Chapter III

MATERIALS AND METHODS

This chapter deals in details about the materials used for prioritization of the watershed for scientific planning and effective management through advanced techniques and the methodologies adopted to achieve the stated objectives of the research proposal. The materials and method is divided into following subsections:

3.1 Description of the study area
3.2 Data acquisition and software used
3.3 Generation of GIS data base
3.4 Erosion hazard parameters
   3.4.1 Geomorphometric parameters
   3.4.2 Estimation of soil loss and sediment yield
3.5 Watershed prioritization
   3.5.1 Prioritization using morphometric analysis
   3.5.2 Prioritization by Saaty’s Analytical Hierarchical Process (SAHP)
   3.5.3 Prioritization by Fuzzy Analytical Hierarchical Process (FAHP)
3.6 Development of Catchment Area Treatment (CAT) plan

3.1 Description of the study area

3.1.1 Location

The Nagwan watershed selected for case study is situated at the Upper Damodar Valley, Hazaribagh district of Jharkhand state in India. This watershed is the second most seriously eroded area in the world (El-Swaify et al., 1982). It accounts for an area of 92.32 km² and lies between 85°16′41″ and 85°23′50″ E longitudes and 23°59′33″ and 24°5′37″ N latitudes. Location map of the study area is shown in Fig. 3.1.
3.1.2 Climate

The area experiences sub-humid sub-tropical monsoon type of climate, characterized by hot summers (40°C) and mild winters (4°C). The watershed receives an average annual rainfall of 1272.5 mm, out of which more than 80% is received during monsoon season (June–October). The average storm intensity considering storms of more than 30 min duration, is about 10 cm/hr. The daily mean relative humidity varies from a minimum of 40% in the month of April to a maximum of 85% in the month of July.

Fig. 3.1: Location map of Nagwan watershed
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3.1.3 Agriculture

Agriculture is considered as the chief economic occupation of the catchment. About 70% of the population of the catchment is rural and their main livelihood is agriculture. The majority of the farmers are still practicing the traditional methods of cultivation, resulting in low productivity. The farmers have to be made aware of the modern technologies matching to their land holdings. The main crops grown are paddy and maize during kharif season and wheat, gram and mustard during rabi season. The agriculture is mostly rainfed as only 20% the area gets irrigation water. The cropping intensity is also quite low i.e. 98%. The irrigation is applied mainly by wells. Prevalence of conventional cultivation practices, characterized by conventional tillage; low fertilizer/manure consumption and local varieties of the crops are mainly responsible for the low crop productivity in the area. Relevant information pertaining to the study area were obtained from secondary sources such as Directorate of Economics and Statistics, Ministry of Agriculture; Directorate of Census (Data Center); DVC, Hazaribagh and Sadar block office of Hazaribagh district.

3.2 Data Acquisition

3.2.1 Meteorological Data

For estimation of the rainfall erosivity and input of weather generator file in SWAT, the rainfall and other parameters were collected from meteorological observatory at Central Rainfed Upland Rice Research Station (CRURRS) Hazaribagh (Appendix-7). The annual rainfall data during the period from 1986-2011 are presented in the Appendix-2.

3.2.2 Topographic Data

The area of Nagwan watershed falls in the topographic map Nos. 73E/5 and 72H/8 on 1:50,000 scale, as collected from Survey of India, Calcutta and show in Fig. 3.2. Topographic map of the study area was prepared by scanning, georeferencing and mosaicking these two toposheets.
3.2.3 Soil Data

Physical and chemical properties of soil play an important role in hydrological modelling. Physical properties like texture, structure, organic matter content, content of salts, detachability and transportability character of soil. Soil having high detachability and transportability are susceptible to erosion. Soil data in the present study are required to assess/estimate susceptibility of soils to be eroded by the rainfall.
Soil maps of the study area were obtained from DVC, Hazaribag. The soil map of the watershed was scanned and digitized in ArcGIS software. Basic soil property such as sand, silt, clay, organic carbon percentages and soil hydrological groups of the study area were also obtained from the Soil Conservation Department DVC, Hazaribag, the details of which are given in Table 3.1.

**Table 3.1: Soil property of Nagwan watershed**

<table>
<thead>
<tr>
<th>Soil types</th>
<th>Sand (%)</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
<th>Organic carbon (%)</th>
<th>Hydrologic group</th>
<th>Soil erodibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silty loam</td>
<td>51.30</td>
<td>29.40</td>
<td>19.30</td>
<td>0.56</td>
<td>C</td>
<td>0.33</td>
</tr>
<tr>
<td>Loamy sand</td>
<td>80.40</td>
<td>11.70</td>
<td>7.90</td>
<td>0.47</td>
<td>B</td>
<td>0.29</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>62.95</td>
<td>20.09</td>
<td>16.96</td>
<td>0.29</td>
<td>B</td>
<td>0.34</td>
</tr>
<tr>
<td>Loam</td>
<td>50.77</td>
<td>22.52</td>
<td>26.71</td>
<td>0.26</td>
<td>C</td>
<td>0.25</td>
</tr>
<tr>
<td>Clay loam</td>
<td>34.35</td>
<td>22.26</td>
<td>43.39</td>
<td>0.22</td>
<td>D</td>
<td>0.19</td>
</tr>
<tr>
<td>Silty clay loam</td>
<td>39.74</td>
<td>24.53</td>
<td>35.73</td>
<td>0.31</td>
<td>D</td>
<td>0.26</td>
</tr>
</tbody>
</table>

3.2.4 Satellite Data

Cloud free digital data of the study area were obtained from National Remote Sensing Center (NRSC), Hyderabad. For generating the land use/land cover information, satellite data of IRS-P6 (LISS IV) images were used. The details of the satellite data are given in Table 3.2 and prepared False Color Composite (FCC) of study area is shown in Fig. 3.3.

**Table 3.2: Details of satellite image used in study**

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Sensor</th>
<th>Spatial resolution</th>
<th>Band</th>
<th>Swath</th>
<th>Row</th>
<th>Path</th>
<th>Date of pass</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRS- P6</td>
<td>LISS- IV</td>
<td>5.6 m</td>
<td>R, B, G</td>
<td>70 km</td>
<td>55</td>
<td>105</td>
<td>22.12.2012</td>
</tr>
</tbody>
</table>
3.2.5 Digital elevation model (DEM)

Topography is one of the prime inputs to any erosion and hydrological study, since it defines the effect of gravity on the movement and flow of water and sediment. Digital Elevation Model (DEM) consists of an array of uniformly spaced elevation data used to represent the topography. A number of DEMs are readily available today, with resolutions ranging from 1 arc second (30 m) to as high as 30 arc second (1 km). In present study Advanced Space-borne Thermal Emission and Reflection Radiometer
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(ASTER) DEM was used because it have better resolution (Taufik et al., 2015), which is accessible at the website http://gdem.ersdac.jspacesystems.or.jp in Tagged Information File Format (TIFF) having a ground resolution of 30 m.

3.2.6 Software used for preparation of thematic map

Software available at National Institute of Hydrology (NIH) Bhopal, Madhya Pradesh were used for the preparation of thematic maps and analysis of data. Details of software used are presented in Table 3.3.

Table 3.3: Details of software use in present study and their distinctive features

<table>
<thead>
<tr>
<th>Name of Software</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ArcGIS (Version 10.1)</td>
<td>ArcGIS is the extensible used GIS tool, It includes all the functionality of ArcView and Arc Editor and adds advanced geoprocessing and data conversion capabilities. Professional GIS users use Arc info for all aspects of data building, modelling, analysis, and map display on screen and output. Arc Catalog is mostly used for creating, dieting and editing the spatial data file (ESRI)</td>
</tr>
<tr>
<td>ERDAS IMAGINE (Version 9.2)</td>
<td>The ERDAS IMAGINE software provides the functions of both image processing and geographic information systems (GIS). These functions include importing, viewing, altering, and analyzing raster and vector data sets</td>
</tr>
<tr>
<td>Other software</td>
<td>Window base software such as - MS office were used to build database and analyse them.</td>
</tr>
<tr>
<td>ArcSWAT</td>
<td>It is a physically based, continuous-time, long-term simulation, lumped parameter, deterministic and originated from agricultural models. The computational components of SWAT can be placed into eight major divisions: hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides and agricultural management.</td>
</tr>
<tr>
<td>SWAT-CUP</td>
<td>SWAT-CUP (SWAT Calibration and Uncertainty Procedures) is designed to integrate various calibration and uncertainty analysis programs for SWAT (Soil &amp; Water Assessment Tool) using different interface. Currently the program can run SUFI2 (Abbaspour, et al., 2007), GLUE etc.</td>
</tr>
</tbody>
</table>
A geographic information system is an integrated software package designed for use with geographic data that performs a comprehensive range of data handling tasks. These tasks include data input, storage, retrieval and output, in addition to a wide variety of descriptive and analytical processes. The object’s attributes or specific characteristics are also contained within the data model. Attributes such as length, area and count are important to distinguish among data models. Current GIS software are capable of storing complex spatial information into separate thematic layers as represented in Fig 3.4.

