ABSTRACT

Watershed management has emerged as a new paradigm for planning, development and management of land, water and biomass resources with a focus on social and environmental aspects following a participatory approach. It involves judicious use of natural resources with active participation of institutions, organizations and community in harmony with the ecosystem. Since watersheds are considered fundamental units for planning and developing natural resources, hence watershed management is essential for planning and development of natural resources for sustainable development. Watershed management plays a key role in areas which require immediate intervention for conservation of natural resources in terms of soil and water management. Remote sensing and Geographic Information System (GIS) has been widely used in watershed management, which involves mapping of varied land forms, soil, drainage, linear features, structural elements, and terrain characteristics. Several studies in different parts of India on watershed management have been carried out in the recent past using remote sensing and GIS techniques (Menris 1997; Thomas et al., 1999; Subba Rao et al., 2001; Tim and Mallavaram, 2003; Nag, 2005; Raju and Kumar 2006; Srivastava and Kumar, 2006; Shanwal and Singh, 2006; Bhatt et al., 2007, Chowdary, 2009). In the present study an attempt has been made to suggest measures for watershed management...
based on morphometric parameters, land use/land cover change analysis, ground water prospects, slope/relief etc. with the help of remote sensing and GIS.

The study has utilised Survey of India (SOI) topographic map on 1:50,000 scale, Standard Geocoded False Colour Composite (FCC) of Indian Remote Sensing satellite (IRS-1D) LISS III data of 2001 and digital data of IRS-P6 LISS III of 2005 having a spatial resolution of 23.5 meter. Meteorological data (temperature and rainfall) of 1971-2006 period was obtained from India Meteorological Department (IMD) Pune, and have subsequently been analyzed, to ascertain the variation in temperature and rainfall trends of the study area. Shuttle Radar Topography Mission (SRTM) data of 90 meter resolution has been used for generating Digital Elevation Model (DEM) and slope map. The data on ground water level obtained from Ground Water department of Government of Rajasthan for the period 1978 – 1995 has been analysed, to assess the general decline in ground water level.

This study involves preparation of base map, drainage map, demarcation of watershed/sub-watershed boundaries, generation of thematic maps using satellite data, morphometric analysis, land use/land cover change analysis, hydrogeomorphological analysis, ground truthing, preparation of DEM and slope. Spatial and non-spatial data have been analyzed using softwares such as Arc-View 3.2, ERDAS IMAGINE 8.7, Geotrans 2.3, Georeferencing software, 3DEM and SAGA 2.0.3. The results obtained from morphometric, Land Use/land cover analysis, hydrogeomorphic mapping, slope /relief etc have been correlated to suggest measures for watershed management. Thematic maps generated from visual
interpretation of IRS data have been digitized using ArcView GIS and polygon topology was built for various thematic maps after editing and cleaning.

The study area i.e. Kakund watershed falls in Bharatpur district and forms part of Gambhir river basin with a geographical area of 295.87 km², bounded by 26° 45' - 27° 00' North longitudes and 77° 15' - 77° 30' East latitudes. The maximum and minimum elevations in the study area are 361 m and 180 m above mean sea level (MSL) respectively, and the general slope of the watershed is from south to north as defined by the course of Kakund river. The drainage pattern of the area is predominantly dendritic to sub-dendritic, however structural controlled pattern i.e. parallel to sub-parallel and trellis are also found at a few places especially in the south. The watershed has been demarcated into seven sub-watersheds namely Narauli, Rudawal, Bankukara, Tarsuman, Nahro, Seupura and Thanadung, on the basis of drainage flow directions, slope, spot height, contour values, elevation etc.

