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Groundwater Recharge Potential Sites in Semi-Arid Region of Man River Basin, Maharashtra State, India: A Geoinformatic Approach

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ABSTRACT

The prosperity of the entire biotic community depends on two broad components of nature; land and water. The basaltic rock is known to have poor storage and transmission capability. It gets fully saturated during monsoon but a situation of rejected recharge results in post-monsoon and early summer months. These aquifers also drain naturally due to high water table gradient formed by sloping and undulating topography. The available and new groundwater recharge potential zones can better augment by adopting a scientific and multi-sectoral approach for making the future plan. The study area encompasses Manganga River basin, bounded between Lat. 17°54' N to 17°00' N and Long. 74°27' E to 75°31' E. The study area is in basaltic terrain with undulating topography. The spatial and non-spatial data generated based on various thematic maps such as geology, lineament density, geomorphology, slope, drainage buffer, land-use land-cover, soil texture and soil erodibility have been prepared using satellite data. The groundwater prospects maps generated by overlay analysis of the spatial thematic maps were grouped into five classes and their distribution are: very good/excellent, good, moderate, poor and very poor. The results show that a major portion of the study area falls in the category 'poor' followed by 'very poor'. Based on the outputs derived from groundwater recharge potential zones, an action plan for watershed development in the study area has been suggested like the development of percolation/water retention ponds at the identified sites and tube/bore/open wells along the dense lineament zones. The aspect related to conjunctive use, groundwater legislation, the involvement of NGO'S, women and community participation, mass awareness, adoption of advanced irrigation system etc. will play an important role in conserving and developing the precious water resources. .

INTRODUCTION

Geoinformatics has been described as "the science and technology dealing with the structure and character of spatial information, its capture, its classification and qualification, its storage, processing, portrayal and dissemination, including the infrastructure necessary to secure optimal use of this information" or "the art, science or technology dealing with the acquisition, storage, processing production, presentation and dissemination of geoinformation". Geoinformatics is integrated studies of remote sensing, Geographic Information System (GIS) and Global Positioning System (GPS). Remote sensing is the art and science of acquiring images of the earth using sensors on aeroplanes or satellites. These images have capabilities for manipulating, analysing and visualizing in a remote sensing software. Remote sensed imagery is integrated within a GIS. A geographic information system (GIS) is a computer-based tool for mapping and analysing feature events on the earth. GIS technology integrates common database operations, such as query and statistical analysis, with maps. GIS manages location-based information and provides tools for display and analysis of various statistics, including population characteristics, economic development opportunities, and vegetation types. GIS allows linking databases and maps to create dynamic displays. Additionally, it provides tools to visualize, query, and overlay those databases in ways not possible with traditional spreadsheets. These abilities distinguish GIS from other information systems and make it valuable to a wide range of public and private enterprises for explaining events, predicting outcomes, and planning strategies. GPS is a satellite-based radio navigation system that provides geolocation and time information to a GPS receiver anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites. In this paper, a geoinformatics approach has been taken to delineate groundwater recharge zones in the study area.

STUDY AREA

Man River is the right bank tributary of the south-easterly flowing Bhima River. The Man River basin spatially occupies parts of Sangli, Satara and Solapur districts of Maharashtra state and is situated between 17°00' to 17°52' N latitude and 74°25' to 75°30' E longitude (Fig. 1). Man River has its origin (head) in the Mahadeva Hills at an altitude of 1054m ASL. The total catchment area of the basin is about 4,626km^2 and the stream length is 154km. It is flowing over basaltic stratum, known as Deccan Plateau which is the eastern part of Western Ghats (Sahyadri Mountain) formed by Quaternary cymatogenic upwarp during the formation of West Coast Fault (WCF) system in the Arabian Sea (Powar 1993). The sea-facing scarp of the eastern fault block of WCF recedes eastward due to weathering, and forms a strip of a low-lying area known as Konkan Coastal Belt (KCB). Hence, Western

