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RESEARCH ARTICLE

Identification of Water Conservation Sites in a Watershed (WRJ-2) of Nagpur District, Maharashtra using Geographical Information System (GIS) Technique

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Abstract The paper deals with the application of Remote Sensing and Geographical Information System (GIS) technique for a watershed development program. For this study, the WRJ-2 watershed falling under Narkhed and Katol Tahsils of Nagpur district, Maharashtra, India is investigated. Various thematic maps (i.e. drainage, geology, soil, geomorphology and land use/ land cover) have been prepared using the remote sensing and GIS techniques. Initially, differential weightage values are assigned to all the thematic maps as per their runoff characteristics. Subsequently, the maps are integrated in GIS environment to identify potential sites for water conservation measures like gully plugs, earthen check dams, continuous contour trenches, percolation tanks, cement bandhara, afforestration and farm ponds, etc. The study depicts that the GIS technique facilitates integration of thematic maps and thereby helps in an identification of micro-zones each with unique characters in-terms of hydrogeology, thus amenable to specific water conservation techniques. It is therefore concluded that, the GIS technique is suitable for an identification of water conservation structures.

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Keywords Geographical Information System (GIS) · Water conservation structures · Thematic maps · Run-off characteristics · Nagpur district · Maharashtra · India.

Introduction

The groundwater resources in the State of Maharashtra have various limitations, mainly attributed to typical physiographical, geological and hydro-geological conditions coupled with vagaries of monsoon (Krishnamurthy et al. 1996; Varade et al. 2011a). Geologically, most of the State (about 80 % areas) is covered by hard rock formation of Deccan trap basalt, and 33 % of geographical area is occupied by hilly portion (CGWB 2003). As a result, the State experiences drinking water scarcity problem. The scarcity situation at a time is alarming and therefore demands adoption of appropriate water conservation techniques. To combat such situation, it has become necessary to identify, develop and implement the groundwater recharge systems. For this, implementations of appropriate water conservation measures to capture the rainwater runoff have become essential (Saraf and Choudhury 1998; Anbazhagan et al. 2005). Realizing this fact, the *Government of Maharashtra* is embarked upon implementation of water conservation through watershed development programs. However, most of the time, the programs lack multidisciplinary approach due to which the desired impact is not achieved. Thus, there exists a demand for development of geospatial technique for estimating watershed characteristics.

Identification of suitable sites for water harvesting structures needs a large volume of multidisciplinary data from various sources, for which, the applications of modern remote sensing and GIS techniques have gained much attention in recent years (Ramaswamy and Anbazhagan 1997; Saraf and Choudhury 1998; Murthy 2000; Anbazhagan and Ramasamy 2001; Braun et al. 2003; Natarajan et al. 2004; Anbazhagan et al. 2005; Prasad et al. 2008; Pandey et al. 2011). The remote sensing and GIS techniques facilitate demarcation of suitable areas for groundwater replenishment by taking into account the diversity of related factors (Durbude and Venkatesh 2004; Jafar et al. 2005; Ravi Shankar and Mohan 2005; Saptarshi and Raghvendra 2009; Balachandar et al. 2010). Remote sensing technique provides a sound realistic database on resources, while the GIS technique not only helps in storage, retrieval and analysis of spatial database in computer system but also facilitates the spatial analysis through intersection and manipulation process. This altogether forms an exclusive tool in designing an approach to arrive at decision support system for particular application. As such to arrive at a clear picture of the situation, the controlling factors have to be treated and integrated giving appropriate weights (i.e., specific to particular area). Overall, the integrated analyses of available resources database provide better understanding of the terrain condition, as it considers all the interrelated resources, which in turn, facilitates the adoption of holistic approach. Therefore, it is felt that multidisciplinary approach would be more suitable to have ever lasting solution, in which, remote sensing and GIS techniques found to be most suitable to evolve appropriate Decision Support System (Waters et al. 1990; Rokade et al. 2004; Ghayoumian et al. 2005; Ravi Shankar and Mohan 2005; Jankowski 2006; Bühlmann et al. 2010). In view of this, an attempt is made here to evolve an appropriate watershed development plan using GIS technique for watershed WRJ-2 falling in Nagpur district of Maharashtra.

Study Area

Nagpur district, the second capital of Maharashtra State, India is situated in the eastern parts of the State and covered under the Godavari drainage basin. The total area of Nagpur district is 9931 km^2 (DRM 2001). The WRJ-2 watershed covering an area of 219.86 km^2 of Katol and Narkhed Tehsils of Nagpur district falls between the latitudes 21°17′30″-21°29′00′′N and longitudes 78°30′00″-78°59′15″ E of SOI toposheet nos. 55 K/11 and 55 K/7 (Fig. 1). The area experiences a tropical climate. The annual rainfall data for the Katol Tehsil show wide variation in rainfall ranging between 539.9 and 1138.8 mm. Similarly, in Narkhed Tehsil it ranges between 520.2 and 1333.8 mm (Table 1). In view of wide variation in the annual rainfall pattern its bearing on groundwater regime of the study area is expected.

