

Integrated geographical information system (GIS)-based decision support system (DSS) approach to identify the site-specific water conservation structures in a watershed of Nagpur district, Central India

Abhay M. Varade¹ · Y. D. Khare² · K. P. Dongre³ · S. Muley⁴ · Gunwant Wasnik¹

Received: 29 September 2015 / Accepted: 30 January 2017 / Published online: 4 March 2017
© Springer International Publishing Switzerland 2017

Abstract Identification of appropriate sites for water conservation is an important step towards maximizing the water availability in semi-arid areas. However, selection of such sites poses a great challenge due to non-consideration of various interrelated controlling factors in the currently adopted practices. In view of this, an attempt has been made here to employ Geographical Information System (GIS) technique for a watershed development program by following a multidisciplinary approach. Integrated analysis of all thematic maps and their respective weightage in GIS platform have evolved a map showing potential zones for water conservation structures and their appropriate measures. Finally, different water conservation structures and measures are recommended for an effective site-specific water conservation plan of the study area. Implementation of this plan will not only help to arrest the free flow of runoff water but also result in the additional groundwater recharge, thus significantly minimizing the water scarcity problems.

Keywords Decision support system · GIS · Water conservation · Runoff · Nagpur · Central India

Introduction

The groundwater resources in the Maharashtra *State* of Central India show various limitations due to typical geological, physiographical and hydro-geological conditions (Dhokarikar 1991; Varade et al. 2012). In addition, factors like vagaries of rainfall, expansion of irrigation, over-exploitation of groundwater, etc., have further aggravated the water scarcity problems in the area (Varade et al. 2011a). The region receives a substantial amount of annual rainfall, even then the groundwater scenario is not very encouraging, primarily due to the imbalance between recharge and groundwater exploitation (GSDA 2004). The large amount of natural precipitation in the form of rainfall is lost through surface runoff, further compounded by the lack of water conservation and harvesting practices. Overall, the water scarcity has transformed into a social problem of poverty due to mismanagement of natural resources. The *State* is, therefore, forced to adopt crisis management measures, such as drilling of new bore wells and supply of drinking water by tankers, which lead to the burdening of public exchequer (Duriaswami 2005). To overcome this situation, it has become necessary to adopt water conservation practices, which involve identification, development and implementation of groundwater recharge systems at appropriate drainage places. Implementation of such structures will not only help to arrest the free flow of runoff water but also would result in the additional groundwater recharge.

Presently, various *Government* and *Non-governmental Organizations* (NGO) are working over to combat such alarming situation in the *State*, in which, lots of efforts are made to collect the baseline data through rigorous hydro-geological fieldwork studies (NRSA 2008). These field-based studies, however, reveal that the conventional investigations are insufficient to identify suitable sites for artificial

✉ Abhay M. Varade
varade2010@gmail.com

¹ P. G. Department of Geology, RTM Nagpur University, Nagpur, MS, India

² Maharashtra Remote Sensing Application Centre (MRSAC), Nagpur, MS, India

³ Central Ground Water Board, Central Region, Nagpur, MS, India

⁴ Groundwater Surveys and Development Agency, Gadchiroli, MS, India

recharge due to their single-line approach based on hydro-geological aspect (Agashe 1990). In fact, an individual resource data do not convey proper information on true potentials and problems of the area of interest, if viewed in isolation. This is because there are many controlling factors that are required to be independently derived and integrated in detail (Ravi Shankar and Mohan 2005). As a result, it is experienced that such a single-line approach loses the very essence of holistic concept. Similarly, these studies are time consuming and cumbersome. Due to all these drawbacks, the identification of appropriate sites for the water conservation programs failed to achieve the desired impact and thus poses a major challenge to the workers involved in this field. Therefore, to obtain a realistic output, it is eminent to study all these interrelated resources for identification of potentials and problems on the field level. Thus, there exists a need to develop a model based on consideration of multidisciplinary data from various sources. In this context, it is felt that the integrated analyses of available resources database would provide better understanding of the terrain conditions, as it considers all the interrelated resources, which in turn, facilitates the adoption of holistic approach. Hence, the spatially geo-referenced database (effectively employed in GIS environment) is considered here to evolve a Decision Support System (DSS) plan for identification of appropriate sites amenable to specific water conservation measures in a watershed (WRJ-4) of Nagpur district of Central India.

