*J. Himalayan Ecol. Sustainable Dev. Vol. 11 (2016)* *ISSN 0973-7502*

# Soil Erosion Estimation of Lidder Watershed, Kashmir Himalaya Using Morgan  Morgan-Finney Model in GIS Environment

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## ABSTRACT

Mapping and assessment of soil erosion risk is an important requirement for soil conservation and natural resource management at watershed scale. The present study involves the application of Morgan-Morgan-Finney (MMF) model in a GIS environment for estimating temporal variability of soil erosion in the Lidder Watershed of the Jhelum basin, Kashmir valley, India for the years 1979, 2005 and 2013. The major input parameters for the model include soil, climate, topography, and land-use. The study area, spread over an area of ~1246 km$^2$, was classified into eight different land use land cover (LULC) and nine soil type classes. Bare rock, forests and pastures are the dominant LULC classes whereas the sandy loam, silty clay and loam are the dominant soil types found in the watershed. Slope in the watershed varied from 0-90°. The model was run to generate the soil erosion potential map of the watershed for the years 1979, 2005 and 2013 and a change in soil erosion from 1979 to 2013 was determined using the change detection analysis. The model results showed that the annual soil loss ranges from 3.1 tons hec$^{-1}$ year$^{-1}$ to 82 tons ha$^{-1}$yr$^{-1}$in 1979, 2.7 tons ha$^{-1}$yr$^{-1}$to 56.7 tons ha$^{-1}$yr$^{-1}$in 2005. However the soil loss relatively decreased in 2013 mainly due to less precipitation observed during the year and ranged from 2.5 tons ha$^{-1}$yr$^{-1}$to 52 tons ha$^{-1}$yr$^{-1}$. It is hoped the spatial estimates of the erosion in the Lidder shall inform appropriate interventions in the watershed, based on the erosion severity predicted by MMF model, for sustainable soil and water resources management.

**Keywords:** Conservation, Jhelum, topography, Lidder

## INTRODUCTION

Soil erosion and land degradation are one of the main problems associated with watershed management issues. Soil erosion is a complex dynamic process by which productive surface soils are detached, transported and accumulated in a distant place resulting in exposure of subsurface soil and sedimentation of water courses and reservoirs downstream. The problem has far-reaching economic, political, social and environmental consequences on account of the on-site and off-site damages (Thampapillai and Anderson, 1994; Morgan *et al.,* 1984). The entire Himalayan region is afflicted by the problem of catchment scale soil erosion with the headwaters generating a large volume of water and sediment and rivers, flowing through this region, transport the heavy load of sediment (Dar *et al.,* 2014). Elaborate and comprehensive estimate of the soil erosion is not available in the Kashmir Himalayan region; however a few studies have been conducted to assess the land degradation problem in the region (Lone *et al.,* 2011; Zaz and Romshoo, 2012). The Himalayan and Tibetan regions cover only about 5% of the Earth's land surface, but supply about 25% of the dissolved load to the world oceans (Raymo and Ruddiman, 1992). Several parametric models have been developed to predict soil erosion at drainage basins, hill slopes and field level (Altaf *et al.,* 2014; De Ploey, 1990; Mati *et al.,* 2006; Phillips, 1990). With a few exceptions, most of the soil erosion models require information on soil type, land use, landform, climate and topography to estimate the soil erosion. Morgan-Morgan Finney-model (MMFM) is a relatively simple conceptual model used to predict soil erosion and deposition on a field scale (Morgan *et al.,* 1984). Parameter inputs on topography, climatic conditions, hydrology, vegetation and soil properties are used in the model to predict the soil erosion at watershed scale (De Jong *et al.,* 1999; Morgan, 2001).

Remote sensing and Geographical Information System (GIS) techniques make it possible to measure various topographic and hydrological parameters at different spatial scales (Altaf *et al.,* 2014; Badar *et al.,* 2013; Romshoo *et al.,* 2012). Remote sensing in conjunction with the GIS has evolved as a powerful tool in estimating soil erosion more accurately as it considers the spatial variability of all topographic parameters (Altaf *et al.,* 2014; Jain *et al.,* 2001; Rao and Kumar, 2004). As there is no gauging station to estimate the soil loss in most of the Himalayan watersheds including Lidder watershed, the conventional methods of soil loss estimation are time consuming and costly. Therefore, MMF (Morgan *et al.,* 1984) is considered a suitable option for estimation of soil loss using remote sensing inputs in a GIS environment. Simulation models are most effective tools for predicting soil erosion processes and provide relevant information for scientific management and conservation of soil, water and vegetation resources at watershed scale. In this study, MMFM was used to estimate the soil erosion in the Lidder watershed, by integrating remote sensing and ancillary data in the geospatial domain. The erosion producing areas were identified for prioritization for watershed management planning.

## STUDY AREA

The Lidder watershed, a major tributary of Jhelum basin, Jammu and Kashmir (Fig.1) is located between 33°4'N-34°15'N & 75°5'E-75°32'

E and covers an area of 1246 km$^2$. The area has a varied topography exhibiting altitudinal extremes from 1600-5200m above mean sea level. The Lidder watershed has a length of 40 km and 5 km width. The watershed is surrounded on the southeast by the Pir Panjal Range, on the north by the Sind Valley and on the northeast by the Zanskar range. Its relief is diverse, comprising of steep slopes, alpine meadows and alluvial fans. The lower part of the watershed is very fertile, hence, ideal for agriculture, whereas, the upper portion comprises of dense pine forests and lush green alpine pastures (Rashid *et al.,* 2010). The climate of the area is sub-humid temperate, experiencing maximum rainfall from March to May, while as heavy snowfall is received during December to February. The temperature varies between a monthly mean maximum of 19°C in July and a minimum of 1.7°C in January with an annual average of 9.5°C (Romshoo *et al.,* 2015). The geology of the area is quite diverse, ranging from Silurian shale, panjal traps, muth quartzite, syringothris limestone, fenestella shale, quartzite and agglomerate slate, ranging in age from Devonian to upper Permian. Drainage of the area is quite significant with most of the drainage flowing into river Jhelum.

## MATERIALS AND METHODS

### Datasets

In order to estimate the erosion from the Lidder watershed, the data from multiple sources was used as input to the MMF model. The data included three date satellite images, ancillary data, ASTER DEM, soil data and meteorological data (Table 1). For determining the land use and land cover (LULC) changes, three date satellite data (1979, 2005 and 2013) of the same season was used to eliminate any errors in the land cover information due to the changing season or time gaps in the acquisition of the data.