Status of Groundwater and its Evaluation

The groundwater assessment of the study area carried out by GSDA (2008) indicates that the watershed WRJ-2 falls in semi-critical category and is on the verge of over-exploitation. The stage of development is reported as 91.63 %. The total recharge indicated is 2626.85 ha meter, while the annual draft from the existing wells is 2286.60 ha meter (GSDA 2008). This suggests that the withdrawal has been increased over the time, indicating overdraft situation in the area. Due to this, many villages in the watershed area experience drinking water scarcity during peak summer season. The problem further aggravates due to wide variation in rainfall pattern as discussed earlier.

With this background, in order to understand the groundwater regime, well inventory studies were carried out in the month of post-monsoon season of year 2009. During the well inventory studies, the hydrogeological data of existing wells from 33 villages (two

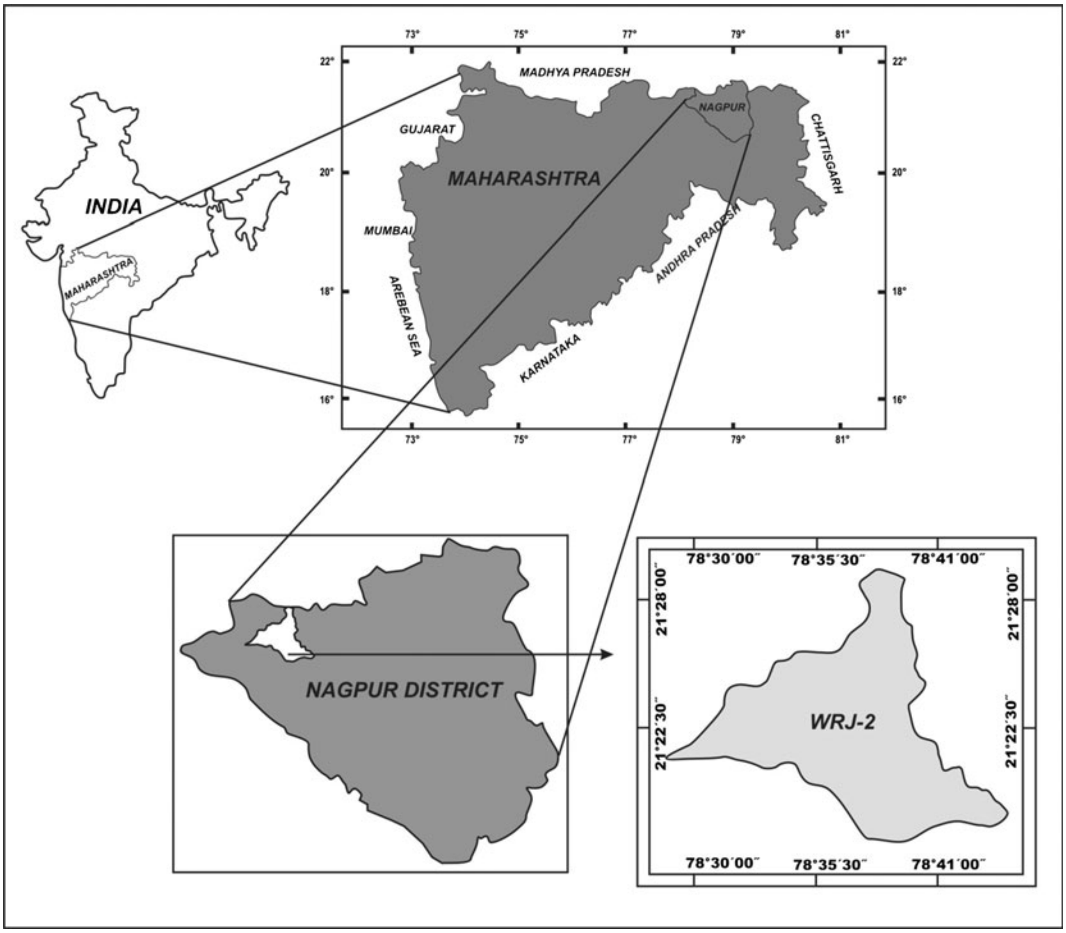

Fig. 1 Index map of WRJ-2 watershed, Nagpur District, Maharashtra

wells from each village) representing the entire watershed area were collected from the field. The data depicts that the total depth of the well ranges between 8 and 18 m below ground level (bgl). The diameter of the wells ranges in between 4 and 10 m, with the average diameters of 4 m. The post-monsoon water level (in winter season) ranges from 2.5–9 m (bgl) whereas, in summer i.e., pre-monsoon, the water level varies between 5 and 15 m (bgl). The average seasonal fluctuation is around 4 to 8 m. The yields of wells were calculated on the basis of pumping hours, capacity of pump *etc.* like parameters. This calculated yield of well ranges from 54 KLPD to 270 KLPD during winter. However, in summer, it ranges from 9 KLPD to 54 KLPD. The groundwater situation revealed through the well inventory studies indicates that the area has good groundwater potential, as the yield found to be as high as 270 KLPD/day. But, in summer the yield reduces to only 9 KLPD to 54 KLPD/day. This reduction in yield is indicative of over-exploitation situation. This is also corroborated by the comparatively higher fluctuation in the groundwater levels i.e., to the tune of 4 to 8 m. The dug well data was further analysed which shows that the depth of weathering in general ranges between 3 and 6 m. However, few wells show abnormal depth of weathering values. Out of total 66 wells, 16 wells show depth of weathering above 6 m which are mostly located along the major streams. While 21 wells, located on the watershed boundary show less than 3 m overburden. It is observed that there is no significant correlation exists in between the depth of weathering and seasonal fluctuation in water levels of the study area. Similarly it is also seen that, recovery rate in winter is very high as compared to summer season. The higher recovery rate in winter is attributed to higher aquifer thickness due to shallow water table condition.

