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Integrating soil hydraulic parameter and microwave precipitation with morphometric analysis for watershed prioritization

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Abstract

Morphometric analysis is a promising technique for watershed management. It provides quantitative descriptions of river basin and useful for understanding the behaviour of hydrological properties. This study is conducted in Pahuj river basin (Bundelkhand Region) Jhansi, Central India to understand the basin characteristics for watershed prioritization. The Shuttle Radar Topography Mission satellite (SRTM) is used to derive the Digital Elevation Model (DEM) and for creation of thematic layers such as drainage order, drainage density and slope map. In total, 20 mini-watersheds are generated for understanding the morphometric analysis and estimating the compound factor for mini-watersheds. For watershed prioritization, soil hydraulic parameter, compound factor and monthly average monsoon precipitation from TRMM (Tropical Rainfall Measure Mission) for 18 years period (1998-2015) are used. The overall analysis indicates that the mini-watershed numbers 18, 19 needs utmost attention for water conservation followed by mini-watershed number 20. Our results are also of considerable scientific and practical value to the wider scientific community, given the number of practical applications and research studies in which morphometric analysis are needed.

Keywords: Morphometric analysis; GIS; TRMM precipitation; SRTM DEM; ROSETTA model; Prioritization

1. Introduction

Rational utilization of soil, water and vegetation are important for sustainable development and management. Thus, the conservation and proper management are necessary for obtaining sustainable solution by adopting different watersheds (Baban, 1999). Watershed is a area of land that act as an inlet for all precipitation and drains into a common water body, such as a river, lake and/or stream (Dunne and Leopold, 1978). (Chow) in 1964 describes the watershed as a unit of area that covers all the land, which drain runoff to a common outlet. Watershed management includes collective form of water practices and relate to the land resources that have optimum production without affecting the nature and rational use in future. The main aim of watershed management is to developed environmentally and economically healthy watershed for the benefit of the whole ecosystem (Gupta and Srivastava, 2010). In our study area, conservation of water is an important and is possible through check dam, nalla, bunds, percolation tank, irrigation tank (Patel *et al.*, 2015). These structures in turn help improving the agricultural productivity, manage flood and drought control and contribute in social and economic development (Aher *et al.*, 2014).

In recent years, Geographical Information system (GIS) and Remote sensing (RS) are considered as an effective tools for watershed management (Ali and Khan, 2013; Patel *et al.*, 2013). Satellite products like digital elevation model (DEM) obtained from Shuttle Radar Topographic Mission (SRTM) are successfully utilized in drainage delineation and calculation of morphometric parameters (Kumar *et al.*, 2010) that are eventually utilized to locate potential sites for water harvesting structures. Morphometric analysis is the most common technique for understanding the stream system of a watershed and also helped in quantitative description of drainage basin in term of stream order, drainage density, bifurcation ration and stream length ratio (Chavare, 2011; Iqbal *et al.*, 2013). It could be also used to provide basin geometry in the form of the area, altitude, volume, slope, profile of the land for understanding the morphology of watershed (Patel *et al.*, 2015).

Rainfall is an important parameter for characterizing the basin in terms of their hydrological responses (Pilgrim *et al.*, 1988; Bracken and Croke, 2007; Hamlet and Lettenmaier, 2007; Srivastava *et al.*, 2015), therefore, the precipitation data from the satellite like Tropical Rainfall Measuring Mission (TRMM) is also used in this study (Yaduvanshi *et al.*, 2015). Many studies confirmed that the TRMM is promising for reliable retrieval of rainfall over a number of regions and found well correlated with the ground-based precipitation measurements (Islam *et al.*, 2012; Gupta *et al.*, 2013). For hydraulic properties, the water characteristic curves can be used to relate soil moisture content (θ) with the matric potential (ψ), and hydraulic conductivity (K). The characteristic curves depend on a set of soil hydraulic properties, which can be described by using the Van Genuchten equation (1980). The Van Genuchten parameters are derived either directly through laboratory experiments or by employing an empirical parameterization approach based on soil properties (Garg and Gupta, 2015) (Schaap *et al.*, 2001). These curves can be utilized to estimate the field capacity at 33kPa, which is an important parameter for determination the water holding capacity of the soil (Srivastava *et al.*, 2013).