ERDAS imagine is a raster-based software package designed specifically to extract information from imagery. It includes a comprehensive set of tools to create accurate base imagery for inclusion into a GIS and ESRI Geodatabase. ERDAS imagine provides a variety of tools such as image orthorectification, mosaicking, reprojection, classification and interpretation that allow the user to analyze image data and present it in formats ranging from printed maps to 3D models.

![GIS World Model](image)

**Fig. 3.4: View of GIS data layer organized into separate themes**

### 3.3 Generation of GIS data base

GIS data base like base map, drainage map, digital elevation model map, delineation of sub-watersheds, soil group map and land use map were prepared with the help of software ArcGIS 10.1 and ERDAS 9.3 for true representation of study area.
3.3.1 Base map

A base map or boundary of the watershed has been prepared with the help of toposheet. The area of Nagwan watershed fall in Survey of India toposheet number 73E/5 and 72H/8 of scale 1:50,000. These toposheet were scanned and mosaicked. After mosaicking, boundary of watershed was precisely delineated manually with polygon tool in ArcGIS.

3.3.2 Digital Elevation map

Digital elevation map of given latitude- longitude was downloaded from ASTERGDEM of 30 m resolution. DEM of the study area was prepared by superimposing base map on downloaded DEM (Fig. 3.5).

Fig. 3.5: Digital elevation model (DEM) map of the Nagwan watershed
3.3.3 Drainage map

The drainage network of Nagwan watershed has been prepared using Survey of India toposheet and Google earth images of the study area. The stream segments of different orders were developed using software ArcGIS 10.1.

3.3.4 Delineation of sub-watersheds

According to IMSD technical guidelines (NRSA, 1995) watershed is classified into sub-watershed (30-50 km²), mini-watershed (10-30 km²) and micro-watershed (5-10 km²) (Chopra et al. 2005). The entire catchment area was divided into sub-watersheds on the basis of drainage pattern, contours and slope.

3.3.5 Soil group map

The soil information of the basin and soil map collected from All India Soil Survey and Land Use Planning (AISS & LUP), Govt. of India have been used for preparation of soil map of the study area.

3.3.6 Land use map

The satellite images purchased from NRSC, Hyderabad were used for preparation of land use and land cover map of the area. The satellite image of IRS- P6 (LISS- IV) was first ortho rectified and then applied the supervised classification with maximum likelihood algorithm for preparation of LULC. In this classification an area or group of pixels belonging to one or more categories of specific land use/land cover were identified. The land uses were classified in different classes. For information on vegetation/ground cover, the land use/land cover map of the study area was prepared with the help of ERDAS IMAGINE (version- 9.2), a popular image processing software.

3.4 Erosion hazard parameters

The prioritization of sub-watersheds for the catchment area treatment plan (CAT) have been identified using various erosive factors known as erosion hazard
Parameters (EHPs). Parameters considered as erosion hazard parameter are geomorphometric parameters, soil loss and sediment yield as advised by different researchers. Morphometric variables and sediment yield are the potential influential factors for prioritization of watershed (Biswas et al., 1999; Khan et al., 2001; Shi et al., 2014). The detail description of these parameter are as follows.

3.4.1 Geomorphometric parameters

3.4.1.1 Area

Area of the watershed and sub watershed was evaluated by calculating the geometry of the derived watershed polygons by using ArcGIS 10.1 software.

3.4.1.2 Perimeter

Watershed and sub watershed perimeter is the length of outer boundary of the watershed that enclosed its area. It is measured along the divides between watershed and may be used as an indicator of watershed size and shape which was computed by using ArcGIS 10.1 software.

3.4.1.3 Basin length

It is the distance between watershed outlet and the farthest point in the watershed which is measured in ArcGIS 10.1 Software.

3.4.1.4 Relief

Difference in the elevation between the highest and lowest point in the watershed and it is measured by using DEM map in ArcGIS 10.1 software.

3.4.1.5 Slope

Slope of the watershed was created by using spatial analysis tool in ArcGIS 10.1 software by using DEM map.
3.4.1.6 Mean bifurcation ratio

Bifurcation ratio ($R_b$) may be defined as the ratio of the number of stream segments of given order to the number of segments of the next higher order (Schumnn, 1956). There are different systems available to account for stream order (Horton, 1945; Strahler, 1952 and Scheidegger, 1970). Strahler’s system was used to ordering the stream as shown in Fig. 3.6. It is observed that $R_b$ is not the same from one order to its next order.

\[ R_b = \frac{N_u}{N_{u+1}} \]  

where, $R_b$ = Mean bifurcation ratio (dimensionless), $N_u$ = number of stream segments of order $u$, $N_{u+1}$ = number of stream segments of next higher order

Fig. 3.6: Representation of Stream order

3.4.1.7 Drainage density

Drainage density is an important indicator of the land with stream eroded topography Horton (1932). This property comes under areal aspect of watershed. It is the ratio of total channel segment length cumulated for all orders within a basin to the basin area, and is expressed in km/ sq. km. The drainage density indicates the closeness in spacing of channels, thus providing a quantitative measure of the average
length of stream channel for the basin. It has been observed that a low drainage density is generally occur in region of highly permeable subsoil material under dense vegetative cover with low relief. High drainage density is the resultant of weak or impermeable subsurface material, sparse vegetation and mountainous relief. Low drainage density to coarse drainage texture while high drainage density leads to fine drainage texture (Strahler, 1964).

For determination of drainage density of sub-watersheds, the drainage map of each sub-watershed were prepared separately and utilize total length of drainage obtained by histogram. The drainage density of sub-watershed may be estimated by the following equation:

\[
D_d = \frac{\sum_{i=1}^{k} \sum_{i=1}^{n} L_i}{A_u}
\]

\[\ldots (3.2)\]

where, \(D_d\) = drainage density (km/km\(^2\)), \(L_i\) = length of \(i^{th}\) segment of drainage, \(n\) = number of segments, \(A_u\) = Area of sub-watershed, \(K\) = Number of stream of all order.

**3.4.1.8 Drainage texture**

Drainage texture ratio (\(D_t\)) is the total number of stream segments of all orders per perimeter of that area (Horton, 1945). It depends upon a number of natural factors such as climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief and stage of development. Higher the drainage texture more will be the erosion. The mathematical expression of drainage texture are,

\[
D_t = \frac{\sum_{i=1}^{k} \sum_{i=1}^{n} N_{iu}}{P}
\]

\[\ldots (3.3)\]

where, \(D_t\) = Drainage texture (km\(^{-1}\)), \(N_{iu}\) = Number of stream segments of order \(u\), \(P\) = perimeter of the basin , \(n\) = Number of stream of given order, \(K\) = Number of stream of all order.
3.4.1.9 Stream Frequency

Stream frequency ($F_s$), is expressed as the total number of stream segments of all orders per unit area (Horton, 1932). It exhibits positive correlation with drainage density in the watershed indicating an increase in stream population will increase in drainage density.

$$F_s = \frac{n}{A} \quad \ldots \text{(3.4)}$$

where, $F_s$ = Channel frequency (km$^{-2}$), $n$ = Number of segments and $A$ = Catchment area of sub-watershed.