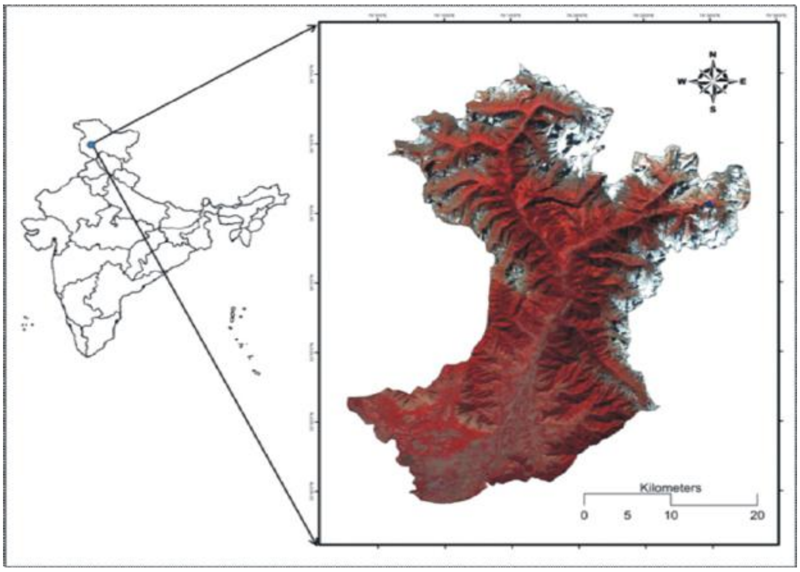


**Fig.1: Study area, the Lidder watershed**

**Table 1: Datasets used in the study**

| Data Set | Acquisition Date | Path/row | Spatial/Temporal Resolution |
|---|---|---|---|
| **Remote Sensing Data** | | | |
| LandSat Thematic Mapper (MSS) | 6September 1979 | 160/36 | 68/83m resampled to 60 m |
| Indian Remote Sensing Satellite (IRS) Linear Imaging Self Scanning Sensor (LISS III) | 19 October 2005 | 92/46 | 23.5m |
| LandSat Enhanced Thematic Mapper Plus (ETM+) | 25 October 2013 | 149/36 | 30 m |
| ASTER DEM | | | 30m |
| **Meteorological Data** | | | |
| precipitation data | 1979, 2005 & 2013 | Lidder valley | Annual |
| Soil maps | - | Lidder valley | 1: 50, 000 |

## METHODS

MMF model requires various thematic layers as input for soil erosion assessment prepared in the GIS environment. These inputs were generated from remote sensing satellite data, soil textural data, topographic data and climatic data. The methodology employed to assess and predict the soil erosion in Lidder watershed involves a number of steps as shown in Fig. 2.

### Soil Erosion Modelling Approach

The MMF model has been successfully used at plot, hill slope and catchment scales in a wide range of environments to predict the soil erosion. A modified version of the Morgan-Morgan Finney erosion/deposition model (MMF-model) was used to quantify erosion rates in this study (Morgan, 2001). The model characterizes the terrain using the DEM, and uses combined multi-temporal remotely sensed data to account for vegetation properties and soil moisture changes. The model estimates annual soil loss by evaluating both rainfall soil detachment and sediment transport over the soil surface. Soil loss determination method consists of two distinct phases; first-one is the water phase and; the second-one is the sedimentation phase. During water phase, kinetic energy of rainfall, overland flow and annual precipitation values are calculated and at the sedimentation phase, rate of soil detachment by raindrop impact and transport capacity of overland flow values are calculated for every pixel for each input data (Faust, 1989). The operating functions and input parameters about the MMF model are discussed below.

**Water phase**

The water phase includes estimation of kinetic energy of the rainfall exerted on the soil and the estimation of the volume of overland flow. Kinetic energy (E), in J/m$^2$, is calculated from annual rainfall data given the intensity of the erosive rain. The kinetic energy is expressed as: $E = KE(DT) + KE(LD)$ (1)

Where, (2)

$$KE(DT) = DT(11.9 + 8.7 * log_{10} I) \quad (3)$$

$$DT = ER - LD,$$

$$KE(LD) = LD((15.8 - PH^{0.5}) - 5.87) \quad (4)$$

$$LD = ER * CC, \quad (5)$$

Where, I = intensity of erosive rain in mm/h, LD= leaf drainage, DT= direct through fall, ER= effective rain, A= permanent interception, PH= plant height and CC= Percentage canopy cover.

The overland flow (Q) in mm is determined from the ratio of soil moisture storage and the amount of rainfall per rainy day. It is mathematically expressed as:

$$Q = R * \exp\left(-\frac{R_c}{R_o}\right) \quad (6)$$

Where,

$$R_c = 1000 * MS * BD * RD \left(\frac{E_t}{E_o}\right)^{0.5} \quad (7)$$

$$R_o = \frac{R}{R_n} \quad (8)$$

Where, R = Annual rainfall (mm), MS: Soil moisture content at field capacity, is the soil moisture storage at field capacity, BD: Bulk density of the top soil layer (g/cm$^3$), RD: Topsoil rooting depth (m), = $\left(\frac{E_t}{E_o}\right)$ Ratio of actual ($E_t$) and potential evapotranspiration ($E_o$), is the amount of rainfall per rainy day, R: Annual rainfall (mm), $R_n$: Number of rain days in the year.

**Sediment phase**

The second phase of the Morgan's model includes the estimation of the rate of detachment by raindrop impact and transport capacity of the overland flow. The formulations are described as follows:

The rate of soil detachment by raindrop impact (F) depends on the kinetic energy (E) of the rainfall and soil detachability index. The rate of detachment (kg/m$^2$) is expressed as:

$$F = K(E * exp^{(-0.05*A)} 10^{-3}) \quad (9)$$

Where K = Soil detachability Index (g/J) and A = Percentage of rainfall contributing to permanent interception and stream flow.

The transport capacity due to overland flow (G) is dependent on the volume of overland flow (Q), crop cover management factor and the topography of the area. This is expressed in kg/m$^2$ as:

$$G = C * Q^2 * \sin(S) * 10^{-3} \quad (10)$$

Where C = Crop cover management factor and S = Steepness of slope expressed in slope angle.

The final mean annual soil erosion loss at a cell(kg/m$^2$) is estimated as the minimum of sediment available F and transport capacity(G).

The model analyses and compares F and G values at each and every pixel/grid and value of annual soil erosion for each pixel will be the minimum of the corresponding pixel values for F and G.