Thus, for an effective watershed management and prioritization, the long term precipitation data from microwave satellites such as TRMM and soil field capacity through Water Retention Curve (WRC) can be integrated with morphometric analysis for an accurate watershed prioritization using Analytical Hierarchical Process (AHP) based multicriteria decision system. Therefore, the main aim of this study is to prioritize the mini watersheds of Pahuj river basin (Bundelkhand Region) of central India through remote sensing, geospatial techniques and soil hydraulic parameters. The methodology will provide a new approach for watershed management and results will have considerable importance for providing an efficient water management and locating harvesting structures (Kanth and Hassan, 2012). This study

could help increasing water potential for irrigation, water supply, recharging ground water, reduce erosion and for controlling the excess runoff or flood.

2. Study area and agro-climate description

Pahuj, a reservoir with 4212.77 km² area, situated approximately 5 km in the west of Jhansi city in the Bundelkhand Plateau. Geographically, it lies between latitude 23°80' and 26°30' N and longitude 78°11' and 81°30' E (**Figure 1**). The important features of Bundelkhand topography is represented by smooth and undulating character. The entire region is marked by subdued topography. The climate of this area is semi-arid type having hot and dry summer and cold winter seasons. The average annual rainfall is 876 mm, out of which about 90% falls between the months of June to September. The mean annual temperature is 24.5°C with maximum and minimum of 33.9°C and 15.1°C respectively. The major crops in this region are bajra, barley, jowar and wheat.

Figure 1 Geographical location of the study area (Pahuj basin)

3. Materials and Methodology

Satellite images of study area are reprojected in to Universal Transverse Mercator projection WGC 1984, Zone 44 North. For the generation of morphometric parameters, the Shuttle Radar Topography Mission (SRTM) C band digital elevation model (DEM) image is used. The ArcGIS 10.1 spatial analyst extension and Arhydro tool were used for DEM fill, flow accumulation and Stream segmentation. The detailed methodology is represented through **Figure 2**.

Figure 2 Flow chart depicting the methodology used in this study

3.1 TRMM precipitation datasets

The Tropical Rainfall Measuring Mission (TRMM) launched in collaboration between NASA and the Japan Aerospace Exploration Agency to study rainfall for weather and climate research. TRMM merged high quality Precipitation Radar (PR), Microwave Imager (TMI), Visible Infrared Scanner (VIRS). TRMM estimates real time information of precipitation at $0.25^\circ \times 0.25^\circ$ spatial resolutions, extending from 50° S to 50° N latitude. TRMM (3B43) monthly precipitation averages and TRMM (3B42) daily and sub-daily (3hr) averages are the significant products for climate research. **TRMM (3B43) precipitation of 18 years (1998-2015) monthly average of monsoon period (June-September) datasets were downloaded from website <http://neo.sci.gsfc.nasa.gov>.** TRMM (3B43) monthly averaged precipitation is used for understanding the long-term hydrological variations in the basin. The monthly average rainfalls during the monsoon months (June-September) for 18 years period i.e. 1998-2015 are used to understand the rainfall trend and pattern. The long-term averaged rainfall are then integrated with the morphometric analysis along with soil hydraulic parameter for prioritization of Pahuj river basin.

3.2 Generation of Spatial datasets

3.2.1 Topography and Drainage network

The Shuttle Radar Topography Mission (SRTM) is a joint mission of National Aeronautics and Space Administration (NASA) and the National Geospatial Intelligence Agency (NGA) for topographical analysis. It provides elevation datasets for the globe at 1 arc second (approx. 30 m) and at 3 arc second (approx. 90 m). **SRTM DEM were downloaded from website <http://www.cgiar-csi.org>.** For watershed delineation, freely available SRTM DEM (90 m) is used. The ArcGIS 3D analyst tool is used to visualize the SRTM DEM. Surface analysis tool of ArcGIS 10.1 is utilized to extract the slope information from SRTM DEM, which was then categorised into three classes as per the IMSD guidelines (1995), (Patel *et al.*, 2015), namely: I) Level to nearly level (0–1%), II) very gentle slope (1–3%), III) gentle slope (3–8%). The

whole basin is divided into 20 mini watersheds as shown in **Figure 3(a)**. Archydro tool using stream segmentation is utilized for drainage delineation in the study area. A dendritic pattern is evident in Pahuj in which the tributary system subdivided into headway like a limb of tree. After literature survey, the methods given by (Horton, 1945) is applied for calculating the stream orders (**figure 3(b)**). The slope map for the study area is shown in **Figure 3(c)**.