3.4.1.10 Drainage intensity

It is the ratio of stream frequency to drainage density (Horton, 1945) and expressed in km$^{-1}$ of the sub-watershed.

$$D_i = \frac{F_s}{D_d} \quad \ldots \text{(3.5)}$$

where, $D_i$ = drainage intensity (km$^{-1}$), $F_s$ = stream frequency, $D_d$ = drainage density

3.4.1.11 Infiltration Number

The infiltration number of a watershed is defined as the product of drainage density and stream frequency (Faniran, 1968) and given an idea about the infiltration characteristics of the watershed. The higher the infiltration number, the lower will be the infiltration and the higher run-off (Pareta and Pareta, 2011).

$$I_f = F_s \times D_d \quad \ldots \text{(3.6)}$$

where, $I_f$ = Infiltration Number, $F_s$ = stream frequency, $D_d$ = drainage density
3.4.1.12 Relative relief

The term given by Melton, (1957) is used to measure the relief of watershed. It is the ratio of maximum basin relief to basin perimeter. This feature comes under the relief aspects of the drainage basin.

\[ R_{bh} = \frac{H}{P} \times 100 \]  

… (3.7)

where, \( R_{bh} \) = Relative relief (dimension less), \( H \) = maximum basin relief (m), \( P \) = basin perimeter (m)

3.4.1.13 Circulatory Ratio

It is ratio of the area of the basin to the area of circle having the same circumference as the perimeter of the basin (Miller, 1953). He described the circulatory ratios of the basin ranges 0.4 to 0.5 indicating strongly elongated and highly permeable homogenous geologic materials. It is influenced by the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin.

\[ R_c = \frac{A_u}{A_c} \]  

… (3.8)

where, \( R_c \) = Circulatory Ratio (dimension less), \( A_u \) = area of basin having stream of order \( u \) in \( \text{km}^2 \), \( A_c \) = area of circle having equal perimeter as perimeter of drainage basin of stream order \( u \) in \( \text{km}^2 \)

3.4.1.14 Form Factor

According to Horton (1932), form factor may be defined as the ratio of basin area to square of the basin length. Smaller the value of form factor, more elongated will be the watershed. The watershed with high form factors (0.71) have high peak flows of shorter duration, whereas elongated watershed with low form factor (Javed et al., 2009).
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\[ R_f = \frac{A}{L_b^2} \]  
\[ \ldots (3.9) \]

where, \( R_f \) = form factor (dimension less), \( A \) = area of basin (sq. km), \( L_b \) = maximum basin length (km)

### 3.4.1.15 Compactness Coefficient

Compactness coefficient is used to express the relationship of a hydrologic basin with that of a circular basin having the same area as of the hydrologic basin. A circular basin is the most hazardous compared to an elongated watershed because it will have the shortest time of concentration before peak flow occurs in the basin.

\[ C_c = \frac{P_b}{P_c} \]  
\[ \ldots (3.10) \]

where, \( C_c \) = compactness coefficient (dimension less), \( P_b \) = perimeter of the basin (km), \( P_c \) = perimeter of the circular basin having area equal to basin (km)

### 3.4.1.16 Sediment production rate

Sediment production rate (SPR) is another important erosion hazard parameters useful in fixing the priority of watersheds for adopting conservation measures. Sediment production is the volume of sediment produced per unit drainage area per unit time. The sediment production rate has been estimated using geomorphology based model proposed by Josh & Das (1982). The SPR model can be described in mathematical terms as:

\[ \log(SPR) = 4919.80 + 48.64 \log(100 + R_f) – 1337.77 \log(100 + R_c) – 1165.65 \log(100 + C_c) \]  
\[ \ldots (3.11) \]

where, \( SPR \) is the sediment production rate in ha-m/100 sq km/year, \( R_f \) is form factor, \( R_c \) is circulatory ratio and \( C_c \) is compactness coefficient.
3.4.1.17 Elongation ratio

Schumn (1956) defined elongation ratio as the ratio of diameter of a circle of the same area as the drainage basin and the maximum length of the basin. Values of $R_e$ generally vary from 0.6 to 1.0 over a wide variety of climatic and geologic condition. $R_e$ values close to unity correspond typically to regions of low relief, whereas values in the range 0.6–0.8 usually associated with high relief and steep ground slope (Strahler, 1964).

\[
R_e = \frac{D_e}{L_{bm}} \quad \ldots (3.12)
\]

where, $R_e$ = elongation ratio (dimension less), $D_e$ = diameter of circle having same area as that of the given drainage basin, $L_{bm}$ = maximum basin length

3.4.1.18 Length of overland flow ($L_g$)

The length of overland flow ($L_g$) is the length of water flow over the ground surface before it gets concentrated into definite stream channel (Horton, 1945). Length of overland flow is one of the important independent variables affecting hydrologic and physiographic development of drainage basins. The length of overland flow is approximately equal to the half of the reciprocal of drainage density. This factor relates inversely to the average slope of the channel and is quiet synonymous with the length of sheet flow to a large degree. This is mathematically expressed as,

\[
L_g = \frac{1}{2D_d} \quad \ldots (3.13)
\]

where, $L_g$ = Length of overland flow (m), $D_d$ = drainage density (m)

3.4.2 Estimation of soil loss and sediment yield

Soil loss and sediment yield are the important parameters for planning of soil and water conservation measures. Various equations are available for estimation of
these parameters, but the selection of appropriate equation is depends on availability of inputs. In the successive section detailed methodology is given for estimation of these parameters.

3.4.2.1 Soil loss estimation

The rate of soil erosion from an area mainly depends upon rainfall, topographic characteristics, soil and vegetation. Therefore, a method which takes these factors into account while estimating soil erosion is expected to produce realistic estimate of rates of soil erosion (Das, 2008). The universal soil loss equation (USLE) is one of such equation that takes factors such as rainfall, topography, soil, and land use into consideration while assessing soil erosion. The USLE is a simple empirical model extensively used to realistically estimate surface soil erosion (Jain and Goel, 2002).

3.4.2.1.1 Universal Soil Loss Equation (USLE) Model

Annual soil loss in form of runoff from different land forms and land uses of the watershed was estimated using the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978). The USLE states that the field soil loss $A$, is the product of six causative factors as expresses by equation mention below.

$$ A = R \times K \times L \times S \times C \times P $$

... (3.14)

where, $A$ is the computed soil loss caused by sheet and rill erosion (t ha$^{-1}$ yr$^{-1}$), $R$ is the rainfall erosivity factor (MJ mm h$^{-1}$ ha$^{-1}$ yr$^{-1}$), $K$ is the soil erodibility factor (t ha h ha$^{-1}$ MJ$^{-1}$ mm$^{-1}$), $L$ is the slope length factor (dimensionless), $S$ is the slope steepness factor (dimensionless), $C$ is the cover and management factor (dimensionless varies from 0 to 1) and $P$ is the support practice factor (dimensionless varies from 0 to 1).

In a large sized watershed, these factors ($R$, $K$, $L$, $S$, $C$ and $P$) show spatial variability. Thus a watershed needs to be discretized into smaller homogeneous areas to capture catchment heterogeneity (Jain and Kothyar, 2001). As the scale becomes
coarser (e.g. larger grid/cell sizes), spatial heterogeneity often decreases due to averaging, which introduces uncertainty (Goodchild, 1998), several methods are available for discretization of watershed into smaller areas. The cell or grid approach is most commonly used due to its adoptability to raster based GIS and ease in the collection of input data using remotely sensed satellite data.

**Calculation of Rainfall erosivity factor (R)**

Rainfall erosivity factor (R) is the basic and important factor in the assessment of soil erosion. The R-factor is defined as the product of kinetic energy of rainfall (E) and the maximum 30 minute intensity (I_{30}) and expressed as EI_{30} (Wischmeier and Smith, 1978), Rainfall erosion index describes its capacity to erode soil from an unprotected field. Also it is the potential capacity of the raindrops to cause detachment of the soil particles from its location and depends on rainfall intensity and its recurrence.

Mathematically rainfall erosivity is calculated by

\[ EI_{30} = \left( \frac{KE \times I_{30}}{100} \right) \]  

\[ \text{Where, } KE = \text{Kinetic energy of the storm in metric tones/ha-cm.} \]

\[ I_{30} = \text{maximum 30 minutes rainfall Intensity of the storm} \]

\[ KE = 210.3 + 89 \log I \]  

\[ \text{Where, } I = \text{rainfall Intensity in cm/h and} \]

To accommodate the natural climatic variations, Wischmeier and Smith (1978), recommended that at least 20 years of pluviographic data should be used. Unavailability of self-recording rain gauges, force the many researchers to establish a simplified relationship between erosivity and depth of rainfall, as depth of rainfall can be measured at all locations conveniently.
In India, involving 45 gauging stations, distribution in different rainfall zones, simple linear relationship between erosivity index and annual or seasonal rainfall has been developed (Singh et al., 1981) as expressed by equation:

Annual R factor, \( R = 79 + (0.363 \times P) \) \( \ldots (3.17) \)

Seasonal R factor, \( R_s = 50 + (0.389 \times P) \) \( \ldots (3.18) \)

where, \( P \) is the rainfall in mm.