## Land use land cover (LULC) mapping

This is one of the important thematic layers for computation of soil erosion at watershed scale. Land cover type, its rooting depth and its management factor plays an important role in the soil erosion and its assessment. LULC map of the Lidder watershed was prepared using LANDSAT MSS (1979), ETM+ (2013) and LISS (2005) data after applying different image processing and on screen digitization approach (Jensen, 2015). LULC maps were provided attributes for A, $E_t$, $E_o$ and C MMF model parameters.

## DEM analysis

ASTER DEM of the study area was used for delineating the basin boundary using the automated algorithms after computing flow direction and flow accumulation grids. A slope grid derived from the DEM was used in computing transport capacity of overland flow in the catchment and finally the erosion estimation.

## Soil data analysis

Soil textural information is very important in computing erosion rate. Soil erodibility depends upon bulk density of the soil, top soil rooting depth and soil moisture content. A soil textural map of the study area was prepared in GIS domain at 1:50,000 scales. This information was utilized to delineate various physiographic soil units from satellite imagery. Attribute raster maps for MS, BD and K were prepared using the corresponding attribute information of these parameters and the soil textural map. To discriminate different physiographic units, various image elements associated with terrain elements such as landform, topography, relief, slope, LULC, erosion condition, etc. were used for physiographic soil mapping.

All the parametric maps such as kinetic energy of rainfall, top soil rooting depth, bulk density of soil, crop cover management factor, ratio of actual to potential evapo-transpiration, soil moisture storage capacity and field data were estimated and fed into the MMF model in GIS environment. Soil erosion estimates for all the land uses at pixel level were computed using the model equations in distributed GIS modelling environment. Soil erosion for the three years;1979, 2005 and 2013 was computed using the same model parameters only changing the LULC and climatic data.

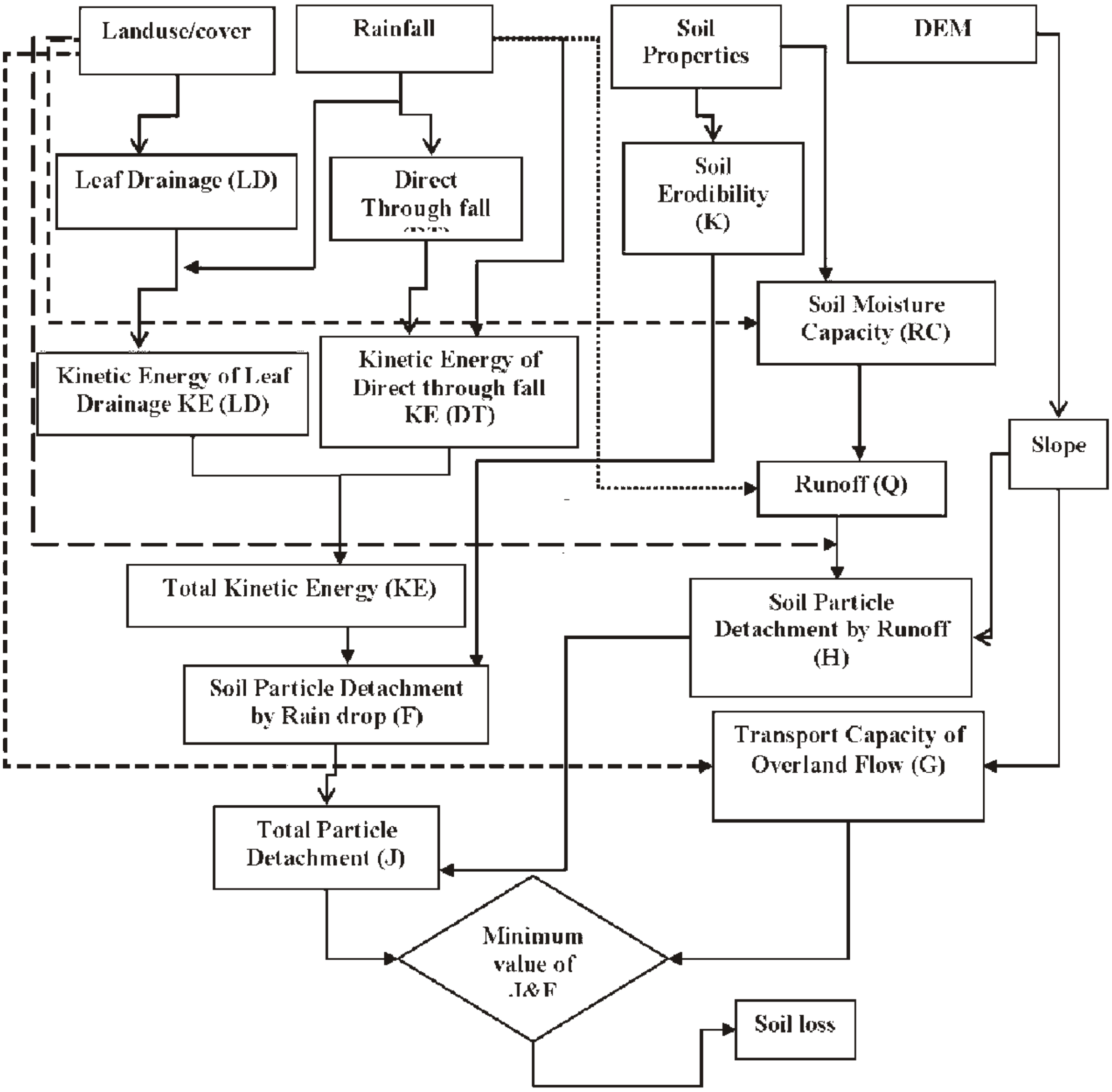


**Fig.2:Flow chart of the methodology adopted for soil erosion estimation study**

## RESULTS AND DISCUSSION

### LULC information

From the analysis of the LULC maps, prepared from the LANDSAT MSS (1979), LISS (2005) and ETM+ (2013) satellite data(Fig.3), it is inferred that the forest cover is the predominant LULC type in the study area. The table 2 shows the forest coverage in the study at 3 different points in time. The forest area in the watershed has decreased from 32.56% in 1979 to 28.37% in 2013. The built-up areas are not showing any changes from 1979 to 2013, primarily due to the limitation of coarse resolution of the 1979 data which is not able to distinctly map the smaller villages and hutments in the watershed.

