Slopes in the catchment varied between 0% - 42% having LS factor values ranging from 0 – 21. The C factor was computed from NDVI (Normalized Difference Vegetative Index) values derived from Landsat-TM data. The P value was computed from existing cropping patterns in the catchment. The annual soil loss estimated in the watershed using USLE was 12.2 ton/ha/yr.

Singh et al. (2012) studied on the Nagwa watershed of Jharkhand state, India. They found that the watershed is a sensitive area for sediment and non-point source pollution. They compare the monthly sediment yield simulation results of the soil and water assessment tool (SWAT) with the multilayer perceptron (MLP) artificial neural network model during the calibration (1993–2004) and validation periods (2005–2007), and determine the most appropriate model for the watershed. The simulated result shows that the annual average sediment yield was 3.1 and 5.0 t/ha for MLP and SWAT model, respectively. Both models generally provided good correlation and model efficiency for simulating monthly sediment yield during calibration and validation. For the SWAT model the coefficient of determination ($R^2$) and Nash-Sutcliffe simulation efficiency (NSE) values were 0.78 and 0.76 during calibration.
and 0.68 and 0.66 during validation, respectively. The MLP model performed better than SWAT with $R^2$ and NSE values of 0.84 and 0.76 during training and 0.77 and 0.74 during validation periods, respectively.

Sridhar et al. (2012) studied, semi-arid region of Kadam watershed that has been delineated into 21 sub-watersheds using GIS environment. Priorities are arrived based on sediment yield index values and the sub-watersheds with the highest sediment yield index value is given the highest priority and vice versa. In the study area six sub-watersheds have been found to be under 'very high' priority, one sub-watershed has been found to be under high priority and fourteen sub-watersheds have been found to be under 'Very low' priority.

Ahmad and Verma (2013) applied USLE model and GIS, for soli loss estimation for the Tandula reservoir catchment area of Tanudula River at Balod Tehsli of Durg district of Chhattisgarh State, India. GIS was used for preparation of different parameters of USLE model. The soil loss obtained from USLE model has been compared with soil estimated by Nayak and Khosla’s method, and it was observed that USLE with GIS gave better result as compared to other methods.

Laosuwan et al. (2013) used GIS and Universal Soli Loss Equation (USLE), to evaluate the risk area of soil erosion in the Maha Sarakham province in Thailand for the year 2010. In this study five parameters of USLE were evaluated for the study area using remotely sensed ground observation and existing map data. Remotely sensed data was the main source of information for the establishment of land use/land cover, geology, geomorphology and soil map, as well as for deriving a scheme of watershed distribution using both digital image processing and visual interpretation. Each of the USLE factors with associated attribute data was digitally encoded in a GIS database to eventually produce five thematic layers. These were then spatially overlaid to produce a resultant polygonal layer. Further these encoded layers were employed with the USLE model to estimate soil erosion.

Mamo and Jain (2013) examined the applicability of the SWAT model in Gumera river basin upstream of Lake Tana, Ethiopia for simulating stream runoff and
sediment load. The area of river basin was discretized into 24 sub catchments using ArcSWAT interface of the model. The semi-automated Sequential Uncertainty Fitting (SUFI2) and fully automated Parameter Solution (ParaSol) calibration process built in SWAT calibration and uncertainty program (SWAT-CUP) were used to calibrate the model parameters using time series of flow and sediment load data of 1994 to 2002 and validated with the observed data from years 2003 to 2006. The coefficient of determination ($R^2$) and NSE values for the daily runoff by using [ParaSol] optimization technique was obtained as 0.72 and 0.71 respectively for the calibration period and 0.79 and 0.78 respectively for the validation period, $R^2$ and NSE values of monthly flow calibration using SUFI2 are 0.83 and 0.78 respectively for validation it was 0.93 and 0.93. For monthly sediment yield by using SUFI2 calibration technique the model evaluation coefficients $R^2$ and NS for calibration was computed as 0.61 and 0.60 respectively, for validation it was 0.84 and 0.83 respectively.

**Tripathi et al. (2013)** carries out morphometric analysis viz; Stream order, Stream length, Bifurcation ratio, Drainage density, Drainage frequency, Drainage texture, Form factor, Circularity ratio, Elongation ratio and Compactness ratio etc. for Seoni river watershed which is a tributary of Narmada Basin. The prioritization and compound parameter values were calculated and finally prioritization of seven sub watersheds was marked. The priority was decided on the basis of rate of soil erosion. Its application provides an efficient and accurate means for evaluation of these characteristics.

**Chandra et al. (2014)** estimated sediment yield for studies of reservoir sedimentation, river morphology and planning of soil and water conservation measures. The Soil and Water Assessment Tool model is utilized for sediment yield estimation in the Burhanpur sub basin measuring an area of 8487 km$^2$ in Upper Tapi catchment. The model has been calibrated and validated using observed run-off and sediment yield data of 12 years at the basin outlet. The average values for Nash-Sutcliffe efficiency (NSE) and RSR for sediment yield are found to be 0.85 and 0.36, respectively, which are within satisfactory limits.
Jaiswal et al. (2014) work out various Erosion Hazard Parameter for Preparation of Catchment Area Treatment plan of Kodar watershed. They found that soil loss occupied the maximum weight (0.33) and the circular ratio had minimum weight of 0.02 at 9.3% consistency ratio. The priority value range from 0.12 to 0.74 of different sub watershed. The study also demonstrated a procedure for analyzing EHP’s and use of those in MCDA for Prioritizing soil erosion vulnerable Zones/ Area.

Patil et al. (2014) assessed the annual rate of soil erosion from the Shakkar River watershed using remote sensing (RS) and geographic information system (GIS) techniques and compared the simulated sediment loss with observed sediment loss. The Shakkar River watershed, lies in Narmada river basin that is situated in Narsinghpur and Chhindwara districts of Madhya Pradesh, India. The universal soil loss equation (USLE) integrated with RS and GIS approach was used to predict the spatial distribution of the soil erosion on a cell basis occurring in the study area. Thematic maps of USLE factors like rainfall erosivity factor (R), soil erodibility factor (K), topographic factor (LS), crop cover management factor (C), and conservation support practice factor (P) were prepared by using annual rainfall data, soil map, digital elevation model (DEM) and satellite image of the area, respectively, in the GIS environment. The annual rate of sediment loss from study area was found to vary between 6.45 and 13.74 t/ha/year (during, 1997 – 2006) with an average annual rate of 10.04 t/ha/year. The percent deviation between simulated and observed values varies between 2.68 and 18.73 % with coefficient of determination (R²) of 0.911.

