Chapter 4
Sustainable Watershed Development Planning

Abstract In semi-arid regions, sustainable water change will help boost quality of soil, and drinking and irrigation water, and this chapter proposes a strategy for the development of land and water resources for sustainable watershed management. The main aim of the study is to directly impact the effects of climate change on groundwater, sustainable farming, and surface water. The planning of artificial groundwater recharge sites relies on zoned mapping. Remote sensing and GIS software is used to demarcate ground and artificial refilling sites. Groundwater and artificial recharge planning maps were created and weighted overlay evaluation methods used for integrated data such as soil types, land capacities, soil pitches, land use/land cover and soil drainage. The maps were classified by Arc GIS software 10.1 with numerical values 1–10.

Keywords Remote sensing · GIS · Soil types · Semi-arid area

4.1 Introduction

In recent years, the role of individual artificial water replenishment planning has become better understood in India. Scientists and NGOs have concentrated on statistical modeling using geological, geomorphological, subsurface, geological, and water-level fluctuation data, and remote sensing and GIS methodology, to extend artificial watershed replenishment systems (Anbazhagan and Ramasamy 2005). GIS and land use are natural companions as both of them deal with spatial details.

With rapid urbanization and increasing population in urban areas, the demand for water is sure to increase and can also contribute to the possible depletion of groundwater reservoirs. Restoring water levels in the depleted groundwater reservoirs (aquifers) can be achieved by artificial recharging. The central and state governments spend a great deal of money on the construction of artificial systems such as percolation ponds and test dams, and scientific research based on specific parameters is required to choose suitable locations, define site-specific processes, estimate surface runoff, and prioritize synthetic recharging activities (FAO 2003). Subsurface reservoirs are very desirable alternatives that are technically feasible for storing excess

C. B. Pande, *Sustainable Watershed Development*,
SpringerBriefs in Water Science and Technology,
https://doi.org/10.1007/978-3-030-47244-3_4

monsoon runoff. Water-spreading strategies include over-irrigation, the construction of basins, the use of engineering techniques, or mechanical modifications to natural conditions such as improving a stream channel (Reddy et al. 2017). In areas where the aquifer has been exhausted by over-development, artificial recharge techniques typically lead to improved sustainable yield and the recovery of surplus surface water for future needs (Moharir et al. 2017; Pande 2014; Patode et al. 2017).

Artificial recharge involves the movement of natural surface water through underground structures. Recharge can be either direct or indirect. For direct recovery, injection wells pump water into an aquifer. The injected water is treated to ensure the area around the injection is no longer clogged. Indirect drainage involves spreading surface water over land so that the water infiltrates the aquifer through the vadose region, the unsaturated layer above the water table.

The goal of this study covering the Akola and Buldhana districts in the Maharashtra semi-arid region was to identify important issues concerning management of groundwater with the aid of state-of-the-art technology (Pande and Moharir 2018c). The study provides unique field and laboratory knowledge with GIS analysis filling fundamental gaps in knowledge associated with the problem of salinity. The research area consists of a variety of erosional surfaces, like terraces in phase. The basin has an aerial length of 328.25 km and is located in two administrative *taluka*s, Balapur and Khamgaon. The basin is filled geologically mainly by Deccan rock types. Most of the cultivated area is irrigated and the soil improved, with the groundwater provided from open and viable wells. In this environment, water tank replenishment by synthetic refilling is necessary.

Preparations for synthetic recharging were made, based on remote sensing data, after the magnitude of the accessible runoff at each watershed had been estimated. The final stage involved the integrated study of multidisciplinary information sets to assemble composite information that is able to answer a variety of queries.

4.2 Priority Groundwater Recharge Zone Mapping

The research uses remote sensing and GIS technology to focus on artificial recharge sites and runoff evaluation methods. Satellite data and aerial photographs from Indian Remote Sensing Satellite (IRS 1A) with Linear Imaging Self-scanning Sensors (LISS II) were used to generate many digitally processed thematic maps with geological and geomorphological parameters. The thematic maps developed by the ARC GIS program show layers such as lithology, lineament, lineament density, composition, rivers, and geomorphology. To assess geological, geomorphological, and hydrological data, the Indian Survey (SOI) has also been used for topographical maps, geophysical resistivities, and area investigations.