3.2.2 Soil map

In watershed management, understanding soil properties such as soil texture, infiltration rate, water holding capacity and wilting coefficient etc are important, as they are the key factors in regulating hydrological responses. The major types of soils in this region are Chromic Haplustert (Clay soil), Typic Ustrocherpts (Silt soil), Vertic Ustrocherpts (Loamy soil), Lithic Ustrothents (Sandy loamy soil). Based on the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP), NRIS (National Resources Information System), the soil type map **downloaded from website <http://www.nbsslup.in/> is used as shown in figure 3(d)**. In Pahuj river basin, typic ustocherpts is dominant characterized by yellowish brown to dark yellowish brown colour and having sandy clay loamy to silt loamy texture. Lithic ustrothents also known as rakar soil, reddish yellow to brown in colour and having sandy loamy texture are found dominant in the shallow to very shallow soils of the hills and hill slopes. The water holding capacities of these types of soils are very low. In some areas, chromic haplustert is also found. This type of soil is characterized by clay texture, high bulk density, water storage capacity and cation exchange capacity. The other type Vertic ustocherpts having clay loamy to sandy clay loamy texture is also exist in the area, characterized by low to moderate water transmission characteristics and moderate cation exchange capacity. In overall, the soil type indicates that the basin is dominated by clayey and silty soil type having high water holding capacity, slow infiltration rate and high runoff, which causes high erosion in the area.

3.3 Morphometric analysis and prioritization of watershed

The ArcGIS 10.1 is used in this study for all the spatial datasets analysis and layer integration. The datasets help in governing the prioritization of watershed by using the IMSD (Integrated Mission for Sustainable Development) guidelines (1995) and can provide possible location of water harvesting structures. According to IMSD guidelines, the slope should be in 1-3%, land use may be barren, shrub land or riverbed, type of soil should be sandy or gravel or clay loamy and geomorphic landform should be flood plain or rocky.

In this method, the delineated layer of mini-watersheds are used to carried out the basic morphometric parameters such as area (A), perimeter(P), length(L), number of streams (N) and basin length (L_b) calculated by the stream length, while the bifurcation ratio (R_b) calculated by the number of streams. Linear and shape parameters are found correlated to each other, calculated by using the equations as given in **Table 1**. Afterwards, compound factor are generated from the linear and shape parameters, subsequently used for the prioritization of mini-watersheds.

In this study, AHP based multi-criteria analysis was used for locating the appropriate water harvesting structure (Patel *et al.*, 2015). For this, first weighted sum and overlay tools were used for the integration of the thematic layers such as drainage density, slope, soil type, compound factor, field capacity and precipitation. To avoid any spatial mismatch, the above-mentioned thematic layers are spatially co-registered to obtain a common spatial reference frame for all the dataset. For overlaying, the weighted sum and MCE technique are used for suggesting the possible location of water harvesting structures.

3.4 Multi-Criteria Evaluation (MCE) and weighting assignment

The MCE analysis based on Analytical Hierarchy Principle (AHP) is given by (Saaty) 1980. In MCE, a pair-wise relation is used for the selection based on a ranking scale 1-9, in which 1 is for least important parameter while 9 is for most important in ascending order of

importance (Srivastava *et al.*, 2012). After pair-wise comparisons, a decision matrix is produced for a linear algebra transformation. The consistency of the selection and the knowledge based judgments are dependent on the eigenvalue of the decision matrix (Gupta and Srivastava, 2010). In final step, the consistency ratio is calculated based on the knowledge-based assignments. According to Saaty, the value of consistency ratio should be less than or equal to 0.1. For consistency ratio, the consistency index (max eigenvalue of the comparison matrix) is calculated, and then divided by the random index to obtain the Consistency ratio. The mathematical form of MCE is described by the equations (1-3).