Remote sensing and GIS: a tool to evolve decision support system

The importance of artificial recharge was realized in India only about five decades ago (Todd 1959). However, the applications of advanced remote sensing and GIS techniques in the identification of suitable sites for water harvesting structures have attracted attention in the recent times (Sarma 1992; Saraf and Choudhury 1998; Anbazhagan and Ramasamy 2001; Durbude and Venkatesh 2004; Natarajan et al. 2004; Anbazhagan et al. 2005; Paul et al. 2008; Saptarshi and Raghvendra 2009; Balachandar et al. 2010; Pandey et al. 2011; Varade et al. 2012). These techniques largely help in characterization, conservation, planning and management of natural resources in general, and water resources in particular. The remote sensing provides a sound realistic database on resources, while the GIS technique helps in the integration and conjunctive analysis of huge volumes of multidisciplinary data, both spatial and non-spatial, within the same geo-referencing scheme. Through integration of these two spatial data management technologies, groundwater development by water harvesting and artificial recharge can be well organized

(Ramaswamy and Anbazhagan 1997; Jafar et al. 2005). Thus, this technique in conjugation facilitates demarcation of suitable areas for groundwater replenishment by taking into account the diversity of related factors and forms an exclusive tool in designing an approach to arrive at a decision support system for particular application (Walsh 1992; Varade et al. 2011b). The multi-criteria evolution techniques are numerical algorithms that define the suitability of particular solution on the basis of input criteria and weights together with some mathematical or logical means of determining trends, when conflict arises (Carver 1991; Jankowski 2006; Malczewski 2006). As such to arrive at a clear picture of the situation, the controlling factors have to be treated and integrated giving appropriate weights (specific to particular area) (Gurugnanam et al. 2008; Weerasinghe et al. 2011). By keeping this in view, an attempt has been made here to employ GIS technique for a watershed development program by following a multidisciplinary approach, for which, a watershed (WRJ-4) falling under Katol and Narkhed *Tehsils* of Nagpur district, Maharashtra *State* of Central India is investigated (Fig. 1).

The study area

Nagpur district, the second capital of Maharashtra, is situated in the eastern parts of the *State* and covered under the Wadha sub-basin of main Godavari drainage basin (CGWB 2003). The watershed WRJ-4 covering an area of 375.04 km² of Katol and Narkhed *Tehsils* of Nagpur district falls between the latitudes 21°02'46"–21°21'08"N and longitudes 78°30'17"–78°43'30"E of Survey of India (SOI) toposheet Nos. 55 K/11 and 55 K/12.

The drainages are ephemeral in nature and follows general slope direction. The area experiences a tropical climate. The major part of rainfall occurs during the southwest monsoonal winds, which prevails in between June to September months. The annual rainfall data for the Katol *Tehsil* show wide variation ranging between 539.9 and 1138.3 mm. Similarly, in Narkhed *Tehsil* it ranges in between 520.2 and 1333.8 mm (Table 1; <http://www.mahaagri.gov.in>). In view of a wide variation in the annual rainfall pattern its bearing on the groundwater regime of study area is anticipated.