Base vector files were created to enable layer evaluation. Following the preparation of these base layers, the drainage layer was converted to a drainage density layer and the lineament layer to a lineament density layer. Reasonable weights were allocated to different land use/cover groups for each thematic map. The weightings were applied to the reclassified DEM based entirely on their topographical suitability for water recharge (Table 8.5). The weightings covered six geological classes, eight geomorphological classes, four soil classes, six drainage densities, and five classes of lineament density. All the allocated weights were averaged by dividing the individual weights for the different layers according to the total weight. These normalized weights were added to the weights already assigned to the thematic layers to give total weights. All the vector layers were converted to raster layers based on the assigned full weights to identify the suitability of the location for groundwater recharge. A site suitability map was developed, reclassified into distinctive groups after the inclusion of all layers: priority (highly suitable), second priority (moderately suitable), and not currently suitable (lowest priority area) (Fig. 8.12).

The quantity of runoff available in every watershed and the artificial recharge planning were carried out using remote sensing data and GIS software. Integration and prioritization of natural resource information was accomplished in the ARC GIS setting by thematic mapping and statistical analysis.

Several related facets of the mapping were evaluated for multi-thematic overlay analysis based on satellite data. For example, IRS LISS-III satellite information was used for the planning of a plane erosion by superposing specific land-use and land cover, geomorphology, soil profile, and streams. Thematic layers and geological data are described based on information provided by the National Office of Land Use Planning and Soil Survey (NBSS and LUP) and the Indian Geological Survey (GSI) (Pande et al. 2018b) (Tables 4.1 and 4.2).

Table 4.1 Geological classes including structure

S. N.	Lithology/structural features	Weighting
1	Massive basalt	1
2	Vesicular basalt	3
3	Amygdaloidal basalt	4
4	Compact basalt	2
5	Fault	5
6	Joint	4

Table 4.2 Geomorphological classes

S. N.	Lithology/structural features	Weighting
1	Plateau	4
2	Alluvial area	6
3	Habitations mask	2
4	Waterbody	1

4.3 Artificial Recharge Site Selection

In water shortfall areas, artificial recharge is a process for extending the natural movement of surface water to underground structures. It is achieved by designing facilities for infiltration or by inducing regeneration from groundwater bodies. In countries like India, artificial recharge planning is critical for the sustainable development of the watershed. The overall success of these activities can be tremendously improved if they are conducted with adequate scientific preparation. Remote sensing and GIS data can be a very useful method of planning for synthetic charging structures, although until now they have not been widely used in India.

In the present research, site selection is based solely on hydrogeological perspectives, and engineering considerations are not included. The following information is usually relevant for selection of an artificial recharge site: recharge water source; suitable geological formation; thickness and permeability of the tissue surrounding the geological formation; proximity of the possible recharge site to the gloomy cone of a fantastic property; and differences in water levels. An attempt was made to classify artificial recharge sites according to elements such as lineaments, hydrogeomorphic and hydrogeological features, land use, and drainage capacity. Weights have been assigned to the thematic maps which determine their relative percentage scores. Overlay analysis of separate thematic layers was performed to determine areas and sites suitable for synthetic recharge. Resource-themed mapping data were extracted from LISS-III satellite imagery from February 2013 with a spatial decision of 23.5 m. Topographical survey sheets, geological maps, and a soil map of the area were also used. Lineament density and hydrological soil classification were defined based on infiltration rate, texture, depth, drainage, and water infiltration capacity. Specific morphometric parameters for the basin were determined using common methods.

A system based on remote sensing and GIS is very useful in assessing suitability for artificial recharge sites in the sub-watershed. The first task was to identify the factors which would facilitate the recharge. The current artificial recharge network in the region has been studied in terms of hydro-geomorphology, topography, and well water levels. Based on these findings, a set of rules was developed to demarcate the most appropriate zones and also to define the exact artificial recharge sites (Pande and Moharir 2015). The thematic maps required for site suitability analysis using the weighted indexing method were: (a) geology; (b) geomorphology; and (c) land use and land cover. The higher-value groups contain the most desirable zones for artificial recharge structures (Fig. 4.1).