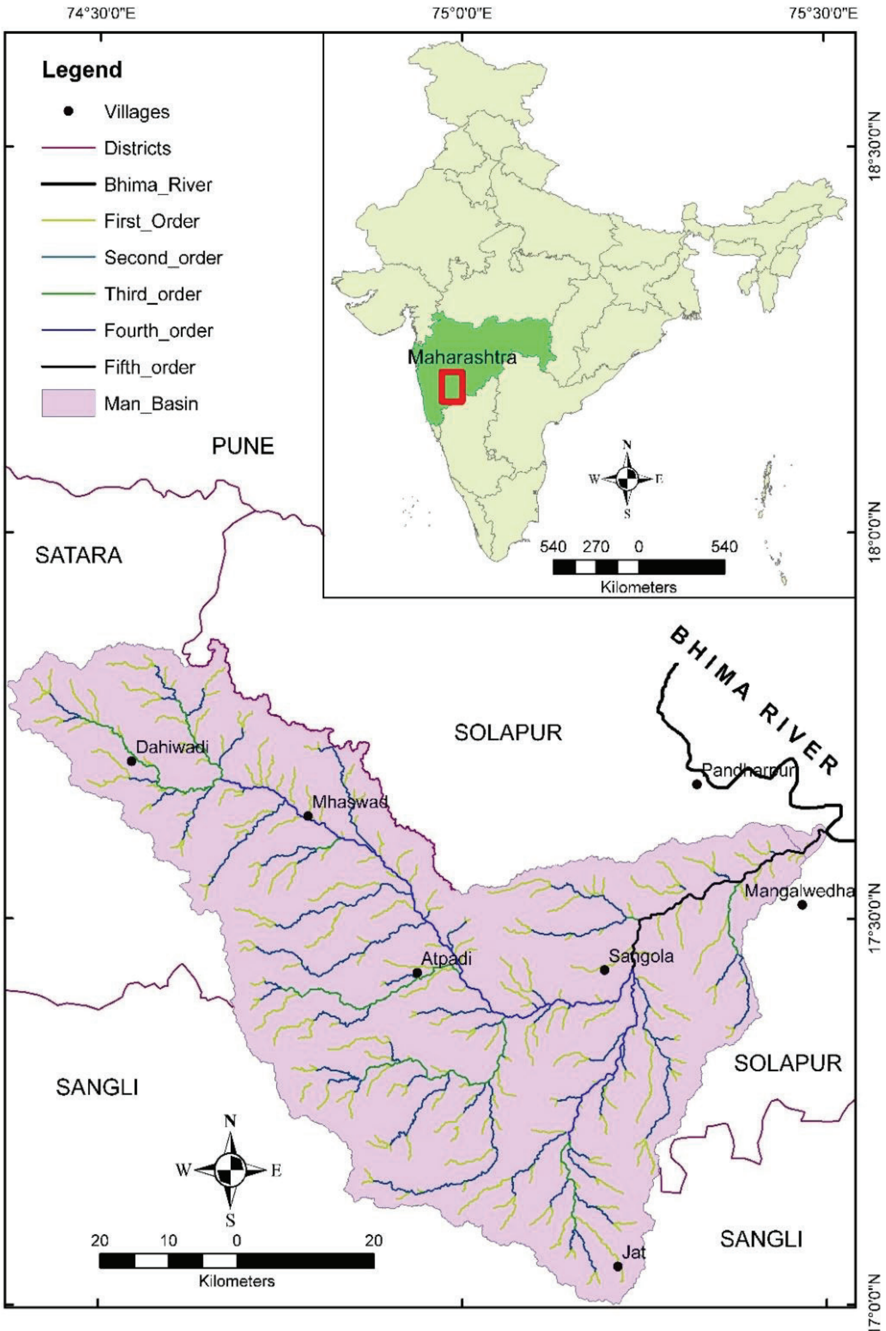

Fig. 1: Location map of Man River basin.

Ghats forms a major drainage divide between westward and eastward flowing river systems. The eastward flowing rivers are longer than westward flowing rivers, which ultimately join Arabian Sea (west coast) and Bay of Bengal (east coast) respectively. The Western Ghats develops rain shadow zone of SW monsoon in the major parts of central and eastern Maharashtra state.

Being a part of the rain shadow zone, the Man River basin experiences dry, semi-arid tropical monsoon type of climate (IMD 2005). According to agro-climatic classification, the study area falls in scarcity zone (Kalamkar 2011). The Man River basin receives annual rainfall between 500 and 700mm, of which 90% precipitation received during June to October months of the SW monsoon season. About 50% precipitation is received during September to October. The monsoonal rainfall pattern is bimodal. The potentially high evapotranspiration rate is because of the high temperature throughout the year. Occasionally flash flood generates and recharges the groundwater. Characteristically, the Man River basin is in the zone of lowest annual rainfall (<600mm) and highest annual water deficit (>900mm) and has its source (head) in lowest rainfall zone, admits it in the class of chronic to the severe drought-prone zone of the semi-arid river basin. The vegetation cover is sparse and is dominated by thorny vegetation, shrubs and grasses. *Acacia* is the most common naturally growing species in the area.

Lithologically, the Man River basin constitutes horizontally disposed "aa type simple" basaltic lava flows of Upper Cretaceous to Lower Miocene origin. At some places, two flows are separated by red bole bed. The red bole bed comprises clay which was deposited between two lava eruptions, and forms a district hydrogeological unit as it can receive, stock and transmit water due to the inherent physical characteristics like porosity and permeability. Recent alluvial formations (2 to 12m thick) overlie basaltic traps. The detrital material consists of silt, clay, silt, sand and gravel, occurring as lenses or patches along the major stream courses. Due to its limited areal extent alluvium do not constitute as potential aquifers.

The basaltic flows derive its status as an aquifer based on its secondary porosity in the form of vesicles, fractures, well developed interconnected jointing pattern, cooling joints and decomposed material (murum) (Powar 1981). Characteristically, a flow has an upper vesicular and amygdaloidal part, a middle part with horizontal and vertical sets of joins and massive and un-jointed lower part. The top-soil overlie on decomposed basaltic material. Factors playing the vital role in the occurrence and movement of groundwater are topography, nature and extent of weathering, jointing and fracture pattern, thickness and depth of occurrence of vesicular basalts. The shallow aquifers in the area are phreatic and unconfined and occur at the depth of 10 to 15m. At places, potential zones encounter at deeper levels in the interconnected fractured zone, which are generally confined down to 60-90m.

Hydromorphologically, the study area has been classified as highly dissected undulating highlands, moderately dissected gently sloping terrain, poorly dissected plain and low land valley fills. Highly dissected undulating highlands (hillocks) forms major run-off zones, moderately dissected gently sloping terrain unit forms recharge zones and poorly dissected plain and low land valley fills are groundwater storage zones (Fig. 2).

The Man River basin is tectonically disturbed (Chandrasekhar 1991), which is dictated by the evidences such as 1. Presence of the combination of dendritic and rectangular drainage pattern, 2. River flows through the structurally controlled valley throughout its course after Najre village, 3. Lengths of right side tributaries are more than lengths of left tributaries is indicative of asymmetric drainage basin and eastward tilt of the drainage basin, 4. The Man river flowing all along its course in south-easterly direction but abruptly changes its course halfway to follow north-easterly direction suggesting stream capture, 5. River has palaeo-channels throughout its course between Najre and Kadlus as well as abandoned channels are observed at Hatid, Shegaon, and Walekhind villages, 6. Thick alluvium covered black cotton soil has been observed near Mangalvedha village at the confluence of Man River and Bhima River and 7. Presence of Sangola gravity 'high'. The Man River basin shows high-level erosional surfaces than the surrounding tributaries of Bhima River and Krishna River. This uniqueness may be one of the causes of groundwater scarcity. The palaeo-channels located in the basin at Mangewadi, Kadlus, Sonand, Baldongi and Balgaon could be the potential recharge zones. These tectonic weaknesses could be the best groundwater recharge zones.

MATERIALS AND METHODS

Delineation of groundwater recharge zones has been carried out using geoinformatics techniques for Man River basin. The groundwater occurrence and movement are directly or indirectly controlled by terrain characteristics such as lithological units, structural disposition, geomorphic set-up, surface water condition, vegetation, etc. Groundwater occurrence being a subsurface phenomenon, its identification is indirectly based on the analysis of some directly observable terrain features. These can be well understood with the help of remote sensing (RS). The revolution in computer technology, the advent of Remote Sensing (RS) and Geographic Information System

(GIS) offers great scope for handling and analysing spatial data including the delineation of groundwater recharge zones (Prasad et al. 2008).

Visual interpretation and digital image analysis of satellite data help in the indication of groundwater recharge zones through 1) Identification of geological structures and the hydrophysical properties, 2) Water-bearing geological formations and water enrichment, 3) Areas of recharge, 4) Places of discharge, 5) Nature of outlet of groundwater to the surface, 6) Depth and conditions for the occurrence of groundwater and 7) Direction of movement.

