SUMMARY AND CONCLUSIONS

Land and Water are vital resources towards ensuring food security, economic and social progress and ultimately for sustenance of life. Soil erosion has a serious environmental crisis in the world today that has led to shrinking of land, water, forest and biodiversity. Human induced activities also led to the significant alteration in natural erosion process. For nation like India great focus on conservation of soil & water to arrest erosion is required by adopting relevant measure & practices. Besides environmental hazards, soil erosion has threatened the global food security due to ever-growing population and its dependency on livelihood of the people who largely depends on the farming especially subsistence agriculture. The dynamics of soil erosion and sediment yield are affected by spatial and temporal characteristics of the catchment like climate, soil type, land use pattern, topography and anthropology activities. Since these factors bear temporal and as well as spatial variability, they can be isolated by discretizing the catchment into smaller homogeneous units and eventually adopting feasible soil erosion models for sub watersheds. However, the major problem with these models is the generation of the relevant input data which are too spatial and rare. As such, GIS and remote sensing techniques coupled with soil erosion model will be a promising and cost-effective tool for estimating the annual soil erosion especially in the un-gauged catchments of the developing countries. Due to lack of proper catchment area treatment planning majority of the areas need have focused planning for conservation, development & utilization of land and water resources. The present study was undertaken to identify the erosion prone area of the Nagwan watershed and to develop the catchment area treatment plan. The watershed is located in upper Damoder Valley of Hazaribagh district, Jharkhand India. The watershed lies between 85°16′41″ to 85°23′50″ E longitudes and between 23°59′33″ to 24°5′37″ N latitudes. For the analysis and development of Catchment area treatment plan, thematic maps i.e. base map, drainage map, contour map, digital elevation model map, sub-watersheds map, soil group map and land use map were prepared with the help of GIS based software ArcGIS 10.1.
The study of the base map shows that the total area of the Nagwan watershed was 92.37 km$^2$ and of dendritic pattern.

Detailed study of drainage map of Nagwan watershed shows that, highest stream order of the watershed was 5th as per Strahler’s stream ordering technique. The number of first order stream was 191, second order stream was 39, third order stream was 9 and fourth order stream was 3. The total length of stream segments of first order was 110.33 km, second order was 34.77 km, third order was 26.39 km, fourth order was 11.82 km and fifth order stream was 7.21 km found.

The average slope of the Nagwan watershed was 9.28 %. The average slope of all the sub-watersheds was also computed and found varied from 7.38 % (SW- 9) to 11.91 % (SW- 3).

The catchment area was divided into 21 sub-watersheds namely SW-1 to SW- 21 with geographical area varying from 2.34 km$^2$ (SW-1) to 7.00 km$^2$ (SW- 6) and the perimeter of the sub-watersheds varies between 6.80 km (SW-1) to 13.53 km (SW-10).

Soils of the study area were grouped into 6 classes depending on soil properties. Area occupied by different soil groups area as follows: Sandy loam (12.30 km$^2$), loamy sand (8.76 km$^2$), silty clay loam (11.31 km$^2$), loam (13.80 km$^2$), silty loam (41.26 km$^2$) and clay loam (4.93 km$^2$). The predominant soil textural classes found were silty loamy and loam in the watershed.

Land use map was prepared from IRS-P6 (LISS-IV) satellite image using ERDAS imagine software (version 9.3). Supervised classification method with a maximum likelihood (ML) technique was applied in multi spectral bands image to generate the land use/ land cover map. Using supervised classification method in ERDAS imagen 9.3 with a maximum likelihood (ML) technique was applied to three multi-spectral bands to generate the land use/cover map. Eight land use classes such as agricultural land (53.31 km$^2$), dense forest (1.64 km$^2$), open forest (5.50 km$^2$), barren land (1.25 km$^2$), water body (1.48 km$^2$), shrubs land (2.15 km$^2$), grass land (24.34 km$^2$) and built up land (2.43 km$^2$) geographical area were identified in study.
area. Agricultural and grass land are the main land uses (maximum occupied area) found in Nagwan watershed.