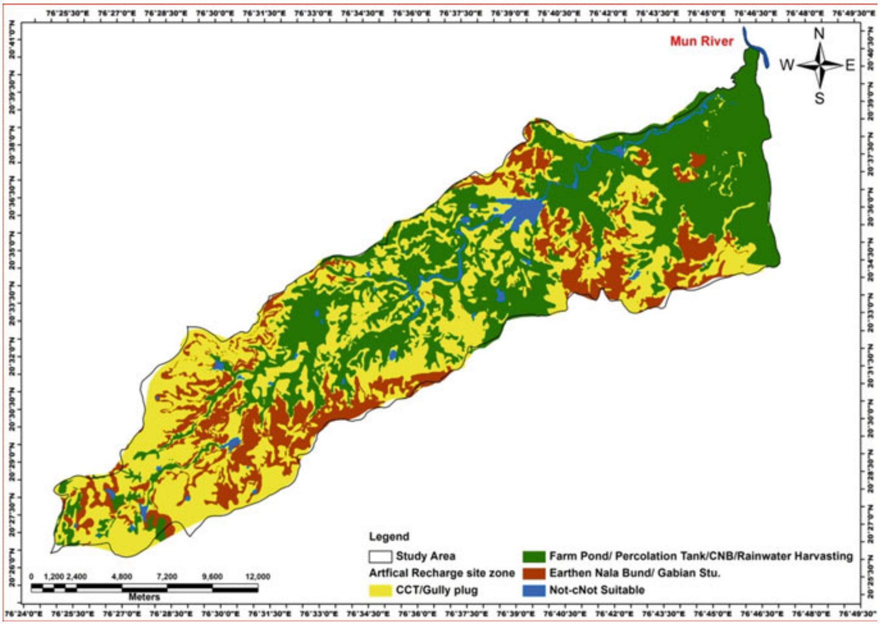

Fig. 4.1 Artificial recharge site zones map

4.3.1 Identification of Priority Groundwater Recharge Sites Using Remote Sensing and GIS Technology

Remote sensing and GIS technologies were used to delineate the sites for groundwater recharge. Remote sensing plays a huge role in the field of development of hydrology and water resources, offering multi-spectral, spatial, and sensor knowledge of surfaces worldwide. One of the main benefits of remote sensing technology for hydrological investigations and monitoring is its capacity for providing information on spatial and temporal formats (Pande et al. 2018a), which are important for effective investigation, prediction, and validation of maps of groundwater recharge sites for the semi-arid environment. However, remote sensing involves significant amounts of spatial information management which needs an environmentally friendly system to handle it. The study promoted the use of advanced geospatial techniques to produce spatial knowledge of potential recharge sites and assess their suitability.

Laterite is the main aquifer in the Mahesh river basin. In this aquifer, groundwater exists in water table conditions and is extensively used for domestic and irrigation purposes (Pande et al. 2019a; Khadri et al. 2015a, b). Depositions of valley filling and weathered basalts often locally reflect significant unconfined aquifers. The small aquifers made of iron ore and broken schistose rocks are, however, not often used. Groundwater in the unrestricted aquifers is under 6 m below ground level. While there is a widespread upward drive in the water table due to rainfall recharge during

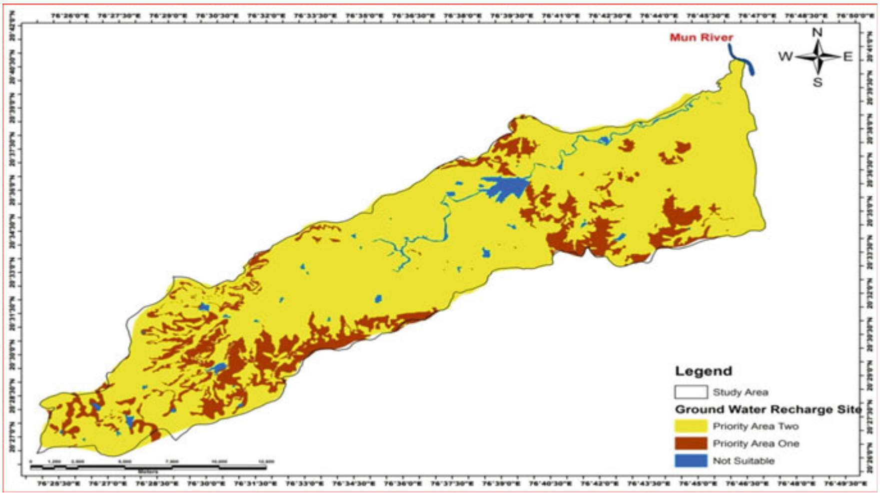

Fig. 4.2 Groundwater recharge site priority area

the monsoon season, the water stages fall abruptly as soon as the monsoon ends, suggesting the unrestricted aquifers along topographic slopes are relatively drainable. The fluctuation of the water table is less than 2 m across a vast watershed area, resulting in a low amount of complex groundwater supply in the watershed (Khadri and Pande 2016b, c). Two groundwater domains turn up at two different topographic levels in the watershed, separated by the Western Ghats escarpment. The tributaries are affluent and acquire base flow throughout the year from the two groundwater domains (Fig. 4.2).