Table 1 Nine years rainfall data of Katol and Narkhed Tehsils of Nagpur District

Tehsil	Year	Annual rainfall in mm
Katol	1999	539.9
	2000	845.7
	2001	876.8
	2002	806.8
	2003	885.1
	2004	625.8
	2005	1045.2
	2006	851.2
	2007	1138.8
Narkhed	1999	1333.8
	2000	569.8
	2001	520.2
	2002	768.8
	2003	712
	2004	552.9
	2005	858
	2006	652.8
	2007	1146.1

On the basis of groundwater scenario discussed above, it is perceived that the groundwater reserve of the study area is under heavy stress due to low rainfall over a long period and over-extraction situation. Thus, there exists an urgent need to implement the water conservation program to restore the water table and to alleviate scarcity situation in the area. Therefore, following methodology has been adopted for identification of appropriate sites for construction of water conservation structures.

Materials and Methods

The selection of sites for water conservation structures need multidisciplinary approach based on integration of spatial database. The remote sensing technique is thus very useful in understanding the spatial distribution of related parameters which has direct bearing on groundwater regime of any area (Thakur and Raghuwanshi 2008). Therefore this technique is inevitable for the hydrological studies, especially in the area of site selection of water conservation structures. In view of this, spatial database on related parameters have been generated using remote sensing technique. Materials and methods in the present work are mainly divided into three steps i.e., 1) spatial database generation, 2) spatial data analysis, and 3) data modeling. The remote sensing and GIS based characteristic image interpretation keys like tone, texture, shape, size, pattern, and association, etc. elements were used for the identification and interpretation of various thematic maps. The IRS-1C LISS III geo-coded digital data (2008) were digitally enhanced with the help of Arc-Info 9.0 software. This digitally enhanced image was interpreted for the preparation of thematic layers *viz.* drainage, geomorphology, soil, geology, land use/ land cover. All these thematic layers were converted into the raster formats in spatial data analysis. The raster layer again reclassified with the suitable weightage which were assigned for each layer. The raster maps of these parameters were assigned respective theme weightage values, and were overlaid and analyzed under the Arc-Info 9.0 software for evolution of water conservation map.

Results and Discussion

Drainage, Geology and Geomorphology

The details on drainage, geology and geomorphology are shown in Fig. 2. Physiographically the study area shows gently sloping undulated topography with general slope towards the west direction. The highest elevation is around 605 m (amsl) towards north, while the lowest altitude is 402 m (amsl) towards the western side. The area is drained by tributaries of the Jam River. The drainages are ephemeral which flow only during the monsoon season. The overall drainage pattern is dendritic.

Geologically, the study area is covered by Deccan trap basaltic lava flows. The multiple lava flow units are mainly divided into vesicular, amygloidal and hard and compact types of basalts (Deshpande 1998; DRM 2001). Occurrences of groundwater in this type of area is confined in secondary permeable structures i.e., fractured and weathered horizons, and in upper unconsolidated materials. In addition to this, a very small part along the major river is covered by alluvial deposit.