In present study, Eqn. 3.17 was used to calculate annual values of R factor in a year. The thematic map of rainfall erosivity factor (R) was developed in the GIS platform.

**Calculation of soil erodibility factor (K)**

Soil erodibility factor (K) is closely related to various properties of soil by virtue of which a particular soil becomes susceptible to be eroded, by either water or wind. The K-factor is expressed as soil loss per unit area per unit R for a unit plot of 22.13 m long having a uniform slope of 9% under continuous fallow and tilled along to the slope).

Mathematically soil erodibility can be expressed as,

\[
K = \frac{A_o}{S \times (\sum EI)} \quad \ldots (3.19)
\]

where, \( K \) = soil erodibility factor
\( A_o \) = observed soil loss
\( S \) = slope factor
\( \sum EI \) = total rainfall erosivity index
Direct measurement of soil erodibility factor is both costly and time consuming and has been found feasible only for a few major soil types with the help of runoff plots.

A simple nomograph was developed by Wischmeier et al. (1971) to determine the K value using five soils types viz, percent of silt (MS; 0.002 — 0.05 mm), percent of very fine sand (VFS; 0.05 — 0.1 mm), percent of sand greater than 0.1 mm, percentage of organic matter content (OM), structure (S) and permeability (P) An analytical relationship for nomograph developed by Wischmeier et al. (1971) is given by the eqn. 3.20.

\[ 100K = 2.1 \times 10^{-4} M^{1.14}(12-a) + 3.25(b-2) + 2.5(c-3) \quad \ldots \ (3.20) \]

where, \( K \) = soil erodibility factor,

\( M \) = percentage silt, very fine sand and sand > 0.10 mm, (%)

\( a \) = organic matter content, (%)

\( b \) = structure of the soil, (very fine granular = 1, fine granular = 2, coarse granular = 3, blocky, platy or massive = 4)

\( c \) = permeability of the soil (rapid = 1, moderate to rapid = 2, moderate = 3, slow to moderate = 4, slow = 5, very slow = 6)

For this purpose soil map of Nagwan watershed was digitized in the ArcMap extension of ArcGIS 10.1. Then the values of K factor for respective soil texture unit were attributed and raster maps of K factor were prepared.

**Calculation of slope length factor (L)**

Slope length factor is defined as the distance from the origin point of overland flow to the point, where, the slope gradient decreases either sufficiently because of which deposition starts or to where the flow connects to a river system (Wischmeier and smith, 1978) as shown in Fig. 3.7.
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Fig. 3.7: Field estimation of the slope length on a side profile of a hill

The slope length factor is dimensionless because it is simply a ratio of the soil loss from a given slope length to the plot size 22.13 m length of slope. It is mathematically expressed as

\[ L = \left( \frac{\lambda}{22.13} \right)^m \]

... (3.21)

where, \( \lambda \) is the field slope length, \( m \) is the exponent varying from 0.2 for slope less than 1%, 0.3 for slope from 1% to 3%, 0.4 for slope from 3% to 5% and 0.5 for slope more than 5% slope.

Calculation of slope steepness factor (S)

Slope steepness factor is defined as the ratio of soil loss from the actual field slope gradient to soil loss from a 9% slope under identical conditions (Renard et al., 1997). Soil loss increases rapidly with slope steepness. Mathematically the slope steepness factor (S) is evaluated from equation
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\[ S = \left[ 0.065 + 0.045G + 0.0065G^2 \right] \quad \cdots (3.22) \]

where, \( G \) is the slope gradient in percent.

The effect of topography on soil erosion is accounted by the LS factor in USLE, which combines the effects of a slope length factor (L) and a slope steepness factor (S). It has been widely known that an increase in the slope length (L) will result in simultaneous increase in soil erosion per unit area, due to the accumulation of surface runoff towards down slope direction. As the slope steepness (S) increases, the velocity and soil erosion of surface runoff also increases.

**Cover and management factor (C)**

The C-factor is defined as the ratio of soil loss from land with specific vegetation to the corresponding soil loss from continuous fallow (Wischmeier and Smith, 1978). It measures the combine effect of vegetation cover and management variables. The factor is based on plant cover, production level and cropping techniques. Typical values of C for different crop cover condition are presented in Appendix- 3.

**Support practice factor (P)**

The P-factor is the ratio of soil loss from field having a certain soil conservation practice to that with up and down slope ploughing (Wischmeier and Smith, 1978). Specific cultivation practices affect erosion by modifying the flow pattern & direction of runoff and by reducing the amount of runoff (Renard and Foster, 1983). The P-factor considers specific erosion control practices such as contour tilling or contour ridging. The absence of any measures is expressed by a value of 1; the factor is about 0.1 when tied ridging is applied on a gentle (Roose, 1996). The value of P factor for different erosion control practices are given in Appendix- 4.

**3.4.2.2 Sediment yield**

Sediment yield is the total sediment load that leaves a drainage basin. Coarse sediment is transported by streams as bed load and fine sediment is transported
as suspended load. In the present study, sub watershed wise sediment yield was estimated by using SWAT model because no data of sediment yield on sub watershed wise was available. Before applying SWAT model, it was calibrated and validated by sediment data of the outlet of the watershed.

**SWAT model**

The SWAT model uses the Modified Universal Soil Loss Equation (MUSLE) equation developed by Williams (1975) (Eqn. 3.23) to simulate the sediment yield from the upland catchments (Neitsch *et al.*, 2005).

\[
\text{Sed} = 11.8 \left( Q_{\text{surf}} \times q_{\text{peak}} \times \text{Area}_{{\text{hru}}} \right)^{0.56} \times K_{\text{USLE}} \times L_{\text{USLE}} \times C_{\text{USLE}} \times P_{\text{USLE}} \times \text{CFRG}
\]

where, Sed is defined as Sediment yield rate (tones/day), $Q_{\text{surf}}$ is the surface runoff volume (mm/day) which is simulated by the runoff component of SWAT, $q_{\text{peak}}$ is the peak runoff rate ($\text{m}^3/\text{s}$), $\text{Area}_{{\text{hru}}}$ is the area of the HRU (ha), $K_{\text{USLE}}$ is the USLE soil erodibility factor (0.013 metric ton m$^2$ hr/ (m$^3$-metric ton cm)), $C_{\text{USLE}}$ is the USLE crop management factor or cover management factor, $P_{\text{USLE}}$ is the USLE support practice factor, $L_{\text{USLE}}$ is the USLE topographic factor, and CFRG is the coarse fragment factor.

**3.4.2.2.1 The details input data prerequisite for model and some important steps of SWAT model are discussed below.**

SWAT model require hydro-meteorological data and spatial data. Spatial data include DEM, land use land cover, soil texture map and in case of predefined stream and sub watershed map. Hydrometeorological data such as precipitation, maximum-minimum temperature, relative humidity, solar radiation, and wind speed were used for sediment yield simulation. Observed sediment data was used for model calibration and validation. Daily weather data of seventeen year (1996-2012) were used for run the model. These weather data splites into three parts, first two year (1996-1997) used as warm period, weather data from 1997-2005 were used for model calibration and remaining data from 2006-2012 were used for the model validation. Different statistics were calculated as required by model and prepared in dot txt format with help of Microsoft office before running the model.
3.4.2.2 Prerequisite of SWAT model

In SWAT model, a watershed was divided into a number of sub-basins in such a way that it must have a tributary channel and a main channel or reach. Each sub-basin were spatially interconnected and runoff flow from one sub-basin to another and to the outlet. These sub-basins are further partitioned into HRUs, which are lumped land areas that are comprised of unique land cover and soil combinations. The partition of sub-basin into HRUs, increases accuracy and gives a much better physical description of the water balance (Arnold et al., 1996; Geza and McCray, 2008). Contrary to flow among sub-basin, there is no interaction between the HRUs. Sediment is predicted separately for each HRU. The procedure for model set-up shown in Fig. 3.8.

