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Integrated Water Resource Development Plan for Sustainable Management of Mayurakshi Watershed, India using Remote Sensing and GIS

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Abstract Integrated watershed management requires a host of inter-related information to be generated and studied in relation to each other. Remote sensing technique provides valuable and up-to-date spatial information on natural resources and physical terrain parameters. Geographical Information System (GIS) with its capability of integration and analysis of spatial, aspatial, multi-layered information obtained in a wide variety of formats both from remote sensing and other conventional sources has proved to be an effective tool in planning for watershed development. In this study, area and locale specific watershed development plans were generated for Mayurakshi watershed, India using remote sensing and GIS techniques. Adopting Integrated Mission for Sustainable Development (IMSD) guidelines, decision rules were framed. Using the overlay and decision tree concepts water resource development plan was generated. Indian Remote Sensing Satellite (IRS-1C), Linear Imaging Self Scanner (LISS-III) satellite data along with other field and collateral data on lithology, soil, slope, well inventory, fracture have been utilized for generating land use/land cover and hydro geomorphology of the study area, which are an essential prerequisites for water resources planning and development. Spatial data integration and analyses are carried out in GIS environment.

Keywords Watershed management · Remote sensing · GIS · Water resource development plan

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1 Introduction

Watershed management implies prudent use of all the natural resources to ensure optimum and sustained productivity. Particularly, concern about widespread soil degradation and scarce, poorly managed water resources in Mayurakshi watershed i.e study area has led to the implementation of watershed management activities. In this context, chalking out an Integrated Water Resource Development Plan that involves targeting groundwater potential zones and identifying suitable sites for artificial recharge assumes importance and holds the promise of making watershed management simpler and more effective. Formulation of proper management plans requires reliable and up-to-date information about various factors such as morphologic (size and shape of the watershed, drainage parameters, topography), soil and their characteristics, land use and land cover etc., that affect the behavior of a watershed. Further, it is necessary to translate the watershed ecosystem dynamics into predictive statements for the analysis of different spatial information (Rao 1999).

Satellite based remote sensing technology meets both the requirements of reliability and speed and is an ideal tool for generating spatial information needs. However, the use of remote sensing technology involves large amount of spatial data management and requires an efficient system to handle such data. The Geographical Information Systems (GIS) technology provides suitable alternatives for efficient management of large and complex databases. Thus, blending of remote sensing and GIS technologies has proved to be an efficient tool and have been successfully used by various investigators for water resources development and management projects as well as for watershed characterization and prioritization (Chalam et al. 1996; Chaudhary and Sharma 1998; Kumar et al. 2001; Ali and Singh 2002; Singh et al. 2003; Pandey et al. 2004; Suresh et al. 2004). Thus, it is generally accepted that sustainable land and water management must be approached with the watershed as the basic management unit. A few more studies are reported where remotely sensed data had been used for the assessment of soil degradation to devise cost effective methods for soil conservation (Jain and Kothyari 2000; Jain et al. 2001; Baba and Yusof 2001; Fistikoglu and Harmancioglu 2002; Sekhar and Rao 2002; Chowdary et al. 2004; Pandey et al. 2007).

Several studies on groundwater potential zoning using remote sensing and GIS technologies have been conducted both in India and abroad (Krishnamurthy and Srinivas 1995; Jankowski 1995; Krishnamurthy et al. 1996; Shahid et al. 2000; Sener et al. 2005; Solomon and Quiel 2006). Gustafsson (1993) used GIS for the analysis of lineament data derived from SPOT imagery for groundwater potential mapping. Sinha et al. (1990), made a study on an integrated approach for localizing well sites through satellite data analysis and resistivity profiling along with vertical electrical sounding which is based on fracture pattern. Panigrahi et al. (1995), Krishnamurthy et al. (2000), Sreedevi et al. (2001), Rao and Jugran (2003) and Ghayoumian et al. (2005) used remote sensing technologies for demarcating zones suitable for groundwater exploration. Application of GIS for groundwater resource assessment has also been reported by Sander (1997), Teeuw (1999) and others. A comprehensive review on the applications of remote sensing and GIS in ground water management is presented by Jha et al. (2007).

Further, Decision Support Systems' (DSS) show greater promise in the strategic planning of soil conservation efforts and can aid in the selection of appropriate soil conservation practices for agricultural watersheds (Montas and Madramootoo 1992; Saxena et al. 2000; Yoshino and Ishioka 2005). Thus, the potential of satellite remote sensing in various applications related to water resources is well established: hence, it is necessary to use this technology not only for targeting of groundwater potential zones, but also for identifying location specific activities such as percolation tanks, check dams, farm ponds etc. Saraf and Choudhury (1998), envisaged GIS and remote sensing technologies in suitability analysis for artificial recharge sites in the hard rock terrain. Applications of remote sensing and GIS in groundwater management such as artificial recharge have been reported by a limited number of researchers (Saraf and Choudhury 1998; Krishnamurthy et al. 2000; Anbazhagan et al. 2005; Shankar and Mohan 2005). Local specific prescriptions to achieve sustainable development could be arrived by effective utilization of space based remote sensing data suitably merged with other collateral socio-economic data under GIS environment. Thus, the present study was taken up with the objective of generating Integrated Water Resource Development Plan for Mayurakshi watershed of Jharkhand state, India using Remote sensing and GIS, keeping in mind the emerging trend of planning where a natural boundary like a watershed is considered as the basic unit for development. The prime task of the present study involves three major components viz., (a) generation of different thematic layers (b) demarcation of groundwater potential zones, (c) generation of integrated water resource development plan involving area specific and location specific activities using a set of logical conditions under GIS environment.

2 Study Area

Mayurakshi watershed which covers an area of about 1,860 sq. km. falling in Dumka and Deogarh districts of Jharkhand state was considered as the case study area. The study area lies between 24° 05′ to 24° 40′ N latitude and 86° 50′ to 87° 25′ E longitude. The location map of the study area is shown in Fig. 1. The climate of the study area is tropical and it experiences three well defined seasons: (1) hot weather from March to June, (2) rainy season from July to October and (3) winter season from November to February. The average annual rainfall in the study area is nearly 1,411 mm. Most of the soils in the study area are sandy loam, loam and clay loam. Red lateritic soils derived from granite gneiss are also found. Paddy and Maize are main crops in the watershed area.

2.1 Identified Problems and Issues of the Study Area

Problems and issues pertaining to the study area were assessed during the field visits.

2.1.1 Terrain Specific Factors

- The study area has been experiencing soil degradation due to inadequate forest cover, denudation of forest, uncontrolled grazing and neglect of available pasture land.