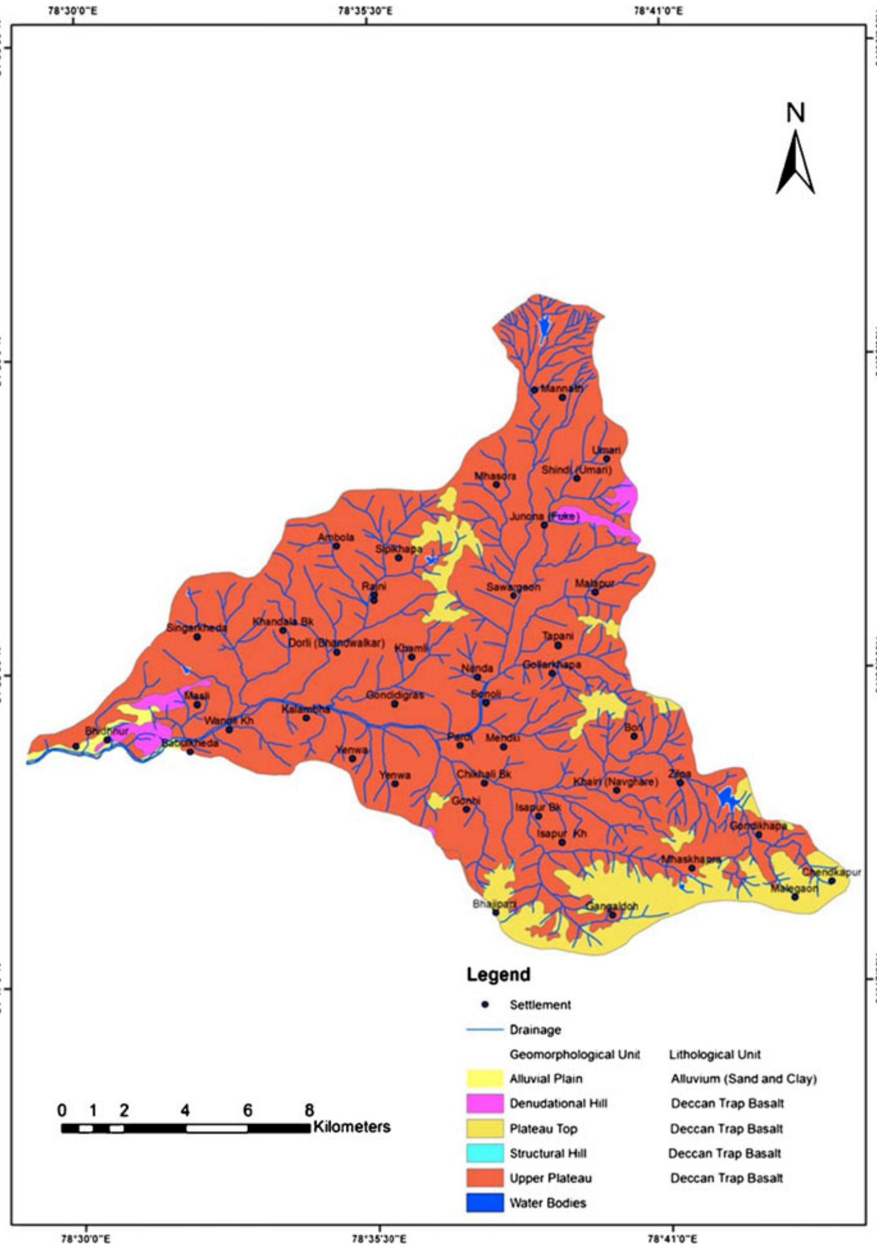

Fig. 2 Drainage, geology and geomorphological map of study area

The groundwater condition of any area is generally assessed through the geomorphological set-up as it reflects subsurface aquifer characteristics viz. weathered thickness, fracture intensity, slope of terrain etc. Therefore, the geomorphological map has a great relevance in groundwater studies (Raghu and Reddy 2011; Varade et al. 2011b). The geo-morphological map for the study area shows that a large part of the watershed is covered by upper plateau, which forms a storage zone because of its physical properties i.e., gentle slope, thick weathered mantle cover etc. Besides this, the other geomorphological landforms such as alluvium, structural and denudational hills and plateau top are also observed in the area. However, these landform features have occupied a very small area in this watershed. Thus the geomorphological situation in the area is favorable for the groundwater occurrence and storage.

Soil Characteristics and Land Use/Land Cover

Soil has a significant impact on the amount of recharge which can infiltrate into the ground surface. Since the entire area is covered by Deccan trap formation, the soil in the area is mainly black cotton soil. The soil map of the study area shows mainly three types of soil textural classes. They are clay loam, clay and sandy loam types of soil textural classes. Out of which, clay loam occurs on high attitude, clay soil spread over most of the parts of watershed area and sandy loam soil is found scattered and located mostly at the foot hill areas. The clayey soil, covering major part of the watershed, is indicative of very gentle slope with the thick weathered mantle. This zone is considered as a favorable area for the groundwater recharge. The details of soil characteristics and land use/ land cover are provided in Fig. 3.

The physiography, geology and soils have a direct relation with the land use pattern (Krishnamurthy and Srinnivas 1995; Trivedi and Singh 2005; Varade et al. 2011b). The existing land use is one of the important aspects to understand the erosional process and genetics of the watershed. It provides vital clues for suitable preventive measures to be applied for all over all