The prioritization of sub-watershed was considered as a primary aspect of the catchment area treatment plan, as entire catchment area can’t be treated simultaneously. The prioritization of sub-watershed help to identify stressed areas. In the present analysis, the Nagwan watershed area was divided in to 21 sub-watersheds and prioritized on the basis of erosion hazard parameters by morphometric analysis and advanced analytical techniques.

Erosion hazard parameters normally termed as EHP, that are considered for identifying priority orders of the sub watershed are soil loss estimation by Universal Soil Loss Estimation (USLE) model, $S_y$ - Sediment yield by SWAT model, $R_b$ - Mean Bifurcation ratio, $D_d$ - Drainage density (km/km²), $D_t$ - Drainage texture (km⁻¹), $F_s$ - Stream Frequency (km⁻²), $D_i$ - Drainage intensity, SPR - Sediment Production Rate (ha-m/100 km²/year), $R_c$ - Circularity Ratio, $C_c$ - Compactness Constant, $R_e$ - Elongation Ratio, $L_o$ - Length of overland flow (m), $R_f$ - Form Factor, $I_n$ – Infiltration Number and $R_{hp}$ - Relative relief.

Soil loss was estimated by using USLE model. The average value of rainfall erosivity ($R$-factor) was 540.92 MJ mm ha⁻¹ h⁻¹ yr⁻¹. Soil map of the study area shows that erodibility factor (K- factor) ranged from 0.19 to 0.34 t ha h⁻¹ MJ⁻¹ mm⁻¹. The slope length and slope steepness ($LS$) factor ranged from 0.00 to 19.54. The C and P-factor maps were generated based on land uses such as agriculture, barren, built-up, dense forests, open forest, grass land, scrubs and water bodies. The value of C-factor varied from 0.009 to 1.00 while P factor ranged from 0.80 to 0.1 respectively for the watershed. The average annual soil loss value was found 12.39 t/ha/year. The average soil loss from the sub-watersheds were worked out and the found the ranged from 6.52 (SW- 2) and 26.41 (SW-21) t/ha/yr.

Sediment yield ($S_y$) for sub-watersheds of the Nagwan watershed were calculated by using SWAT model and observed to be ranged between 1.33 (WS- 11) to 2.13 (WS- 13) tonnes/ha.
Sediment production rates (SPR) of all the sub watersheds were determined utilizing geomorphological parameters such as farm factor, circulatory ratio and compactness coefficient and found to varies from 2.41 ha-m/100 km²/year (SW-14) to 0.07 ha m/100 km²/year (SW-21).

Relative relief of the sub watershed varied from 0.39 (SW- 21) to 1.27 (SW- 17) per cent. The maximum and minimum drainage density (Dd) were found to be 3.77 and 1.44 km/km² in respect of sub-watershed SW-18 and SW-9. The channel frequency of all the sub-watersheds ranged from 1.04 km² (SW-9) to 7.79 km² (SW-18). Form factor (Rf) of the study area varied from 0.199 km²/km² (SW- 5) to 0.799 km² / km² (WS- 13). The value of circulatory ratio (Rc) of sub watersheds ranged between 0.25 (SW-21) to 0.71 (SW-19). The compactness coefficient (Cc) ranged from 1.18 (SW-19) to 1.99 (SW-21), the elongation ratio (Re) from 0.50 (SW-4) to 1.01 (SW-13), mean bifurcation ration (Rb) from 2.25 (SW-1, 20, 21) to 7 (SW-7), the drainage texture from 0.51 (SW-9) to 3.99 (SW-20). The Nagwan sub watershed represented a low drainage intensity varying from 0.64 (SW-10) to 2.06 (SW-18). The length of overland flow of the sub watersheds ranged from 132.59 (SW-18) to 348.42 (SW-9) while infiltration number from 1.50 (SW-9) to 29.36 (SW-18).