Groundwater status of watershed WRJ-4

The groundwater assessment details of the study area carried out by Groundwater Surveys and Development Agency (GSDA), Government of Maharashtra reveal that watershed WRJ-4 falls in semi-critical stage category and is on the verge of over-exploitation. The stage of development is reported as 93.3%. The total recharge indicated is 3961.49 ha meter, while the annual draft from the existing wells is 3695.96 ha meter. The water

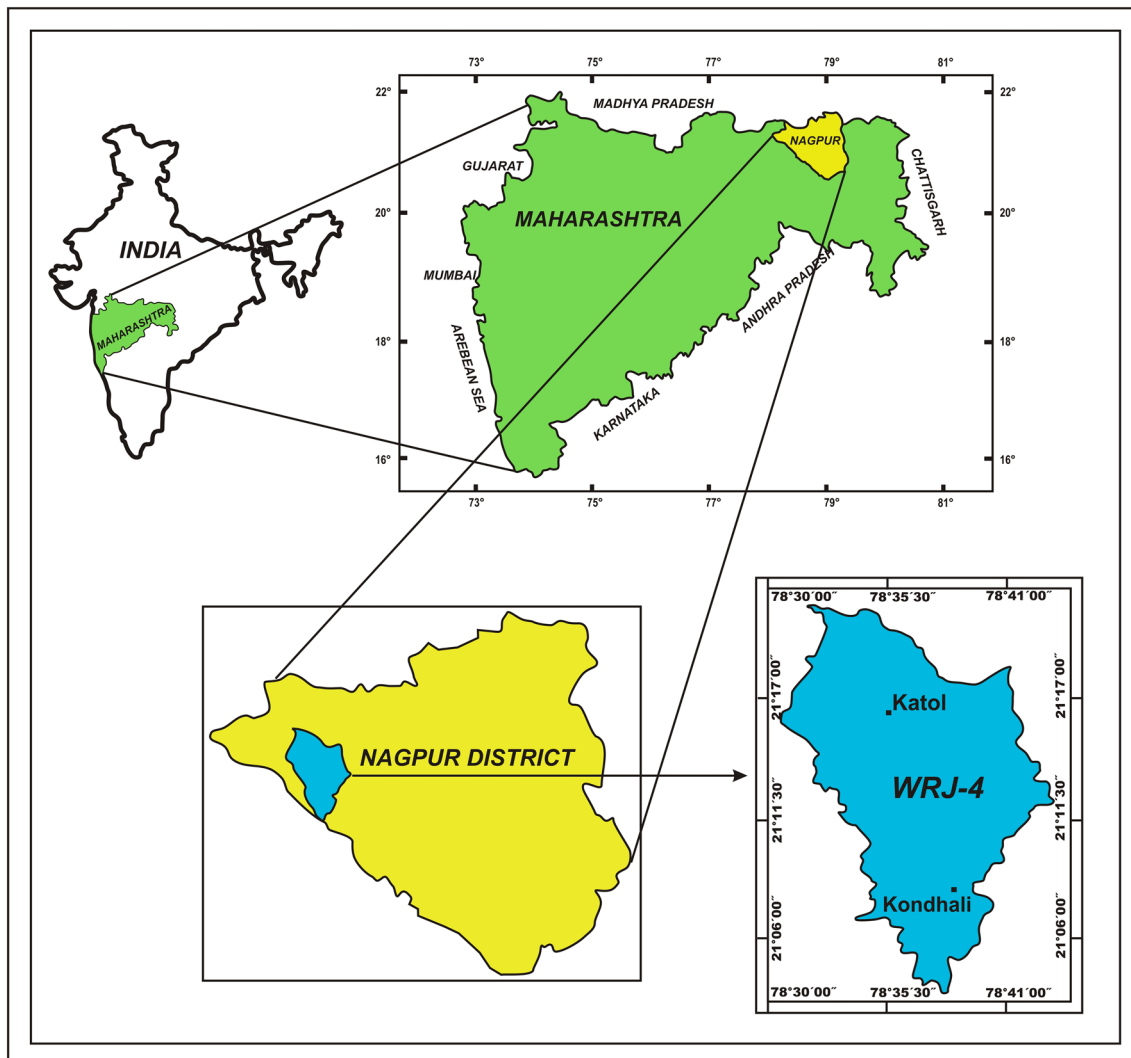


Fig. 1 Index map of the study area (WRJ-4 watershed)