Although remote sensing (RS) data do not directly detect deeper subsurface resources, it has been effectively used in groundwater exploration as RS data aid in drawing inferences on groundwater potentiality of the region indirectly. The freshwater surface resources are normally considered to form subsurface water resources. These sources of surface water are directly detected by satellite RS data as water absorbs most of the radiation in the infrared region, which helps in the delineation of even smaller water bodies. Vegetation, which is easily detected through spectral reflectance, is indicative of the water saturation and moisture of the ground. RS data help indirectly by giving certain ground information that aid in drawing inferences on groundwater recharge zones of the area.

Primarily, the infiltration capacity of the soil determines the groundwater potentiality. The speed of infiltration is dependent upon mainly on porosity and permeability of the soil and the velocity of the surface run-off. Infiltration reduces to a great extent for the steeply sloping ground

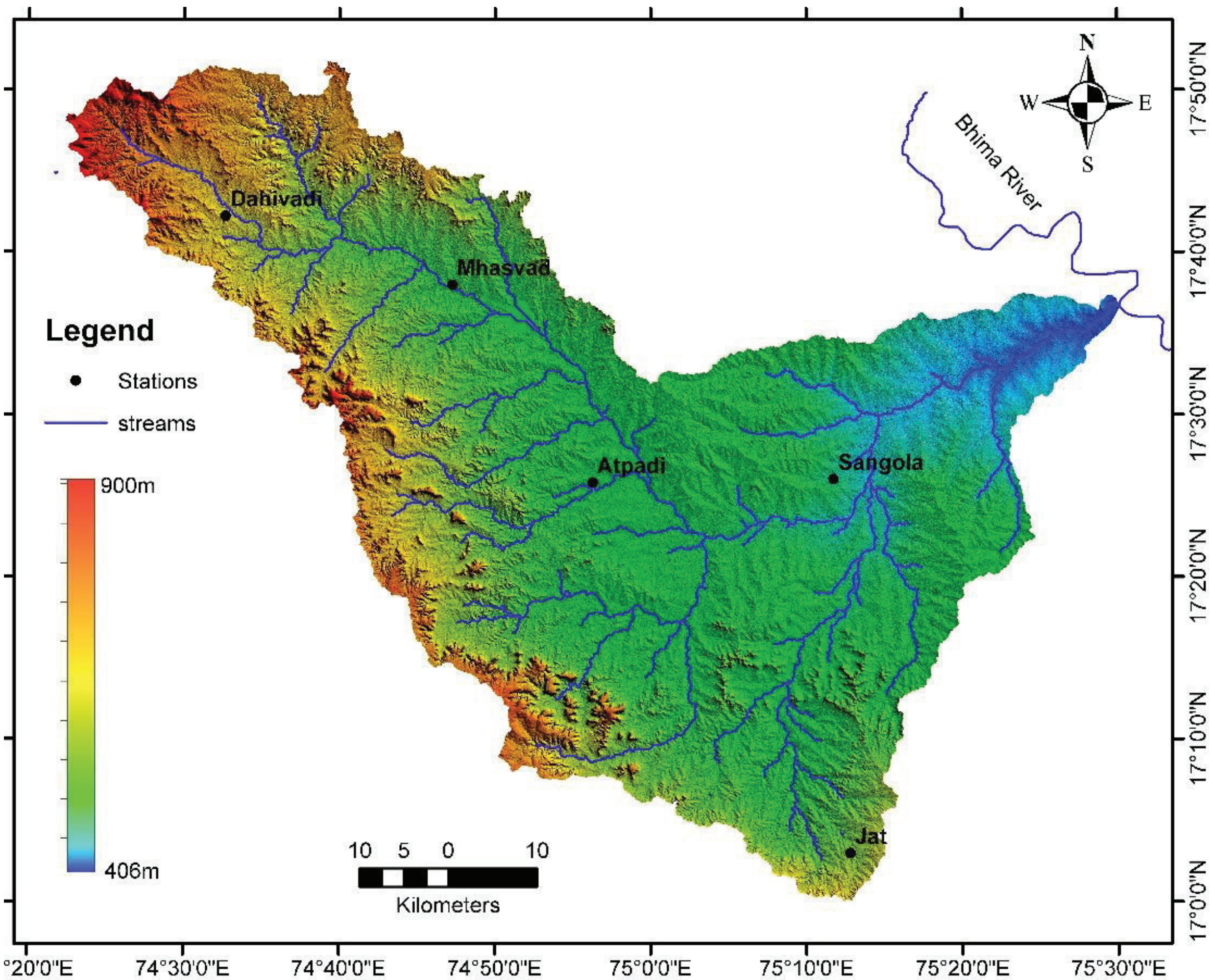

Fig. 2: Colour coded Digital Elevation Model (DEM) of Man River Basin with locations of rain gauge stations.

surface as the velocity of surface run-off increases sharply. Also, a vegetative cover gives a higher infiltration capacity compared to barren lands. Factors which help in the storage of groundwater are 1. infiltration capacity, 2) porosity and permeability of the soil, 3) velocity of the surface run-off, 4) vegetation (vegetative cover increases infiltration capacity) and 5) thickness of the porous and permeable zone.

Digitally enhanced products of the LANDSAT 7 ETM+ satellite images have been used in this study for the delineation of land-use/land cover and geomorphology of the study area. Survey Map of India (1:50,000) have been used to delineate the drainage and contour lines. The orders were designated to each stream following Strahler stream ordering technique (Strahler 1964). Buffers were generated for each stream proportional to their groundwater prospects. DEM was generated through 20m contour lines and used to derive the slope (%). The Soil map published by National Bureau of Soil Survey (scale 1:5,00,000) and the geological map published by Geological Survey of India (scale 1:2,50,000) were used to generate the soil and geology map of the study area. Various thematic maps prepared for the study area were verified in the field with the help of handheld GPS instrument. The spatial database layers like geomorphology, lineament density, slope in degrees, land use/land cover, rainfall erosivity and soil type were used to delineate the groundwater recharge zones. Appropriate weightage was assigned to each of the map layers based on their groundwater prospects. Ranks were also assigned to each subclasses of the thematic maps (Table 1). Lithologically the entire study area exposes basalt stratum uniformly and there is no change in lithology, hence lithological thematic map has not been prepared.

All the thematic maps were converted into raster maps (30 x 30 m grid) and superimposed by weighted overlay method (rank and weightage wise thematic maps), for the delineation of the groundwater recharge zones. The groundwater recharge zones were grouped into five classes; very high, high, moderate, low, and very low. Dug well inventory has been carried during the pre and post-monsoon to understand the hydrogeology of the study area. The wells were located in the field using a Garmin handheld GPS. Fig. 3 depicts the illustration of the methodology of the study.