Fig. 3 Soil characteristics and land use/ land cover map of study area

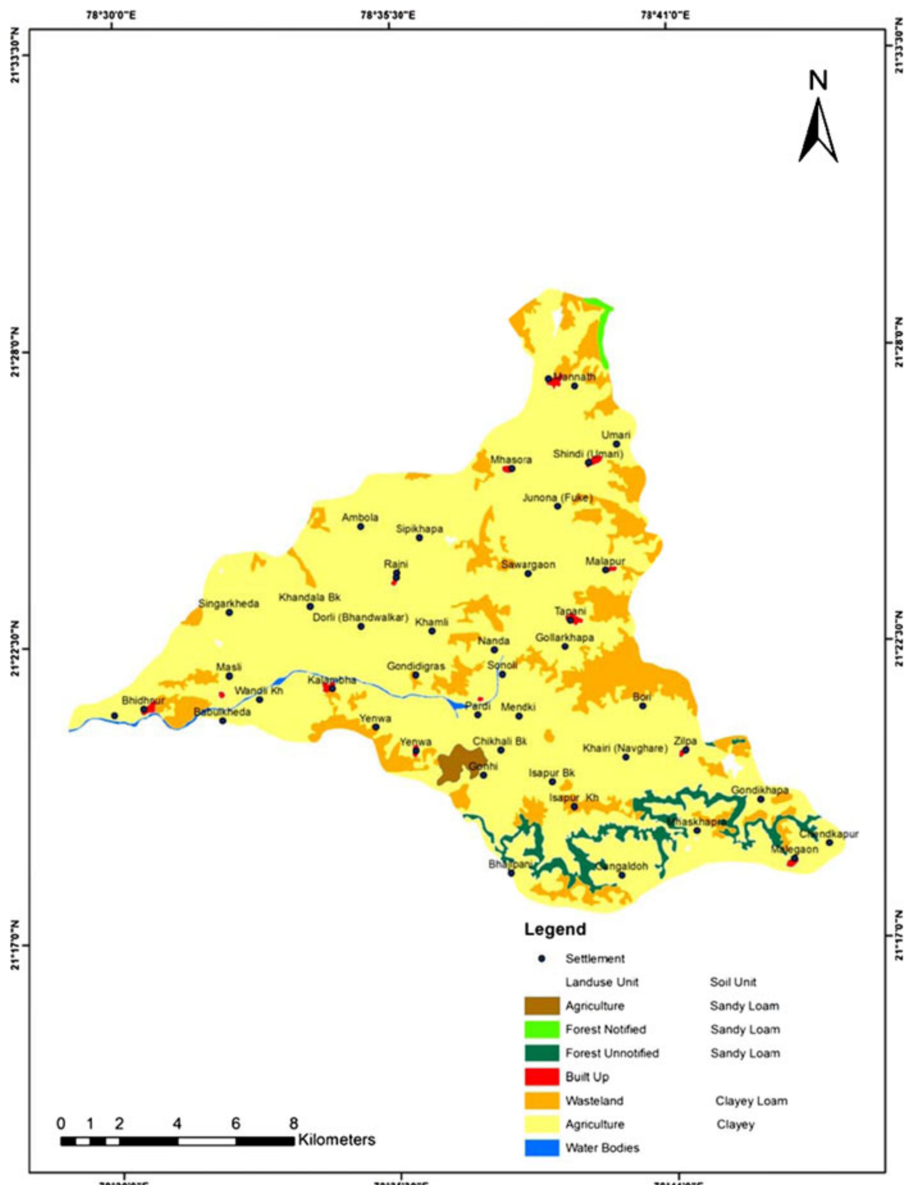

Table 2 Weightages for different classes of geomorphology map

Sr. No.	Classes	Zone	Characters	Weightage	Runoff characteristics	Feasible water conservation structure
1.	Structural / Denudational hills	Run-off	• Slope >10 % • Soil shallow (<30 cm) • Land use predominantly forest and wasteland	300	Maximum	Water arresting structures
2.	Plateau top	Recharge	• Slope 3–10 % • Soil shallow (>30 cm) • Land use predominantly single crop and wasteland	200	Moderate	Recharging structures
3.	Upper plateau and Alluvium	Storage	• Slope 0–1 % • Deep shallow (>1 m) • Land use predominantly agriculture (single/double crop)	100	Minimum	Storage structures

corrective treatment measures for soil conservation, water conservation and all over developed and management of watershed area. The land use/ land cover map of the study area shows that agriculture is the major land use. The wasteland is occupied in the eastern part and very small part is occupied by forest. The forest cover area is confined to high attitude regions. The agricultural practices need huge water for cultivation of crops. Under this situation of intensive agricultural practices, over-exploitation of groundwater in this area is anticipated.

Integrated Analysis

The selection of sites for water conservation structures is a multidisciplinary task (Murthy 2000; Deshpande 2003). Similarly, an approach of ridge to valley development is very essential as all the components of watershed contribute towards one or other form of recharge. So it is necessary to integrate generated spatial database in GIS environment (Pandey et al. 2011). By considering this, in the present work, the resource maps of geomorphology, soil and land use were digitized into the GIS environment in the form of thematic layers using Arc-Info 9.0 software on the scale of 1:50,000 to facilitate integration of interrelated thematic layers. The weightage were assigned to each layer according to its runoff characteristics (Tables 2, 3 and 4). The weightage are merely qualitative and not quantitative, indicating expression of relativity within the different units. Thus, higher weightage indicate high runoff while the low weightage shows low runoff condition and *vice-a-versa*. Each thematic layer is classified in

Table 3 Weightages for different classes of soil map

Sr. No	Classes	Zone	Characters	Weightage	Runoff characteristics
1.	Clay Loam	Run-off	• Slope >10 % • Hills and foot hills • Dominant land use predominantly forest and wasteland	30	Maximum
2.	Sandy Loam	Recharge	• Slope 3–10 % • Plateau top • Dominant land use single crop agriculture and wasteland	20	Moderate
3.	Clay	Storage	• Slope <1 % • Upper plateau • Dominant land use single crop/ double crop agriculture	10	Minimum

Table 4 Weightages for different classes of land use/ land cover map

Sr. No	Class	Zone	Weightages
1.	Waste Land	Run-off	3
2.	Forest	Recharge	2
3.	Agriculture	Storage	1
4.	Built up Land	-	1000
5.	Water Body	-	0

three hydromorphic classes *viz.* runoff zone, recharge zone and storage zone corresponds to water divide, middle reaches and lower plains (zone of accumulation of groundwater). This has very good relation with the groundwater potential i.e. runoff zone is unsuitable for occurrence of groundwater, whereas the storage zone is suitable for groundwater development. Similarly, all these zones are amenable to specific water conservation structures.

In the second stage, all the thematic layers are integrated in GIS environment to identify potential land unit for specific water conservation structure.