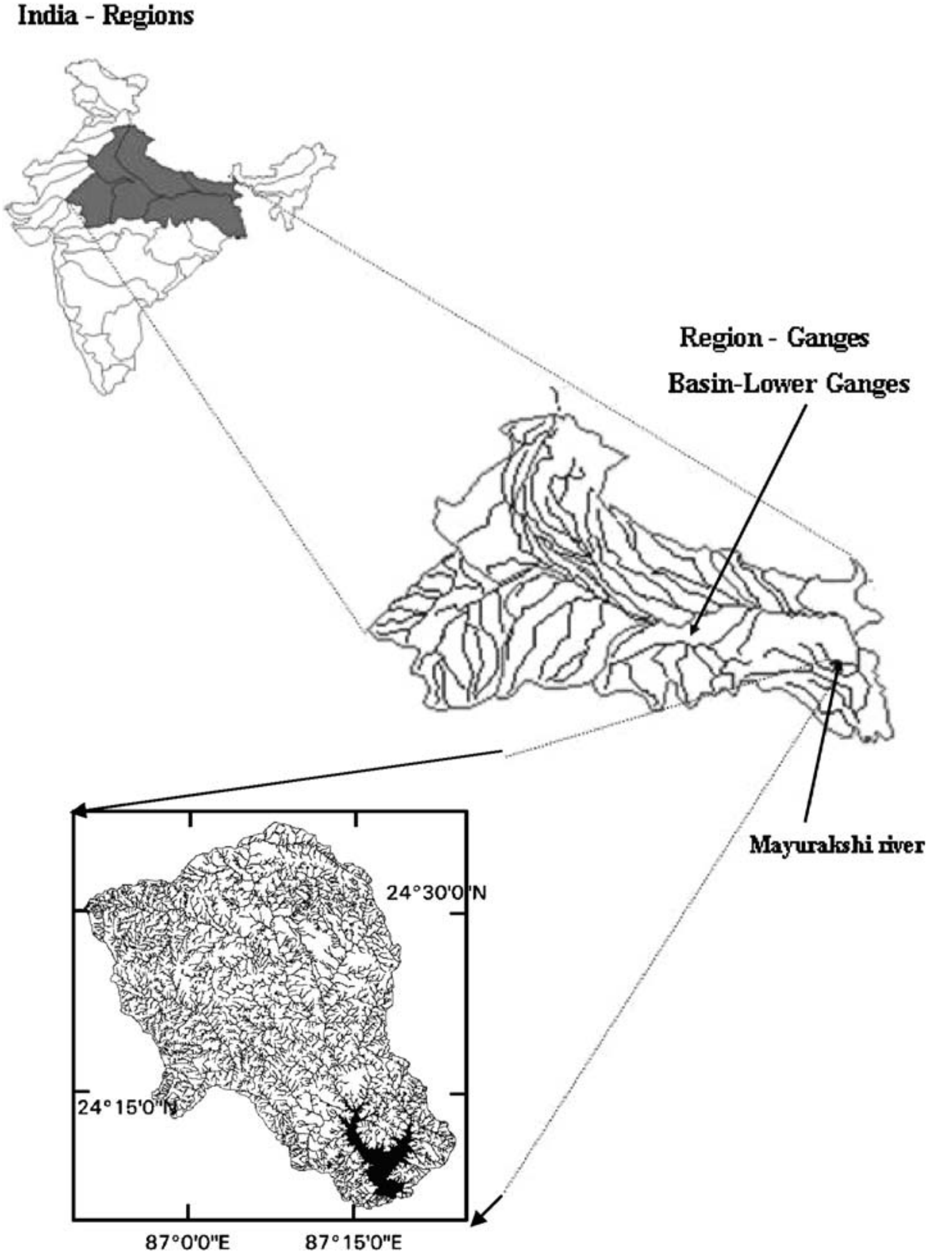

Fig. 1 Location map of the study area

- Geologically comprises hard rocks having adverse hydraulic characteristics and poor to moderate groundwater potential.
- The watershed is characterized by high drainage density /frequency and causing excessive soil erosion and surface run-off.

2.1.2 Socio-Economic Factors

- Predominantly illiterate tribal population and extreme backwardness has made the people insensitive about their problems and their solutions.
- Paucity of land and water resources and industries there by lack of employment opportunities have rendered people an annual migratory community in search of livelihood.
- Poor per capita income thereby poverty has created more complex issues like social exploitation, social conflicts, etc.

2.1.3 Management Based Factors

- Land management is extremely poor. Very thin vegetation cover, large scale deforestation, over grazing and intensive tilling of land slopes have caused alarming rate of soil erosion.
- Groundwater resource potential is time bound and highly localized. Considerable work needs to be done to enhance the recharge through water harvesting structures.

3 Methodology

This approach involves preparation of different thematic maps (resource maps) by using remote sensing data and/or by conventional sources. The critical analysis of thematic maps derived from satellite data interpretation and other collateral data leads to identification of problems and potentials of each of the thematic information in terms of its availability, sensitivity, severity and criticality of the resources for the optimum utilization of the resources. Combining these thematic layers under GIS environment using a set of logical conditions, integrated water resource development map for each watershed was generated; identifying suitable areas for development of groundwater and location of recharge sites depending on the terrain. Boolean logic has been used for the selection of artificial recharge sites. Based on the remotely sensed information and conventional data, the study watershed was further subdivided into a number of microwatersheds of area of 500–1,000 ha depending on specific characteristics of drainage for identifying suitable conservation and management measures and suggesting optimal exploitation of water resources (IMSD 1995). Thus, remote sensing and GIS enables to arrive at natural resource management solutions by adopting a holistic approach.

3.1 Generation of Spatial Database

Inputting the spatial data generated from various sources is foremost step for GIS analysis. In the present study, drainage network, contour map, spot heights, surface water bodies and village location maps were generated from the Survey of India toposheets on 1:50,000 scale. Subsequently, drainage network map and surface water bodies were updated using satellite data (Fig. 2). The drainage is typically dendritic there by reflecting almost homogeneity of lithology. Further, stream ordering suggested by Strahler (1964) was carried out, as it is important parameter in planning of soil conservation measures. Digital Elevation Model (DEM) with a spatial resolution