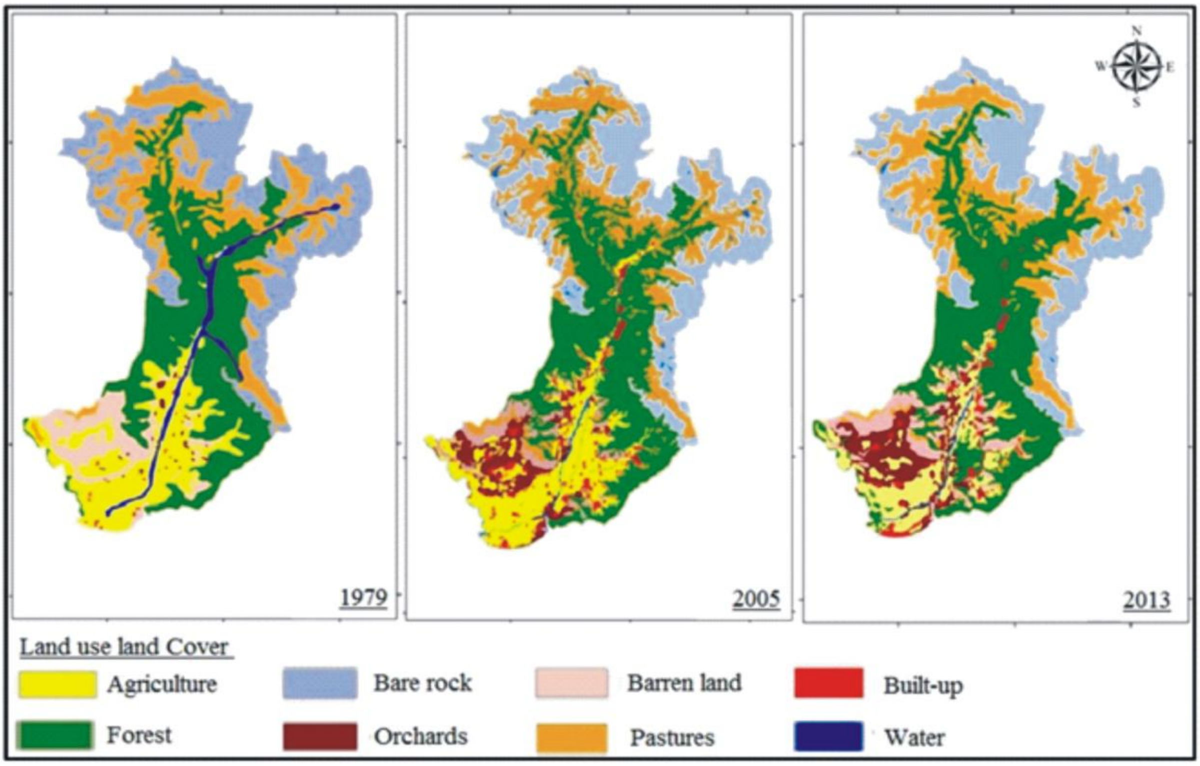


**Fig.3: LULC maps of Lidder watershed in 1979, 2005 and 2013**

**Table 2: Change of LULC area in Lidder watershed from 1979-2013**

| LULC | 1979 | | 2005 | | 2013 | |
|---|---|---|---|---|---|---|
| | Area ($Km^2$) | % of area | Area ($Km^2$) | % of area | Area ($Km^2$) | % of area |
| Agriculture | 160.51 | 12.88 | 149.29 | 11.98 | 136.25 | 10.93 |
| Bare Rock | 366.95 | 29.45 | 331.24 | 26.58 | 326.82 | 26.23 |
| Barren | 40.67 | 3.26 | 45.47 | 3.65 | 65.74 | 5.28 |
| Built up | 2.19 | 0.18 | 21.08 | 1.69 | 27.22 | 2.18 |
| Forest | 405.69 | 32.56 | 398.25 | 31.96 | 353.50 | 28.37 |
| Orchard | 4.78 | 0.38 | 53.90 | 4.33 | 105.49 | 8.47 |
| Pasture | 235.09 | 18.87 | 228.10 | 18.31 | 218.86 | 17.57 |
| Water | 30.13 | 2.42 | 18.68 | 1.50 | 12.13 | 0.97 |
| Total area | 1246.00 | 100.00 | 1246.00 | 100.00 | 1246.00 | 100.00 |

Agriculture lands occur in the downstream of the watershed and cover approximately 12.88%, 11.98% and 10.93% of total study area in 1979, 2005 and 2013 respectively. The other land use classes found in the study area are bare rock, barren lands, built-up, orchards, pastures and water bodies. The spatial extents of the LULC type for the three dates are given in table 2. The analysis of the LULC data reveals that among all the LULC classes, orchards show increase in the area from 0.36% in 1979 to 6.95% in 2013 while as the pastures decrease in area from 18.87% to 17.57% in 2013. However, the area under water bodies and water courses has decrease from 2.42% in 1979 to 0.97% in 2013.

**Slope data analysis**

The slope map was generated using the ASTER DEM and is shown in Fig.4. The study area was classified into five slope classes ranging from 0º to 89º. Table 3 shows the spatial distribution of the slope categories in the watershed. From the analysis of the slope data, it is clear that about 42 % of Lidder watershed is having flat to low slope while as the medium to high degree slopes covers 52% of the watershed area which means that a significant area in the watershed is vulnerable to severe threat of soil erosion.

**Table3: Area under different slope classes in the Lidder watershed**

| Slope in degrees | Area in $km^2$ | %age area |
|---|---|---|
| 0 - 17.88 | 525.5 | 42.17 |
| 17.89 - 35.75 | 303.7 | 24.37 |
| 35.76 - 53.63 | 331.3 | 26.59 |
| 53.64 - 71.5 | 66.9 | 5.37 |
| 71.51 - 89.38 | 18.6 | 1.50 |
| **Total area** | **1246.0** | **100.00** |