The priorities of the criteria are estimated by the principal eigenvector “*e*” of the matrix “*M*”, as.

$$Me = \lambda_{\max} e \quad (1)$$

where λ_{\max} is the largest eigen value of the matrix “*M*” and the eigenvector “*e*”. The eigenvector is normalized to yield a vector of weights corresponds to individual attributes.

The Consistency ratio (*CR*) and Consistency Index (*CI*) are important parameters for weighing analysis and decision-making process. The value of CR decides whether the assessment is successful or not. $CR < 0.1$ indicates a good consistency. However, if it is > 0.1 the comparison is inconsistent and hence there appears a need for reassessment. The *CR* and *CI*, can be expressed by equation 2 and 3 respectively,

$$CR = CI / RI \quad (2)$$

$$CI = (\lambda_{\max} - n) / (n - 1) \quad (3)$$

where *n* is the number of variables; *RI* is the Random Inconsistency

s

3.5 ROSETTA model

The pedotransfer functions (PTFs) are used to estimate soil hydraulic parameters through empirical relationships between the basic soil properties and to predict the soil water

content at a pre-defined potential. A number of PTFs based on linear and non-linear regressions and artificial neural networks are available in literature (Rawls and Brakensiek, 1989; Vereecken *et al.*, 1989; Scheinost *et al.*, 1997; Wosten *et al.*, 1999; Schaap *et al.*, 2001; Minasny and McBratney, 2002) that relates the descriptive equations like (Van Genuchten, 1980) with measured soil properties. In the current study, ROSETTA model (Schaap *et al.*, 2001) based on neural network analysis and supported by bootstrap method is used. The model implements five hierarchical methods, based on the increasing number of input parameters to predict soil hydraulic properties (such as water retention parameters, saturated and unsaturated hydraulic conductivities) (Schaap *et al.*, 2001). **The input parameters are calculated by various soil properties such as soil texture, porosity/ bulk density, organic matter etc. In this study, the water retention curves were estimated by using the soil texture only. In India, the measurements at 33 kPa and 1500 kPa pressure (Wösten *et al.*, 2001) serve as the benchmark for soil water content estimation at field capacity (upper limit of water availability by plants) and wilting point (lower limit of water availability by plants) respectively (Adhikary *et al.*, 2008). The most widely used van Genuchten equation (Van Genuchten, 1980) can be represented by:**

$$\theta(h) = \theta_r + \frac{\theta_s - \theta_r}{(1 + (\alpha h)^n)^m} \quad (4)$$

where θ_r and θ_s are the residual and saturated water content respectively, α is the scaling parameter, n is the curve shape factor and m is an empirical constant, which can be related to n by

$$m = 1 - \frac{1}{n}. \text{ For } n > 1.$$

The predictive accuracy of the pedotransfer function for water retention curve are in the range of other published research (Saxton *et al.*, 1986; Adhikary *et al.*, 2008; Stumpp *et al.*, 2009; Puhmann and von Wilpert, 2012).

4. Results and discussions

4.1 Morphometric analysis

Morphometric analysis is a quantitative methods that help evaluating the hydrological characteristics for watershed management. For this, morphometric analysis can be divided into following parts such as: 1) Basic parameters, 2) Linear parameter, and 3) Shape parameter. For computing and analysis of morphometric characteristics of basin, the mathematical equations are provided in **Table 1**.

Table 1. Empirical formulas used for calculating morphometric parameters (Ratnam *et al.*, 2005; Patel *et al.*, 2012).

4.1.1 Basic Parameters

4.1.2 Drainage Area, Perimeter and Basin length

The drainage area (A) of any watersheds is an important parameter. The result shows that watershed number 7 covers maximum area of approx. 592.32 Km² while watershed number 1 has the minimum area of approx 39.05 Km². The basin perimeter (P) can be defined as the length of the watershed as shown in **table 2**. The basin length is directly proportional to the drainage area and it is probably most important for hydrological computation. Basin length can be defined “as the distance measured along the main channel from the watershed outlet to the basin divide”. The result shows that the basin length varies from 11.60 Km to 49.84 Km (**table 2**).