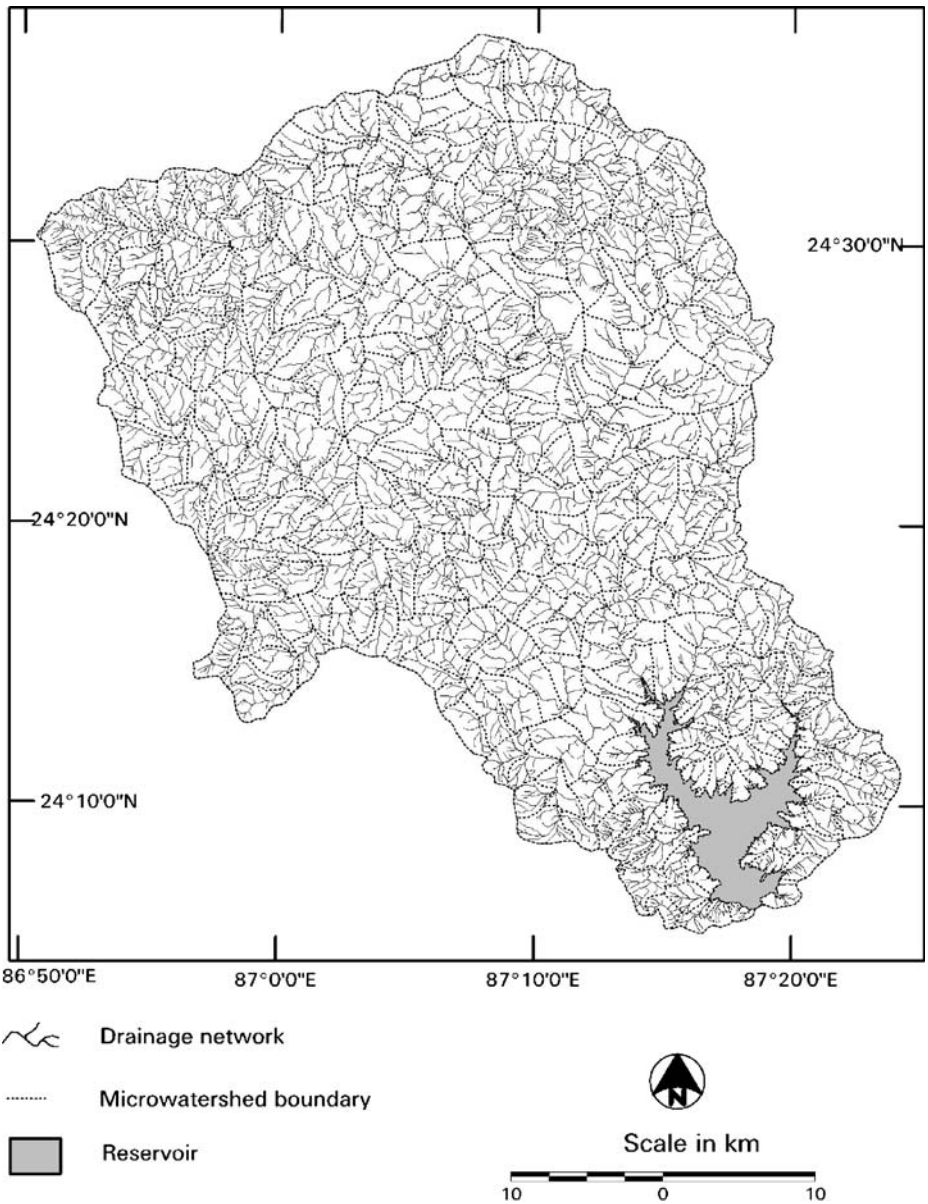

Fig. 2 Drainage network of the study area

of 23 × 23 m (Spatial resolution of IRS–1C LISS-III data) was generated from the digitized contour and spot height coverages for the entire watershed. Subsequently, slope map was generated from the DEM and reclassified as per guidelines of IMSD (1995) (Fig. 3). Soil map was digitized from the published soil map of National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) and presented in Fig. 4. The detailed soil characteristics of the study area are presented in Table 1.

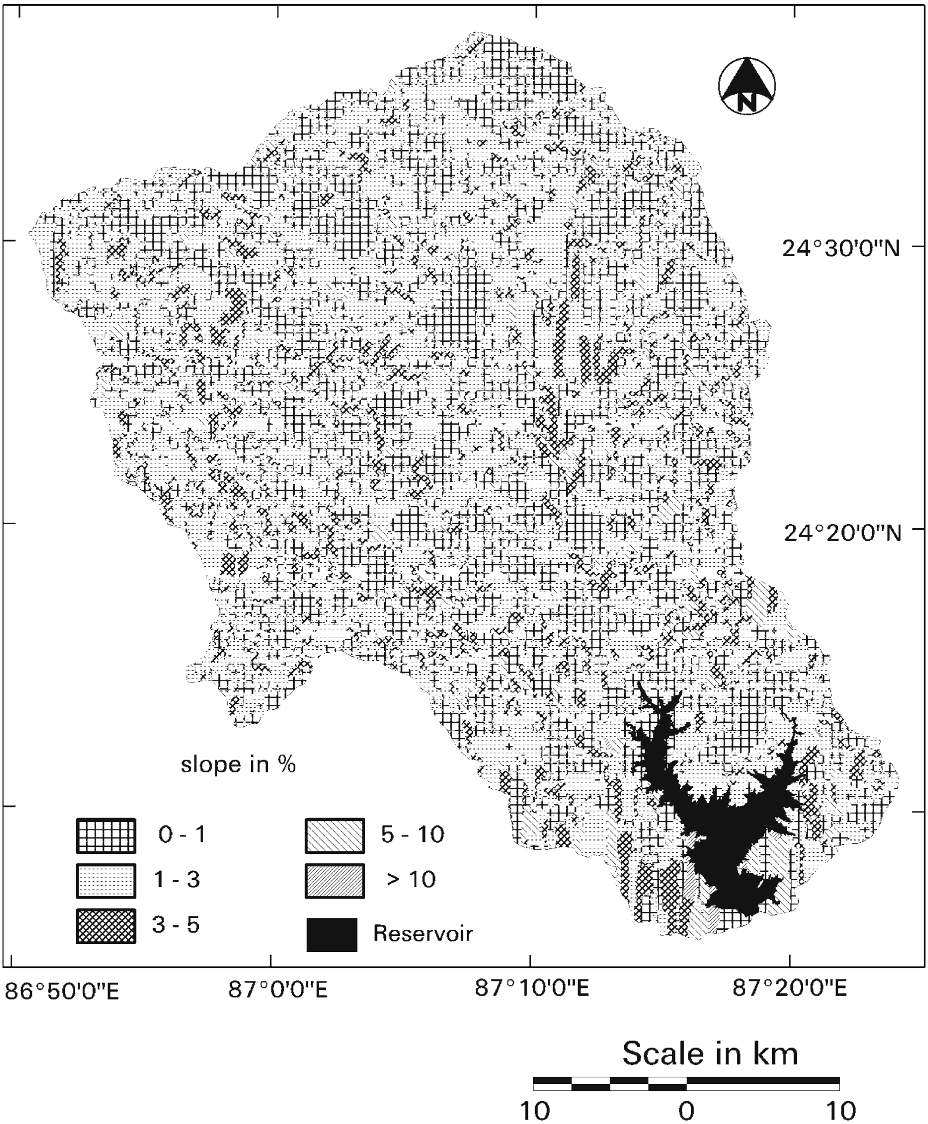

Fig. 3 Slope map of the study area

In the present study, land use/land cover and hydro-geomorphological maps were generated using the cloud free digital data of IRS-1C, LISS-III, sensor of path-107 and row-55 (23.5 m spatial resolution) acquired on 4th March, 2002 in four spectral bands (band 1: 0.45–0.52 μm; band 2: 0.52–0.59 μm; band 3: 0.62–0.68 μm and band 4: 0.77–0.86 μm). The analysis was carried out using ERDAS IMAGINE-8.4 digital image processing software. Initially, the satellite data for this year was geo-referenced with Survey of India topographical maps of the study area after matching some of the identifiable features like crossing of roads, railways, canals, bridges etc.