RESULTS AND DISCUSSION

The results of thematic maps prepared from the special database are as follows.

Table 1: Weightage and scores assigned to various parameters and subclasses for assessing groundwater recharge zones.

Sr No.	Parameters	Sub Classes (map units)	Score	Weight %
		Man River Channel	5	
1	Geomorphology	Valley	4	30
		Lower Plateau	3	
		0.0 to 0.25	2	
2	Lineament density	0.26 to 0.50	4	20
		0.51 to 0.75	5	
		< 5 Gentle	5	
3	Slope (degree)	5- 20 Moderate	3	20
		>20 Steep	0	
		Perennial river / Sand Riverine	5	
		Irrigated crop land	3	
4	Landuse/ Land cover	Rainfed cropland	2	10
		Shrubs / grasses	1	
		Bare areas	1	
		425-450	2	
5	Rainfall erosivity	451-470	4	10
		471-490	5	
		Deep black	5	
6	Soil Type	Medium black	3	10
		Coarse shallow	3	

Geomorphology: Geomorphologically the area represents rolling topography by residual hillocks formed by denudational processes 800mto 1054m ASL covered by basaltic lava flows. The hill slopes are gentle to steep in nature. The intermittent valleys or pediment zones are represented by stream courses and agriculture fields. The lower plateau, valleys and river channel are the predominant geomorphic units (Figs. 1 and 2). The lower plateau (76.5%) indicates moderate groundwater recharge. The valleys (21.86%) are landforms formed by fluvial activity proved to be good recharge potential zones. They show recent sediments deposited by the streams. This geomorphic unit possesses high groundwater recharge potential. The geomorphic unit containing river channels (1.64%) in alluvial formation possesses very high groundwater recharge potential.

Lineament density: Features of structural origin are structural hills, ridges and valleys. Structural ridges are poor groundwater recharge zones. Whereas subsurface fractures

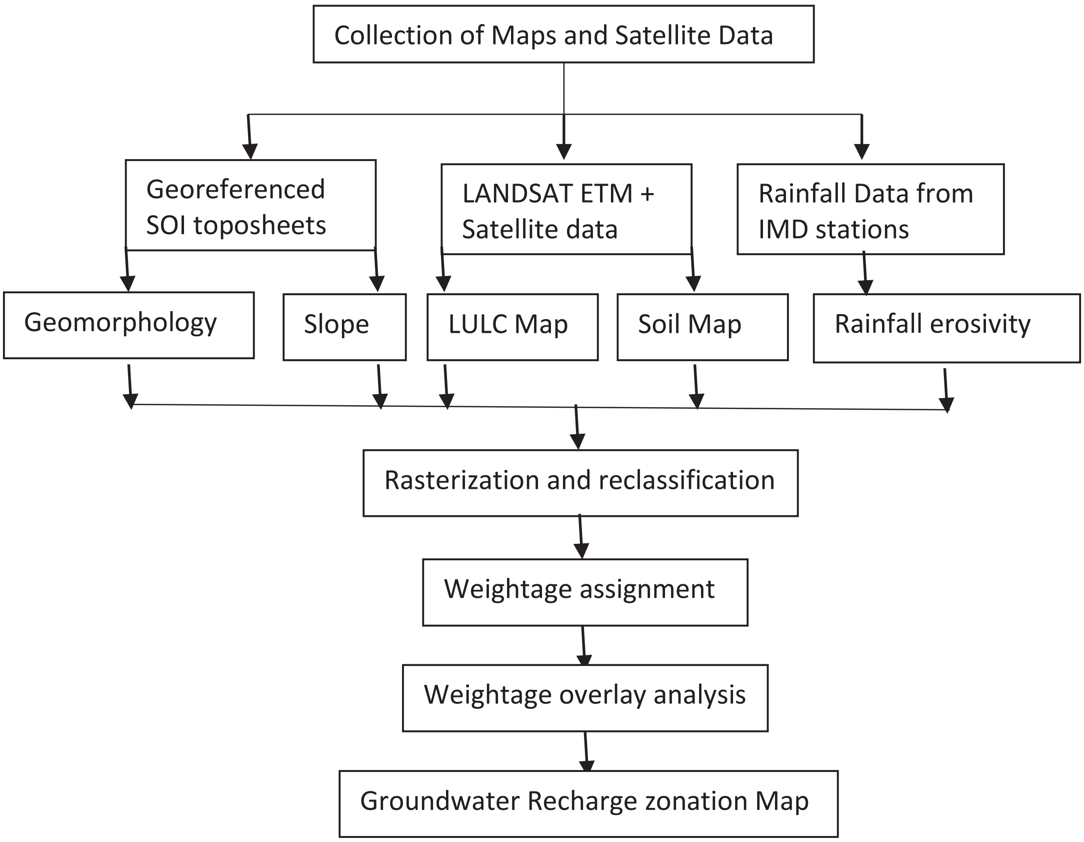

Fig. 3: Flow Chart of the methodology adopted in the present study.

Table 2: R-factor (Rainfall erosivity) in the study area.

Sr. No.	Rain gauge stations	Rainfall intensity (I) in inches/30 min/year						R-Factor
		2012	2013	2014	2015	2016	2017	
1.	Jat	0.18	0.63	0.38	0.15	0.58	0.42	426
2.	Atpadi	0.18	0.36	0.36	0.23	0.27	0.56	475
3.	Sangola	0.25	0.36	0.36	0.23	0.24	0.56	466
4.	Dahiwadi	0.90	0.23	0.32	0.22	0.20	0.39	489
5.	Mhaswad	0.90	0.23	0.32	0.22	0.20	0.39	489