Fig. 3.8: The flow diagram of SWAT model set-up
3.4.2.2.3 User-Defined Watersheds and Streams

If this option is chosen, user-defined streams must be added as well. The watersheds and streams must be geometrically consistent, with 1 stream feature per sub-basin. Outlets to sub basins will defined as small distance upstream from the end point of the stream, which requires that a stream end point fall coincident on a watershed boundary. Streams are required to follow ‘From_Node’ and ‘To_Node’ topology representative of the streamflow network. Errors in this topology will not be picked up by the ArcSWAT interface and will lead to errors in the model structure developed.

3.4.2.2.4 HRU analysis

All the three maps land use/land cover, soil and slope were overlaid and reclassified to create the hydrological response units (HRUs) with unique land use, soil and slope classes. The threshold values for creation of HRUs were assumed as 2% for land use class, 5% for soil class and 8% for slope class, creating 302 HRUs spread over the 21 sub basins of the study area. HRUs consist of homogeneous land use and soil type (also, management characteristics).

3.4.2.2.5 Calibration of model

Before calibration, model was warmed up by using 2 year meteorological data of Jan 1996- Dec 1997. For calibration the data of 1998-2005 was used. Calibration approach for present study was automatic with the help of SWAT- CUP using SUFI-2 method.

3.4.2.2.6 SWAT-CUP

The SWAT- CUP model was used for the automatic calibration that change the uncertain model parameters into systematically model parameters. After run of the model the required outputs were extracted in the form output files. The SWAT- CUP have a advantages feature that it directly take the required information from the out file of the SWAT model. SUFI-2 algorithm of SWAT-CUP was selected for calibration Fig. 3.9.
3.4.2.2.7 The conceptual basis of SUFI-2

The program SUFI-2 was used for calibration and uncertainty analysis. SUFI-2 accounts the all sources of uncertainties such as uncertainty in driving variables (e.g., rainfall), conceptual model, parameters, and measured data. The degree to which all uncertainties are accounted is quantified by a measure, referred as the P-factor (Abbaspour et al., 2007), which is the percentage of measured data bracketed by the 95% prediction uncertainty (95PPU). The 95PPU is calculated at the 2.5% and 97.5% levels of the cumulative distribution of an output variable obtained through Latin hypercube sampling. As all forms of uncertainties are reflected in the measurements (e.g., sediment), the parameter uncertainties generating the 95PPU account for all uncertainties. Breaking down the total uncertainty into its various components is of some interest, but quite difficult to do, and as far as the authors are aware, no reliable procedure yet exists. Another measure quantifying the strength of a calibration/uncertainty analysis is the so called R-factor, which is the average thickness of the 95PPU band divided by the standard deviation of the measured data.
SUFI-2, hence seeks to bracket most of the measured data (large P-factor, maximum 100%) with the smallest possible value of R-factor (minimum 0).

The concept behind the uncertainty analysis of the SUFI-2 algorithm is depicted graphically in Fig. 3.10. This Figure illustrates that a single parameter value (shown by a point) leads to a single model response (Fig. 3.10a), while an uncertain parameter (shown by a line) leads to the 95PPU illustrated by the shaded region in (Fig. 3.10b). As parameter uncertainty increases, the output uncertainty also increases (not necessarily linearly) (Fig. 3.10c). Hence, SUFI-2 starts by assuming a large parameter uncertainty (within a physically meaningful range), so that the measured data initially falls within the 95PPU, then decreases this uncertainty in steps while monitoring the P-factor and the R-factor. In each step, previous parameter ranges are updated by calculating the sensitivity matrix (equivalent to Jacobian), and equivalent of a Hessian matrix, followed by the calculation.

![Fig. 3.10: A conceptual illustration of the relationship between parameter uncertainty and prediction uncertainty](image)

3.5 Watershed prioritization

3.5.1 Prioritization using morphometric analysis

Watershed prioritization using morphometric parameters have been conducted by various researcher for different watershed. This method of prioritization is already
in use but have certain limitation. The morphometric parameter selected for present study are as follows: Mean bifurcation ratio, Drainage density, Drainage texture, Stream frequency, Drainage intensity, Infiltration Number, Relative relief, Circulatory Ratio, Form factor, Compactness coefficient, Elongated ratio, and Length of overland flow. Selection of these parameters are on the basis of recommendation of different researcher stated in previous chapter. Some parameter like Mean bifurcation ratio, Drainage density, Drainage texture, Stream frequency, Drainage intensity, Infiltration Number, Length of overland flow, and relative relief have direct relation with the erosion. Higher the value, more is the erosion. For prioritization of sub watersheds the highest value of these parameters were ranked as 1st and next highest value as ranked 2nd and so on. Other parameters like Circulatory Ratio, Elongated ratio, Form factor, and Compactness coefficient have inverse relation with the erosion (Nooka et al., 2005). Lower the value, more is the erosion. Thus the lowest value of these factors was ranked 1st and next lowest value as ranked 2nd and so on. The highest value was rated last in rank. After ranking of every single parameter, the ranking value for every micro-watershed was averaged to arrive at a compound value ($C_p$). The Compound value is based on the average of all parameters in single micro-watershed, with least rating value was assigned highest priority, next highest value was assigned second priority and so on (Javed et al., 2009; Kiran and Srivastava, 2012). The micro-watersheds which got the highest $C_p$ value was assigned last priority.

### 3.5.2 Prioritization by Saaty’s Analytical Hierarchical Process (SAHP)

Analytical Hierarchical Process (AHP) is a multi-criteria decision method that utilizes hierarchical structures to represent a problem and subsequently prioritization for alternatives based on the judgment of the user (Saaty, 1980).

The Saaty’s AHP is a matrix of all selected erosion hazard parameters and define the intensity of importance (by Saaty’s rating scale) among the parameters (Appendix-8). In the present study, fifteen different factors termed as erosion hazard parameters (EHPs) have been used for construction of AHP comparison matrix. These include soil loss, sediment production rate, sediment yield, Drainage density, Drainage texture, Stream frequency, Drainage intensity, Infiltration Number,
Circulatory Ratio, Elongated ratio, form factor, Compactness coefficient, Mean bifurcation ratio, Length of overland flow and relative relief. The size of comparison matrix in Saaty’s AHP is equal to number of parameters (n) in the form of square matrix (Appendix- 8). The relative importance between two factors can be scaled qualitatively between 1 and 9. The weightage 1 indicates the equal importance to both factors, while 9 indicates that one factor is absolutely more important than others. The comparison of each parameter with others is made to complete the comparison matrix of size (n × n) and total no. of comparison comes out to be \( ^nC_2 \). For filling the upper triangle of the matrix, each time two parameters were considered one by one and considering the relative importance, a value between 1 and 9 is assigned. Low triangle of matrix was filled by reciprocal values of upper triangles.

The degree of importance between two factors in the matrix is filled on the basis of field experience, survey results, judgment of decision makers, result reported by researchers and comparison guidelines presented by saaty’s (1980) in Table 3.4. For example, when soil loss and form factor are used in a pair-wise comparison and it is decided that soil loss is absolutely important than form factor, a number 9 will be used to fill the element in upper part of comparison matrix. The elements in the lower part of matrix can be filled by taking reciprocal of corresponding elements in the upper matrix such as, if an element \( A_{ij} = \alpha \), then \( A_{ji} = 1/\alpha \) and if \( i = j \), then \( A_{ij} = A_{ji} = 1 \).