4.3.2 Groundwater Resource Evaluation

A critical problem in groundwater production is the observable measurement of the aquifer recharge. Groundwater recharge assessment includes a proper understanding of recharge and discharge procedures and their interrelationship with geological, geomorphological, soil, land use and climatic factors affecting the watershed region. Several strategies are used for quantitative groundwater recharge comparison: (a) groundwater fluctuation degree and basic yield technique; (b) rainfall infiltration technique; and (c) soil moisture balance system. The groundwater degree fluctuation and specific yield approaches are used in the current study to quantitatively estimate groundwater recharge in the semi-arid territory. Traditional groundwater recharge assessment techniques are limitations, despite their ease and broad applicability in various hydrogeological systems (Khadri and Pande 2014a, b).

Groundwater movement is governed by natural boundaries. In traditional approaches such as the water-level fluctuation method, the average fluctuation of the water level is measured as part of the field analysis. Spatial variation in the charging factors is not taken into account. In the remote sensing and GIS-based approach, attention is given to the spatial distribution of variables, so that a data layer for the whole of a watershed can be planned. Remote sensing records also provide the most accurate ground data, minimizing fieldwork. Seasonal data are necessary for recharge estimation (Khadri et al. 2013).

4.3.3 Weighted Index Overlay for Identification of Groundwater Potential Zones

Weighted index overlay analysis (WIOA) is a simple and straightforward technique for a joint analysis of multi-class maps. The usefulness of this approach lies in the ability to include the element of human judgment in the study. The WIOA method contemplates the parameters and their sub-groups. A simple weighted overlay technique has no trend scale. Measurement criteria are defined, and importance is assigned to each parameter. Determination of all types of weighting is the most integral part of integrated analysis since the output is usually organized with the correct weighting (Pande et al. 2019b). Looking at the relative value leads to a clearer description of real conditions in the field. Prospective groundwater zones were delineated considering the hydro-geomorphic conditions of nearby weighted indexing, taking into account five important parameters: geomorphology; geology; soil; land use/land cover; and water level (Fig. 4.3 and Table 4.3).

4.3.4 Runoff Estimation

Another important element in artificial recharge work is the estimation of water available as runoff. In our study, following the estimate of runoff, areas for artificial regeneration were prioritized based entirely on the available water and aquifer measurements at each watershed. To estimate runoff in the watershed areas, a database of the following is required: aerial coverage of different land use and land cover, hydrological soil group, and rainfall.

4.4 Groundwater Availability

During the dry season (pre-monsoon) the thickness of a water column that has been drilled through the entire thickness of the unconfined aquifer is a good measure of the availability of groundwater in a given vicinity. Wells are graded based on the thickness of the water column, meaning that the wells in the Mahesh river basin were