Shi et al. (2014) considered land use composition, land use pattern, morphometric variables, and soil properties at the sub-watershed scale as potentially influential factors. The results revealed that the land use composition and land use pattern exerted the largest effects on the specific sediment yield and explained 65.2% of the variation in the specific sediment yield. A set of physiographic indices was also found to have a large effect on the specific sediment yield and explained 17.7% of the observed variation in the specific sediment yield.
Singh et al. (2014) evaluated the process-based Soil and Water Assessment Tool (SWAT) model and the data-driven Radial Basis Neural Network (RBNN) model for simulating sediment load for the Nagwa watershed in Jharkhand, India, where soil erosion is a severe problem. The SWAT model calibration and uncertainty analysis were performed with the Sequential Uncertainty Fitting algorithm version 2 and the bootstrap technique was applied on the RBNN model to analyse uncertainty in model output. Comparison of the results of the two models shows that the value of r factor ($r = 0.41$) in the RBNN model is less than that of SWAT model ($r = 0.79$), which means there is a wider prediction interval for the SWAT model results. They found more values of observed sediment yield were bracketed by the 95PPU in the RBNN model. They concluded that the RBNN model estimates the sediment yield values more accurately and with less uncertainty.

Devatha et al. (2015) have worked on estimation of soil loss using USLE model for kulhan watershed of Shivnath basin, sub-basin of Mahanadi, Chhatisgarh, India by Remote Sensing (RS) and Geographic Information System (GIS) tool. The five major input parameters used in the study are rainfall erosivity factor (R), Length slope factor (LS), soil erodability factor (K), vegetation cover factor (C) and erosion control factor (P). The rainfall erosivity factor had been determined from annual rainfall data of study area. The soil survey data was used to develop the soil erodability factor and DEM of study area was used to generate topographic factor (LS). The value of cover management factor and support practice factor were obtained from land use land cover map. It was found that mean annual soil loss for the entire watershed area is 0.1783 ton/ha/year and the highest value of estimated soil erosion potential is 556 ton/ha/yr.

Machiwal et al. (2015) estimated soil erosion potential and identified the critical areas for soil conservation measures of an ungauged catchment situated in Aravalli hills of Udaipur district, Rajasthan, India. The soil erosion was estimated for 10 year period (2001-2010) by Universal Soil Lose Equation (USLE) model using Geographical Information system (GIS) and remote sensing techniques. Thematic maps of six USLE model parameters, i.e., rainfall erosivity (R-factor), soil erodibility
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(K-factor), slope length (L-factor), slope steepness (S-factor), crop and management (C-factor), and support practice (P-factor), were prepared in GIS platform. They found $R$-factor ranged from 1,522.93 to 10,225.88 MJ mm ha$^{-1}$ h$^{-1}$ year$^{-1}$ in the years 2006 and 2008, respectively, when the annual rainfall was 984.3 and 572.2 mm, and $K$-factor was highest for fine loam soil while the lowest value was for coarse loamy sand. The lowest value of the $L$-factor (0.736) was in accordance with the high slopes nearby catchment boundary; whereas the highest value (0.832) was for almost zero slopes in 34\% area nearby waterbodies. Opposite to the $L$-factor, the $S$-factor values were high (>4) for the higher slopes nearby catchment boundary and the lowest values for the zero slopes. The $C$-factor value in 170.36 km$^2$ or 48.91\% of the area is 0.1 while the value is zero for waterbodies and builtup lands. The $P$-factor value in 250.36 km$^2$ or 71.87\% of the area is 0.8. The mean annual soil erosion in the major portion of the catchment (231.13 km$^2$ or 66.38\%) exceeds 10 t ha$^{-1}$ year$^{-1}$ indicating high to very severe soil erosion conditions prevailing in the catchment.

\textbf{Yadav et al. (2015)} used the Sediment Yield Index (SYI) model of the All India Soil and Land Use Survey (AIS & LUS, 1990) for identification of priority sub-watersheds in Benisagar reservoir catchment of Madhya Pradesh. The SYI values of individual 36 sub watersheds have been computed and categorized in very high, high, medium, low and very low priority classes. The significant variation in SYI values calls for conservation planning, and concluded that 41.93 sq km area which is nearly 50\% of total catchment comes under very high and high priorities need immediate attention for soil conservation measures.

2.3 \textbf{Prioritization of watershed using Morphometric parameters}

Morphometric analysis is a significant tool for understanding the hydrological process. The morphometric analysis provides indirect estimates of physiography of the watershed, which can be used for efficient planning and management of soil and water resources for sustainable development of the watershed.

\textbf{Singh and Singh (1979)} conducted a comparative study on morphometric evaluation of Himalaya and the peninsular uplands. The study is based on
A review of literature on the use of topographical maps, aerial photographs and field observations in the region. They employed four principal methods i.e. relative relief, dissection index, drainage texture and slope to identify morpho units. It is noted that these four principal morphometric attributes are significant enough in understanding the morphological character.

**Agrawal (1998)** has examined the drainage pattern through aerial data in Naugarh area of Varanasi district, Uttar Pradesh. In the quantitative evaluation of morphometric parameters which include stream length, frequency, bifurcation ratio, drainage area and density and some shape parameters etc have been studied using methods outlined.

**Biswas (1999)** worked out prioritization of sub watersheds of Midnapore district, West Bengal, based on morphometric analysis in terms of stream length, bifurcation ratio, drainage density, stream frequency, texture ratio, form factor, circulatory ratio and elongation ratio. The subwatersheds have been analysed through Sediment Yield Index (SYI) model also and the results tally in with the present approach. The study indicates that morphometric analysis using Remote Sensing and GIS could be used effectively for prioritization of sub watershed even without the soil map of the concerned study area.

**Shrimali et al. (2001)** presented mapping, monitoring and prioritizing the areas based on their susceptibility to degradation using Remote sensing and Geographic Information System. They studied 42 km² Sukhna Lake catchment in the Shiwalik hills for the delineation and prioritization of erosion-prone areas. The catchment was classified in six land use classes: forest, agriculture, scrub, barren hills, streambed and settlements. These classes were divided into sub-classes based on the cover characteristics. Erosion-prone areas were classified further by integration of a digital elevation model or DEM-derived slope, aspect and flow length. To get an ordered priority of the erosion-prone areas, a cumulative erosion index was computed from the rating given to the three main causative factors, i.e., slope, soil erodibility, and land cover, on a scale of 1-7 for each grid.
Kumar and Kaur (2002) have been used remote sensing and GIS techniques for the determination of morphological characteristics of watersheds of Ferozpur Jhirka, which is one of the block, that is full under the drought prone area and one of the block of Integrated Mission for Sustainable Development (IMSD) program. The basin characteristics have been analyzed in term of the morphometric parameters such as stream length, bifurcation ratio, drainage density, stream frequency, texture ratio, elongation ratio etc. They concluded that morphology may be useful for water resource planning of an area.