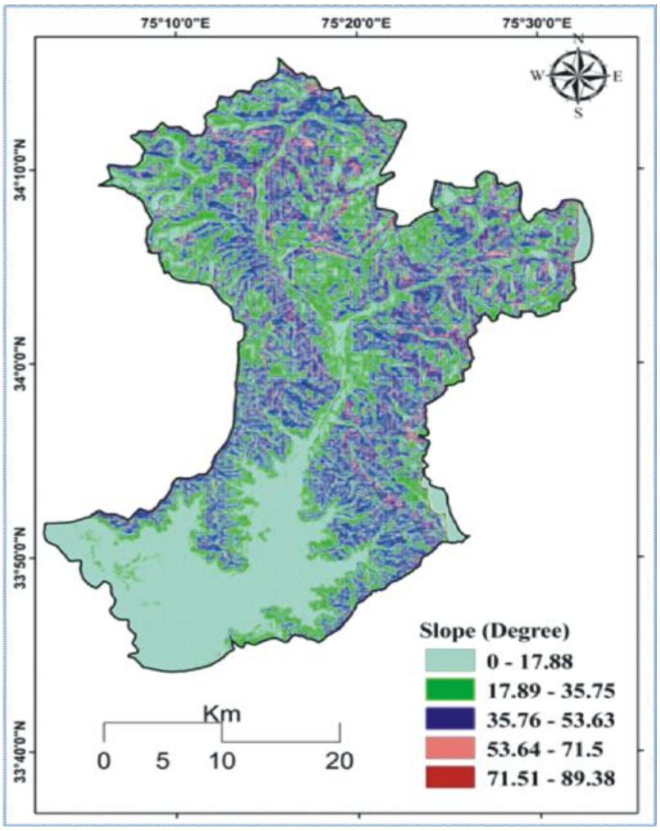


**Fig.4:**

**Soil data analysis**

Soil map provides information regarding soil type and soil texture in terms of sand, silt, and clay and is a very important input parameter for sediment yield estimation using MMF model. The soils in the watershed vary from sandy, clay, loam to silt.

Lidder watershed is dominated by sandy loam and rocky outcrop, covering 33.5% and 29.32% of the watershed area respectively. Clay, clay loam, loam, sand, sandy loam, silt, silty clay, silty clay loam and silt loam cover 1.02 %, 9.81 %, 0.08 %, 3.05 %, 10.53 %, 0.04 %, 1.01 %, 10.5 % and 1.14% of the watershed area respectively. Soil erodibility factor (K- factor) was computed using the data available in the literature. K factor ranges from 0 to 1. Bulk density and field capacity

(%) was taken from typical values suggested by Morgan *et al.* (1984). The soil parameters viz. texture, soil moisture at saturation, bulk density and soil erodibility factors are given in Table-4.

**Table 4: Soil parameters used in the MMF model in Lidder watershed**

| Soil Texture | Soil moisture at saturation (MS ) % | Bulk density (BD) g/cc | Soil erodibility factor (K) |
|---|---|---|---|
| Sandy Clay Loam | 0.25 | 1.2 | 0.1 |
| Sandy Loam | 0.28 | 1.2 | 0.7 |
| Silty Clay Loam | 0.26 | 1.1 | 0.8 |
| Rock Out Crop | 0 | 0 | 0 |
| Clay | 0.45 | 1.1 | 0.05 |
| Clay Loam | 0.4 | 1.3 | 0.7 |
| Loam | 0.2 | 1.3 | 0.8 |
| Silty Clay | 0.3 | 0 | 0.5 |
| Silt | 0.2 | 1.3 | 1 |

## Meteorological data analysis

Rainfall data of the years 1979, 2005, and 2013 from January-December was used to compute rainfall related parameters for input into the MMF model. The values of R, $R_o$ and $R_n$ are given in Table5**.** A typical value for Intensity of erosive rain 10 mm/h for temperate climate was used in the model (Morgan, 2001).

**Table 5: Values for Rainfall parameters used in MMF Model**

| Year | Rainfall R (mm) | Number of rainy days($R_n$) | Amount of rainfall per day $R_o$ | Intensity of erosive rain |
|---|---|---|---|---|
| 1979 | 1455.32 | 165 | 8.82 | 10(mm/h) |
| 2005 | 1255.52 | 115 | 10.92 | |
| 2013 | 1161.8 | 137 | 8.48 | |

## Soil Erosion Estimation

The input parameters derived from LULC like interception, crop management and ratio of Actual to Potential Evaporation ($E_t/E_0$); soil**(**soil moisture at saturation, Bulk density, BD and soil erodibility factor K); DEM (Degree slope) and meteorological data (rainfall, number of rainy days, intensity of erosive rain) were integrated in GIS environment using MMF model and the annual soil erosion was estimated. The MMF model approach separates soil erosion in two phases viz: water phase and sediment phase. Water phase uses annual precipitation to determine the kinetic energy of rain for each LULC present in the watershed for prediction of rain splash detachment and overland flow. The leaf drainage, direct through fall, kinetic energy and overland flow were calculated using the model equations (5, 3, 1 and 6 respectively) and outputs are shown in Fig.5 for years 1979, 2005 and 2013.