4.1.3 Total length of Stream (L) and Stream Order

Stream length is the addition of all stream lengths in a particular order. The total length of stream and various stream orders are shown in **table 2**. Stream length is single most important

characteristics of watershed. The results can be directly used to calculate the linear and shape parameters. Drainage density is significant feature estimated by stream length of the watersheds. Stream order categorised according to their position, order and magnitude. The concept of stream order given by (Horton, 1945; Strahler, 1957). According to this concept, first order stream has no tributary while second-order streams are generated by the confluence of two first-order streams and so on. However, total number of stream segments decreases as the increment of number of the stream order. In the study area, stream orders are calculated using the ArcGIS 10.1 software. Among the 20 mini-watersheds, the mini-watershed numbers 7, 8 and 12 are having 43, 40, 30 streams respectively. While, in watershed number 7, out of 43 streams, 33 are related to the stream order I. The watershed numbers 10, 15, 16 and 19 are related to the stream orders (I) and (II), while watershed numbers 1, 2, 17, 19 belongs to the stream order (V) (**Table.3**).

Table.3 Stream order of Pahuj watersheds

4.2 Linear Parameter

4.2.1 Bifurcation ratio, length of overland flow and texture ratio

Bifurcation ratio is defined as the ratio of the number of streams in one order to the number of streams of the next higher order (Schumm, 1956; Nag, 1998). The lower value of bifurcation indicates a less disturbed watershed without any distortion in the drainage pattern (Nag, 1998; Patel *et al.*, 2015). The value of Bifurcation ratio for different mini-watersheds are shown in **table.2** Watershed number 6 has the maximum value 6.00, while the watershed number 1 has the minimum value 2.00. Length of overland flow is the length of water flow over the ground surface before it combines into the definite stream channels. It can be expressed as half of reciprocal of the drainage density (Horton, 1945) and found inversely related to the average channel slope (**table 2**). The texture ratio represented as the ratio of first stream order to the perimeter of the basin. The value of texture ratio varies from 0.280-0.061 as shown in **table 2**.

4.2.2 Drainage density and frequency

Drainage density provides quantitative measure of average length of stream for whole watershed. Drainage density is the ratio of total length of stream to the area of watershed. Drainage density altered by relief, soil and rock properties, climate, and landscape evolution processes. A high value of drainage density shows a higher number of drainage network and therefore less residence time for rainwater and vice versa. The value shown in table 2 varies from 0.835-0.003. Stream frequency is the ratio of total number of stream segment of various order to the area of the basin (Horton, 1932). Stream frequency correlated well with the drainage density. Watersheds having lower values of stream frequency has a lesser chance of flood occurrence. The main characteristics of stream frequency depend on the rock structure, infiltration capacity, vegetation cover, relief, and subsurface material permeability

4.3 Shape parameter

4.3.1 Shape factor, form factor and Elongation ratio

Shape factor expressed as the square of the basin length per unit area of the basin (Horton, 1945). In the study area shape factor varies from 2.82-3.96, which indicates that the shape of basin is elongated. The form factor represented as area of the basin divided by square of the basin length. The value of form factor found always less than 0.7854 (for a perfectly circular basin) (Javed *et al.*, 2011). Smaller value of (Ff) indicates that the basin is elongated. If the shape of basin is elongated generally a flatter peak flow for longer duration can be obtained. Flood flows of such elongated basins are easier to manage than the circular basin. The results indicates that the watershed no. 1 is having maximum form factor of 0.353, while a minimum value is obtained for watershed no.7 (0.243) as shown in **table 4**. Elongation ratio can be represented as the ratio between the diameter of the circle of the same area of the basin to the maximum length of the basin (Schumm, 1956). Higher value of elongation ratio indicates that the basin have high infiltration capacity and low runoff. Strahler's suggested that these values

generally lies between 0.6 to 1.0 over a wide range of climate and geological condition (Strahler, 1964). Thus the shape of basin is categorised according to the index of elongation ratio, (a) circular Basin (0.9-0.10), (b) oval basin (0.8 to 0.9), (c) less elongated basin (0.7-0.8), d) elongated basin (0.5-0.7), e) more elongated basin (<0.5). In this study, the values is found between 0.557-0.670 indicates an elongated basin as confirmed by form factor.