The normalized principal eigenvector which is called priority vector, for example element in weightage matrix (Appendix- 9) was obtained from using compression matrix as which is presented in Appendix- 8. The eigenvalue (\( \lambda \)) of priority vector was computed by dividing average eigenvalue to particular weight of erosion hazard parameter (EHP). For consistency index (CI) the principal eigenvalue (\( \lambda \) max) was obtained by adding all eigenvalue (Appendix- 9). As the decisions regarding relative importance between parameters are subjective vary from person to person and hence a consistency check may be employed to judge the consistency of decisions in Saaty’s AHP analysis.
Table 3.4: Saaty’s rating scale

<table>
<thead>
<tr>
<th>Intensity of importance</th>
<th>Definition</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal importance</td>
<td>Two factors contribute equally to the objective</td>
</tr>
<tr>
<td>3</td>
<td>Somewhat more important</td>
<td>Experience and judgment slightly favour one over the other.</td>
</tr>
<tr>
<td>5</td>
<td>Much more important</td>
<td>Experience and judgment strongly favour one over the other.</td>
</tr>
<tr>
<td>7</td>
<td>Very much more important</td>
<td>Experience and judgment very strongly favour one over the other.</td>
</tr>
<tr>
<td>9</td>
<td>Absolutely more important</td>
<td>The evidence favoring one over the other is one of the highest possible validity.</td>
</tr>
<tr>
<td>2, 4, 6, 8</td>
<td>Intermediate values</td>
<td>When compromise is needed.</td>
</tr>
</tbody>
</table>

3.5.2.1 Consistency check

The consistency of judgment can be checked by estimating consistency ratio (CR) which can be computed by the following equation:

\[
CR = \frac{CI}{RI} \times 100 \quad \quad \quad \text{... (3.24)}
\]

where, CI is the consistency index and RI is the random consistency index. The consistency index is a unitless number depending on size of matrix (number of parameters) can be estimated using Eqn. 3.25.

\[
CI = \frac{\lambda_{\text{max}} - n}{n-1} \quad \quad \text{... (3.25)}
\]

where, \( \lambda_{\text{max}} \) is the principal eigen value obtained from priority matrix and \( n \) is the size of comparison matrix. Random consistency index (RI) also dependent on matrix size (n) was given by Saaty after generating reciprocal matrix of various sizes (Saaty, 1980). The average random consistency ratios (RI) for different sizes of matrix are given in Table 3.5.
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Table 3.5: Random consistency index for different values of n

<table>
<thead>
<tr>
<th>N</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>RI</td>
<td>0.0</td>
<td>0.0</td>
<td>0.58</td>
<td>1.12</td>
<td>1.24</td>
<td>1.32</td>
<td>1.41</td>
<td>1.45</td>
<td>1.51</td>
<td>1.48</td>
<td>1.56</td>
<td>1.57</td>
<td>159</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

If consistency ratio (CR) is less than 10%, the subjective evaluation about decision may be considered as consistent.

3.5.2.2 Priority Assessment

Since EHPs depend on several factors and vary significantly, it is necessary to convert this variation in the same range for all EHPs by normalization to ensure that no layer exerts an influence beyond its determined limit. The normalized value of an EHP for a watershed is determined by the following Eqn. 3.26.

\[ W_{ij} = \frac{(NUB_i - NLB_i)}{(OUB_i - OLB_i)} (EHP_{ij} - OLB_i) \]  \quad \quad \text{(3.26)}

where, \( W_{ij} \) is the normalized value of \( i^{\text{th}} \) EHP of \( j^{\text{th}} \) watershed, \( NUB_i \) and \( NLB_i \) are the normalized upper bound and lower bound for \( i^{\text{th}} \) EHP. \( OUB_i \) and \( OLB_i \) are the original upper bound and lower bound for \( i^{\text{th}} \) EHP. \( EHP_{ij} \) is the original value of \( i^{\text{th}} \) EHP for \( j^{\text{th}} \) sub-watershed. Generally, the normalized range is generally considered in the range of 0 to 1 and the equation can be converted as:

\[ W_{ij} = \frac{(EHP_{ij} - OLB_i)}{(OUB_i - OLB_i)} \]  \quad \quad \text{(3.27)}

After estimating the normalized values of all EHPs (\( W_{ij} \)) for all the sub-watersheds and Saaty’s weight for each EHP (\( X_i \)), the final priority of a sub-watershed (\( F_j \)) can be determined using the following equation.

\[ F_j = \sum_{i=1}^{n} X_i W_{ij} \]  \quad \quad \text{(3.28)}
The sub-watersheds now can be grouped in different priority classes using final priority obtained from SAHP analysis. After determining the final priority for all sub-watersheds it has been grouped in five classes of priority namely very high, high, moderate, low and very low on the basis of priority ranking.

### 3.5.3 Watershed prioritization using Fuzzy Analytical Hierarchical Process (FAHP)

The methodology used include selection and computation of EHPs for sub-watersheds, computation of weightage of EHPs using FAHP based decision support and finally prioritization of sub-watersheds for identification of environmentally stressed areas. Jaiswal et al. (2015), gives the flow chart for proposed FAHP based decision support is in Fig. 3.11.

![Flow chart of Fuzzy AHP based decision support model for prioritization of sub-watersheds](image)

**Fig. 3.11:** Flow chart of Fuzzy AHP based decision support model for prioritization of sub-watersheds
3.5.3.1 Computation (Assigning) of Weightage

As it has already been stated in the introduction, Saaty (2008) believes that some uncertainty is lying in the nature of AHP method. The principle of AHP theory lies on uncertainty in decision that creates basis of applying fuzziness in AHP. The AHP for MCDS constructs a matrix of pair-wise comparisons (ratios) between the factors affecting the decision. Also Buckley (1985) has raised questions about certainty of the comparison ratios used in the AHP. He had considered a situation in which the decision-maker can express feelings of uncertainty while he/she is ranking or comparing different alternatives or criteria. The method he has used to take uncertainties into account is using fuzzy numbers instead of crisp numbers in order to compare the importance between the alternatives or criteria. A numerical value between 1 and 9 have been suggested by Saaty to indicate how one criterion is important than other as stated in Table 3.4, (Saaty, 1980). The size of comparison matrix in AHP may be a square matrix with size equal to number of parameters (n) considered for making decision.

3.5.3.2 Fuzzy weightage

As Buckley (1985) has considered, trapezoidal membership functions is adopted for fuzzy numbers in this work to fuzzify the comparison ratios. In specific case, by selecting the parameters of membership function according, trapezoidal shape is converted to triangular.

Suppose that the a fuzzy number is described as \((\alpha, \beta, \gamma, \delta)\) where \(0 < \alpha \leq \beta \leq \gamma \leq \delta\) and at which \(\alpha, \beta, \gamma\) and \(\delta\) are the four parts of the fuzzy number, the membership function for any given fuzzy number is shown by \(\mu(x)\) and these two numbers form an ordered pair \((x, \mu(x))\). The description of fuzzy number means that the membership function is 0 to the left of \(\alpha\). Then a line connects the two points \((\alpha, 0)\) and \((\beta, 1)\). After that it is constant at value 1 between \(\beta\) and \(\gamma\). Then a line connect the two points \((\gamma, 1)\) and \((\delta, 0)\) and finally membership function equals zero in the right of \(\delta\). Fig. 3.12 illustrates a fuzzy membership function of a fuzzy number.
A corresponding fuzzy ratio of $a_{ij}$ is shown with a bar sign above it i.e. $[\tilde{a}_{i,j}] = [\alpha_{i,j}, \beta_{i,j}, \gamma_{i,j}, \delta_{i,j}]$. So from now on, the bar sign above a variable, means that it is fuzzy.

![Fuzzy memberships function of a fuzzy number](image)

**Fig. 3.12: Fuzzy memberships function of a fuzzy number**

### 3.5.3.3 Consistency ratio in fuzzifying the pairwise ratios

Consider $\overline{A} = [\tilde{a}_{i,j}]$ where $[\tilde{a}_{i,j}] = [\alpha_{i,j}, \beta_{i,j}, \gamma_{i,j}, \delta_{i,j}]$ and let $\beta_{ij} \leq a_{ij} \leq \gamma_{ij}$ for all $i,j$; If $A = [a_{i,j}]$ is consistent then $\overline{A}$ is also consistent, where $i$ and $j$ may vary from 1 to $n$.