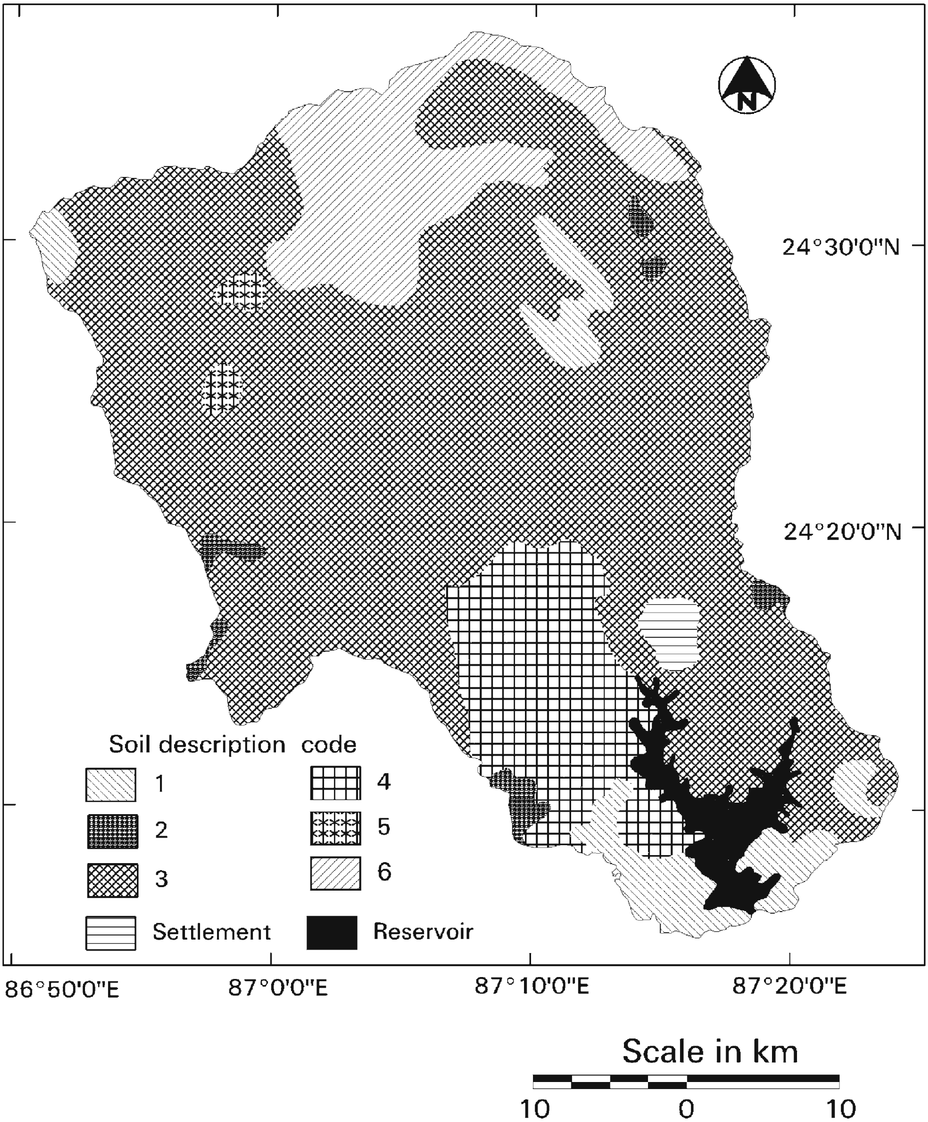

Fig. 4 Soil map of the study area

on both the base map as well as on the satellite data. Efforts were made to ensure that the ground control points (GCP) are uniformly distributed on the image. A second order polynomial model was generated and care was taken to keep the RMS error less than a half pixel.

In the present study, land use/cover, geomorphology and lineament maps were generated using IRS-1C LISS-III data in conjunction with conventional maps on 1:50,000 scale. The hydro-geomorphology map and detailed description of hydro-geomorphological classes of the study area were presented in Fig. 5 and Table 2

Table 1 Soil characteristics of the study area

Soil code	Characteristics
1	Very deep, Imperfectly drained, fine, soils on gently slopping landscape with loamy surface texture and moderate erosion; associated with: Shallow, well drained, loamy soils on moderately steeply slopping land loamy surface texture and severe erosion
2	Shallow, somewhat excessively drained, gravelly loamy soils on gently sloping hill slope with loamy surface texture and severe erosion; associated with: Deep, moderately well drained, fine-loamy soils with loamy surface texture and moderate erosion
3	Very deep, moderately well drained, fine-loamy soils on very gently slopping hill slope with loamy surface texture and moderate erosion; associated with: Deep, imperfectly drained, fine-loamy surface texture and moderate erosion
4	Very deep, well drained, fine-loamy soils on gently slopping undulating plateau with loamy surface texture and severe erosion; associated with: Deep, well drained, fine-loamy soils with loamy surface texture and severe erosion
5	Shallow, well drained, gravelly loamy soils on gently slopping undulating plateau with loamy surface texture and severe erosion; associated with: Deep, moderately well drained, fine-loamy soils on moderately slopping and with loamy surface texture and moderate erosion
6	Deep, moderately well drained, fine soils on gently slopping undulating plateau with loamy surface texture and moderate erosion; associated with: Very deep, moderately well drained, fine-loamy soils on moderately slopping land with loamy surface texture and severe erosion

respectively. The landforms identified in this area are dominantly of erosional type. However, fluvial depositional features are also observed along the river valleys/terraces. For generation of land use/cover map, supervised classification was performed employing the Bayesian Maximum Likelihood Classifier (MLC). MLC, a parametric decision rule, is a well developed method from statistical decision theory that has been applied to the problem of classifying image data (Niblack 1985; Settle and Briggs 1987).

Further, important maps such as slope map and ground water prospect maps were derived respectively from contour and hydrogeomorphological maps. All these maps were encoded as GIS layers and standardized for integrated analysis under GIS environment. All encoded digital data, coverages, and model variables in the GIS were spatially organized with the same resolution and co-ordinate system.

3.2 Groundwater Prospective Zone Map

Since, groundwater can not be seen directly from remotely sensed data, its presence must be inferred from identification of surface features which act as an indicator of groundwater (Das et al. 1997; Ravindran and Jeyaram 1997). Hence in the present study, hydro-geomorphological details derived through the visual and digital interpretation of the enhanced satellite products were used for delineating the groundwater prospective zone maps of the study area. Hydrogeomorphological maps depict important geomorphic units, landforms and underlying geology so as to provide an understanding of the processes, materials/lithology, structures and geologic controls relating to groundwater occurrence as well as groundwater