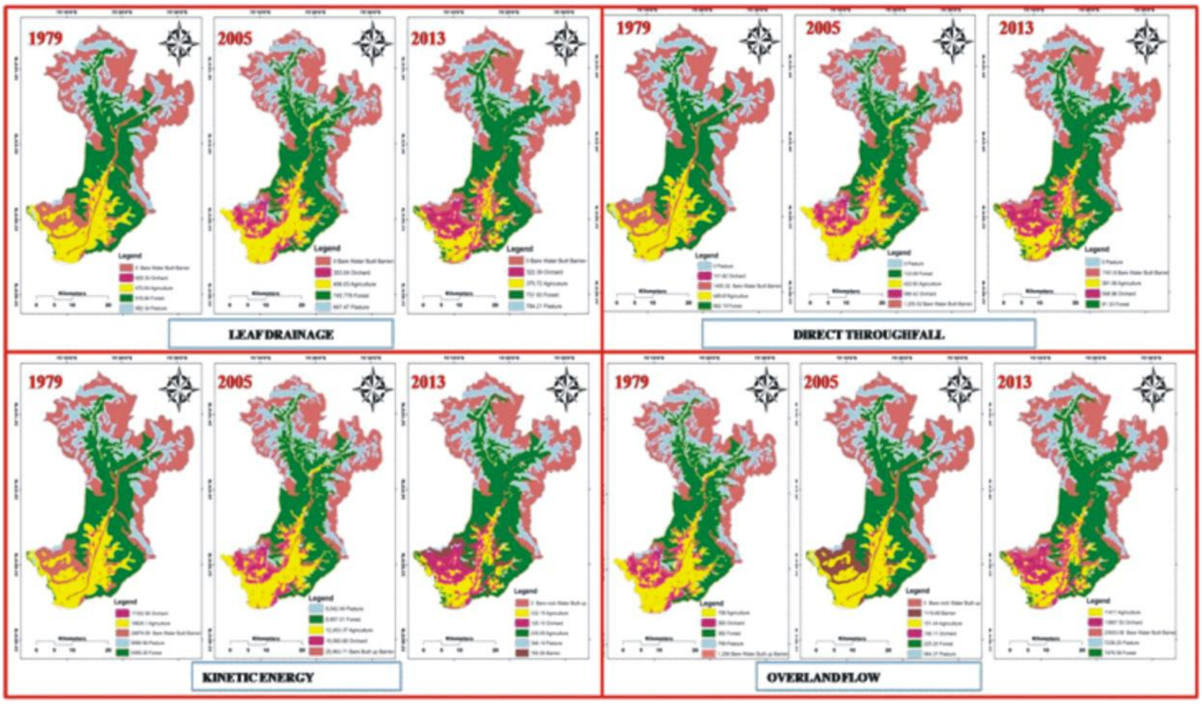
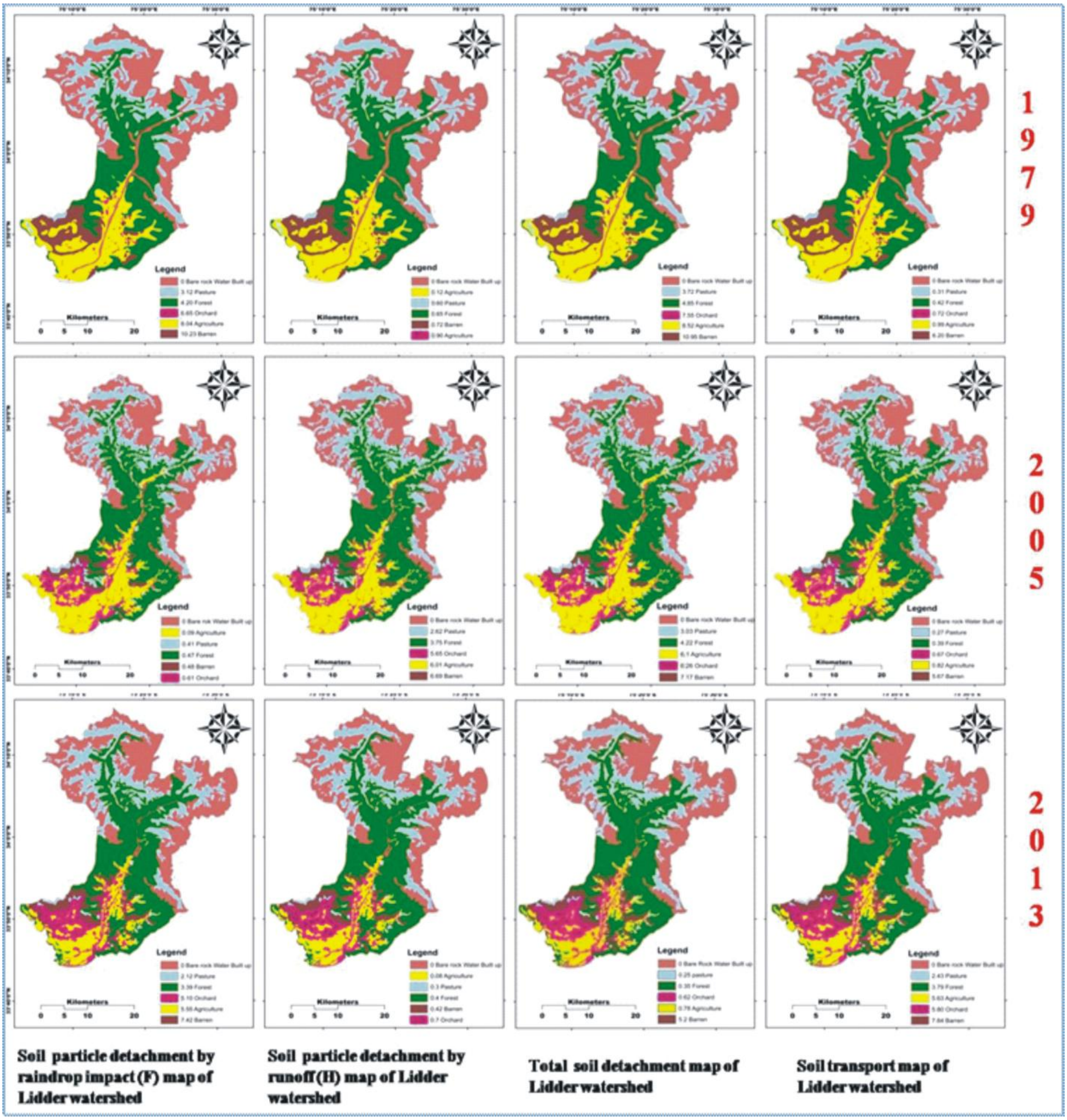


**Fig.5: Leaf drainage, Direct through fall, Kinetic energy and Overland flow of Lidder watershed**

Total Kinetic energy (E) for all the three years was calculated for 1979 (175335 J/$m^2$), 2005 (147868J/$m^2$) and 2013 (135769J/$m^2$) given in Table-6. From the data given in the table, it is clear that highest kinetic energy was found for water bodies, built-up, barren and bare rock during all the 3 years while as overland flow for bare rock, built-up and water bodies was estimated to be 0 mainly due to the zero interception because of the lack of any vegetation and soil cover for the LULC types. The estimation of Q is linked to the soil depth and vegetation in the MMF model which is non-existent in case of the three LULC types and the model therefore calculates zero overland flow and no soil loss from these land cover types which is a limitation of the MMF model. From the perusal of the table and figure, it is clear that vegetation, soil depth and precipitation play a significant role in soil erosion and surface runoff.

The sediment phase of the MMF model estimates the rate of soil detachment by rain drop impact (splash) which depends upon the kinetic energy (KE) of rainfall, erodibility (K) of the topsoil and transport capacity of overland flow. These properties are in turn a function of the amount of rainfall, topographic slope (S) and crop management factor. The values for the crop cover management factor were taken from Morgan (1995). Different types of the vegetation covers have different resistance to the detachment and the movement of the soil particles. Rate of soil detachment F (Kg/$m^2$) and transport capacity of overland flow G (Kg/$m^2$) are calculated for each year (1979, 2005, and 2013) and are shown in Fig. 6