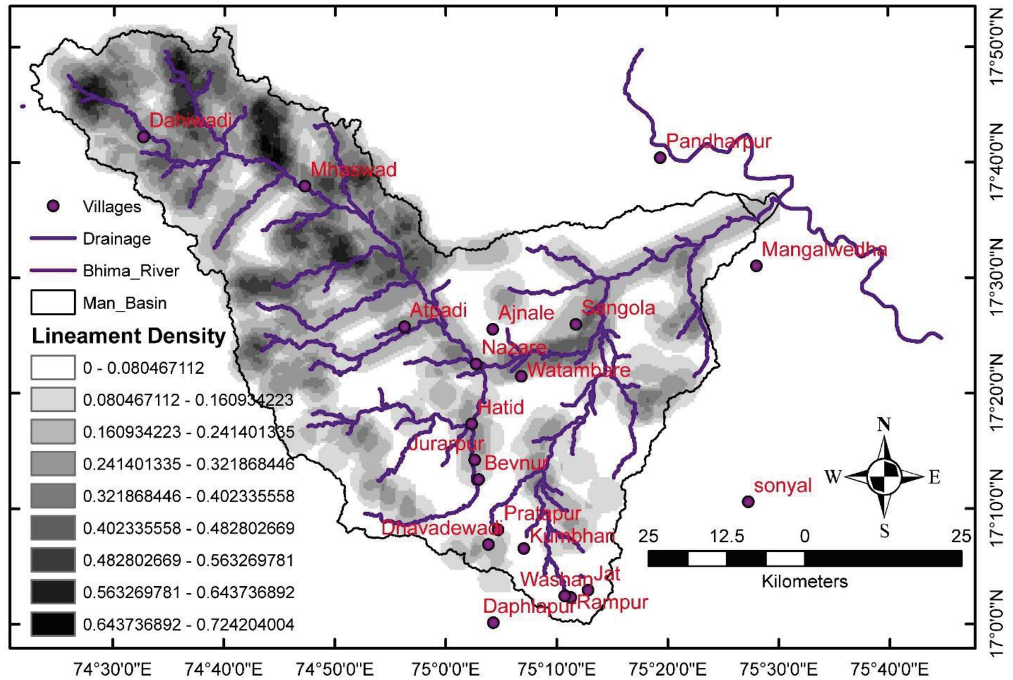

Fig. 4: Lineament density map.

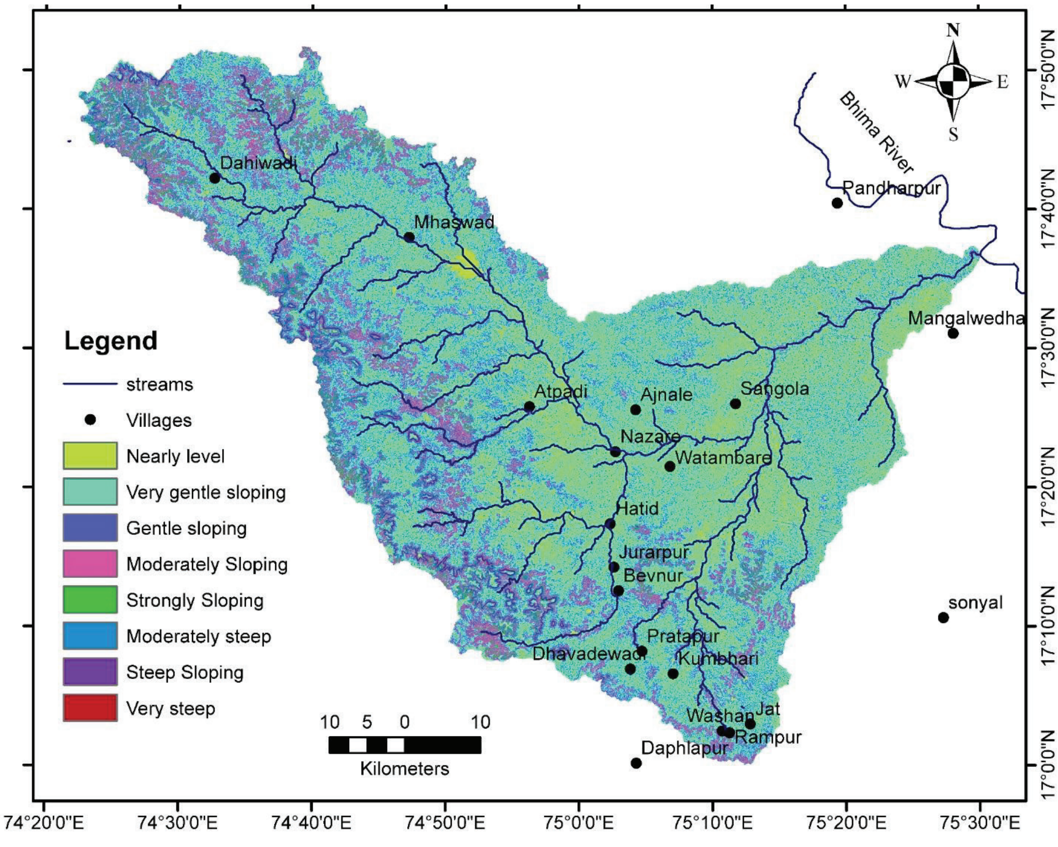

Fig. 5: Classified slope map of the study area.

and joints qualify as good groundwater recharge zones. The lineaments are surface expressions of subsurface weak zones such as fractures, joints, faults, etc. and are observed as faint lines of straight or curved nature, change in grey level tones, linear growth of vegetation and abnormal straight course of the stream, which can be accurately mapped after ground check. Mapping of lineaments can be achieved by the edge enhancement process called "spatial filtering" of satellite data. Prasad & Sivaraj (2000) used IRS LiSS-III satellite data and aerial photographs to locate structurally controlled weaker zones, i.e. lineaments suitable for groundwater accumulation. The density variation of lineaments was achieved in the ArcGIS environment and presented as a thematic map (Fig. 4). The region of higher lineament density is in the dark shade which is considered as potential groundwater recharge zones.

Slope: Slope plays a key role in the groundwater occurrence as infiltration is inversely related to the slope (Mondal et al. 2009). A major portion (84.21%) of the Man River basin falls under 'Gentle slope' class (0 to 5 per cent). 'Moderate slope' (5 to 20 percent) constitute 15.69% and 'Steep slope' (> 20 percent) form only 0.1% of the total area (Fig. 5). The dominance of the lower slope classes (0 to 20 %) is a favourable feature for groundwater recharge and its potential depends on underlying lithology as well as geomorphology. A break in the slope *(i.e.* steep slope followed by gentle slope) generally promotes an appreciable groundwater infiltration (Saraf et al. 1998)

Land use land cover: The land use in the study area is classified in to nine types (Fig. 6). The major area is covered by mosaicked vegetation, shrubs and grasses (35.24%), followed by irrigated cropland (24.39%) and rain-fed and mosaicked