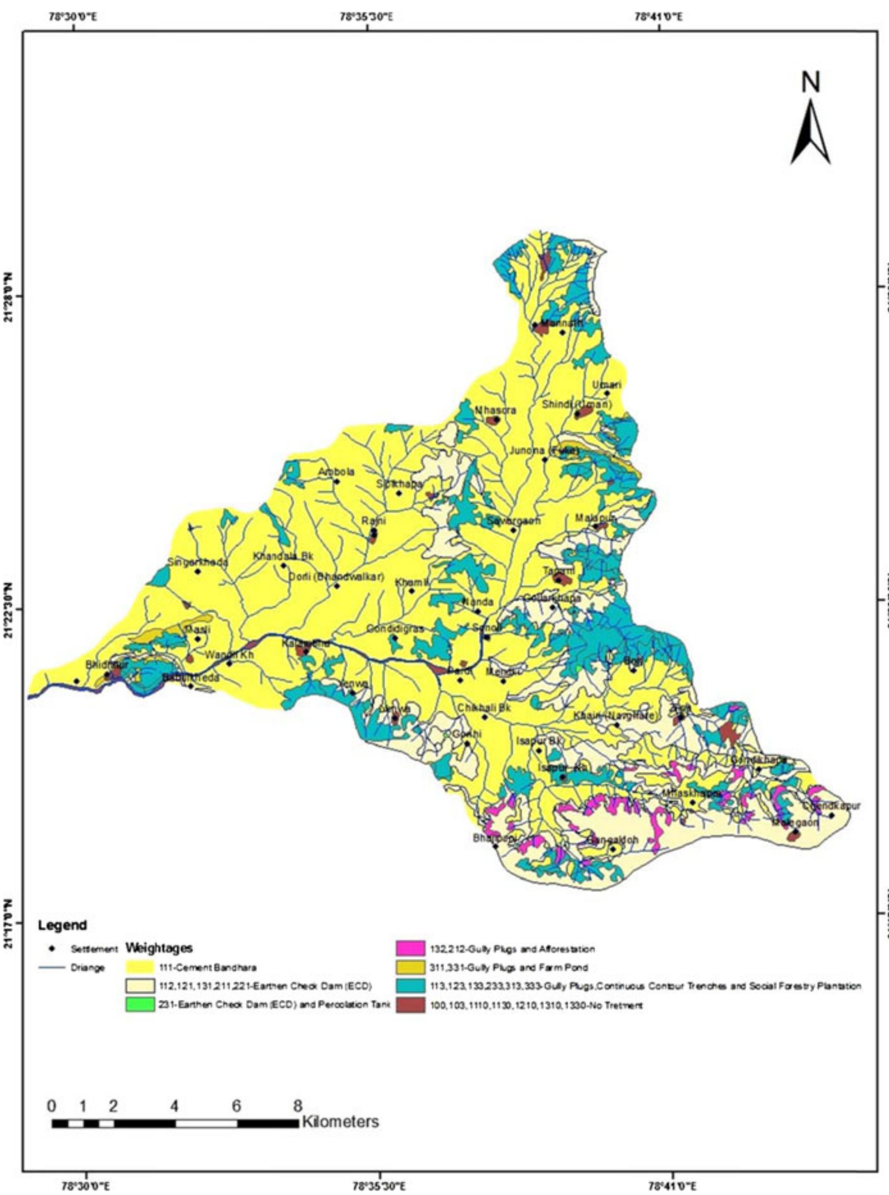

Fig 4 Water conservation map of the study area

Accordingly, the classes of geomorphology, soil and land use were assigned with three, two and single digits, respectively. The integration of these layers has given rise to different polygons having a value in three digits. These 3-digit polygons are important for the identification of specific type of structures as each digit of the polygon is indicative of its character in the form of land use, soil and geomorphology. A final map was evolved which shows different polygons with unique integrated values amenable to specific structures, since each polygon possess a unique hydromorphic character. The polygons of run-off characters were identified as a suitable area for the construction of run-off arresting structures; polygons of recharge characters were recognized as a suitable area for construction of recharge structures; and the polygons of storage characters were recognized as suitable for construction of storage structures. This baseline principle was considered to select the site specific structures in the area. Finally, the integrated polygon values were classified as per their hydromorphic zones and the respective structures for the specific zones were suggested (Fig. 4).

By applying these weightage values, all the three thematic maps were integrated in GIS environment. In a process, total eighteen combinations have been emerged and each combination represents specific terrain character and therefore amenable to specific water conservation treatment.

Table 5 Water conservation treatment in integrated polygons of the study area

Sr. No.	Total Integrated Weightage Values	Polygon Characters	Feasible Water Conservation Treatment
1.	132	• Forest,	
2.	212	• Clay loam,	• Gully Plugs
		• Upper plateau	• Afforestration
3.	113	• Predominantly waste land	• Gully Plugs,
4.	123	• Sand and clayey loam soil	• Continuous Contour Trench (CCT)
5.	133	• Confined to hilly areas	• Social Forestry
6.	233		• Plantation
7.	313		
8.	333		
9.	213		
10.	311	• Agricultural lands on hills	• Gully Plugs
11.	331	• Sandy loam soil	• Farm Pond
12.	231	• Agricultural lands on plateau tops	• Earthen Check Dams (ECD)
		• Sandy loam soil	• Percolation Tank
13.	112	• Agricultural lands on plateau top	• Earthen Check Dams (ECD)
14.	121	• Upper plateau	
15.	131	• Clay loam soil	
16.	211		
17.	221		
18.	111	• Agricultural land on upper plateau and alluvial plain	• Cement Bandhara

Evolution of Water Conservation Plan

The integrated analysis has helped in evolution of appropriate water conservation plan in the study area by adopting the ridge to valley development concept. Based on the results of integrated analysis and terrain characteristics of each polygon, following water conservation plan has been evolved and recommended (Table 5).