The major lithological unit exposed in the study area is sandstone belonging to the Vindhyan Super-group. The sandstone is massive, hard and compact but at places has joints/fractures. It is mostly barren but at some places supports scanty vegetation. Quarrying activity has been reported at several places and the stone is being used extensively in construction industry. Quaternary formation in the form of alluvium constitutes the other major geological formation especially in the northern and north-eastern parts of the study area where intensive agriculture is practiced. The study area is dominated by two types of soils i.e. sandy and sandy loamy soils, the later is dominant in the northern part of the study area, whereas the former is
reported from the southern part of the study area, the thickness of the soils varies between 0 and 17 cm.

Hydrogeomorphologically, the study area has severally geomorphic units such as alluvial plains valley fills, plateau, buried pediments, pediments, intermontane valleys, residual hills and linear ridges. Alluvial plains form a predominant unit in the northern part of the study area and are defined by lithology consisting of unconsolidated sediments of sand, silt, clay and gravel. Valley fills are products of streams dumping their sediment load along their courses due to obstruction to or reduction in their flow velocity. Valley fills are sandwiched between Vindhyan plateau and hills and ridges of Bhandar Group. Plateau is a table like land, which is broad, elevated and almost level and represents Vindhyan sandstone in the southern and eastern parts of the study area. Buried pediments are present in the central part of the Kakund watershed, and is characterized by undulated topography, accedented slope, thin alluvial cover, and higher elevation as compared to alluvial plain. The pediments in the area are developed on sandstones, and show a considerable amount of weathered material brought down from the plateau. The intermontane valleys are mostly structure controlled, narrow and linear depressions, filled with colluvial and fluvial deposits brought down from the plateau, and are of varying grain size mostly sand, silt and clay. Residual hills are isolated hills and hillocks represent sandstone lithology, attains an elevation of 251 m, and occupies a relatively small area. Linear ridges are present as hogback and cuesta ridges, characterized by massive structure and high resistance to erosion.
Morphometric analysis of the sub watersheds has been carried out under three major heads i.e. linear aspects, areal aspects and relief aspects. Linear aspects include stream order, stream number, stream length mean stream length, stream length ratio, bifurcation ratio. The areal aspects include drainage density, stream frequency, drainage texture, basin shape, form factor, circulatory ratio, elongation ratio, length of overland flow, constant of channel maintenance and compactness coefficient, whereas relief aspects include relief ratio, basin length, sinuosity index and ruggedness number. Regression of number of stream number with stream order of all seven sub-watersheds show variation from general trend indicating a regional upliftment of the area. The stream length ratio (RL) between streams of different orders reveals variation in each sub-watershed which may be attributed to variation in slope and topography. Narauli and Rudawal show an increasing trend in stream length ratio from lower order to higher order indicating mature geomorphic stage. In Bankukara, Tarsuman, Nahro, Seupura and Thanadung, stream length ratio (RL) values vary from one order to next order which indicate their late youth stage of geomorphic development. The stream length ratio (RL) of Kakund watershed shows variation from one order to another order which also indicate late youth stage of geomorphic development. Bifurcation ratios (Rb) of the sub-watersheds indicate some structural control over drainage development. Higher Rb values in Bankukara, Tarsuman, Seupura and Thanadung sub-watersheds indicate structural control drainage pattern. Under the relief aspects; higher relief ratio (Rh) in Tarsuman and Seupura sub-watersheds indicate steep (9-12°) to very steep slopes (12 - 15°) and high relief, whereas lower Rh values in Narauli, Rudawal and Bankukara sub-