Swamy et al. (2002) have carryout the morphometric analysis of the basin by preparing drainage map on 1:50000 scale based on SOI toposheets and supplemented by satellite imageries. The morphometric parameters are computed using GIS and related to hydrogeological conditions of the basin. The basin is dominantly characterized by dendritic pattern common in granitic areas and indicates that the underlying rocks offer uniform resistance in horizontal direction suggesting uniform lithology. The elongated shape of the basin with medium bifurcation ratio hints moderate flows. The smaller number of streams and greater stream length indicate permeable strata in central and eastern portion of the basin. The high drainage density in the western part of the basin and the small value of constant of channel maintenance indicates the impermeable nature of sub-surface formation in the western part. The small value of the length of over land flow confirm the course texture of the basin especially the central and eastern parts conducive for ground water recharge and thus form potential areas for ground water development. This is due to higher order stream and larger catchment area.

Pareta (2003) studied the detail morphometric characteristics of Karawan watershed in Dhasan basin, which itself is part of the mega Yamuna basin in Sagar district, Madhya Pradesh. They have computed more than 85 morphometric parameter of all aspects. Based on all morphometric parameters analysis; they concluded that the erosional development of the area by the streams has progressed well beyond maturity and that lithology had an influence in the drainage development. These studies are very useful for planning rainwater harvesting and watershed management.
Vittala et al. (2004) conducted morphometric analysis, of sub-watersheds in the Pavagada area of Tumkar district in South India, using Remote Sensing and G.I.S. techniques. The study area covered 570 km$^2$ on Pennar river basin. The morphometric analysis of 9 sub-watersheds showed that the Devedabetta sub-watershed possesses circular shape while remaining sub-watersheds mark elongated pattern.

Chopra et al. (2005) carried out morphometric analysis of two sub-watersheds using remote sensing and GIS techniques. Detailed drainage map prepared from aerial photographs and SOI toposheets was updated using latest IRS-1D PAN sharpened LISS-III analog data. Updated drainage maps were used for the morphometric analysis of the two sub-watersheds. Both the sub-watersheds show dendritic to sub-dendritic drainage pattern with moderate drainage texture. High bifurcation ratio indicates a strong structural control on the drainage. Logarithm of number of stream vs. stream order show deviation from straight line indicating regional upliftment. In spite of mountainous relief, low drainage density value indicates that the area is underlain by impermeable sub-surface material. Circulatory and elongation ratios show that both the sub-watersheds have elongated shape.

Nooka et al. (2005) prioritize the sub watersheds using Sediment Yield Index (SYI) and morphometric analysis in Tarafeni watershed in Midnapur district. This study employed IRS ID LISS-III digital data, topographical sheets and other reference maps. Among the morphometric parameters bifurcation ratio, drainage density, form factor, stream frequency, elongation ratio, circulatory ratio, texture ratio, length of overland flow & compactness coefficient have been employed to priorities the watersheds. The study points out that a total of 21 sub-watershed fall in very high prioritized category in which 24 checks dams were proposed on 3rd, 4th and 5th order streams. It is underlined that integrated study of SYI model and morphometric analysis yield good results in prioritization of watersheds.

Galgale and Shinde (2006) described morphological characteristics like stream order, drainage density, aerial extent, watershed length and width, channel length, channel slope and relief aspects of watershed that are important in understanding the hydrology of watershed. Runoff response of the watershed is
different for different slopes, shapes, length widths and area of watershed. Response is also affected by the factor like drainage density, length of over land flow, stream frequency, relative relief and relief ratio.

Narendra and Rao (2006) used Resourcesat - I data to provide continuity in operational remote sensing with its enhanced capabilities in the field of land and water resources management. GIS tools and image processing technique are used to identify the morphological features and water resources of the Meghadrigedda watershed. The morphometric parameters such as linear aspects and aerial aspect of six sub watersheds of the watershed were determined. To improve the ground water level, thirteen suitable sites were identified for the construction of check dams in Meghadrigedda watershed.

Thakkar and Dhiman (2007) has studied about morphometric analysis and prioritize the eight mini watersheds, located between Bayad taluka of Sabarkantha, using Remote Sensing and GIS techniques. The morphometric parameters considered for analysis are stream length, bifurcation ratio, drainage density, stream frequency, texture ratio, form factor, circularity ratio, elongation ratio and compactness ratio. He found that highest bifurcation ratio among all the mimi watersheds is 9.5 which indicates a strong structural control on the drainage. The maximum value of circularity ratio was 0.1197 and elongation ratio was 0.66. The form factor values are in range of 0.29 to 0.34 which indicates that the watershed has moderately high peak flow for shorter duration. They calculate the compound parameter values and prioritization rating of eight mini watersheds by the lowest compound parameter value is given the highest priority.

Javed et al. (2009) made an attempt for the prioritization of sub-watershed, based on morphometric and land use characteristics using remote sensing and GIS techniques in Kanera watershed of Guna district, Madhya Pradesh. Various morphometric parameters, namely linear and areal have been determined for each sub-watershed and assigned ranks on the basis of value / relationship so as to arrive at a computed value for a final ranking of the sub-watershed. Lower value of bifurcation ratio are characteristics as less structurally

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control on the drainage development, value (0.008 to 0.013) of relief ratio suggesting gentle slope, the lower value of drainage density shows that the region underlain by highly permeable material with vegetative cover and low relief. Stream frequency has positive correlation with the drainage density suggesting increase in stream population with respect to increase in drainage density, value (2.50 to 3.46) of drainage density indicating coarse drainage texture. They found higher value (0.71) of form factor is closer to circular basin and suggests lower peak flows of longer duration.

Pankaj and Kumar (2009) made an attempt to evaluate the morphometric parameter which requires preparation of drainage map, contour map, ordering of the various streams and measurement of catchment area, perimeter, relative relief, relief ratio, length of drainage channels, drainage density, drainage frequency, bifurcation ratio, texture, channel maintenance, which help to understand the nature of the drainage basis. All the sub-watersheds are basically of 5\textsuperscript{th} to 6\textsuperscript{th} order, drainage patterns are mainly dendritic to sub dendritic. The drainage pattern of the song river basin is mainly structurally controlled and the area is characterized by high to moderate relief.