**Soil particle detachment by raindrop impact (F) map of Lidder watershed**

**Soil particle detachment by runoff (H) map of Lidder watershed**

**Total soil detachment map of Lidder watershed**

**Soil transport map of Lidder watershed**

**Fig.6: Maps showing intermediate output of the Sediment phase of MMF model**

**Table 6: MMF Model input Parameters (Water Phase) for different LULC types**

| LULC | Year | Agriculture | Bare Rock | Barren | Built up | Forest | Orchard | Pasture | Water |
|---|---|---|---|---|---|---|---|---|---|
| ER | 1979 | 960.5 | 1455.3 | 1455.3 | 1455.3 | 1018.7 | 1091.5 | 982.3 | 1455.3 |
| | 2005 | 828.6 | 1255.5 | 1255.5 | 1255.5 | 878.9 | 941.5 | 847.5 | 1255.5 |
| | 2013 | 766.8 | 1161.8 | 1161.8 | 1161.8 | 813.3 | 871.4 | 784.2 | 1161.8 |
| LD | 1979 | 470.6 | 0.0 | 0.0 | 0.0 | 916.8 | 409.3 | 982.3 | 0.0 |
| | 2005 | 406.0 | 0.0 | 0.0 | 0.0 | 745.8 | 353.0 | 847.5 | 0.0 |
| | 2013 | 375.7 | 0.0 | 0.0 | 0.0 | 731.9 | 322.4 | 784.2 | 0.0 |
| DT | 1979 | 489.9 | 1455.3 | 1455.3 | 101.8 | 682.2 | 682.2 | 0.0 | 1455.3 |
| | 2005 | 422.6 | 1255.5 | 1255.5 | 1255.5 | 133.1 | 588.4 | 0.0 | 1255.5 |
| | 2013 | 391.1 | 1161.8 | 1161.8 | 1161.8 | 81.3 | 549.0 | 0.0 | 1161.8 |
| KE_DT | 1979 | 10091.3 | 29979.6 | 29979.6 | 29979.6 | 2098.7 | 14053.1 | 9067.0 | 0.0 |
| | 2005 | 8705.7 | 25863.7 | 25863.7 | 25863.7 | 2741.7 | 12112.8 | 0.0 | 25863.7 |
| | 2013 | 8055.8 | 23933.1 | 23933.1 | 23933.1 | 1675.4 | 11308.6 | 0.0 | 23933.1 |
| KE_LD | 1979 | 4202.8 | 0.0 | 0.0 | 0.0 | 7270.5 | 3299.0 | 9067.0 | 29979.6 |
| | 2005 | 3747.7 | 0.0 | 0.0 | 0.0 | 6115.4 | 2947.9 | 8042.5 | 0.0 |
| | 2013 | 3355.2 | 0.0 | 0.0 | 0.0 | 5804.2 | 2599.0 | 7238.3 | 0.0 |
| Total Kinetic Energy | 1979 | 19628.1 | 29979.6 | 29979.6 | 29979.6 | 9369.3 | 17352.1 | 9067.0 | 29979.6 |
| | 2005 | 12453.4 | 25863.7 | 25863.7 | 25863.7 | 8857.0 | 15060.7 | 8042.5 | 25863.7 |
| | 2013 | 11411.0 | 23933.1 | 23933.1 | 23933.1 | 7479.6 | 13907.5 | 7238.3 | 23933.1 |
| Overland Flow | 1979 | 151.4 | 0.0 | 1119.7 | 0.0 | 225.2 | 158.1 | 564.4 | 0.0 |
| | 2005 | 158.1 | 0.0 | 1255.5 | 0.0 | 381.6 | 364.5 | 798.3 | 0.0 |
| | 2013 | 122.2 | 0.0 | 785.6 | 0.0 | 235.1 | 125.1 | 348.2 | 0.0 |

ER= Effective rainfall; LD= Leaf drainage; DT= Direct through fall; KE_DT= kinetic energy due to Direct through fall; KE_LD= kinetic energy due to Leaf drainage

From the perusal of the data provided in the table 7, it is evident that the soil particle detachment by runoff (H); soil particle detachment by raindrop impact (F); Detachment (J); Transport (G) i.e. all intermediate outputs from the sediment phase of the model are showing high soil erosion rate in barren lands approximately 5 to 10 Kg/m$^2$during all the three years while as some of the LULC classes like bare rock, water bodies and built-up show no erosion mainly due to the absence of the soil cover. Soil loss in the Forests is about 0- 5 Kg/m$^2$ during the three time periods. The soil loss in the forests can be associated with the increasing anthropogenic pressures (deforestation) or natural pressures (landslides). Orchards also show considerable soil loss due to the cropping practices in vogue for these lands. The final soil erosion loss was taken as minimum of F and G for each LULC class.

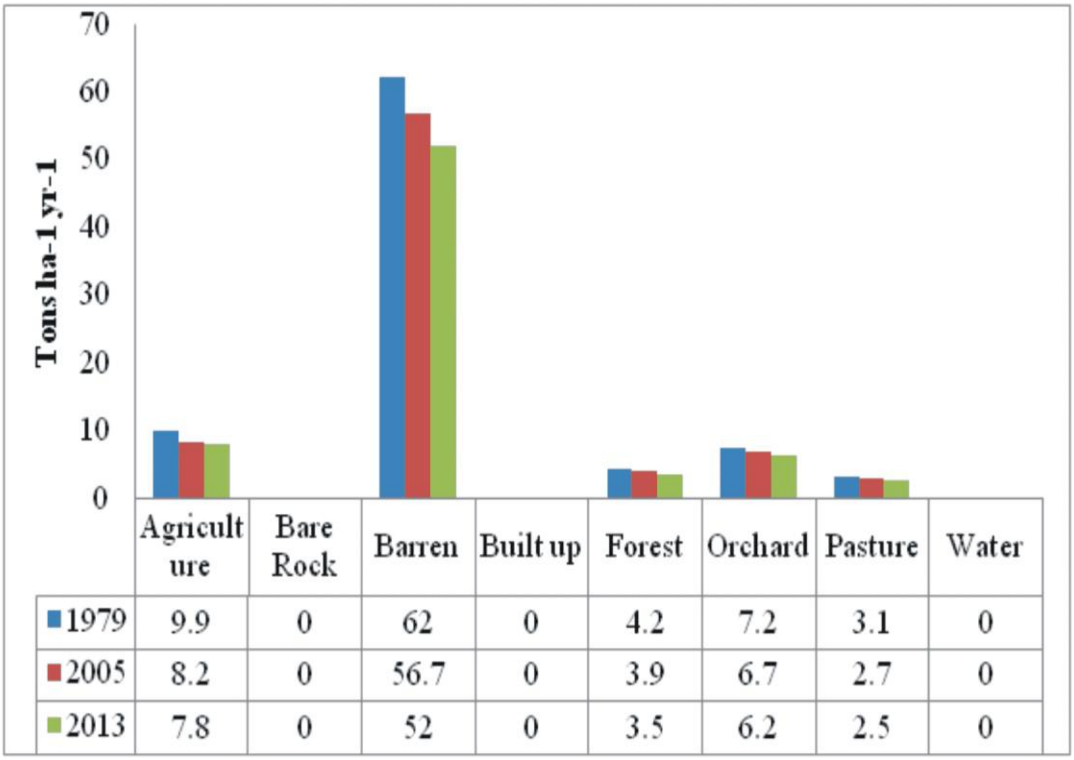
**Table 7: MMF erosion model output (Sediment phase) of Lidder watershed**