watersheds suggest very gentle slope (0 to 3°) and low relief. However, moderate slope (6 - 9°) is found in Nahro and Thanadung sub-watersheds. The sinuosity index (Si) of the sub-watersheds varies from 1.42 in Narauli to 2.22 in Rudawal sub-watershed. The results of the sub-watersheds suggest that the streams are in their youth stage, show Si value 1.6 and thus can be attributed to the phenomenon of rejuvenation. Ruggedness number (Rn) of Seupura and Thanadung sub-watersheds is quite high which indicate their susceptibility to erosion. The areal aspects of the seven sub-watersheds suggests that Narauli and Rudawal sub-watersheds fall in low drainage density category suggesting permeable subsoil material and presence of vegetative cover. Bankukara (3.79) and Tarsuman (3.25) sub-watersheds have relatively high drainage density and indicate less permeable material, sparse vegetative cover and moderate to high relief. The other sub-watersheds, i.e. Nahro, Seupura and Thanadung represent medium to high drainage density which is indicative of impermeable material, sparse vegetative cover and moderate to high relief. The drainage density of the whole Kakund watershed is 2.19 km/km² which falls under medium density category. Narauli (1.83) sub-watershed possesses very coarse drainage texture, Rudawal and Seupura have coarse drainage texture, whereas Tarsuman, Nahro and Thanadung show moderate drainage texture. Only Bankukara (11.75) sub-watershed represents very fine drainage texture. The Kakund watershed as a whole has 11.77 value, which also falls under very fine drainage texture category. Areal parameters suggest that the Narauli, Rudawal, Bankukara, Tarsuman, Nahro, Seupura and Thanadung sub-watersheds are more or less elongated in shape.
Land use/land cover (LULC) analysis of the sub-watersheds has been carried out through visual interpretation of multi-temporal data of IRS 1D LISS III data of 2001 and IRS P6 LISS III data of 2005. The LULC categories delineated the study area include Cultivated land (CL), Uncultivated land (UCL), Dense forest (DF), Open forest (OF), Open scrub (OS), Wasteland (WL) (Culturable), Water body (WB), Barren/Rocky area (RA) (Unculturable), Rock quarry (RQ) and Built up land (BL). A comparative land use/land cover change assessment reveals that during 2001-2005 period, the study area has lost 5.24 km² (1.77%) of Cultivated land due to a combination of natural (decline in average rainfall, absence of assured irrigation, decline in water table) and anthropogenic factors and has been converted into uncultivated/wasteland. The area under uncultivated land has increased from 24.85 km² (8.40%) in 2001 to 29.65 km² (10.02%) in 2005. Dense forest has shown an increase of 0.11 km² (0.03%) area from 2001 to 2005 due to the shrinkage of waterbody i.e. Baretha lake. The increase in dense forest is reported along the periphery of the waterbody due to the high moisture content where natural vegetation has grown into a well developed dense forest. Open forest has reduced from 84.47 km² in 2001 to 82.62 km² in 2005 whereas Open scrub has decreased from 21.51 km² (7.27%) in 2001 to 20.48 km² (6.92%) in 2005. Wasteland (Culturable) has increased from 4.93 km² (1.67%) in 2001 to 9.02 km² (3.05%) in 2005 mostly in Narauli, Rudawal, Nahro and Thanadung. The area under waterbody has decreased from 4.98 (1.68%) km² in 2001 to 3.83 (1.29%) km² in 2005. The barren/rocky area (Unculturable) has shown a decrease from 20.98 km² (7.08%) in 2001 to 20.54 km² (6.94%) in 2005 due to the expansion of rock quarrying activity. Rock quarry has
increased from 8.32 km$^2$ (2.82%) to 8.76 km$^2$ (2.96%). The built up area has increased from 1.94 (0.66%) km$^2$ in 2001 to 2.20 km$^2$ (0.74%) in 2005. The decrease in area under open forest and open scrub may be attributed to anthropogenic activities including human and cattle population pressure. The increase in the area under wasteland (Culturable) category is probably due to natural degradation of soil, especially in cultivated land, open forest and sparse vegetation areas. The analysis shows that the whole Kakund watershed has reported change in LULC categories in 19.41 km$^2$ area which is at about (6.53%) of the watershed area.