Sreedevi et al. (2009) attempted to study drainage morphometry and its influence on hydrology of Wailapalli watershed, South India. The study reveals that the elongated shape of the basin is mainly due to the guiding effect of thrusting and faulting. The lower order streams are mostly dominating the basin. The development of stream segments in the basin area is more or less affected by rainfall. The mean $R_b$ of the entire basin is 3.89 which indicate that the drainage pattern is not much influenced by geological structures. Relief ratio indicates that the discharge capability of these watersheds is very high and the groundwater potential is meager.

Mishra and Nagarajan (2010) used remote sensing and Geographical Information System (GIS) techniques for morphometric analysis and prioritization of sub-watersheds for Hati watershed in Kalahandi district of Odisha, India. The entire study area has been further divided into 12 sub-watersheds named SWS1 to SWS12, ranging in geographical area from 30 km$^2$ to 202 km$^2$ and has been taken up for
prioritization. The drainage density of sub-watersheds varies between 1.09 to 3.36 km/km² and low drainage density values of sub-watershed SWS11 indicates that it has highly resistant, impermeable subsoil material with dense vegetative cover and low relief. The elongation ratio varies from 0.6 to 0.8 which indicates high relief and steep ground slope. The high value of circularity ratio for SWS11 sub-watershed (0.8) indicates the late maturity stage of topography. The compound parameter values are calculated and the sub-watershed with the lowest compound parameter is given the highest priority. The sub-watershed SWS1 has a minimum compound parameter value of 4 is likely to be subjected to maximum soil erosion and susceptible to natural hazards. Hence it should be provided with immediate soil conservation measures.

Rao et al. (2010) used GIS and image processing techniques for the identification of morphological features and analyzing their properties of the Lower Gostani River Basin (LGRB) area in Andhra Pradesh state, India. The basin morphometric parameters such as linear and aerial aspects of the river basin were determined. It was observed that the drainage density value is low which indicates the basin is highly permeable subsoil and thick vegetative cover. The circularity ratio value reveals that the basin is strongly elongated and highly permeable homogenous geologic materials.

Sharma et al. (2010) described that the GIS technique is being very widely used in the sustainable development of natural resources. They used geographical information System (GIS) approach as a tool for determining quantitative description of basin geometry i.e. morphometric analysis. The result obtained from GIS analysis suggests that the ratio between cumulative stream length and stream order is constant throughout the successive orders of basin. The computation of morphometric parameters like stream length, drainage density, stream frequency, texture ratio, form factor, circulatory ratio, and elongation ratio reveals that the higher value of bifurcation ratio, stream frequency and form factor indicate high runoff, low recharge and mature topography, in case of the high relative relief, critical from erosion point of view. Low value of drainage density indicates that it has highly resistant, impermeable sub soil material with dense vegetation cover and low relief. It was
observed from the prioritization of sub watersheds, the sub watershed number 2 has got highest priority because of high erosion intensity considering the morphometric analysis.

**Vemu et al. (2010)** carried out watershed prioritization of reservoir catchment based on vegetation, morphological parameters, and average annual soil loss using geographic information system (GIS) and remote sensing techniques. This study integrates the watershed erosion response model (WERM) and universal soil loss equation (USLE) with a geographic information system (GIS) to estimate the erosion risk assessment parameters of the catchment. The total catchment is divided into 15 sub-watersheds. Various erosion risk parameters are determined for all the sub-watersheds separately. Average annual soil loss is also estimated for the sub-watersheds using USLE. The integrated effect of all these parameters is evaluated to recommend the priority rating of the watersheds for soil conservation planning.

**Lakshmamma et al. (2011)** studied about morphology analysis of Gundal watershed, Gundlupet taluk, Chamarajanagar district, Karnataka, India to determine the drainage characteristics of Gundal watershed using topographic maps. This watershed divided into 25 sub-watersheds. The drainage patterns of the sub-basins are dendritic and parallel, the basin includes highest 4th order stream and the area covers 790 sq. km. The analysis clearly indicates some relations among the various attributes of the morphometric aspects of the watershed and helps to understand their role in sculpturing the surface of the region.

**Malik et al. (2011)** studied in Lidder catchment which comes in the western Himalayas part with an area of 1159.38 km² (10% of the river Jhelum catchment). Various linear and areal aspects of the catchment were computed at watershed level. This was achieved using GIS to provide digital data that can be manipulated for different calculations. The analysis has revealed that the total number as well as total length of stream segments is maximum of first order streams and decreases as the stream order increases. Horton’s laws of stream numbers and stream lengths also hold good. The bifurcation ratio between different successive orders is almost constant. The drainage density values of the different watersheds exhibit high degree of positive
correlation (0.97) with the stream frequency suggesting that there is an increase in stream population with respect to increasing drainage density and vice versa.

**Nag et al. (2011)** studied morphometric analysis of Dwarakeswar watershed, Bankura district, West Bengal, India, using spatial information technology. Remote sensing (RS) coupled with geographical information system (GIS) has come out as an efficient tool in delineating drainage pattern and water resource management and its planning. He studied that the area is characterized by fine drainage texture and lower drainage density indicating the basin is characterized by highly resistant permeable material with low relief. The overall drainage pattern of the Dwarakeswar watershed reflects a dendritic pattern. Dendritic pattern, in general, is considered as a group of resequent streams within homogeneous lithology and gently sloping topography. This study would help the local people to utilize the resources for sustainable development of the basin area.

**Sethupathi et al. (2011)** conducted study of Bargur and Mathur sub watersheds of Ponnaiyar River basin. The result shows that drainage network exhibits dendritic drainage pattern. Stream order ranges from fourth to sixth order. Drainage density varies between 1.26 to 2.94 km/ km². Texture ratio of drainage basins range between 2.59 to 15.46, and the mini watersheds are classified as moderate to fine drainage texture excepting 4 mini watersheds which are classified as fine to very fine drainage texture. The stream frequency of Bargur and Mathur sub watersheds ranges between 2.36 to 7.28. The stream frequency is low in most of the sub-watersheds indicating low relief and high permeability, however, four sub-watersheds show high stream frequency, indicative of high relief and low infiltration capacity of bedrock.

**Patel et al. (2012)** worked on Prioritization of mini-watersheds through morphometric analysis by using Geographical information system & remote sensing and proven to be an efficient tool for locating water harvesting structures. In prioritization of mini-watersheds, morphometric analysis is utilized by using the linear parameters such as bifurcation ratio, drainage density, stream frequency, texture ratio, and length of overland flow and shape parameters such as form factor, shape factor, elongation ratio, compactness constant, and circularity ratio. The different
prioritization ranks are assigned after evaluation of the compound factor. They created and analysed digital elevation model from Shuttle Radar Topography Mission (SRTM), digitized contour, and other thematic layers like drainage order, drainage density, and geology in ArcGIS 9.1 platform. Combining all thematic layers with soil and slope map, the best feasibility of positioning check dams in mini-watershed has been proposed.