Three methods such as morphometric analysis, Saaty’s AHP and Fuzzy AHP using different erosion hazards parameters (EHP) were used for the prioritization of sub-watersheds.

Morphometric analysis approach of watershed prioritization shows that total area 33.66 km² should be put under very high and high prioritization category and require immediate execution of catchment area treatment plan and remaining 13 sub-watersheds categorized of medium, low and very low priorities category and the implementation of soil conservation measures may apply at later stage of development.

Saaty’s analytical hierarchy process (SAHP) & Fuzzy analytical hierarchy process (FAHP) along with different number of erosion hazard parameters (EHP’s) from 9 to 15 were used to prioritize the watershed under reference. 13 number of Erosion Hazard Parameters were optimized for watershed prioritization. As such this was taken as base for determining the final priority scores for sub watershed.
The analysis of results of sub-watersheds’ prioritization using FAHP revealed that out of 21 sub-watersheds, 4 sub-watersheds (SW- 17, SW- 18, SW- 20 and SW-16) covering a total area of 14.41 km\(^2\) and 7 sub-watersheds (SW- 13, SW- 19, SW-14, SW- 5, SW- 6, SW- 8 and SW- 1) measuring 34.08 km\(^2\) could be categorized as very high and of high priority orders, respectively and needed holistic approach in respect of soil conservation measures and catchment area treatment plan of the earliest. 4 sub watersheds (SW- 21, SW- 4, SW- 3 and SW- 15) of moderate priority, 3 sub watersheds (SW- 7, SW- 2 and SW- 12) under the low priority while remaining 3 sub watersheds (SW- 11, SW- 9 and SW- 10) very low priority category.

The study also included suggestive measures in terms of catchment area treatment plans to be reinforced in the sub watershed of the Nagwan watershed on the basis of priority ranking. The soil and water conservation measures considered were broadly classified in three categories as mechanical measures, agronomic measures and biological measures. The check dams have been suggested in streams of third and higher order, with the more than 3 % slope in forest area. The gully plugs were suggested for forest, undulating areas with first to second order streams having the steep slopes (2-3%) with coarse grained soil. Similarly, boulder bunds have been suggested in crop areas with semi-pervious to pervious soil type with first to third order streams having the 2 to 3 % slopes and percolation tanks for third to fourth order streams with 2 to 3 % slopes having semi-pervious to pervious soil in waste lands. In this study Erosion control structures (Check dams, gully plugs etc.) (37), Water Harvesting Structures (Farm pond, percolation tanks, surface dykes etc.) (07), were also suggested for the development of the catchment area.

The implementation of recommend catchment area treatment plan (CAT) for the Nagwan watershed will improve to a greater extent the overall health of the catchment. The proposed soil and water conservation measures will alleviate the current problems of acute soil erosion from the catchment area, reduces the siltation in the reservoir and improve water availability in the catchment. It also enhances the life span of the reservoir, ground water status, and agriculture productivity of land of the catchment area.

Remote sensing, GIS and multi-criteria decision analysis approaches such as Fuzzy Analytical Hierarchy Process (FAHP), Saaty’s Analytical Hierarchy Process...
(AHP) demonstrated the imperative role in morphometric characterization and prioritization of sub-watersheds for the management and sustainable development.

**Salient finding are as under**

- Among analyzed approaches of watershed prioritization, morphometric analysis was found to be simple and relevant. However it requires validation with real time data set for realistic outcome, but there is lacuna of real time data and validation of result.
- Fuzzy AHP method of watershed prioritization were found to be quite complex. The results is validated by consistency check.
- Different method of prioritization gave different results, suggesting use of multiple methods along with validation before arriving at relevant conclusion.
- Instead, incorporating large number of parameter, it is advisable to go for selective and relevant erosion hazard parameter by optimization.
- The proposed soil and watershed conservation measure will help minimizing existing problems of acute soil erosion in the catchment area and subsequently reduce the sediment concentration siltation and enabling excessive water yield from the catchment.