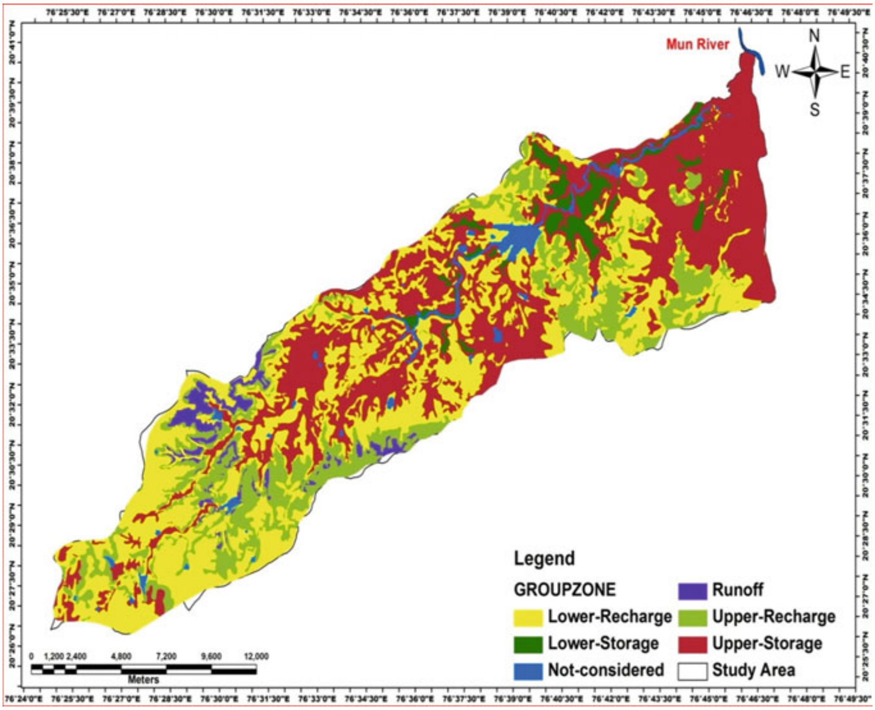

Fig. 4.3 Recharge zone map

drilled through the entire thickness of the unconfined aquifer (Moharir et al. 2020). In two consecutive years of water observations for the post-monsoon (November) and pre-monsoon (May) seasons, a specific value for the water column has been estimated by subtracting the depth of groundwater below ground from the overall depth of the property underground (Patode et al. 2016). If the water column remains 50% above the post-monsoon water level then the water availability is classed as good. Between 25ô and 50% it is average, and less than 25% is bad (Fig. 4.3).

4.5 Groundwater Potential Zones

The drainage basin morphology is an important aspect of geomorphic research. Many hydro-geomorphological features, together with their geological parameters, can be observed and evaluated using remote sensing techniques. This is very useful for the preparation of integrated hydro-geomorphological maps for groundwater concentrations (Khadri et al. 2016a). Using satellite imagery visual analysis, topographical maps, and topic search, the area can be divided into numerous hydro-geomorphic units demarcating workable construction zones (Pande et al. 2017).

Table 4.3 Ratings for parameters on a scale of 1–10

Parameter	Ranks (in %)	Classes/units	Weight
Hydro-geomorphology	25	Moderate	6
		Moderately dissected	5
		Slightly dissected	3
		Undissected	1
		Weathered	4
Land use and land cover	20	Agriculture	7
		Wastelands	4
		Forest	2
		Built-up land	1
		Water bodies	7
Slope	15	0–3.26	4
Digital elevation model	15	260–598	5
Water level	25	6.1–7.2	3
		7.2–8	2
		8–8.7	3
		8.7–9.5	4
		9.5–11	4
		11–12	2
		12–14	2
		14–17	2

Hydro-geomorphological units such as alluvial plains and filled valleys are the most suitable exploration and production zones in groundwater analysis (Khadri et al. 2015c, d) and are classified as good to very good. Upland (deep, moderate, shallow) regions are identified as moderately favorable, and denuded upland regions with low lineament density are the least favorable areas for groundwater exploration and development. Figure 4.4 shows that the southern part of the basin has excellent groundwater capacity relative to the upper-middle and northeastern part, and this has also been tested in the field. This knowledge is very useful for the further production of groundwater within the study area (Biswas et al. 2009; Kale and Kulkarni 1993).

Once all thematic maps had been integrated, the groundwater potential map was divided into several zones. The map clearly shows that the alluvial plain, which consists of sand, silt, and clay with a near-level slope and very low drainage density, has very good potential and is a highly promising area for groundwater extraction along with lineaments. The structural, denuded, and residual hills are potentially low to extremely poor groundwater zones (Fig. 4.4) but they act as runoff areas. Lineaments, especially joints, fractures, and their intersection, enhance the potential of a hydrogeomorphic unit. This potential groundwater map provides the basis for future exploration (Pande et al. 2019b).