4.3.2 Compactness coefficient and Circulatory ratio

Compactness coefficient can be expressed as the ratio of basin perimeter to the circumference of a circular area, which is equals to the area of watershed. It is inversely related to basin elongation and responsible for causing erosion in the watershed. Lower values of compactness coefficient shows a more elongated basin and less erosion and vice versa. The result shows that the values are found in the range 1.47-3.22 (**table 2**). Circularity ratio is a ratio of basin area (A) to the area of circle having the same circumference as the perimeter of the basin (Miller, 1995). According to (Miller, 1995) the range of circularity ratios varies from 0.4 - 0.5, which indicates that basin is strongly elongated in shape, possibility of less erosion, lesser runoff and highly pervious geologic materials. The result shows that watershed number 1 is having the highest value of 0.462, while lowest (0.096) is recorded for the watershed number 7 as shown in table 2.

4.3.3 Compound factor and prioritized ranks

In morphometric analysis both linear and shape parameters are well related with each other. The linear parameters shows a direct correlation with the erodability that means higher the value, the more will be the erodability (Ratnam *et al.*, 2005) (Patel *et al.*, 2015). Thus, rank 1 is assigned to those watersheds that are having the highest value of linear parameter (or highest erodability) and so on. Contrary to linear parameter, the shape parameters indicate an inverse relationship to the linear parameters, that means lower the value of shape parameters, the higher

will be the erodability. Thus, rank 1 assigned to the watersheds having the lowest value of shape parameter followed by second lowest (rank 2) and others. Therefore, at first the prioritizations of mini-watersheds are carried out by using the linear and shape parameters. Afterwards, a compound factor (CF) is generated using the ranking from the linear and shape parameters. CF is computed by summation of all the ranks obtained from linear and shape parameters and by dividing it by the total number of parameters. Based on the value of compound factor, final ranking of mini-watersheds are generated through AHP-MCE and other inputs. Thus in all delineated mini-watersheds, the higher ranks are assigned to those mini-watersheds that are having the lowest compound factor and so on (**table 3**). After the analysis, the watershed number 11 is assigned rank 1, which is having the least compound factor value of 6.5 followed by watersheds 12 and 20 with second and third ranks and so on. The results of compound factor are shown in table 3.

Table 2 Analyzed morphometric parameters

Table 3 Calculation of compound factor and prioritized ranks

Figure 4(a) Drainage density of area (b) Prioritized rank map of T, Bs, Re, Lo, Rc, Rb, Cc, Fu, Dd, Rf, CF

4.4 Soil hydraulic parameters

Soil hydraulic properties are important for water and solute transport. Water transport occurs in soil through the connected pores. The hydraulic properties of the soil can be estimated in laboratory by using the field soil samples. However, these techniques are not used here because of practical and economic constraints, and instead ROSETTA model is used which is well tested at many locations. ROSETTA is based on Pedotransfer functions, which can be used to estimate the soil hydraulic properties using the basic soil information. The soil hydraulic properties are based on the water retention curves (WRCs), which can be defined as the amount

of water retained in a soil under a definite matric potential. WRCs strongly affected by soil texture, structure, organic matter etc and can be used to estimate field capacity of soil. In the study area, clay and silt soil types are found dominant as compared to the loamy soil type. As the variation in soil types determines soil moisture retention capacity of soil, ROSETTA based on soil type is used for obtaining the field capacity of the soil. The estimated water retention curves for the four soil types in the study region are shown in **Figure 5**. From the results, the field capacity for clay ($0.33 \text{ m}^3/\text{m}^3$) is found higher than the silt soil ($0.28 \text{ m}^3/\text{m}^3$), which indicates a slow infiltration rate as compared to the loamy ($0.23\text{m}^3/\text{m}^3$) and sandy ($0.16\text{m}^3/\text{m}^3$) soils. Therefore, more soil water will be retained in the upper soil layers in case of clay and silt soils. Thus, during the heavy rain periods, these soils tend to accumulate more water and cause a higher chance of flooding in the basin.