The Narauli sub-watershed has reported 5.46 km$^2$ (6.53%) area affected by land use/land cover change during 2001 – 2005 period. The figures for other sub-watersheds are 4.30 km$^2$ (10.19%) for Rudawal, 1.88 km$^2$ (6.31%) for Bankukara, 1.44 km$^2$ (8.52%) for Tarsuman, 3.34 km$^2$ (7.85%) for Nahro, 1.8 km$^2$ (5.95%) for Seupura and 2.10 km$^2$ (4.73%) for Thanadung sub-watersheds respectively.

Hydrogeomorphological mapping has been carried out using IRS LISS III FCC and the study area has been divided into three zones i.e. runoff zone, infiltration zone and discharge zone based on the geomorphic landforms, terrain conditions and lithological characteristics. The delineation of the hydrogeomorphic units aimed at demarcating areas of groundwater recharge/discharge and potential zones for development. The structural hills, residual hills and linear ridges constitute runoff zones, whereas the burried pediments and pediments represent zones of infiltration. Intermontane valleys, alluvial plains and valley fills act as discharge zones. The study reveals that valley fills possess good to very good groundwater prospects,
followed by alluvial plains and buried pediments which seem to possess moderate to good groundwater prospects. Lineaments that are present on the hilly terrain (plateau) and cut across some of the tributaries may also prove to be moderately potential zones as they allow surface water to infiltrate through weak zones, otherwise the plateau has poor groundwater potential. Nearly 100 lineaments have been demarcated on the Vindhyan plateau, varying in length from a few meters to more than one kilometer. The general trend of the majority of the lineaments is NE-SW with a few trending in NW-SE as well. Lineament density of an area can indirectly reveal the groundwater potential of that area since the presence of lineaments usually denotes a permeable zone. High values of lineaments density are recorded in the southern and south eastern parts of the study area having moderate groundwater prospects. Low lineament density is found in some isolated areas in the eastern part of the watershed. The hydrogeomorphic units in the area corroborate well with the existing groundwater conditions and geomorphology of the area.

The groundwater prospects maps derived from integration of geology, hydrogeomorphology and lineament suggests that Narauli and Rudawal sub-watersheds fall under moderate to good groundwater category. Bankukara, Tarsuman, Nahro, Seupura and Thanadung fall in the poor to moderate groundwater prospects category since their major area falls under poor to moderate groundwater prospects zone.

The present study makes an attempt to correlate morphometric parameters, land use/land cover analysis, groundwater prospects, lineaments, slope/relief, to
obtain results for watershed management practices/measures. Strategies and measures suggested for the study area include crop rotation in Narauli and Rudawal sub-watersheds, since cultivated land is the predominant land use category in these sub-watersheds. Percolation ponds may also be constructed in Narauli and Rudawal sub-watersheds, since they possess conducive lithology in the form of alluvium besides sandy soil. Check dams have been suggested for Bankukara, Tarsuman, Nahro, Seupura and Thanadung sub-watersheds, since these sub-watersheds possess medium to high lineament density as well as high drainage density, moderate to steep slope, and poor to moderate groundwater prospects. The construction of check dams will certainly enhance the availability of surface water during the summer as well as in recharging the aquifer. Plantation activity is suggested for Nahro, Seupura and Thanadung sub-watersheds since open forest/scrub is the predominant land cover category in these sub-watersheds which has seen a decline in its areal extent and needs regeneration and restoration. Rock quarrying should be restricted/banned in Tarsuman, Nahro and Bankukara sub-watersheds, in order to restore the ecological balance.

The suggested measures/strategies are expected to preserve the watershed and sub-watersheds from further deterioration in terms of soil, water and forest resources which will be environmentally and socially beneficial to the local people. This study demonstrates application of remote sensing and GIS techniques in watershed characteristics, LULC change detection, hydrogeomorphic mapping and delineation of groundwater potential zone apart from identification of suitable sites for selection
of check dams/water harvesting structures. The results of the present study may be useful to the planners and decision makers at district and sub-division level for undertaking development work, which may be beneficial to the local community and may bring socio-environmental changes at watershed level.