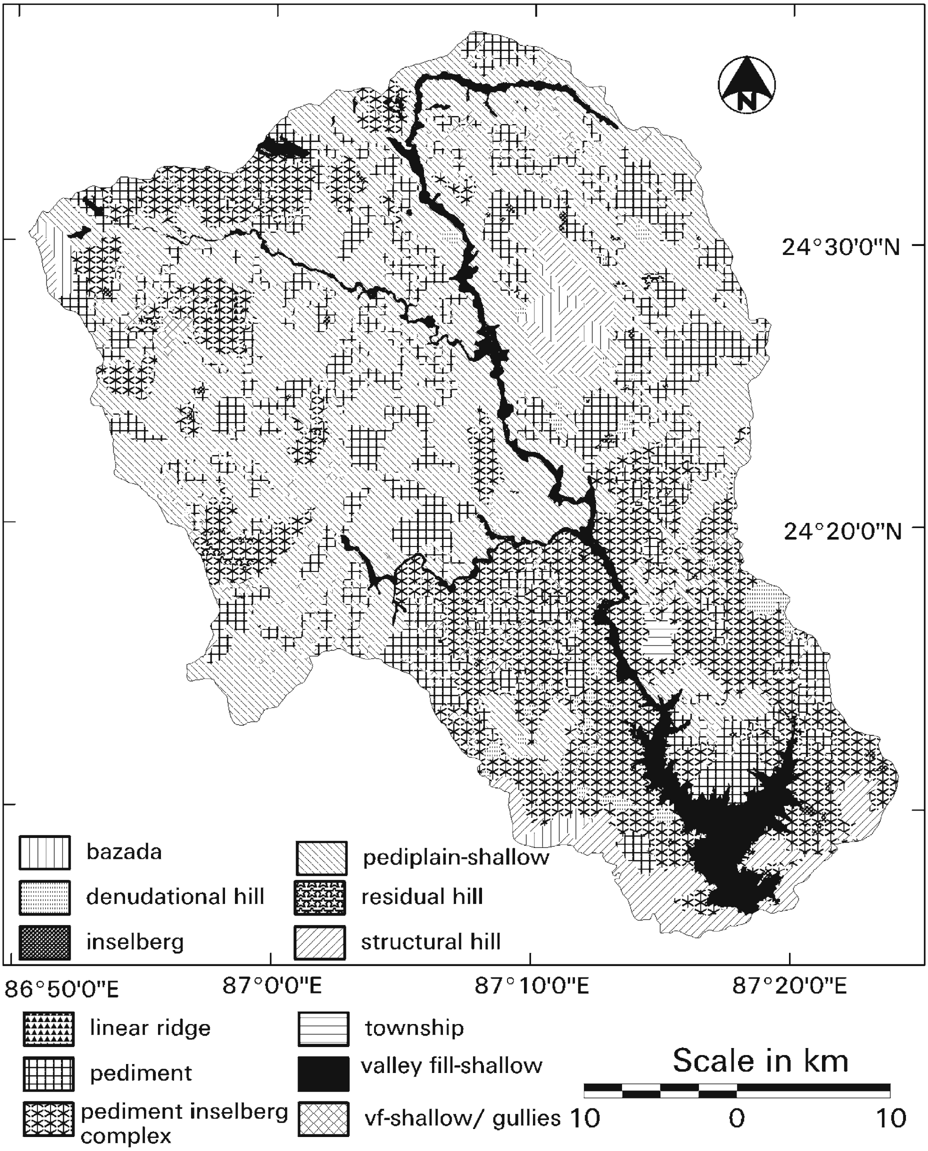

Fig. 5 Hydro-geomorphological map of the study area

prospects. Such maps depicting prospective zones for groundwater targeting are essential as a basis for planning and execution of area specific activities. Their characteristics and groundwater prospects are given in Table 2. Each polygon in the hydro-geomorphological map was categorized according to its recharge characters as either (1) Good, (2) Moderate, (3) Moderate to poor, (4) Poor. Good and moderate groundwater prospect zones are mainly dominated by geomorphic units like valley fill and pediplains respectively. The lineaments are the surface manifestation of linear

Table 2 Hydro-geomorphological characteristics of the study area

Hydro-geomorhological unit	Characteristics	Groundwater prospect zones
Valley fill—shallow/ gullies	Nearly level surface along the river courses with gravel, coarse—fine sand, clay etc.	Good
Shallow weathered pediplain	Gentle to moderate slope with sparse vegetation	Moderate
Pediment	Moderate slopes with a veneer of detritus and broad undulating rock floor. Dike exposures are seen at some places	Moderate to poor
Pediment inselberg complex	A number of small isolated island like hills that stands out in prominence in a dome form because of their resistance to weathering within the extensive pediment zone	Moderate to poor
Inselberg	Steep slopes occupying lesser dimensions	Poor
Residual hill	This is characterized by the hills, which are relatively less in spatial extent and occur as isolated land masses left over due to differential weathering	Poor
Denudational hills	These are an exfoliated, elongated feature with a fractured and jointed rocky area still affected by the process of denudation	Poor
Bazada	Favorable zones for construction of artificial recharge structures	Moderate
Structural hills	These are amphibolite schist, ironstone meta sediments and mainly act as runoff zones	Poor
Linear ridge	Linear ridge of resistant material and acts as a runoff zone	Poor

features like joints and fractures. They have been demarcated from the imagery as linear features and are ascertained after ground truthing. Groundwater potentiality of a higher order is indicated where lineaments run along and across the alluvial zone. The criteria for delineation of groundwater potential zones was adopted from Krishnamurthy et al. (1992), Krishnamurthy and Srinivas (1995), Panigrahi et al. (1995), and Rao and Jugran (2003).

3.3 Generation of Water Resource Development Plan

The comprehensive water resource development plan generation using GIS includes planning of area and locale specific activities in the study watershed. Area specific activities are generally the areas where certain type of water resource activity is recommended for implementation. The exploitation of the areas of tube well including shallow tube wells, dug-cum-bore wells and dug wells fall under area specific activities. Water conservation measures like check dam, percolation tank, underground barrier etc. fall under location specific activities.

3.3.1 GIS Model for Planning Area Specific Activities

Area specific model is generally decision model in which area specific activities were identified using boolean logic under GIS environment. Boolean modelling involves the logical combination of thematic maps resulting from the application of conditional operators. In the present study, a set of boolean logic was developed for evaluating the suitability for each of the area specific categories (Table 3). Groundwater potential zone map derived from hydro-geomorphological map constitutes one of the important parameter for planning area specific activities. The statements in the Table 3 were converted to each of the input coverage into temporary binary coverage form where class 1 indicates areas that satisfy and class 0 indicates all remaining class. The actual assignment of class values for each of the input coverage must be known from feature attribute table. For all the statements of this procedure, temporary coverages were created whose values are either 1 or 0 depending upon whether the respective condition is true or false. In the final stage, all the temporary coverages were combined applying boolean ***AND*** operator so that areas of prospective area is 1 if all combinations are true otherwise the class is 0.

3.3.2 GIS Model for Planning Location Specific Activities

Locale specific GIS model use selection process of sites which are usually prescriptive. These local specific GIS models involve the application of set of criteria resulting from analysis of scientific, economic and social factors. In the present study, developmental structures such as farm pond, check dam, under ground barrier and percolation tanks are suggested in the watershed taking characteristics of the watershed into account. The guidelines for the selection of suitable sites for location specific activities are adopted from IMSD (1995), Adiga and Krishna Murthy (2000) and Shankar and Mohan (2005) and presented in Table 4. In order to identify the exact location of a structure, different thematic layers; drainage network with drainage order, soil, slope and land use/cover were integrated under GIS environment. Subsequently, locations in which the defined conditions (Table 4) of the different thematic layers were fulfilled are identified for location specific activity.

Table 3 Criteria adopted for planning of area specific activities

Area specific activity	Criteria
Zone of bore wells	Where good category of groundwater prospect exists *AND* where present land use is crop land *OR* fallow land *AND* where slope is 0–3% *AND* lineament and lineament intersection points
Zone of dug-cum-bore well	Where moderate groundwater prospects exists *AND* within land use category of crop land *OR* fallow OR waste land *AND* under the slope category less than 3% *AND* less than 60 ft depth to hard rock
Zone of dug well	Where groundwater potential should be moderate to poor or poor *AND* land use/land cover must be crop land *OR* fallow OR waste land *AND* slope should be less than 1%

Table 4 Site selection criteria for planning of location specific activities

Type of location specific activity	Slope (%)	Land use	Soil permeability	Drainage	Favourable conditions
Check dams	< 10%	River stream (near by agricultural land)	Moderate to highly permeable	Up to 3rd order	Catchment area should be around 25 ha Presence of irrigation wells in the downstream of the proposed structure Preferable in the areas having high water table fluctuations Areas closer to lineaments
Percolation tank	0–3%	Open land/waste land, drainage course	High soil permeability	2nd and 3rd order	Stream bed can also used if sufficient catchment is available Preferred near the perennial streams Lineaments/fracture zones preferable
Underground barrier	0–3%	River bed	High soil permeability	4th–7th order	Preferable in the areas where thickness of river bed is greater than 5 m Sandy and gravel bed Across the streams which flow linearly for a considerable distance Sufficiently wide stream bed perennial streams
Farm pond	0–3%	Agricultural areas	Low permeability	1st order/sheet wash area	Lineament/fracture zones should be avoided

4 Results and Discussion

For demarcating the areas suitable for area and location specific activities, essential pre-requisites such as land use/cover map and groundwater potential map are generated using remote sensing. The spatial distribution of land use/cover classes of the study area was shown in Fig. 6. The land under agricultural practice is mainly occupied in the northern and central parts of the study area i.e. in upstream parts