Table 1 Thirteen years rainfall data for the study area

Sr. no.	Year	Tehsil	Total rainfall (mm)	Tehsil	Total rainfall (mm)
1	1999	Katol	539.9	Narkhed	1333.8
2	2000		845.7		569.8
3	2001		876.8		520.2
4	2002		806.8		768.8
5	2003		885.1		712
6	2004		625.8		552.9
7	2005		1045.2		858
8	2006		851.2		652.8
9	2007		1138.3		1146.1
10	2008		724.8		569.8
11	2009		841.6		796.9
12	2010		947.7		1035.6
13	2011		798.8		764.9

table trend shows declining nature in the pre-monsoon, reflecting heavy withdrawal situation in the area (GSDA 2008). This overall suggests that the withdrawal is being increased over the time, which is indicative of overdraft situation. Due to this reason the *Orange* crop of the area is badly affected. Similarly, many villages in the watershed experience drinking water scarcity during peak summer season. The problem further enhances due to wide variation in rainfall pattern as discussed earlier. Therefore, there exists a timely need to implement the water conservation schemes to restore the water table and to alleviate scarcity situation in the area. In view of this, following methodology has been adopted for the identification of appropriate sites for construction of water conservation structures.

Materials and methods

The watershed development program envisages construction of various water conservation structures as well as implementation of appropriate land treatments by adopting the concept of ridge to valley development. Each water conservation structure is site specific and, therefore, suitable in a particular discrete environmental set-up (Varade et al. 2012). Therefore, there exists a need to evolve a model based on multidisciplinary approach for selection of sites to derive the maximum benefits. In view of this, an attempt has been made here to identify the areas of specific terrain characters through integrated analysis of resources database in the GIS environment. For this purpose, the materials and methods are divided into three steps, i.e., (1) generation of spatial database on interrelated layers such as geomorphology, soil, and land use/land cover; (2) spatial data analysis; (3) data modeling. The materials used for study involve the Survey of India toposheet (55 K/11 and 55 K/12) on 1:50,000 scale. The same have been used to prepare base and drainage maps of the study area (Fig. 2).

The spatial database on various themes has been created using remote sensing technique, in which, image characters such as tone, texture, shape, size, pattern, and association have been used to delineate the various polygons. In the process, initially, the IRS-1C LISS III geo-coded digital data (2008) is enhanced using the image enhancement technique, i.e., band stretching, and subsequently a false colour

composite (FCC) of the study area has been generated using the bands 2, 3 and 4 with the help of Arch-Info 9.0 software. The image so generated is then interpreted visually to delineate unit boundaries of drainage, geomorphology, soil, land use/land cover themes. Subsequently, these thematic layers are converted into the raster formats in spatial database analysis using Erdas-Imagine 8.3 software. To identify a polygon of unique characters, weightages are assigned to an individual theme as per its relative runoff characters and are further integrated into the GIS platform to evolve polygons of unique characters in terms of geomorphology, soil and land use. Each polygon is, therefore, amenable to specific water conservation structure. The findings of the study are discussed below.

Results and discussion

Drainage and physiography

The drainage map of the study area indicates that the area forms a closed basin with slope towards north. The drainage density is high in the southern region indicating predominance of runoff, while in the northern region the density is low, implying the storage nature of the area. The watershed area is drained by the River Jam and its sub-tributaries. The River Jam is a tributary of main River Wardha. The drainage pattern is predominantly dendritic (Fig. 3).