Romshoo et al. (2012) worked on Geoinformatics for assessing the impact of morphometry control on hydrological response of watershed. They selected the five watersheds (W1, W2, W3, W4 and W5) of the upper Indus basin for detailed studies to understand the influences of geomorphology, drainage basin morphometry and vegetation patterns on hydrology. From the morphometric analysis, it is evident that the hydrologic response of these watersheds changes significantly in response to spatial variations in morphometric parameters. Results indicate that W1, W2 and W5 contribute higher surface runoff than W3 and W4 because W5 having highest drainage density followed by W1 and W2.

Sarma et al. (2012) attempted to prioritize the sub-watersheds for adopting the conservation measure. The prioritization is based on land use and slope analysis using Remote Sensing and GIS techniques in Khanapara–Bornihat area of Assam and Meghalaya state (India). The study shows the significance changes in land use pattern especially in settlement and forest lands from 1972 to 2006. Slope map of the sub-watersheds prepared from the contour values in the toposheets show the wide variation of slope in the area ranging from 0° to 87°. Based on the extent/nature of land use/land cover changes over time and land use/land cover slope relationship analysis, the sub-watersheds are classified into three categories as high, medium and low in terms of priority for conservation and management of natural resources.

Sarmah et al. (2012) studied morphometric analysis of a highland microwatershed (Wah Umbah) area by using remote sensing and geographic information system (GIS) techniques. Detailed drainage map of the area was prepared from Survey of India (SOI) toposheets which was updated using IRS-1D PAN sharpened LISS-III analog data. Updated drainage maps were used for the drainage
pattern analysis of the study area, The Wah Umbah microwatershed shows a sub-trellis drainage pattern with moderate drainage texture.

Sridhar et al. (2012) studied, semi-arid region of Kadam watershed that has been delineated into 21 sub-watersheds using GIS environment. Priorities are arrived based on sediment yield index values and the sub-watersheds with the highest sediment yield index value is given the highest priority and vice versa. In the study area six sub-watersheds have been found to be under 'very high' priority, one sub-watershed has been found to be under high priority and fourteen sub-watersheds have been found to be under 'Very low' priority.

Aher et al. (2014) developed Weighted Sum Analysis (WSA) technique for ranking of each hydrological unit, using the weightages assigned to morphometric parameters. Considering WSA approach, sub-watersheds were alienated into very high, high, medium, low and poor priority zones. The results illustrate that 51.66% of sub-watersheds are in the moderately to highly susceptible zones, which shows potential areas for preferential conservation works planning. The WSA is a viable approach and will be useful to different stakeholders such as agriculturists and natural resources managers for better decisions making.

Chandniha and Kansal (2014) carried out morphometric analysis for prioritization of nine sub-watersheds of Piperiya watershed in Hasdeo river basin. Finally, the prioritized score on the basis of morphometric behavior of each sub-watershed is assigned and thereafter consolidated scores have been estimated to identify the most sensitive parameters. The final score of entire nine sub-watersheds is assigned as per erosion threat. The sub-watershed with the least compound parameter value was assigned as highest priority. However, the sub-watersheds has been categorized into three classes as high (4.1–4.7), medium (4.8–5.3) and low (>5.4) priority on the basis of their maximum (6.0) and minimum (4.1) prioritized score.

Gajbhiye et al. (2014) carried out prioritization on 14 sub-watersheds of Manot River catchment, which is a tributary of the Narmada River. After analysis of morphometric parameters, compound parameter values are calculated and
prioritization rating of 14 sub-watersheds is carried out. The sub-watershed 13 that has the lowest compound parameter value of 3.63 is likely to be subjected to maximum soil erosion; hence, it requires immediate attention to providing soil conservation measures. Morphological parameters-based prioritization is in good agreement with the geological field investigation carried out during the field work.

**Ibrahim et al. (2014)** shows that the morphometric parameters derived from Cartosat DEM data provide good and satisfactory information about the catchment characteristics and it also reveals that accuracy of the watershed delineation depends upon the resolution of DEM.

**Sharma et al. (2014)** used remote sensing and GIS (Geographical Information System) technology to generate information regarding factors affecting soil erosion. These factors include soil type, vegetation, topography and various watershed properties such as drainage density, form factor etc. The present study is carried out in Kanhiya nala watershed of Gusuru river which is a tributary of Tons river basin in Madhya Pradesh, India. The study area is divided into nine sub-watersheds and different topology, vegetation, soil and morphology related indices are estimated separately for each sub watersheds. The integrated effect of all the parameter is evaluated to find different areas vulnerable to soil erosion. Two sub watersheds i.e. 1 and 8 were identified as very high susceptible to soil erosion.

**Sujatha et al. (2014)** characterizes the micro watersheds of the Palar sub-watershed using morphometric analysis and assesses its risk by land use and land cover features. Morphometric analysis reveals that micro watersheds 5 and 6 are most susceptible and 2 & 3 as low susceptible. Land use analysis shows that micro watersheds 2 and 4 fall under high priority category while 5 and 6 under low priority category. Integration of the morphometric and land use analysis shows that only micro watershed 1 falls under the same category in both analyses and need to assign higher priority.

**Singh et al. (2014a)** used hydrological module of Arc GIS software for delineation 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 indicate that the drainage pattern is not much influenced by geological structures. The present study reveals that SRTM DEM based hydrological evaluation at watershed scale is more applied and precise as compared to other available techniques.

Singh et al. (2014b) showed that GIS technique can serve as vital tool in generating water resources action plan, drainage pattern and geomorphic indicator for location of recharge and discharge area analysis. The present study area, Kawali river watershed of the Giri river in district Sirmaur and Solan of Himachal Pradesh has been divided in 5 sub-watersheds. The maximum and minimum drainage density ($D_d$) has been found as 3.72 and 2.77 km/km² for sub-watershed 5 and 4, respectively, which confirms the recognition that the study area is underlain by impermeable subsurface material having sparse vegetation and mountainous relief. The top priority should be given to sub-watershed 5 and least to sub-watershed 4 to take up the soil and water conservation work in Kawali river watershed.

Chandrashekar et al. (2015) carried out detailed morphometric analysis using ARC-GIS for Manchanabele reservoir catchment and Nelligudde reservoir catchment of Arkavati river system. The results of the morphometric analysis reveal that Manchanabele catchment which is less elongated have high erosion and peak flow. It has a strong relief and steep ground slope. However, Nelligudde reservoir catchment which is elongated more have low soil erosion and medium peak flow. It has an average steep slope with medium relief.