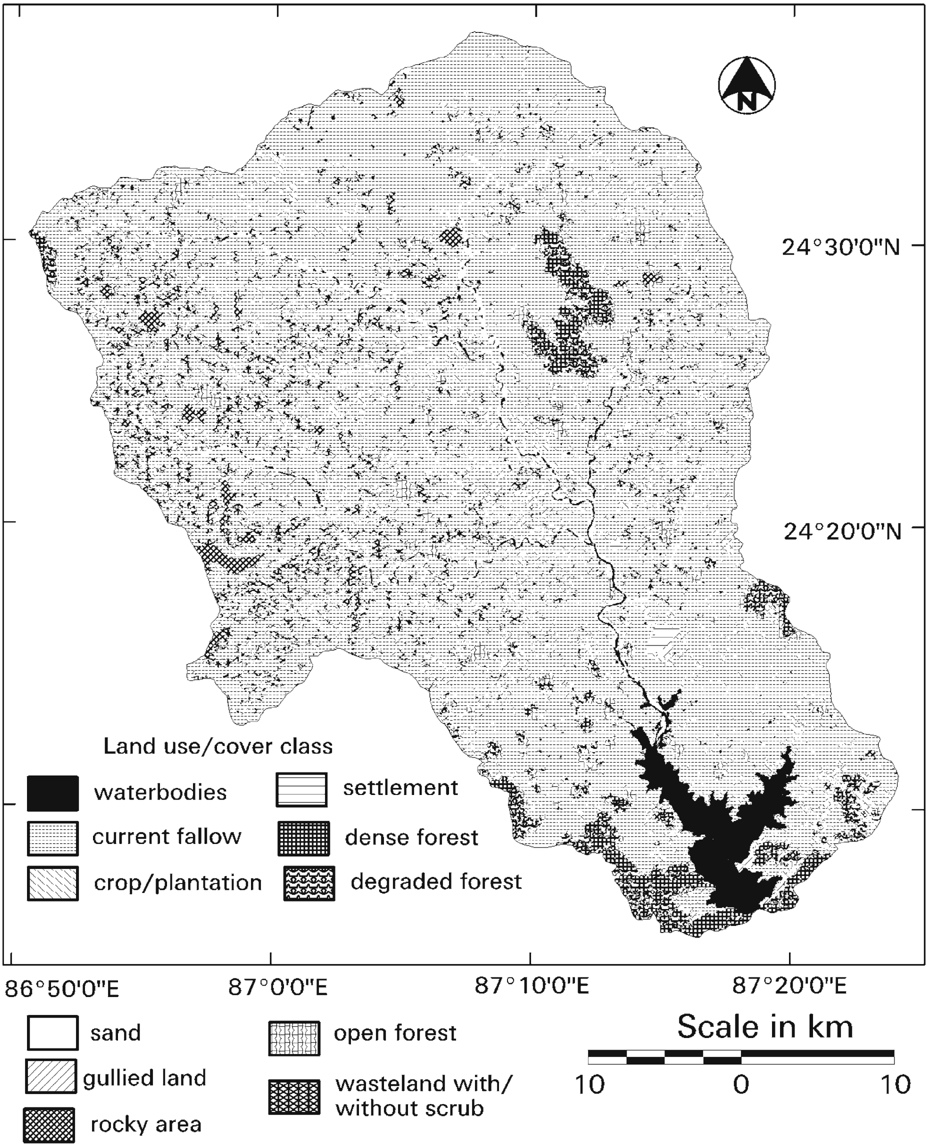

Fig. 6 Spatial distribution of land use/cover classes of the study area

of the watershed. The estimated overall classification accuracy based on 534 random samples representing various land use/cover categories, shows 87.7 per cent which was calculated using a confusion or error matrix (Lillesand and Kiefer 1994). The kappa coefficient ($\hat{k}$) of 0.86, originally developed to measure observer agreement for categorical data (Cohen 1960) indicates a very good to excellent agreement (Manserud and Leemans 1992). The groundwater potential map generated for the case study area is shown in Fig. 7. Integrated water resource development plan involving area specific activities and location specific activities is generated under

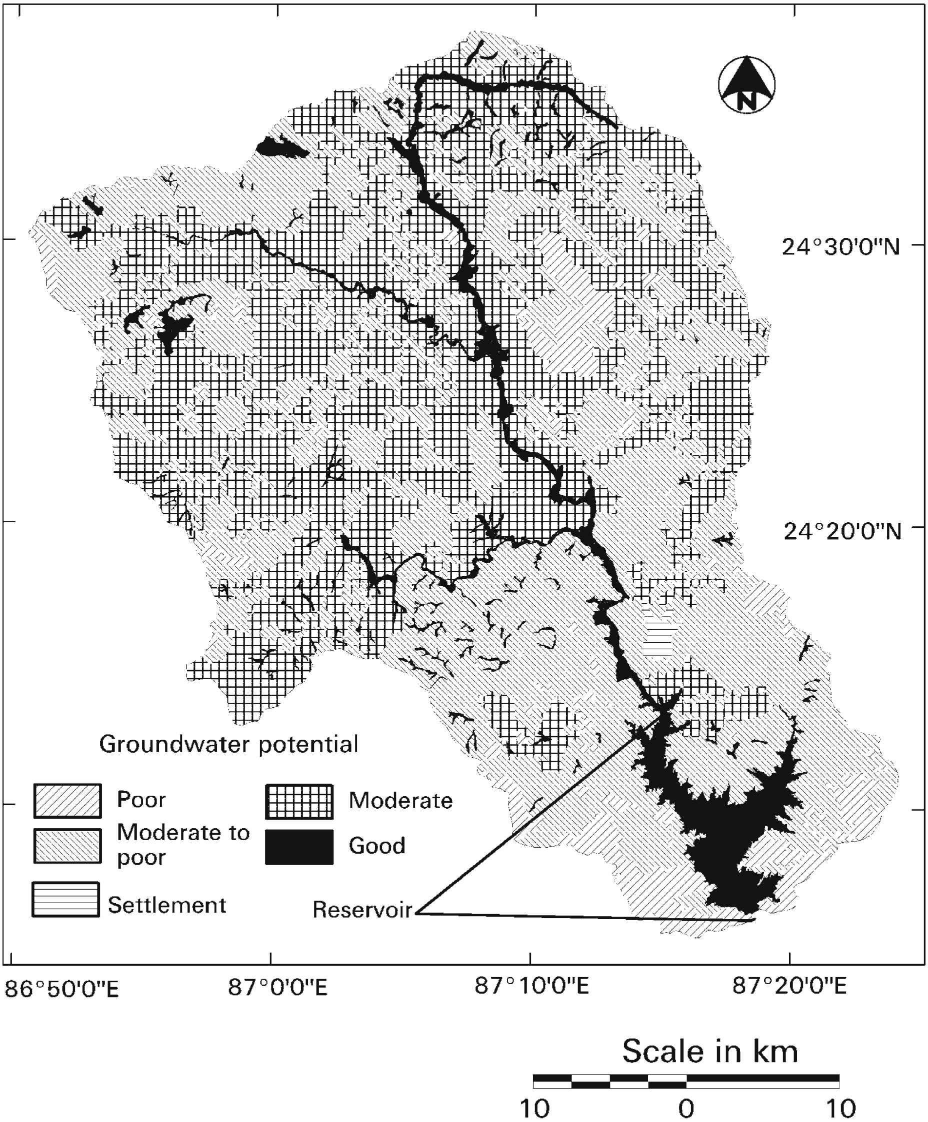

Fig. 7 Groundwater potential map of the study area

GIS environment and shown in Fig. 8a–b. Figure 8a show the delineation of study area into four zones based on the criteria suggested in Table 3. Zone 1 refers to unsuitable zone for groundwater exploitation where as Zone 2, Zone 3 and Zone 4 corresponds to Zone of Bore wells, Zone of Dug-cum Bore wells and Zone