Figure 5. Water Retention Curve for different soils in Pahuj River Basin

4.5 Rainfall distribution

Microwave precipitation from TRMM during monsoon period is used for understanding the trend and pattern of rainfall in the Pahuj river basin. For this study TRMM 3B43 Version 7 monthly precipitation average of 18 years (1998-2015) are used. The rainfall intensity of 18 years (1998-2015) period during the months of June-September is interpolated by the Inverse Distance Weighted method (IDW) in ArcGIS 10.1 Figure 6(a). The main advantage of IDW method is that it is intuitive and more efficient than the other methods. **In figure 6(b) the average time series graphs are plotted for understanding the distribution of rainfall over entire region. The box-whisker plot of TRMM precipitation data is shown in figure 6(c). The boxes have lines at the lower quartile, median (centre line), and upper quartile values. Whiskers extend from each end of the box to the minimum and maximum values, including the outliers. Outliers are data with values beyond the ends of the whiskers and are displayed in the form of circle.**

The box plots are used to understand the spread and skewness in the dataset. The plot indicates that there is a gradual increase in rainfall from June to July and then follow a decreasing pattern from August to September. This indicates that within monsoon months, the highest rainfall is received during the July followed by August month.

Figure.6 Monthly average rainfall distribution (1998-2015) a) Spatial distribution of rainfall b) Time series graph c) Box whisker plot

4.6 Multicriteria Evaluation (MCE) and prioritization of watershed

For prioritization of watershed, six parameters such as soil type, drainage density, slope, compound factor rank map, field capacity and rainfall are used. These six parameters are selected on the basis of hydrological characteristics such as infiltration, water residence time, velocity of water and the soil erodability. Each factor represented in Table 5 is rated according to its limiting condition explained by literature survey (Critchley *et al.*, 1994; Ratnam *et al.*, 2005; Mbilinyi *et al.*, 2007; Gbanie *et al.*, 2013; Pollacco *et al.*, 2013; Jamali *et al.*, 2014; Krois and Schulte, 2014; Patel *et al.*, 2015). The rating factor varies from 1-9. A higher rating indicates that the factor has a high degree of influence on deciding the location of watershed harvesting structure, while the influence factor shows the overall weight for watershed prioritization. Then the consistency in terms of CR and CI for weighting assignment is generated after the AHP-MCE analysis. In AHP-MCE the weighting is assigned for decision-making (Choi *et al.*, 2012), based on the importance of each factor through the pairwise comparison. For watershed prioritization, a highest normalized weighting is assigned to compound factor (CF) of 41.9% followed by soil type (8.9%), drainage density (15.0%), slope (25.7%), field capacity (5.2%) and rainfall (3.2%). The value of Consistency ratio (CR) is found around 0.030, which is less than 0.1 shows that the weighting taken for the watershed prioritization is appropriate (table 5). On the basis of this analysis, a final integrated map is

prepared for watershed prioritization and categorised into six zones, namely, 1) Very low 2) Low 3) Moderate 4) High 5) Very high, in which the water harvesting structures are needed as shown in **Figure 7**.

Table 5 Pair wise comparison matrix of features

Figure 7 Prioritized map for implementation of water harvesting structures

5. Conclusions

Remote sensing and GIS are promising tools for watershed prioritization in integration with morphometric analysis and soil hydraulic parameters. The AHP-MCE approach has been used in this study for integrating the layers obtained from remote sensing and GIS, hydraulic models and morphometric analysis, and subsequently used for the watershed ranking and prioritization in the Pahuj River basin. The finding indicates that the mini-watersheds 13-20 need utmost attention for restoration because of low stability and high degradation. On the other hand, mini-watersheds (1, 2, 3, 7) are having low priority because of high stability and low disturbances.

The overall analysis indicates that the integration of morphometric analysis with TRMM precipitation data and soil hydraulic parameters can provide useful and more accurate information for soil and water conservation. The prioritization of watersheds will help reducing the runoff and provide guidance for flood control in the Pahuj River basin. The proposed methodology can also be utilized for water resources development in a timely and cost effective manner. Further, the results can be used to understand the related hydrological processes in the Pahuj River basin. Further exploration of this approach is recommended to the hydro-meteorological community, so that useful experience and knowledge could be accumulated in the technical literature domain for the other geographical regions and climatic conditions.

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