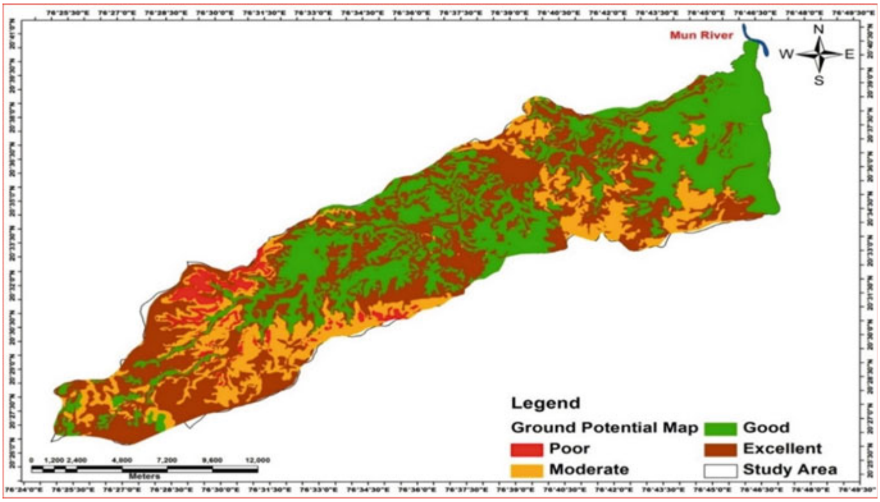

Fig. 4.4 Groundwater potential zones map

Table 4.4 Groundwater potential area classes and area covered

Groundwater potential	Area (km^2)	Percentage
Poor	181.37	55.25
Moderate	109.24	33.28
Good	34.53	10.52
Excellent	3.0	0.91
Total area	328.25	100

4.5.1 Excellent

The excellent zone includes valley fill, flood plains, and low-lying areas as well as lineament intersections such as cracks, fractures, and joints. It usually includes areas where unconsolidated sediments have been deposited, such as gravel, sand, silt, and clayey sand. These have high water retention potential, as they allow maximum percolation between the grains due to their maximum pore space. This zone covers an area of approximately 3 km^2 and forms 0.91% of the study area (Fig. 4.4 and Table 4.4).

4.5.2 Good

All the remaining controlled geological structures fall into the strong potential category. Many areas with low-lying and gentle slopes are also included. In general, sandstone is capable of storing and transmitting water through interstices and pore spaces between the grains and is considered ideal for aquifers. Areas of exposed sandstone also come into this category. This region covers an area of around 34.53 km^2, 10.52% of the study area (Fig. 4.4 and Table 4.4).

4.5.3 Moderate

This zone comprises mainly areas where the recharge state and the water-yielding capacity of the materials underlying it is neither suitable nor bad. Topographically, it occupies the smooth, gently sloping hilltops. While the lithology includes good water-bearing rock formations such as sandstone, the potential is reduced by the slope, where maximum runoff is present. The moderate zone typically includes low water-bearing rock formations such as silty shale, which in turn is distinguished by the presence of secondary structures within it. The moderate zone is evenly distributed within the study area, covers an area of 109.24 km^2, and occupies 33.28% of the total study area (Fig. 4.4 and Table 4.4).

4.5.4 Poor

This zone is located primarily in the elevated regions. Much of the precipitation flows out as surface runoff in the high relief regions, leading to poor conditions for infiltration under the ground. The groundwater yield is therefore usually deemed low unless the elevated areas are traversed by geological systems, and possess high drainage density and sufficient water-bearing rock formations. The poor zone is mostly scattered along the ridges and covers the majority (55.25%) of the study area.

4.6 Conclusion

Thematic mapping of the study area and its inherent characteristics was performed using geospatial techniques. Recently collected groundwater data from specific wells identifies an increase in groundwater depletion and shows the water table has a seasonally declining pattern. Dendritic to sub-dendritic drainage patterns with a moderately dense drainage texture were found in the sub-watersheds covering the study region. High bifurcation ratios indicated good structural drainage power and strong headward erosion. Overlay analysis of various thematic layers (geomorphology, slope, drainage, drainage depth, and land use) culminated in the production of a final map giving a general understanding of the area's potential for groundwater and showing suitable groundwater recharge areas. The incorporation of the thematic layers used a model developed using GIS techniques.

Groundwater is a precious finite resource. Increasing population, urbanization, and the expansion of agriculture have, over the years, led to unscientific groundwater exploitation creating conditions of water stress. A cost-effective and time-efficient technique for proper groundwater resource assessment and management planning is needed. Groundwater planning software involves a large amount of data coming from different sources. As successfully demonstrated in this report, integrated remote sensing and GIS can provide the proper forum for decision taking on groundwater studies based on convergent analysis of large volumes of multidisciplinary data. The groundwater potential map is a systematic project that takes into account major control factors that affect water yield, artificial recharge location, and groundwater quality. The map is important as the basis for groundwater exploration planning and execution.

The following conclusions may be drawn from the study.

a. The role of remote sensing and GIS-based methods of groundwater resource evaluation were developed and demonstrated in the study.
b. The study shows that recharge sites located on a gentle slope and lower-order streams are likely to provide artificial recharge to a larger region.
c. In selecting suitable sites for artificial recharge, a model combining geology, land-use ground cover, geomorphology, contour, soil, and digital elevation was found to be very useful.
d. The change in land use is primarily due to hydrological factors.

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