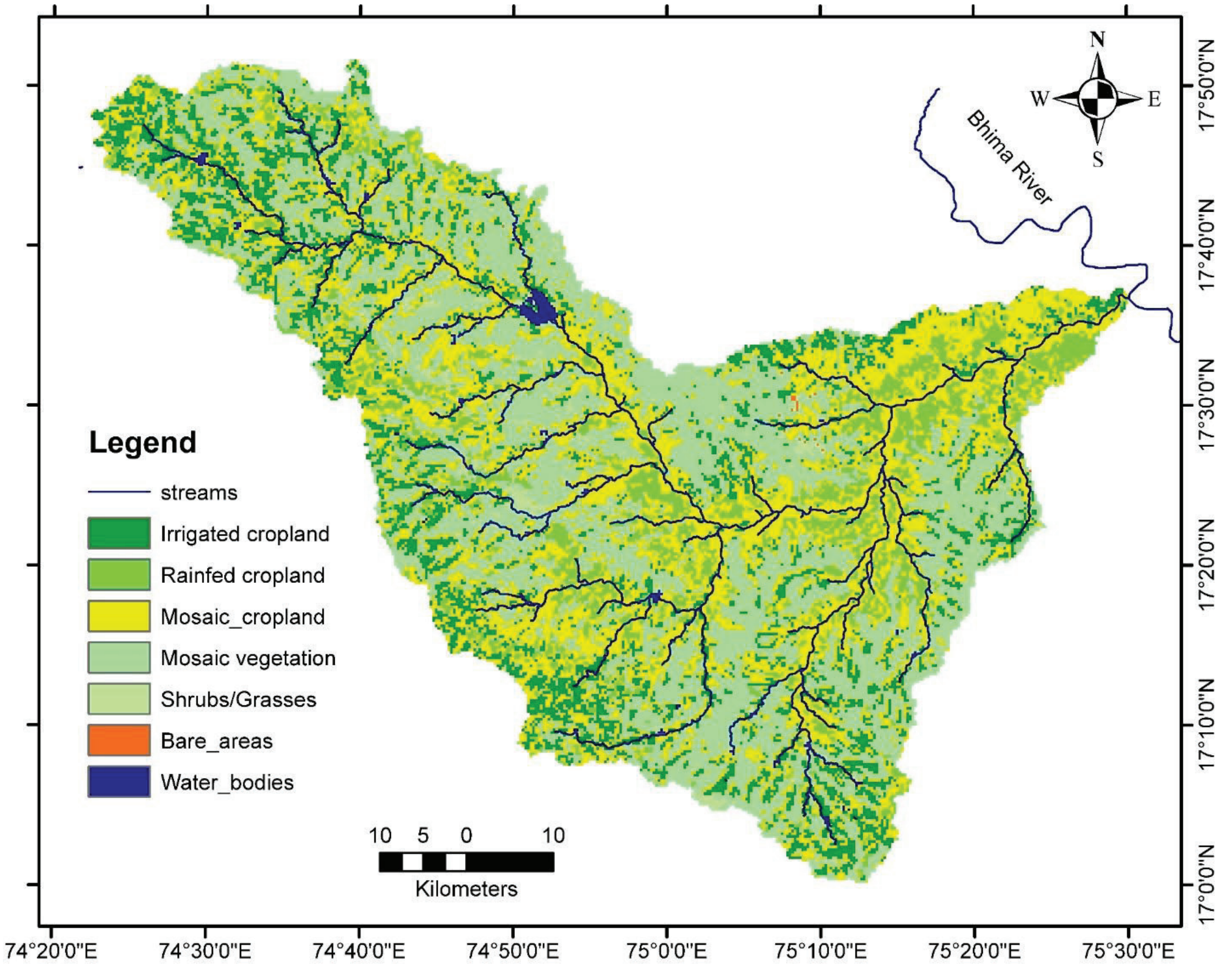

Fig. 6: Land Use Land Cover (LULC) map of the study area.