1. Gully Plugs: These are suggested at first order streams and gullies. They check the velocity of running water in the upper reaches hilly track with high sloping topography.
2. Continuous Contour Trenches (CCT): Contour trenches are used both on hill slopes as well as on degraded and barren waste lands for soil and water conservation and afforestation purposes. The trenches break the slope and reduce the velocity of surface runoff. It can be used in all slopes irrespective of rainfall conditions (i.e., in both high and low rainfall conditions), varying soil types and depths.
3. Earthen Check Dam (ECD): A check dam is generally constructed on small streams and long gullies formed by the erosive activity of water. The ideally a check dam is located in a narrow stream with high banks. Check dams are earthen structures constructed across the streams higher than 2nd order. These are used as water harvesting structure for irrigation and domestic use. A check dam serves many purposes like a) It cuts off the runoff velocity and reduces erosive activity; b) The water stored improves soil moisture of the adjoining areas and allows percolation to recharge the aquifers.
4. Percolation Tank: These are the recharging structures constructed in the recharge area. The percolation tank facilitates the storage of runoff over a longer period which in turn recharges subsurface aquifer system.
5. Farm Pond: These are the low cost structures constructed in agricultural land located on higher reaches. The farm ponds are used for protective irrigation in prolonged dry spell in monsoon season.
6. Afforestration: This is one of the important measures usually taken in forest land to arrest the runoff water.
7. Cement Bandhara: This structure is generally constructed on the area of intensive agricultural practices across the higher order streams. The cement Bandhara stores a large quantity of water and therefore helps to recharge the surrounding aquifer system.

Implementation of this program will help in reducing surface run-off which in turn could recharge subsurface aquifer. In addition to this, soil erosion would also be reduced considerably.

Conclusions

The recommended water conservation techniques are site specific and thus expected to derive maximum impact. The overall analysis of watershed WRJ-2, falling under Narkhed and Katol Tahsils of Nagpur district, Maharashtra on the basis of GIS techniques as well as ground truth information lead toward the following conclusions:

1. The integration of the geomorphology, land use/land cover, soil as three distinct layers in the GIS environment has proved to be very useful in identifying potential areas for groundwater development and priority areas for implementation of water conservation programs.
2. For the effective water conservation plans in the watershed area (WRJ-2), the water conservation treatment structures like gully plugs, continuous contour trenches (CCT), earthen check dams, percolation tanks are recommended. The implementations of such structures will definitely help to combat over the scarcity situation in the area.
3. It is also concluded that the integrated resource analysis helps in the identification of un-biased potential zones for particular structures.
4. The method is found to be suitable as it reduces time of field study and money.
5. The sites selected on the basis of integrated analysis are realistic as all the interrelated thematic layers are considered for the integration purpose.
6. The study has demonstrated utility of resources database for evolving site specific water conservation plan.

Presently a large groundwater database is being generated in the country under the Rajiv Gandhi National Drinking Water Mission (NRSA 2008). The database generated in the present work can prove significant in dealing with the problems associated with the groundwater development such as identification of sustainable source of drinking water and selection of appropriate sites for the water conservation structures.

References

Anbazhagan, S., & Ramasamy, S. M. (2001). Remote sensing based artificial recharge studies-a case study from Precambrian Terrain, India. In P. J. Dillon (Ed.), *Management of aquifer recharge for sustainability* (pp. 553–556). Adelaide: ISAR-4, Balkema, Lisse.

Anbazhagan, S., Ramasamy, M., & Dasgupta, S. (2005). Remote sensing and GIS for artificial recharge study, runoff estimation and planning in Ayyar basin, Tamilnadu India. *Environmental Geology, 48*, 158–170.

Balachandar, D., Alaguraja, P., Sundaraj, P., Ruthavelmurthy, K., & Kumarswamy, K. (2010). Application of remote sensing and GIS for artificial recharge zone in Sivaganga district, Tamilnadu, India. *International Journal of Geometics and Geosciences, 11*, 84–97.

Braun, G. M., Levine, N. S., Roberts, S. J., & Samel, A. N. (2003). A geographic information systems methodology for the identification of groundwater recharge areas in Waukesha County, Wisconsin. *Environmental & Engineering Geoscience, 9*(3), 267–278.

Bühlmann, E., Wolfgramm, B., Maselli, D., Hurni, H., Sanginov, S. R., & Liniger, H. P. (2010). Geographic information system–based decision support for soil conservation planning in Tajikistan. *Journal of Soil and Water Conservation, 65*(3), 151–159.

CGWB (2003). *Ground water resources and development potential of Nagpur District, Maharashtra, and annual action programme 1999–2000* (pp. 1–11). Central Region, Nagpur: Central Groundwater Board.

Deshpande, A. S. (2003). A geomatics approach in establishment of methodology for watershed eco-development system. *Ecology, Environment and Conservation, 9*(1), 91–94.

Deshpande, G. G. (1998). *Geology of Maharashtra* (p. 223). Banglore: Geological Society of India.

DRM (2001). *District resource map for Nagpur District, Maharashtra*. Central Region: Geological Survey of India.

Durbude, D. G., & Venkatesh, B. (2004). Site suitability analysis for soil and water conservation structures. *Journal of the Indian Society of Remote Sensing, 32*(4), 399–405.