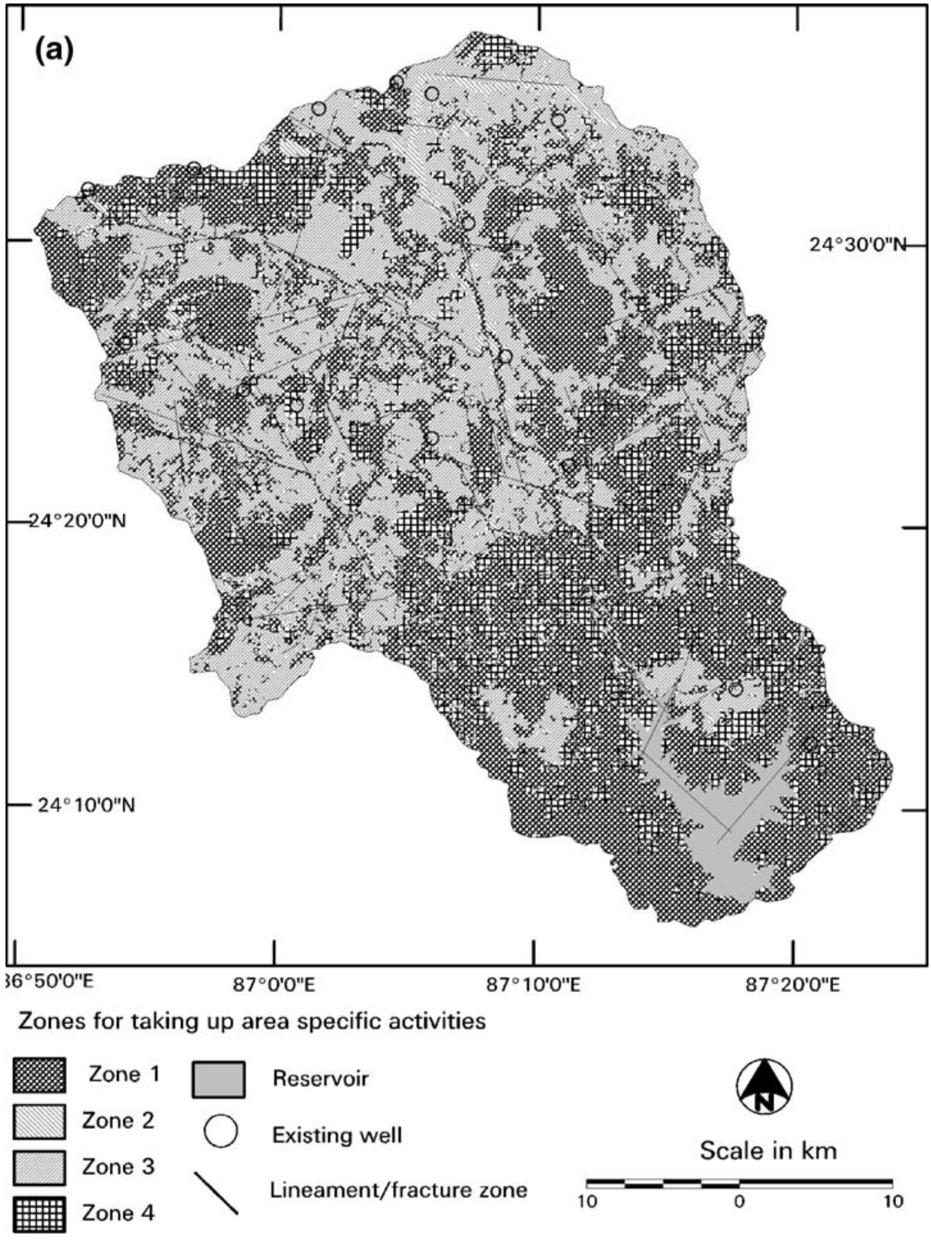

Fig. 8 Integrated water resource development plan for the study area. **a** Area specific activities **b** Location specific activities

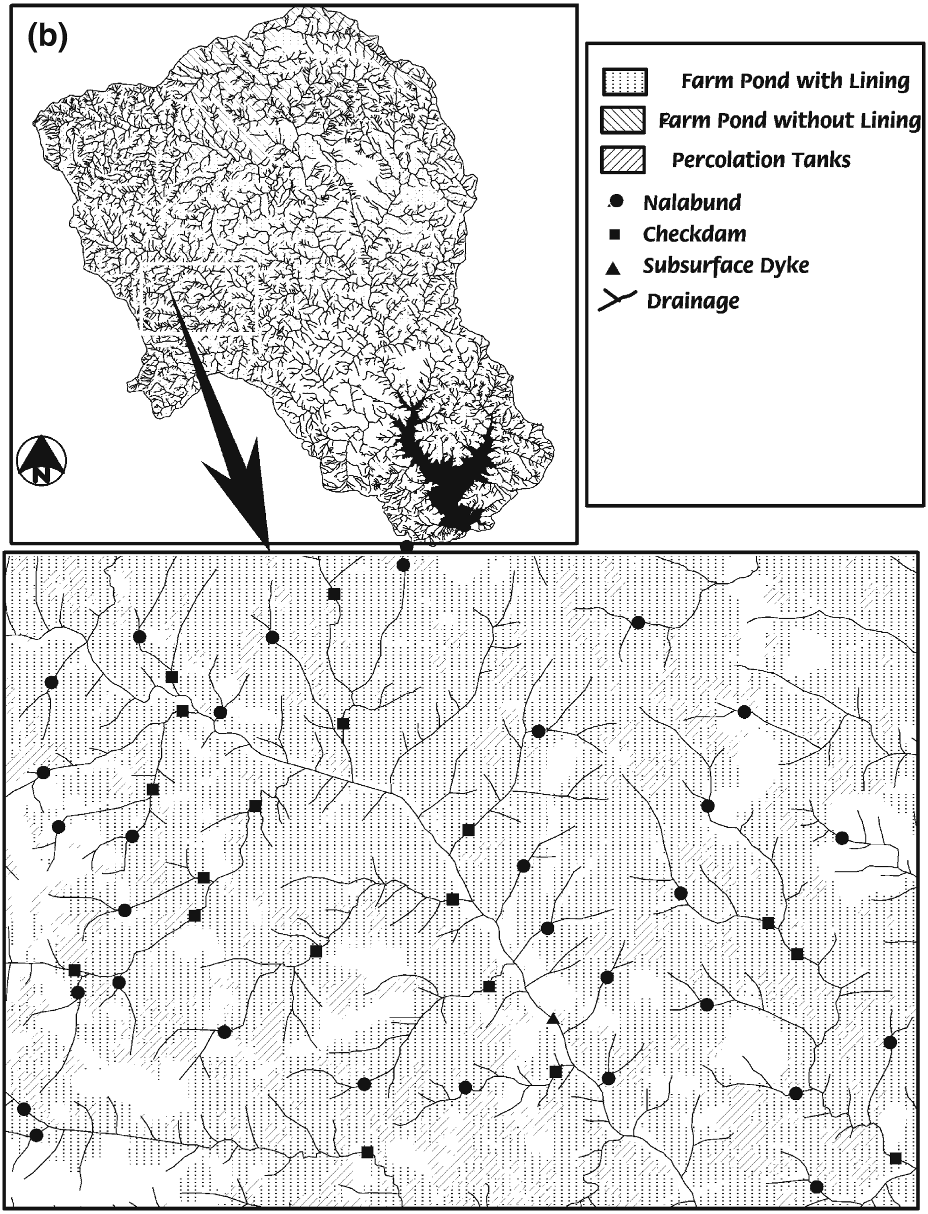

Fig. 8 (continued)

of Dug well respectively. Thus, Fig. 8a shows only the possible classes that are suitable for groundwater exploration. The water resources development plan clearly depicts the zones of exploitation, development and conservation. The exploitation of prospective groundwater zones has been suggested through tube wells, shallow tube wells and dug wells based on the geological strata and requirements. Dug-Cum-Bore well zone was identified where thickness of the weathered materials is moderate and underlying rocks are fractured forming a good aquifer. Lineament and fracture zones that are important for decision making are also delineated (Fig. 8a).