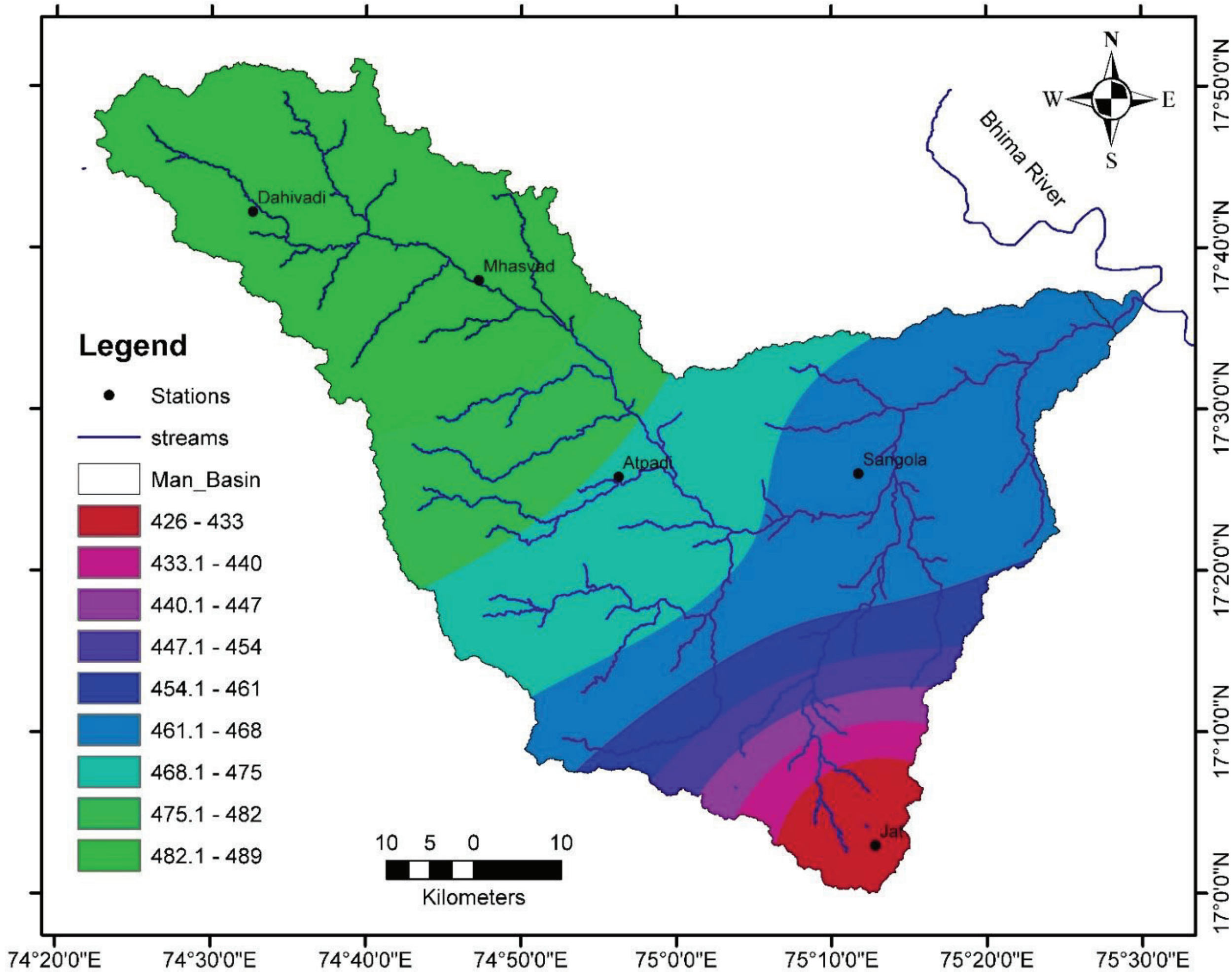

Fig. 7: Rainfall erosivity (R-factor) map of the study area.

cropland (11.40%) of very good water potential, and barren land (10.23%), etc.

Rainfall erosivity (R): It is the annual total value of the erosion index (EI_{30}) for a particular location. Computation of EI_{30} from recording type rain gauge chart is described by Singh et al. (1981). It is the average annual summation (EI) values in a normal year's rain. The erosion-index is a measure of the erosion force of specific rainfall. When other factors are constant, storm losses from rainfall are directly proportional to the product of the total kinetic energy of the storm (E) times its maximum 30-minute intensity (I). Storms less than 0.5 inches are not included in the erosivity computations because these storms generally add little to the total R value. R factors represent the average storm EI values over a 22-year record. R is an indication of the two most important characteristics of a storm determining its erosivity, the amount of rainfall and peak intensity sustained over an extended period. The erosivity of rainfall varies greatly by location. The rainfall record for six years was collected from rain gauge stations (Jat, Atpadi, Sangola, Dahiwadi and Mhaswad) in the Man River basin. The obtained data were calculated for rainfall erosivity using equation 1 and presented in Table 2.

After determining the E and I_{30} values for each storm throughout the record, they are to be multiplied by each other and then summed on a per year basis. The average of these annual sums over the period of record is the R-factor.

$$R = \frac{1}{n}\sum_{j=1}^{n}\left[\sum_{K=1}^{m}(E)(I_{30})\right]_j \quad \ldots(1)$$

Where, K is the number of the individual storms up to m which is the total number of storms in a year, and j is the

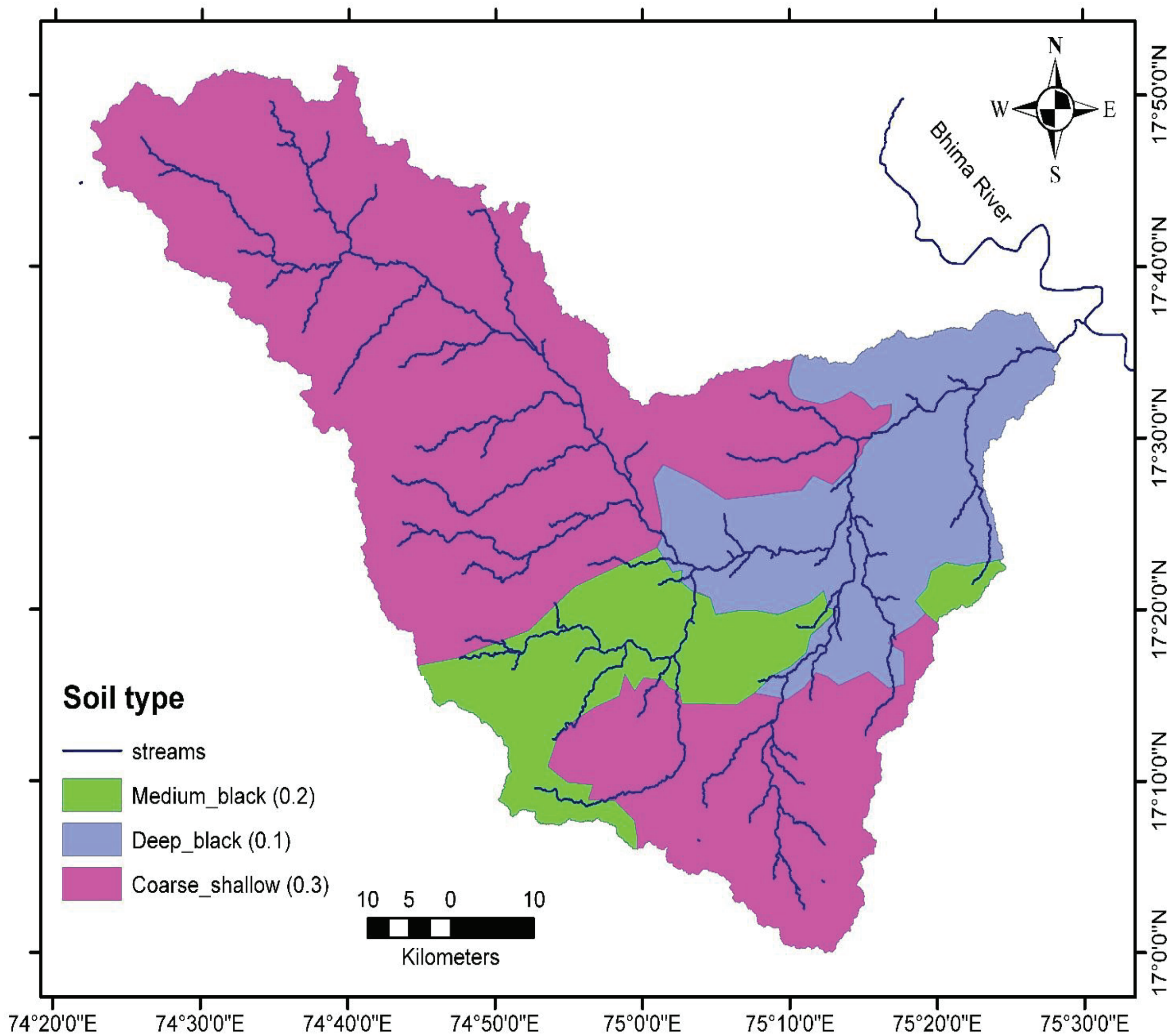

Fig. 8: Soil map of the study area.

number of the year up to n which is the total number of the years over which data was collected.