Ghayoumian, J., Ghermezcheshme, B., Feiznia, S., & Noroozi, A. A. (2005). Integrating GIS and DSS for identification of suitable areas for artificial recharge, case study Meimeh Basin, Isfahan, Iran. *Environmental Geology, 47*, 493–500.

GSDA (2008). *Groundwater surveys and development agency annual report for the year 2007–08*. Nagpur: District Office.

Jafar, G., Ghermezcheshme, B., Feiznia, S., & Noroozi, A. A. (2005). Integrating GIS and DSS for identification of suitable areas for artificial recharge, case study Meimeh Basin, Isfahan, Iran. *Environmental Geology, 47*, 493–500.

Jankowski, P. (2006). Integrating geographical information systems and multiple criteria decision-making methods. *Classics from IJGIS: twenty years of the International Journal of Geographical Information Science and System., 9*(3), 265–296.

Krishnamurthy, J., & Srinivas, G. (1995). Role of geological and geomorphological factors in ground water exploration: a study using IRS LISS data. *International Journal of Remote Sensing, 16*(14), 2595–2618.

Krishnamurthy, J. N., Venkatesa, K., Jayaraman, V., & Manivel, M. (1996). An approach to demarcate groundwater potential zones through remote sensing and geographical information system. *International Journal of Remote Sensing, 17*, 1867–1884.

Murthy, K. S. R. (2000). Groundwater potential in a semi-arid region of Andhra Pradesh: a geographical information system approach. *International Journal of Remote Sensing, 21* (9), 1867–1884.

Natarajan, D., John, B. S., Balaguru, B., Nagamurugan, N., Soosairaj, S., & Arockiasamy, D. I. (2004). Identification of conservation priority sites using remote sensing and GIS – A case study from Chitteri hills, Eastern Ghats, Tamil Nadu. *Current Science, 86*(9), 1316–1323.

NRSA (2008). *Ground water prospects mapping using remote sensing and geographical Information System, Rajiv Gandhi National Drinking Water Mission Project* (p. 256). National Remote Sensing Agency Manual.

Pandey, A., Chowdary, V. M., Mal, B. C., & Dabral, P. P. (2011). Remote sensing and GIS for identification of suitable sites for soil and water conservation structures. *Land Degradation & Development, 22*(3), 359–372.

Prasad, R. K., Mondal, N. C., Banerjee, P., Nandakumar, M. V., & Singh, V. S. (2008). Deciphering potential groundwater zone in hard rock through the application of GIS. *Environmental Geology, 55*(3), 467–475.

Raghu, V., & Reddy, M. K. (2011). Hydrogeomorphological mapping at village level using high resolution satellite data and impact analysis of check dams in part of Akuledu Vanka Watershed, Anantapur District, Andhra Pradesh. *Journal of Indian Geophysical Union, 15*(1), 1–8.

Ramaswamy, S. M., & Anbazhagan, S. (1997). Criteria and techniques of detecting site specific mechanism for artificial recharge- a case study from Ayyar basin, India. *Journal of Geological Society of India, 50*, 449–456.

Ravi Shankar, M. N., & Mohan, G. (2005). A GIS based hydrogeomorphic approach for identification of sites specific artificial recharge technique in the Deccan volcanic provenance. *Journal Earth System Science, 114*(5), 505–514.

Rokade, V. M., Kundal, P., & Joshi, A. K. (2004). Water resource development action plan for Sasti Watershed Chandrapur District, Maharashtra using Remote sensing and Geographical Information System. *Journal of the Indian Society of Remote Sensing, 32*(4), 359–368.

Saptarshi, P. G., & Raghvendra, R. K. (2009). GIS- based evaluation of micro-watersheds to ascertain site suitability for water conservation structures. *Journal of the Indian Society of Remote Sensing, 37*, 693–704.

Saraf, A. K., & Choudhury, P. R. (1998). Integrated remote sensing and GIS for groundwater exploration and identification of artificial recharge sites. *International Journal of Remote Sensing, 19*(10), 1825–1841.

Thakur, G. S., & Raghuwanshi, R. S. (2008). Prospects and assessment of groundwater resources using remote sensing techniques in and around Choral River Basin, Indore and Khargaon Districts, M.P. *Journal of the Indian Society of Remote Sensing, 36*, 217–225.

Trivedi, R. K., & Singh, R. M. (2005). A micro-level approach for integrated watershed investigation development planning and artificial recharge site selection for ground water in Malani river watershed. *Gondwana Geological Magazine, 20*(2), 137–146.

Varade, A. M., Wath, P., Dongre, K., Khare, Y. D., & Khandare, H. (2011a). Integrated approach using remote sensing & GIS for assessment of groundwater situation in parts of Chandrapur and Gadchiroli Districts of Maharashtra. *Journal of Indian Geophysical Union, 15* (4), 195–205.

Varade, A. M., Wadwekar, M., Kolte, D., Dongre, K., & Khare, Y. D. (2011b). Identification of groundwater potential zones in and around Nagpur city, Maharashtra using remote sensing and GIS. *Gondwana Geological Magazine, 26*(2), 129–138.

Waters, P. V., Greenbaun, D. B., Smart, P. L., & Osmaston, H. (1990). Application of remote Sensing to groundwater hydrology. *Remote Sensing Reviews, 4*(2), 223–264.