Fig. 2 Flowchart showing methodology adopted in the work

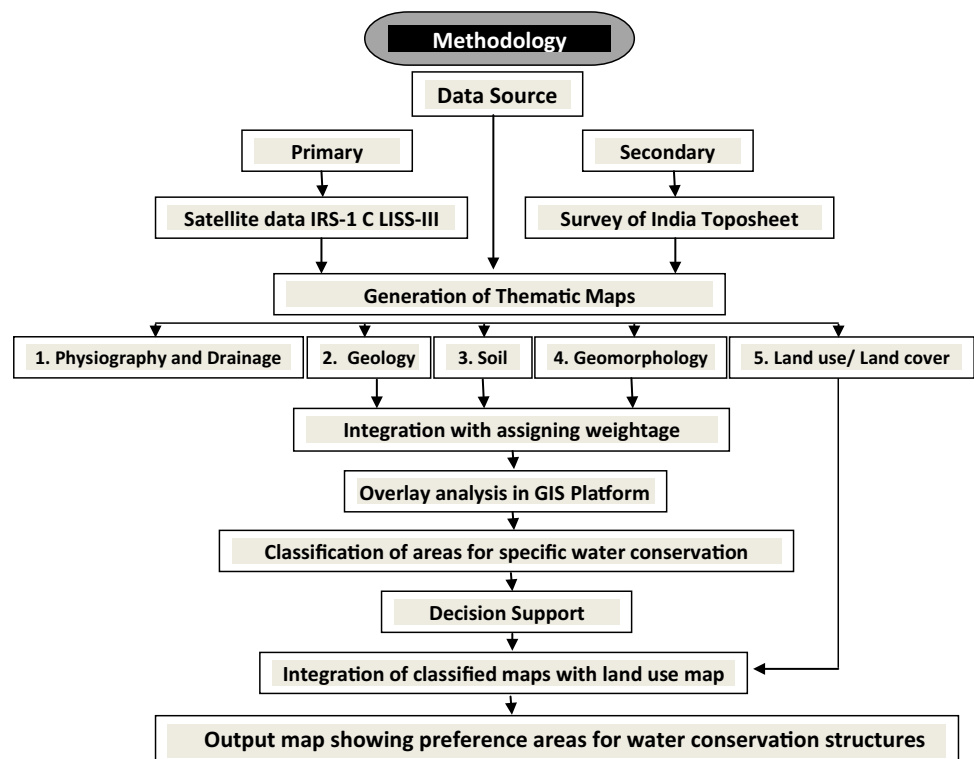
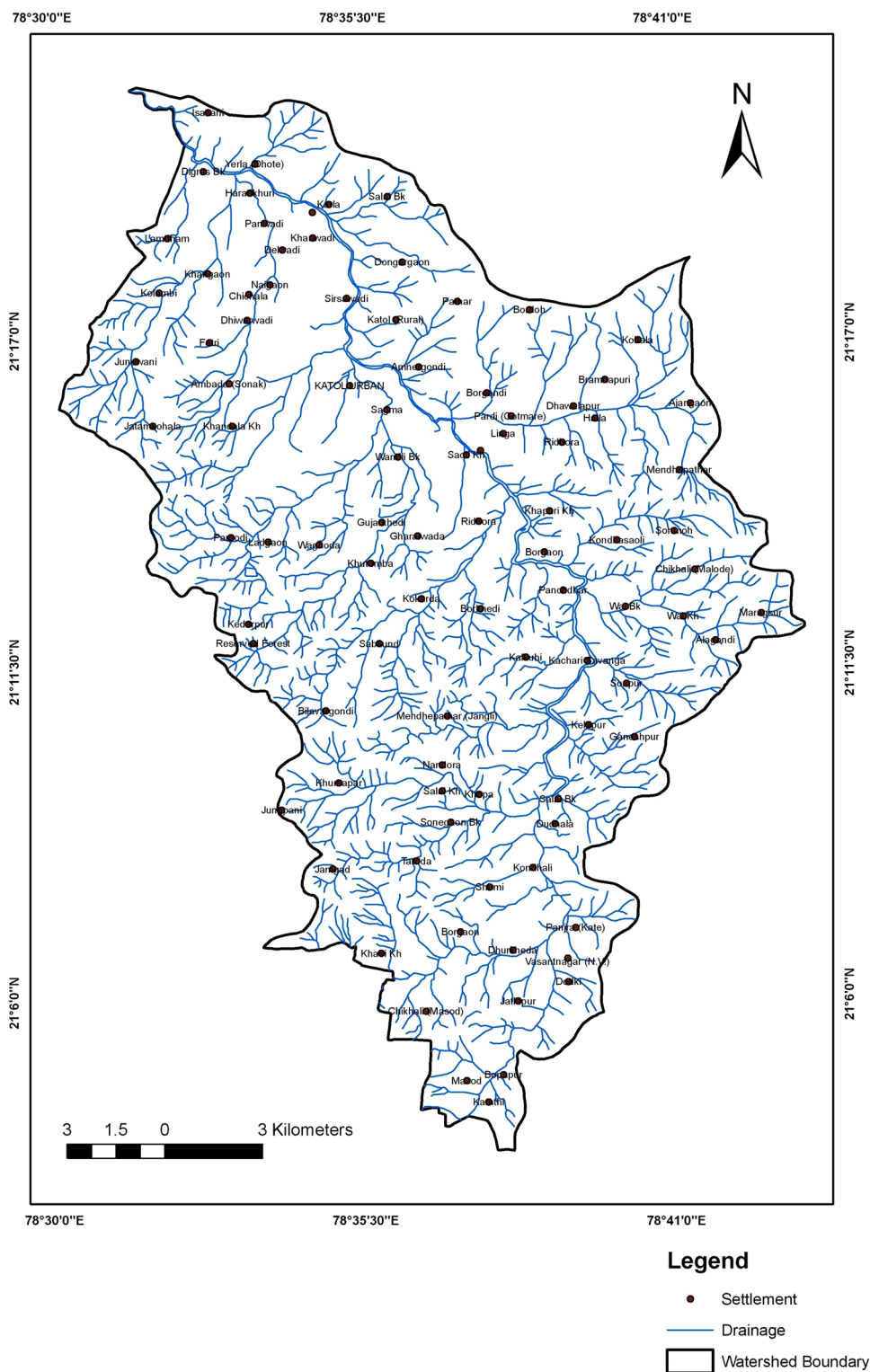