Sindhu et al. (2015) delineated thirteen watersheds on the basis of drainage pattern and topography to understand the hydrological process of the catchment at the watershed level. The drainage density of the watersheds varies from 1.36 to
3.42 km/km² which indicate that the area is coarse texture. Runoff was estimated using USDA Soil Conservation Services (SCS) Curve Number model. The information such as land use/land cover and hydrological soil group map derived from remotely sensed data were overlaid through Arc GIS software to assign the curve number on polygon wise. Soil erosion was estimated by using Universal Soil Loss Equation (USLE). The weighted soil erosion estimated for the catchment was 19 t/ha/year, which is a moderate soil loss and needs conservation measures.

Taufik et al. (2015) reviewed mapping of Bungbuntu watershed using Aster GDEM and SRTM DEM. The main difference is Aster GDEM using thermal, whilst radiometric images and SRTM using radar wavelength. These DEMs were used to determine Bungbuntu watershed boundary using hydrology and geomorphology analyses. The results showed Aster GDEM and SRTM have significant different values compared to BPDAS (Government Field Data) but generally morphometric information was still in the same class range. However, DEM generation failed to determine channel network. DEM produced by SRTM had better elevation accuracy than ASTER GDEM contrary to the resolution of elevation on each DEM source.

Batar et al. (2016) studied the Swan catchment of Una district, Himachal Pradesh. They adopted weightage system for sub-watershed prioritization based on its factors and after carefully observing the field situation. The basis for assigning weightage to different themes was according to the relative importance to each parameter in the study area. The weightage system adopted here is completely dependent on local terrain and may vary from place to place. The prioritization results of study shows that 4 sub-watersheds SWL36, SWL6, SWR54, and SWR69 need very high priority, 29 sub-watersheds need high priority, 16 sub-watersheds fall in medium priority and 32 sub-watersheds fall in very low and Low priority.

2.4 Prioritization using Saaty’s analytical hierarchical process (SAHP)

The applications of AHP to complex decision situations have numbered in the thousands (De Steiguer et al., 2003) and have produced extensive results in problems involving planning, project selection, customer requirement rating, resource
allocation, priority setting, site selection and selection among alternatives (Bhushan and Kanwal, 2004). Other areas have included forecasting, total quality management, business process re-engineering, quality function deployment, and the balanced scorecard (Forman and Gass, 2001), for example in banks (Haghighi et al., 2010; Oyatoye et al., 2010; Seçme et al., 2009), manufacturing systems (Iç and Yurdakul, 2009; Tseng and Lee, 2009; Yang et al., 2009), operators evaluation (Sen and Çinar, 2010), drugs selection (Vidal et al., 2010), construction method selection (Pan, 2009), route planning (Niaraki and Kim, 2009), and many others.

De Steiguer et al. (2003) used analytic hierarchy process (AHP) as a means of assisting the implementation of integrated watershed management and also means for assisting in the plan selection process in solving watershed management problems.

Yahaya et al. (2008) studied about causative factors responsible for flooding in watershed i.e. annual rainfall, basin slope, drainage network, land cover and the type of soil. In this study Multi-criteria Evaluation (MCE) approaches is employed. In MCE, two methods, pair wise comparison method (Analytical Hierarchy Process-AHP) and Ranking Method are used to calculate the weights of each factor. Using AHP the weightage derived for each factors were, Rainfall 33.9%, Drainage network 25.5%, Slope of the river basin 19.7%, Soil type 15.2% and Land cover 5.7%.

Kafaky et al. (2009) used the AHP method for providing weight to criteria and sub-criteria of the forest areas ecological assessment with a (GIS)-based MCDM approach for multiple-use planning in order to reduce degradation and improving sustainability. Sub-criteria were mapped in GIS environment using available data, fieldwork and IRS P- 6 data. A priority map for each land use was created using GIS-based WLC model. The final priority map was produced of overlying all priority maps. Ecological capability map were generated with editing priority map using present land use map, IRS P6 data, forest laws and fieldwork. The Weights of criteria and sub- criteria was defined for all land uses with consistency ratio <0.10. The most important criteria and sub-criteria for each land use were resulted, too. The final priority map was indicated preference of suitable land uses for each area, ecologically.
Intarawichian and Dasananda (2010) used analytical hierarchy process (AHP) and weighted linear combination (WLC) methods to produce landslide susceptibility map of the lower Mae Chaem Watershed in the north of Thailand. The study was carried out using remote sensing data, field surveys and geographic information system (GIS) tools. The ten factors that influence landslide occurrence, such as elevation, slope aspect, slope angle, distance from drainage, lithology, distance from lineament, soil texture, precipitation, land use/land cover (LULC) and NDVI were considered. The landslide susceptibility index (LSI) was calculated using the WLC technique based on the assigned weight and rating given by the AHP method. The result of analysis was verified using existing landslide locations where the accuracy rate of 64.90% was accomplished.

Kayastha et al. (2013) studied on the analytical hierarchy process (AHP) for landslide susceptibility mapping. A landslide susceptibility map is prepared on the basis of available digital data of topography, geology, land-use and hydrology. In this study, 11 causative factors were considered, i.e. slope aspect, slope angle, slope curvature, relative relief, land use, geology, distance from faults, distance from anticline folds, distance from syncline folds, distance from streams and annual rainfall. The results show that the very high susceptible zone, which covers only 10% of the study area, contribute about 39% of the observed landslides, and the high susceptible zone, which covers only 20% of the study area, contribute 31% of the observed landslides.

Ranjan et al. (2013) used different erosion hazard parameters (EHP’s) affecting the process of soil erosion in the watersheds. Bina river basin lies in between $23^0$ 18' to $23^0$ 45' N latitudes and $78^0$ 07' to $78^0$ 32' E longitudes was selected as study area contributes total geographical area of 1111.58 km$^2$. Saaty’s Analytical Hierarchical Process was adopted to prioritize sub-watersheds. Determination of priority for study area all the EHP’s for 28 sub-watersheds have been determined, normalized and weight for each watershed are determine using the AHP comparison matrix and weight of EHP’s. The priority of all sub-watersheds was categorized in to very high, high, moderate, low and very low.
Jaiswal et al. (2014) prioritized the Benisagar dam catchment that has been divided into 36 sub-watersheds with their areas ranging from 0.77 to 6.53 km$^2$. They analyzed nine EHPs responsible for soil degradation and soil loss in GIS environment using revised universal soil loss equation (RUSLE) model (SL), sediment yield (SY), sediment production rate (SPR), sediment transport index (STI), slope (Slp), drainage density (Dd), channel frequency (Cf), form factor (Rf), circulatory ratio (Rc) for various sub-watersheds have been computed. The pair wise comparison matrix and final weights for all the EHP’s have been determined using SAHP with the acceptable limit of consistency ratio. The final priority ranks for sub-watersheds have been computed by summing the multiplication of SAHP weights and their corresponding normalized values of EHP’s. From the analysis, it has been observed that eight sub-watersheds covering 20.15 km$^2$ and seven sub-watersheds covering 19.41 km$^2$ areas fall under very high and high priority respectively.