In fuzzifying the pairwise ratios $(a_{ij})$, if the conditions mentioned in the theorem are satisfied and also if consistency ratio of the main matrix $A$ is low, then the fuzzified matrix $\overline{A}$ can also be considered as a matrix which has low consistency ratio. The mentioned considerations and conditions are satisfied during the fuzzifying of the ratios in all steps of this work so all fuzzified matrices in the study are consistent.
The weightage from fuzzy matrix can be computed either by geometric mean method or $\lambda_{\text{max}}$ methods; which provide nearly same results for small consistency ratio. The normalized principal eigenvector, which is called priority vector is used in $\lambda_{\text{max}}$ to assign the weights for different parameters. In the present case, geometric mean method is used to compute fuzzy membership function for the weight using following Eqn. 3.29 to 3.32.

$$
\alpha_i = \left[ \prod_{j=1}^{n} \alpha_{ij} \right]^{1/n} \quad \text{and} \quad \alpha = \left[ \sum_{i=1}^{n} \alpha_i \right] \quad \cdots (3.29)
$$

$$
\beta_i = \left[ \prod_{j=1}^{n} \beta_{ij} \right]^{1/n} \quad \text{and} \quad \beta = \left[ \sum_{i=1}^{n} \beta_i \right] \quad \cdots (3.30)
$$

$$
\gamma_i = \left[ \prod_{j=1}^{n} \gamma_{ij} \right]^{1/n} \quad \text{and} \quad \gamma = \left[ \sum_{i=1}^{n} \gamma_i \right] \quad \cdots (3.31)
$$

$$
\delta_i = \left[ \prod_{j=1}^{n} \delta_{ij} \right]^{1/n} \quad \text{and} \quad \delta = \left[ \sum_{i=1}^{n} \delta_i \right] \quad \cdots (3.32)
$$

The fuzzy membership function describing the weight of different parameters is defined by the following Eqn. 3.33.

$$
\bar{x}_i = \mu(x_i) = \left[ \alpha_i, \beta_i, \gamma_i, \delta_i \right] \quad \cdots (3.33)
$$

The centroid method is employed to de-fuzzify the membership function, which gives crisp weightage for all the parameters used in the analysis. The formula used to compute crisp weights $x_i$ of membership function $\mu(x_i)$ between the limits $\alpha$ and $\delta$ (Zimmermann 2001), is.

$$
x_i = \frac{\int_{\alpha}^{\delta} \mu(x_i) dx}{\int_{\alpha}^{\delta} \mu(x_i) dx} \quad \cdots (3.34)
$$
3.5.3.4 Consistency Check

The comparative importance between the members in Fuzzy AHP is subjective and depends on personal ability or understanding about the subjects and feedback from different sources. Therefore, a consistency check was employed to judge the consistency of decisions in FAHP analysis. The consistency of judgment is checked by estimating consistency ratio \((CR)\) computed using the Eqn. 3.24. The consistency index depends on size of matrix (number of parameters) and the consistency in decision process and is estimated using the Eqn. 3.25.

A unitless random consistency index \((RI)\) depends on matrix size \((n)\) after generating reciprocal matrix of various sizes (Saaty, 1980). The average \(RI\) for different sizes of matrix is given in Table 3.5. If \(CR\) is less than 10%, the subjective evaluation about decision is considered as consistent.

3.5.3.5 Priority assessment

The EHPs considered may vary in the diverse ranges and requires to be brought on same scale. Normalization approach to restrict the variation in the range from 0 to 1 is applied using Eqn. 3.27. The final priority \((F_j)\) of a watershed in the present FAHP based MCDS is computed by summing the product of normalized value of EHP and its corresponding weights obtained from FAHP analysis, as Eqn. 3.28.

After getting the final priorities of all sub-watersheds in the study area, they are grouped in different priority classes for deciding the intensity and urgency of soil conservation measures.

3.6 Development of catchment area treatment (CAT) plan

The catchment area are generally neglected and leading to soil detachment and its transportation, siltation of the reservoir. This also leads to depletion of ground water resources due to inadequate ground water recharge. Integrated approach,
therefore is needed to overcome this problem for which catchment area treatment plan using RS and GIS for sustainable development of the region are suggested.

The spatial thematic information were used to develop the catchment area treatment (CAT) plan of the Nagwan watershed with optimal utilization of the resources for sustainable agriculture in terms of land and water resource development. The CAT plans were digitally prepared by creating the various thematic and base maps using ArcGIS 10.1 software.

The CAT plan when executed arrest degradation of lands by regulating water flow on slopes and prevent the transportation of soil from higher level to that of lower ones, facilitate harvesting structures for storage and improve the ground water augmentation. The CAT plan includes preparation of a management plan for treatment of erosion prone area of the catchment through suitable measures mechanical or agronomic. The criteria adopted in suggesting soil and water conservation measures are given in Table 3.6.

3.6.1 Suggested soil and water conservation measures

The suggested soil and water conservation measures can be classified in to three broad groups as, mechanical, agronomic and biological measures.

3.6.1.1 Mechanical measures

Engineering/mechanical measures of soil and water conservation include various engineering techniques and structures constructed across the direction of the flow of rainwater with the objective of dividing of long slopes in to a series of shorter ones in order to reduce the velocity of runoff thereby minimizing the soil and water losses. Mechanical protection measures (engineering measures) are the first line of defense against soil erosion and water runoff concentration.

Soil and water conservation measures (material) should be cost effective. The principles to be kept in mind while planning mechanical measures are (Haridas, 2005):
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- Enhancing time of concentration and allowing more runoff water to get absorbed in site.
- Intercepting long slope to series of shorter ones for reducing velocity for the runoff water.
- Protection against damage due to excessive runoff.

Some of important mechanical measures are described below. It is always better to go for earthen structures with the locally available materials instead of high cost masonry structures as far as possible.

3.6.1.1.1 Check dam

Check dam is a small barriers built across the direction of water flow on shallow rivers and streams (up to third order) with medium slopes. The structures reduce runoff velocity, minimize erosion and improves ground water recharge and also facilitate water harvesting. Ideally a check dam is located in a narrow stream with high banks.

Check dams are proposed at points where water table fluctuations are very high, stream is influent or intermittently effluent. The parameters to be considered for the construction of check dams are slope, soil cover and its thickness and hydrological conditions such as rock type, thickness of weathered strata, fracture, depth of bed rock etc. There should be some irrigation wells in the downstream of the proposed structure.

3.6.1.1.2 Gully plug

Gully plugs can be defined as stones or available local materials placed across gullies or valleys, so as to capture nutrients, silt and moisture. Stones are often embedded into the upper surface of spillway aprons and wells to provide support for the next layer. Gully Plugs are built utilizing local materials such as stones, clay and bushes across small gullies and streams running down the hill slopes carrying drainage to tiny catchments during rainy season. Gully Plugs help in conservation of
soil and moisture. The sites for gully plugs may be chosen whenever there is a local break in slope to permit accumulation of adequate water behind the bunds. Gully erosion occurs when the shape of the terrain concentrates water flow over or through the land; and the soil is not cohesive enough to prevent soil loss. Gully erosion is best controlled by diverting water flow to it rather than by trying to stop erosion in the gully. Gully formation takes place due to improper and non-judicious use of the land usually on steep slopes. Thin layers of soil from the unprotected sloping land are first removed by the flowing water. Watershed programs in India mainly focus on gully control measures in soil and water conservation treatment plan. This is due to the fact that there is acute shortage of land in the villages and the potential danger the gully may create on the upstream and downstream lands.

3.6.1.1.3 Boulder bund

Boulder structures are generally constructed in lower order streams (Small or medium gullies) to arrest upstream erosion, soil loss and hold/ regulate velocity of runoff towards downstream to facilitate the growth of vegetation. It is temporary structure of 1.2 to 1.5 m deep and 5- 6 m wide of locally available boulder/ pebbles.

3.6.1.1.4 Percolation tank

Percolation tank is an artificially created surface water body, in highly permeable land so that surface runoff is made to percolate and recharge the ground water storage. Percolation tank should be constructed preferably on third to fourth order steams, located on highly fractured and weathered rocks, which have lateral continuity downstream. The downstream should have sufficient number of wells and cultivable land to benefit from the augmented ground water.

The size of percolation tank should be governed by percolation capacity of the strata in the tank bed. Normally percolation tanks are designed for storage capacity of 0.1 to 0.5 MCM. It is necessary to design the tank to provide a ponded water column generally between 3 & 4.5 m. The percolation tanks are mostly earthen dams with masonry structure only for spillway. For dam’s up to 4.5 m height, cut off trenches
are not necessary and keying and benching between the dam seat and the natural ground is sufficient.

3.6.1.5 Bench terracing

Bench terracing involves modification of land surface through construction of ridges, channels on steep slope for control of soil erosion and moisture conservation. Generally in steep slope more reduction of slope length by contour bunding may not be able to reduce the intensity of scouring action of runoff water. In such case it is essential to modify the degree of slope. The material excavated from the upper part of the terrace is used in filling the lower part. By bench terracing, the original ground is converted into level-step-like fields constructed by cutting and filling. This measure reduces the slope considerably. It also helps in the uniform distribution of soil moisture, retention of soil and nutrient and also better application of irrigation water.