The thematic map of rainfall erosivity is prepared (Fig. 7) using the data from Table 2. The region of higher rainfall erosivity resist infiltration, hence, found to be non-potential groundwater recharge zone. Soil conservation practices should be undertaken in these regions to increase the infiltration rate.

Soil type: Three types of soils are generally seen in the Man River Basin, namely; medium black, deep black and coarse shallow (Fig. 8). Coarse shallow type of soil constitutes the most predominant region in the study area. The topsoil and the subsoil are highly pervious and facilitate good recharge. Riverine alluvium soil is seen all along the banks of Man River. They predominantly contain sand fraction. Brown hydromorphic soil is mostly confined to valley bottoms of the undulating portions. They have been formed as a result of transportation and deposition of material from the adjoining hills and slopes, and also through deposition by rivers. The deep black soil has a high water holding capacity which facilitates infiltration, while medium black and coarse shallow soils have moderate to low infiltration capacities respectively.

Potential groundwater recharge zones: Groundwater recharge zones (Fig. 9) were delineated through the integration of the reclassified raster map layers of geomorphology, lineament density, slope, landuse/land cover, soil erosivity and soil type using the weighted overlay analysis in Arc-GIS platform. The result shows that the distribution of groundwa-

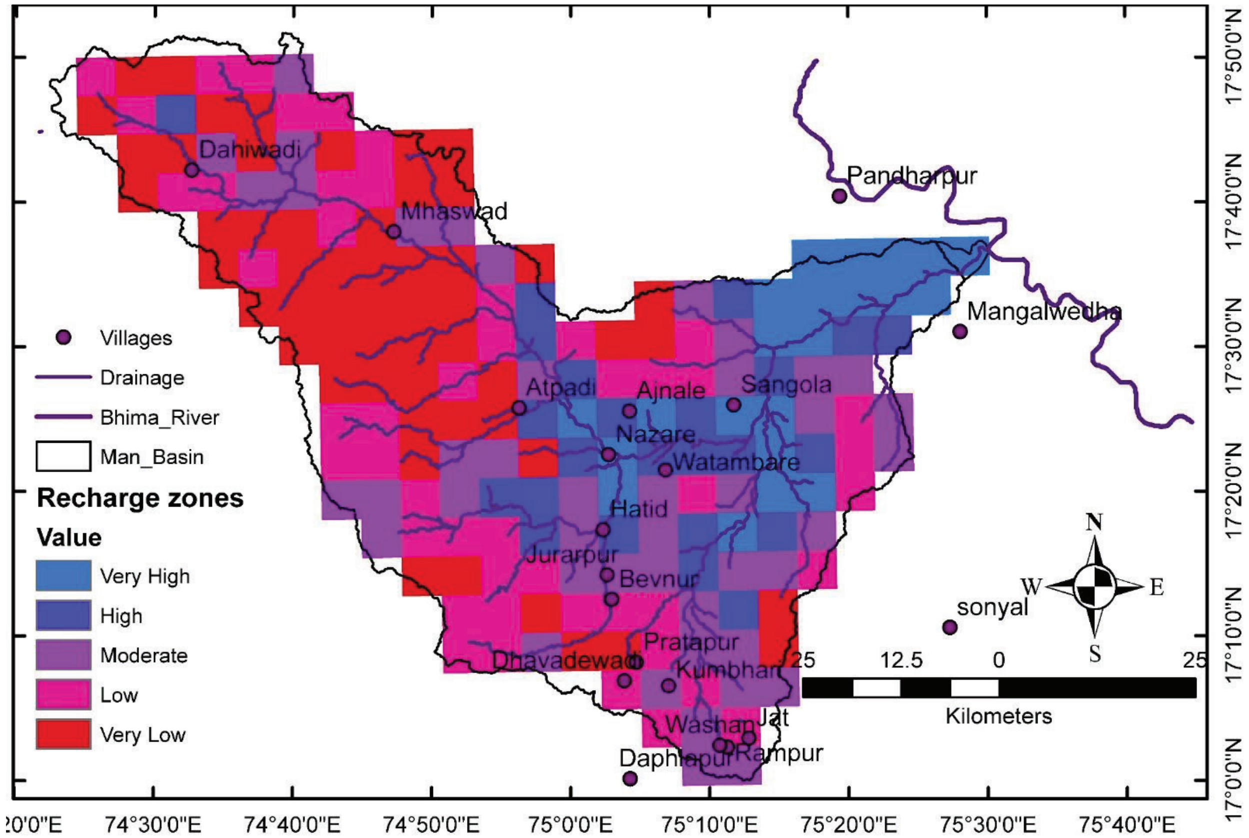

Fig. 9: Potential groundwater recharge zones in the Man River basin.

ter prospect 'very high and high' is confined to only 16.49% of the study area, falls in valleys close to the perennial higher order streams at lower reaches of the Man river. The major portion of the study area falls in 'moderate' (41.09%) class followed by 'low to very low' (42.42%).

CONCLUSIONS AND RECOMMENDATIONS

The occurrence and movement of groundwater in an area are largely controlled by rainfall, and the characteristics of the terrain features like landforms, lineaments or structural control, soil type, topography, landuse/land cover, soil erosivity, etc. The study demonstrated the utility of RS and GIS technique in delineating potential groundwater recharge zones for a geographical area of the semi-arid region. The groundwater prospect zones delineated for Man River basin will serve as a base for further artificial recharging, water shade management and soil conservation for planners.

Following recommendations are suggested:

- Hilly areas and foothills should follow both soil and water conservation activities such as continuous contour trenching (CCT), Nala bunds, Gabion structure, Vegetative bunds, Loose boulder bunds, Terracing etc. The construction of medium and minor irrigation project at foothills are also feasible with lined or pipe canal system.
- Plain or pediment: This area requires groundwater augmentation by constructing percolation tanks, cement plugs and K.T.Weirs, at appropriate and need-based locations on scientific lines.
- The area showing rising water level trend and having shallow water level ranging from 3m to 6 m bgl during pre-monsoon needs groundwater development at favourable locations.
- Semi critical and over-exploited watersheds intensive site-specific artificial recharge measures coupled with public awareness at every level is the need of the hour.
- Town/City/Urban areas: the rooftop rainwater harvesting for artificial recharge should be made mandatory. So that the available resources for drinking water supply should remain sustainable.

- Women and community participation, mass awareness, adoption of advanced irrigation system etc will play an important role in conserving and developing the precious water resources.

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