### 2.5 Prioritization based on Fuzzy analytical hierarchical process (FAHP)

Fuzzy AHP has been widely used, by different researches for different purposes like car rental selection problem (Tang et al., 2005), Electronic industry (Somsuk et al., 2011), food service strategy (Hwang et al., 2006), prioritization of an employee’s performance measurement attributes under fuzziness (Aggarwal et al., 2013), selecting the best tunnel ventilation system (Mirhedianyatif et al., 2013), Prioritization of human capital measurement indicators (Bozbura et al., 2007), software evaluation (Cebeci et al., 2009; Chang et al., 2009), underground mining method selection (Naghadehi et al., 2009), web development platform (Sarfaraz et al., 2011), operation research (Celik et al., 2015), eco-environmental vulnerability assessment for reservoir area (Li et al., 2009). Some important review related to watershed prioritization are sited here.

Aher et al. (2013) used multiple criteria decision making (MCDM) through Fuzzy Analytical Hierarchy Process (FAHP) and Geographical Information System (GIS) techniques for identifying critical / priority sub-watersheds falling in transaction zone between mountainous and water scarcity region of Western Part of India. The
morphometric characterization of eight sub-watersheds was obtained through the measurement of distinct linear, areal and relief aspects of the sub-basins. Ranking of each hydrological unit was carried out by using fuzzy logic and the Analytical Hierarchy Process (AHP). The results of FAHP analysis showed that Circulatory Ratio, Form Factor and Elongation Ratio are observed to be the most important factors for vulnerability of soil and water resources over the basin. On the basis of FAHP approach, sub-watersheds were considered as vulnerability assessment units and were alienated into four prioritization levels: low, medium, high and very high levels. The sensitivity analysis as well as a comparison between the FAHP technique and the earlier outcomes obtained with conventional techniques, such as AHP and compound parameter method, were also studied.

Jaiswal et al. (2015) presents an efficient multi-criteria decision support model (MCDSM) to prioritize susceptible areas in a watershed for soil conservation measures based on impact analysis of topography, climate, morphology, soil, land cover, management and conservation factors. The MCDS model has been developed based on fuzzy analytical hierarchical process (FAHP) by computing its weights of nine erosion hazard parameters (EHPs). For computing weights of EHPs in FAHPS, triangular, narrow rectangular, medium rectangular and wide rectangular fuzzy membership functions have been used followed by the geometric mean method to determine the final weight matrix. The test of consistency ratio showed wide rectangular function as the most effective one in determining the weights of EHPs with soil loss as the most sensitive and circulatory ratio as the least sensitive parameter. The final priorities of the sub-watersheds have been determined using weight and their corresponding normalized values of EHPs. Based on the clustering of final priorities, the sub-watersheds have been categorized into four groups of priorities, i.e., very high, high, medium, low and very low for soil and water conservation measures. The derived methodology can successfully be used in prioritization of soil conservation measures in a basin for developing catchment area treatment plan.
Rahaman et al. (2015) prioritize the Sub Watershed Based on Morphometric Characteristics using Fuzzy Analytical Hierarchy Process and Geographical Information System. They attempted to study various morphological characteristics and uses the Geographical Information System (GIS) and Multi Criteria Decision Making (MCDM) through Fuzzy Analytical Hierarchy Process (FAHP) techniques for identification of critical sub watersheds situated in transaction zone between mountainous and water scarcity region of kallar watershed, Tamil Nadu on the basis of morphometric parameters. The morphometric characterization was obtained through the measurement of three distinct linear, areal and relief aspects over the eleven sub-watersheds. Each morphometric parameters were ranked with respect to the value and weightings obtained by Fuzzy Analytical Hierarchy Processes (FAHP). Based on FAHP approach, sub watersheds were evaluated and divided into five prioritization zones: very less, less, medium, high and very high classes. The FAHP techniques is a practical approach for identification of the sensitive priority zones and is useful for better management practices such as implementation of land and water resource management, conservation and sustainable agricultural development.

2.6 Development of Catchment Area Treatment plan (CAT)

Sreedevi et al. (2005) carried out hydro geomorphological, hydrogeological and geophysical investigations in the Pageru River basin of Cuddapah district, Andhra Pradesh, to delineate potential zones for future groundwater exploration. The hydro-geo-morphological data are further supported from evidence of the water-table fluctuation in wells and resistivity of the saturated formations. The results indicate that the favorable, moderately favorable and poor zones characterized geo-morphologically, have water-level fluctuations in the range of 0-2, 2-6 and above 6 m, respectively. The resistivity of these zones are also in the range of 1-26, 40-466, and >1,900 ohm-m

Prakash et al. (2007) suggested alternative sustainable land use comprises taking into consideration present land use/land cover, soils, slope, and geomorphology. The watershed management from a different perspective, by stressing the development of the watershed for agriculture activities; first, by
implementing soil and water conservation works. The next step is to suggest alternative sustainable land uses based on soil and water conservation measures, groundwater prospects, land capability, and present land use/land cover in the area. The new approach is found to be very useful, as it takes into consideration basic factors necessary for the overall development and management of the watershed, and ensures stoppage of further degradation of the resources through appropriate soil conservation measures and land uses.

**Kumar et al. (2008)** determined potential sites for construction of rainwater harvesting structures in the Bakhar watershed of Mirzapur District, Uttar Pradesh, India. Each theme was assigned a weightage depending on its influence on ground water recharge. Each class or unit in the map was assigned a knowledge based ranking of one to four depending on its significance in storage and transmittance of groundwater, and these values were multiplied with layer weightage to form score. The final map showing different categories of suitability sites for water harvesting structures such as Check dams, Contour bunding, Recharge pits, Wells and Contour trenching have been suggested.

**Singh et al. (2009)** conducted a case study to identify suitable sites for water harvesting structures in Soankhad watershed, Punjab using Remote Sensing and Geographical Information System (RS-GIS). The IRS-1C: P-6 satellite imagery of the Soankhad watershed was used. The suitable sites were not found for nala bunding and farm ponds due to steep slope, less soil thickness and high runoff velocity. Fourteen check dams and six percolation tanks were proposed for the construction as per Integrated Mission for Sustainable Development (IMSD) guidelines.