| | Year | Agriculture | Bare Rock | Barren | Built up | Forest | Orchard | Pasture | Water |
|---|---|---|---|---|---|---|---|---|---|
| (H) Kg/m$^2$ | 1979 | 0.12 | 0 | 0.72 | 0 | 0.65 | 0.9 | 0.6 | 0 |
| | 2005 | 0.09 | 0 | 0.48 | 0 | 0.47 | 0.61 | 0.41 | 0 |
| | 2013 | 0.08 | 0 | 0.42 | 0 | 0.4 | 0.7 | 0.3 | 0 |
| (F) Kg/m$^2$ | 1979 | 8.04 | 0 | 10.23 | 0 | 4.2 | 6.65 | 3.12 | 0 |
| | 2005 | 6.01 | 0 | 6.69 | 0 | 3.75 | 5.65 | 2.62 | 0 |
| | 2013 | 5.55 | 0 | 7.42 | 0 | 3.39 | 5.1 | 2.12 | 0 |
| (J) Kg/m$^2$ | 1979 | 8.52 | 0 | 10.95 | 0 | 4.85 | 7.55 | 3.72 | 0 |
| | 2005 | 6.1 | 0 | 7.84 | 0 | 4.22 | 6.26 | 3.03 | 0 |
| | 2013 | 5.63 | 0 | 7.17 | 0 | 3.79 | 5.8 | 2.43 | 0 |
| (G) Kg/m$^2$ | 1979 | 0.78 | 0 | 6.2 | 0 | 0.42 | 0.72 | 0.31 | 0 |
| | 2005 | 0.82 | 0 | 5.67 | 0 | 0.39 | 0.67 | 0.27 | 0 |
| | 2013 | 0.78 | 0 | 5.2 | 0 | 0.35 | 0.62 | 0.25 | 0 |

H= Soil particle detachment by runoff;F=Soil particle detachment by raindrop impact;

J=Detachment;G=Transport

Among all the LULC types, the highest erosion rates were observed in barren lands with 62 tons ha$^{-1}$yr$^{-1}$, 56.7 tons ha$^{-1}$yr$^{-1}$ and 52 tons ha$^{-1}$yr$^{-1}$ during 1979, 2005 and 2013 respectively mainly due to the higher kinetic energy of rainfall and lack of vegetation on bare lands which a significant factor for triggering soil erosion. Next to barren lands, agriculture lands showed high rate of soil loss 9.9 tons ha$^{-1}$yr$^{-1}$, 8.2 tons ha$^{-1}$yr$^{-1}$, 7.8tons ha$^{-1}$yr$^{-1}$ respectively for the years 1979, 2005 and 2013 respectively. Orchards showed 7.2 tons ha$^{-1}$yr$^{-1}$, 6.7 tons ha$^{-1}$yr$^{-1}$, and 6.2 tons ha$^{-1}$yr$^{-1}$ respectively for 1979, 2005 and 2013. Among the vegetated LULC types, the lowest soil loss was estimated in pasture lands with 3.1 tons ha$^{-1}$yr$^{-1}$in 1979, 2.7ton ha$^{-1}$ yr$^{-1}$ in 2005 and 2.1tons ha$^{-1}$ yr$^{-1}$in 2013 respectively, From the forest areas in the watershed, the annual soil loss was estimated at 4.2 tons ha$^{-1}$yr$^{-1}$, 3.9 tons ha$^{-1}$ yr$^{-1}$ and 3.5 tons ha$^{-1}$ yr$^{-1}$during 1979, 2005 and 2013 respectively. Bare rocks, water and built-up did not yield any soil erosion due to the lack of soil cover on these LULC types. Fig. 7



| | Agriculture | Bare Rock | Barren | Built up | Forest | Orchard | Pasture | Water |
|---|---|---|---|---|---|---|---|---|
| ■1979 | 9.9 | 0 | 62 | 0 | 4.2 | 7.2 | 3.1 | 0 |
| ■2005 | 8.2 | 0 | 56.7 | 0 | 3.9 | 6.7 | 2.7 | 0 |
| ■2013 | 7.8 | 0 | 52 | 0 | 3.5 | 6.2 | 2.5 | 0 |

**Fig.7: Soil loss of Lidder watershed from 1979 to 2013**

## CONCLUSIONS

In the present study, soil erosion was estimated using the Morgan-Morgan Finney model in GIS environment. GIS platform provides a faster and efficient method for geospatial data integration and modelling and the outputs could be better quantified and visualized. From the results obtained in this study, it can be seen that the total model soil erosion estimates from the Lidder watersheds for years 1979, 2005 and 2013 are 86.4 tons ha$^{-1}$yr$^{-1}$, 78.2 tons ha$^{-1}$yr$^{-1}$ and 72 tons ha$^{-1}$yr$^{-1}$ respectively. The declining trend of the soil loss from the Lidder watersheds is attributed to the varying erosive rainfall intensity and amount of the annual precipitation. These factors play an important role in triggering soil erosion. It is hoped that the estimates of the soil loss for various LULC types in the Lidder watershed would constitute an important information and knowledge for developing LULC management strategies to minimize the soil loss from various LULC types. The model estimates of the soil loss could not be validated with the observed sediment or erosion data as there is no practice of field observation of the erosion processes in the watershed. However, it is observed that the model estimates of soil loss have logical basis with the LULC types. The study showed that the soil loss from the vegetated areas like forests and pastures is significantly lower than the unprotected barren lands. MMF model results showed a lower overland flow (Q) for the built up, bare rock and water LULC type due to the limitations of the model as the Q is linked to the soil depth and vegetation in the model which is non-existent in case of the three LULC types.

## ACKNOWLEDGEMENTS

The research work was conducted as part of the Ministry of Environment, Forests and Climate Change (MoEF&CC), Govt. of India and Space Application Centre (SAC), ISRO sponsored research project titled "Desertification Status Mapping" and the financial assistance received under the project to accomplish this research is thankfully acknowledged. The authors express gratitude to the anonymous reviewer for his valuable comments on the earlier version of the manuscript that has improved its content and structure.

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