To understand the accuracy of prospective groundwater zones, an attempt is made to field verify the results in the study area. For this purpose, overall 15 existing well sites are field investigated for their suitability in terms of GIS and given in Table 5. From the Table 5, it was observed that all the wells we come across during the field visit are dug wells. Out of 15 dug wells, two are found in the Zone 1 i.e unsuitable for groundwater exploitation, and 12 dug wells were found in Zone 3 and Zone 4 respectively. One of the limitation is that the information presented in the Table 5 is not exhaustive, but it indicated that the GIS analysis for delineation of the study area into different zones is very much useful. However, specific land use class can be checked for precise location of the structure. The present utilization of land use/land

Table 5 Details of some of existing wells in the study area

Well location	Type of well	Zone as per GIS analysis	Depth to watertable (ft.) (Pre monsoon–Post-Monsoon)
87^0 04′ 35″ E 24^0 35′ 40″N	Dug well	Zone 4	9–25
87^0 05′ 58″E 24^0 35′ 15″N	Dug well	Zone 3	4–28
87^0 10′ 56″E 24^0 34′ 20″N	Dug well	Zone 3	8–27
87^0 07′ 26″E 24^0 30′ 37″N	Open well	Zone 3	9–18
87^0 08′ 54″E 24^0 25′ 51″N	Dug well with lining	Zone 2	9–22
87^0 01′ 33″E 24^0 34′ 41″N	Dug well	Zone 3	2–14
86^0 56′ 40″E 24^0 32′ 31″N	Dug well	Zone 1	9–23
86^0 52′ 33″E 24^0 31′ 44″N	Dug well with lining	Zone 4	14–24
86^0 54′ 02″E 24^0 26′ 14″N	Dug well	Zone 4	21–28
87^0 21′ E 24^0 12′ N	Dug well	Zone 4	14–23
86^0 58′ 42″E 24^0 24′ 35″N	Dug well	Zone 1	11–28
87^0 00′ 45″E 24^0 24′ 02″N	Dug well	Zone 3	7–17
87^0 06′ 04″E 24^0 22′ 53″N	Dug well	Zone 3	6–20
87^0 11′ 24″E 24^0 21′ 56″N	Dug well	Zone 3	2–25
87^0 18′ E 24^0 14′ N	Dug well	Zone 4	9–16

Zone 1 Unsuitable, *Zone 2* zone of bore wells, *Zone 3* zone of dug cum bore wells, *Zone 4* zone of dug wells

cover of an area provides a clue about the level of utilization. For example, areas that fall under land with or without scrub can be rated higher, since if an area is not presently utilized it may be due to non-availability of groundwater or non-suitability of the terrain. Further, the use of other factors like farmer's consensus, present policy of bank loaning sector and present government policy to take up tube wells in the area granting permission and concession can also play important role for planning precise location.

In hard rock areas, the underlying lithological units do not have sufficient primary porosity and permeability. Thus, additional recharge by location specific activities becomes necessary to augment the ground water in regions where it is insufficient. The drainage order map is overlaid on soil map, slope map and land use map in order to identify the sites that satisfy the criteria as mentioned in Table 4. Percolation tanks can perform efficiently only in areas where drainage pattern with catchment characteristics or closed watershed conditions are available within the favourable area (Shankar and Mohan 2005). Soil characteristics invariably control penetration of surface water into an aquifer system and hence percolation tanks should be planned in the areas that are characterized by highly permeable soils than the areas of low permeability. Rainwater harvesting technique (collection of runoff in small farm ponds) helps in recycling water for raising agro-horticulture crops. Rain water harvesting not only alleviates soil erosion in the region but also directly addresses the temporal discontinuity between the availability of rainfall and crop moisture demand. Unlike large irrigation works, rainwater harvesting is well suited to the soils and mountainous topography of the region. Check dams are recommended across the 2nd and 3rd order streams, with low to moderate slopes. It is expected that check dams may help in improving the irrigation potential for the area under double cropping system and agro-forestry on the plateau top by further reducing the denudation process. Wherever possible, these dams were located close to lineaments as they play dominant role in the occurrence and movement of groundwater in the hard rock areas. Depending on field conditions, 300 m around the lineament was considered as the favourable zone for artificial recharge (Krishnamurthy et al. 2000). Firstly, these structures reduces runoff velocity there by minimizes erosion and secondly allow the retained water to percolate and thus results in increased recharge in the wells located down stream of the structure. Moreover rainwater harvesting facilities do not require long construction delays and can deliver benefits the same year they are built. They can be built upon indigenous agricultural systems and are commensurate with the level of technology available in rural areas. However, some slots should be provided in the check dam so as to allow passing through early monsoon flow. The late/post monsoon flow is collected in the reservoir by plugging the slots with either wooden planks or similar other suitable device.

In the present study, underground barriers were planned across the higher order streams (4–7th order) as they are sufficiently wide (with −6 m thick valley fill) and the chance of flow of water in these streams throughout the year is high. Specifically, these structures obstruct drainage, reduce the baseflow, evaporation rate, thereby promote infiltration and ground water recharge. Shankar and Mohan (2005) suggested that the construction of a series of underground barriers is the most suitable recharge technique specially on the long linear stretches of the river courses as it lead to quick flow of water thereby gets little time for infiltration. To facilitate the phase wise implementation by the State Government/NGO, all the watersheds needs to be prioritized. In particular, these measures should be able to provide supplemental irrigation and ensure minimum submergence, as most of the land is under agriculture. Further, these area and local specific actions involve the application of set of criteria resulting from GIS analysis of scientific factors, which needs to be integrated with social factors also. This associational analysis not only helps in better understanding of the cause and effect related to problems/limitations but also helps in assessing the potential that exists in the study area for its betterment. Although an attempt has been made for generation of integrated water resource development plan by an integrated analysis through a combination of different thematic layers and boolean logic method in the GIS platform, but detailed field inspection are likely to improve the results of this analysis. This limitation can be further reduced with the help of high spatial resolution satellite data and finer scale of mapping (1:10,000) for different thematic layers. The suggested water resource development plan is expected to result in the transformation of the existing land use practices into sustainable ones that will meet the needs of the present population and future generation without endangering the environment.

5 Conclusions

For generation of integrated water resource development plan, thematic layers such as hydro-geomorphology, land use /land cover and lineament features were generated from the remote sensing data and integrated with drainage, soil and slope maps under GIS environment. Further, GIS modeling was done to demarcate the zones of suitable groundwater exploitation structures and artificial recharge structures by using Boolean logical operators like AND, OR, NOT and XOR. The interpretation of remote sensing data in conjunction with ancillary data and sufficient ground truth information makes it possible to identify and outline various ground features such as geological structures and geomorphic features that serve as direct or indirect indications of groundwater occurrence. Thus, integrated remote sensing and GIS can provide the appropriate platform for convergent analysis of large volume of multi disciplinary data and decision making for development of integrated water resource development plan. Remote sensing data can especially play significant role in generation of parameters from remote areas of watershed and enable us to arrive at natural resource management solutions by adopting a holistic approach. The methodology developed may be applied to similar terrain conditions, with some local considerations and modifications.

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