**Chowdhury et al. (2010)** proposed a methodology to delineate artificial recharge zones as well as to identify favorable artificial recharge sites using integrated remote sensing (RS), geographical information system (GIS) and multi-criteria decision making (MCDM) techniques for augmenting groundwater resources in the West Medinipur district of West Bengal, India, which has been facing water shortage problems for the past few years. The artificial recharge map thus obtained divided the study area into three zones, viz., and ‘suitable,’ ‘moderately suitable and unsuitable’
according to their suitability for artificial groundwater recharge. It was found that about 46% of the study area falls under ‘suitable’ zone, whereas 43% falls under the ‘moderately suitable’ zone.

Gupta et al. (2010) attempted to identify groundwater potential zones in the hilly terrain of the Pavagarh region. The various thematic maps prepared for delineating groundwater potential zones are lineament density, drainage density, digital elevation model (DEM), slope map and land use/land cover (LULC). A multi-criteria evaluation technique (MCE) is used to investigate a number of choice possibilities and evaluate suitability according to the associated weight of each factor. A map is obtained which shows the classification of the area into good, moderate and low groundwater potential zones.

Kushwaha et al. (2010) demonstrated that the application of remote sensing, GIS and GPS for preparation of sustainable land and water resources development action plans for Pathri Rao sub watershed in Haridwar district of Uttarakhand. High resolution IKONOS satellite imagery was used for detailed land use/cover mapping on 1: 12,500 scale. Various primary and secondary database layers on land use/cover, forest density, biodiversity, slope, aspect, elevation, hydro geomorphology, soil types, soil erosivity and crop suitability were generated. They also consider the social, ecological and economic factors. A set of decision rules was then applied and data layers were integrated in GIS environment for preparation of the scientific and sustainable land and water resources development action plans for the study area.

Walia et al. (2010) used satellite imagery and Survey of India toposheets to generate several layers of maps such as watershed boundary, drainage, soils, land use and land cover, physiography, slope and soil erosion of Moolbari watershed using Geographic Information System technique. The watershed has been broadly divided into six physiographic units. Drainage pattern is dominantly rectangular and trellis and drainage density is 18 per sq. km. About 45% of the total area is under forests. The cultivated land is estimated to be 20% of the total area and the rest is mostly under grazing and scrub land. Soil physiographic relationship was established during detailed soil resource mapping. The texture of soils is dominantly loam/silt loam to
clay loam with varying proportions of gravel. The soils are rich in organic matter. They are slightly to strongly acidic in reaction. The distribution of soils in the watershed is related to physiography, land use/land cover, slope and aspect.

**Yassir (2010)** used the remote sensing and GIS techniques of the Asifabad and Wankadi Taluks, parts of Adilabad district of Andhra Pradesh, India lying between latitudes 18°45’ to 19°35’N and longitudes 78°55’ to 80°0’E for the development of action plan for land and water resources management mainly based on the land use/land, cover, geomorphology and slope of the area using the sources like Multi spectral imageries (ETM+), RADAR (SRTM) data, GSI Maps and SOI toposheets. To increase the groundwater recharge and vegetative cover to control soil erosion, various action plans like construction of recharge structures, afforestation etc has been proposed.

**Pandey et al. (2011)** developed watershed development plan for a small agricultural watershed of Karso, Hazaribagh, India using remote sensing and GIS techniques. The conceptual framework for plan and site suitability mapping for soil and water conservation structures is developed and subsequently, these parameters were integrated with other thematic information viz., land use/cover, drainage, slope, and soil in the GIS environment to arrive at a decision regarding a suitable site for soil and water conservation structures (nala bund, check dam, and percolation tank).

**Mukherjee et al. (2012)** attempted to find out the groundwater potential zones within an arid region of India supported by the scientific investigation of lithology, geomorphology, geohydrological characterization of geological formations and their interrelationship. The groundwater potential zones have been classified into five categories like very poor, poor, moderate, good and excellent. The result also has been validated by yield data collected from existing sources and it confirms that the higher yield categories are falling within excellent groundwater potential zones where yield ranges from 23 to 40.3 l/s and lower values ranging from 8.1 to 10.6 l/s are falling within poor groundwater potential zones.
Patel et al. (2012a) used Geo-visualization concept for positioning water harvesting structures in Varekhadi watershed consisting of 26 mini watersheds, falling in Lower Tapi Basin (LTB), Surat district, Gujarat. The different prioritization ranks were assigned after evaluation of the compound factor. 3 Dimensional (3D) Elevation Model (DEM) from Shuttle Radar Topography Mission (SRTM) and DEM from topo contour were analyzed in ArcScene 9.1 and the fly tool was utilized for the Geo-visualization of Varekhadi mini watersheds as per the priority ranks. Combining this with soil map and slope map, the best feasibility of positioning check dams in mini-watershed no. 1, 5 and 24 has been proposed, after validation of the sites.

Agarwal et al. (2013) demonstrated the capabilities of Remote Sensing (RS) and Geographic Information System (GIS) techniques for the demarcation of suitable sites for artificial recharge of groundwater aquifers, in the Loni watershed, located in Unnao and Raebareli districts, Uttar Pradesh, India. In this study, the SCS-CN model, groundwater depth data and morphological parameters (bifurcation ratio, elongation ratio, drainage density, ruggedness number, relief ratio, and circulatory ratio) have been used to delineate the recharge sites for undertaking water conservation measures. Augmentation of water resource is proposed in the watershed by constructing runoff storage structures, like check dam, percolation tank and nala bund. The site suitability for these water harvesting structures is determined by considering spatially varying parameters, like runoff potential, slope, groundwater fluctuation data and morphometric information of the watershed.

Kaliraj et al. (2015) investigated the groundwater recharge potential zone and suitable sites for artificial recharge structures in the River Vaigai upper basin, Theni district, Tamil Nadu, using GIS-based multi-parameter weighted overlay method. The groundwater recharge potential map shows the twenty suitable sites for artificial recharge structures such as percolation ponds, loose rock check dams, and water absorption trench (WAT) in various parts of the study area. The effective recharge practices such as percolation ponds and check dams are highly suitable for gentle-sloped barren and agricultural plains in the northwestern and northeastern parts.
Whereas, the barren valley fill, bajada and streams intersecting lineaments along the middle-eastern and central part are suitable for constructing WAT and check dams.

Khadse et al. (2015) conducted studies for the formulation of catchment area treatment plan based on watershed prioritization with soil erosion studies using remote sensing techniques, corroborated with Geographic Information System (GIS), secondary data and ground truth information. On the basis of soil erosion classes, the watersheds were grouped into very high, high, moderate and low priorities. High-priority watersheds need immediate attention for soil and water conservation, whereas low-priority watershed having good vegetative cover and low silt yield index may not need immediate attention for such treatments.