3.6.1.6 Contour bunding

Contour bund consists of narrow-based trapezoidal embankments (bunds) constructed across the slope and along the contours (contour lines) on fields where the slope is not very steep and soil is fairly permeable to impound runoff water behind them so that all the impounded water is absorbed gradually into soil profile for crop use. A series of such bunds divide the area into strips and act as a barrier to the flow of water, as a result of which the amount of velocity of runoff are reduced, resulting in reduced soil erosion.

3.6.1.7 Graded bunding

Graded bunds consist of small bunds constructed with a slope of 0.1 to 0.4% in order to dispose of excess water at non erosive velocity through the graded channels which lead to naturally depressed area of the land. These are recommended for area more than 600 mm rainfall having highly impermeable soils. The purpose of graded bunding is to make run-off water to trickle rather than to rush out. Graded bunding is restricted to 6% slope and in specific cases it may be extended to a slope
of 10%. The height of bund should be at least 45cm and top width may vary with height of the bund. Grassed water ways are necessary to prevent soil erosion downstream and failure of the bunds.

3.6.1.2 Agronomic Measures

Agronomic measures of soil and water conservation help in reducing the impact of raindrops on soil surface through interception and reduce splash erosion. These practices also help in enhancing infiltration opportunity time and thereby reducing runoff and overland flow. Minimizing in runoff and soil losses are achieved through land management practices and associated agronomic measures. The plant canopy protects the soil from the impact of the rain drop and the grasses and legumes produced dense sod which helps in reducing soil erosion and the vegetation provides organic matter to soil. Agronomic measures (vegetative measures) provide second line of defense. Vegetative (agronomic) methods can usually control erosion if they are applied soon enough, but areas that have already been seriously damaged may need mechanical methods of repair. The common agronomic measure are contour farming, strip cropping, contour strip cropping, vegetative barriers and grassed waterways etc.

3.6.1.3 Grazing management

The various method of controlled grazing include, early versus deferred grazing wherein the deferred grazing is restricting or delaying grazing to enable the vegetation to grow well and produce abundant seeds for the regeneration of grazing lands; rotational grazing which includes the yearlong grazing in blocks and components with the aim to give rest to part of the land and hence provide full opportunity for the vegetation to grow and develop well; deferred rotational grazing aims at achieving both objectives of providing grazing to domestic livestock and providing rest to grazing land for regeneration.
Table 3.6: Guide line in suggesting soil and water conservation measures

<table>
<thead>
<tr>
<th>Structure</th>
<th>Slope (%)</th>
<th>Drainage</th>
<th>Soil</th>
<th>Land use/ Land cover</th>
<th>Geomorphological land form</th>
<th>Advantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bench Terracing</td>
<td>6-10%</td>
<td>_</td>
<td>Shallow Soil not having permeability</td>
<td>Agriculture Field</td>
<td>Steep slope, low rainfall</td>
<td>Uniform impounding of water, Reduced the existing steep slope to mild slope.</td>
</tr>
<tr>
<td>Contour Farming</td>
<td>2-10%</td>
<td>_</td>
<td>Alluvial and black deep lateritic soils</td>
<td>Agriculture Field</td>
<td>Area where runoff is 10% of precipitation lower point of natural Depressions</td>
<td>Prevention of soil erosion, increased supply of moisture to the plant, control flash floods</td>
</tr>
<tr>
<td>Strip Cropping</td>
<td>&lt; 3</td>
<td>-</td>
<td>All type</td>
<td>Agriculture Field</td>
<td>Gently sloping land</td>
<td>Shortening length of slope, reducing velocity of runoff,</td>
</tr>
<tr>
<td>Land leveling</td>
<td>any slope</td>
<td>-</td>
<td>Non Shallow Soil</td>
<td>Agricultural Land with rainfall</td>
<td></td>
<td>Reduced the velocity of water, reduced the chance of soil erosion</td>
</tr>
<tr>
<td>Check dam</td>
<td>&gt; 3%</td>
<td>3rd order &amp; higher stream</td>
<td>Sandy Gravel zone</td>
<td>Waste land on either bank, forest land</td>
<td>Buried pediment</td>
<td>Surface water harvesting life irrigation, Drinking water facility, partially recharges structure.</td>
</tr>
<tr>
<td>Vegetative barriers</td>
<td>Perpendicular to the dominant slope &lt; 10%</td>
<td>-</td>
<td>All type</td>
<td>Agriculture Land</td>
<td>On crop land fields where water or wind erosion is a problem, or where water to be needs conserved.</td>
<td>Facilitate benching of sloping topography, reduced surface runoff, divert runoff to a stable outlet, provide wildlife habitat</td>
</tr>
<tr>
<td>Farm Pond</td>
<td>1-2%</td>
<td>-</td>
<td>Semi Pervious to impervious, All soil except in light textured soils</td>
<td>Single crop area</td>
<td>Area where runoff is 10% of precipitation lower point of natural depressions.</td>
<td>Lifesaving irrigation, drinking water for livestock horticulture development recharge to ground water</td>
</tr>
</tbody>
</table>

Contd…
## Materials and Methods

<table>
<thead>
<tr>
<th>Structure</th>
<th>Slope (%)</th>
<th>Drainage</th>
<th>Soil</th>
<th>Land use/ Land cover</th>
<th>Geomorphological land form</th>
<th>Advantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boulder Bund</td>
<td>2-3%</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; to 3&lt;sup&gt;rd&lt;/sup&gt;</td>
<td>Severe soil erosion semi pervious to pervious</td>
<td>Single crop area</td>
<td>Buried pediment (M), Buried pediment (S), Buried pediplain, pediment</td>
<td>Soil conservation runoff retardant, delay recharge of water, Recharge to ground water.</td>
</tr>
<tr>
<td>Gully Plug</td>
<td>2-3%</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; to 2&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>Soil erosion</td>
<td>Single crop area, forest waste land</td>
<td>pediment, Buried pediment (S)</td>
<td>Soil conservation runoff retardant structure’s soil moisture, recharge to ground water.</td>
</tr>
<tr>
<td>Percolation tank</td>
<td>2-3 %</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt; to 4&lt;sup&gt;th&lt;/sup&gt;</td>
<td>Semi pervious to pervious</td>
<td>Waste land</td>
<td>Buried pediment fractured and weathered rock zone</td>
<td>Induced artificial drinking water, well in downstream.</td>
</tr>
<tr>
<td>Surface dykes</td>
<td>1-3%</td>
<td>higher order stream defined banks</td>
<td>thick sand/gravel cover below river bed up to impervious stratum</td>
<td>Waste land on either bank</td>
<td>Buried pediment, Buried pediplain</td>
<td>Induce percolation of river flow during flood through pervious recharge in surrounding region rise in ground water</td>
</tr>
<tr>
<td>Contour Bund</td>
<td>1-6%</td>
<td>-</td>
<td>All type except deep clayey soils</td>
<td>Agricultural land</td>
<td>steep slope, low rainfall</td>
<td>Reduced soil loss, increase infiltration time, reduced velocity of flow</td>
</tr>
<tr>
<td>Graded Bunding</td>
<td>0.1-0.4%</td>
<td>-</td>
<td>Clay soil even with lesser rainfall</td>
<td>Agricultural land</td>
<td>on crop land fields where water or wind erosion is a problem as where water to be needs conserved</td>
<td>Acts primarily as drainage channels for reducing and regulating the excess runoff water and draining the same with a mild and non-erosive velocity.</td>
</tr>
</tbody>
</table>
3.6.1.4 Afforestation

Afforestation is the growing of forests where there is no forests earlier like abandoned cropland, pastureland, or grasslands, due to adverse factors such as unstable soil or aridity. In various arid, tropical and sensitive areas, once the forest cover is destroyed, the land quickly dries out and becomes inhospitable to new tree growth. Other critical factors include over grazing by livestock and over-harvesting of forest resources.

3.6.1.5 Reforestation

Reforestation is the re-establishment of the forest either naturally or artificially after its removal, or planting more trees. Reforestation is carried out on land where trees have been recently removed due to harvesting or natural disasters such as fire, land slide, flooding or volcanic eruption.