Fig. 3 Drainage and physio-graphical map of the study area



Physiographic situation of the area, as inferred through drainage map, reflects that the watershed area possesses a moderate slope and undulating topography. The highest

altitude ranges between 603 m (amsl) towards southwest and 400 m (amsl) towards northwest part of the watershed. The general slope of the area is in the northwest direction.

Geology

To understand the groundwater situation of the study area, a geological map has been prepared which shows predominance of Deccan trap basaltic lava flows (98% of the total area of watershed). The multiple lava flow units are mainly divided into vesicular, amygdaloidal and compact types of basalt (Deshpande 1998). Thus, a multilayered aquifer system is expected in the area, in which, vesicular zone of each lava flow unit is suitable for artificial recharge through water conservation measures. Only a small area of the watershed occurring in the northwestern and central parts of the watershed is covered by Recent alluvium deposit. This unit confines to storage zone and, therefore, is suitable for specific water conservation structures. The geological map of the WRJ-4 Watershed is shown in Fig. 4.

Soil characteristics

The soil map of any area has a good correlation with geomorphic situation and, therefore, corroborates groundwater situation (Varade et al. 2012). The surface runoff potential is also dependent on the soil texture of the area (Preeja et al. 2011). In view of this, the soil map of the study area has been generated using remote sensing technique. The map shows distribution of four types of soils in the study area, viz., clay loam, clayey soil, sandy loam to loam, and sandy loam to sandy clay (Fig. 5). The sandy loam to sandy clay covers hilly area, whereas the clayey soil has occupied maximum area of the watershed. The sandy loam to loam and clayey loam have covered a little area in the western part of the watershed. The clayey soil which covers the major portion of the watershed implies that the soil is dominated by clay and not totally clayey. In the present study the soil depths have been inferred from Tables 2 and 3.

Geomorphology

The groundwater situation in hard rock terrain is mainly dependent on the geomorphological set-up. The Deccan trap which covers 83% of the *state* of Maharashtra form one of the major aquifer systems in this region. The Deccan trap lava flow acts as good aquifer in which the permeability of different lava flow units has a very good correlation with the geomorphological set-up. Therefore, it is necessary to understand the geomorphological set-up particularly for planning the water conservation policies. Hence, the geomorphological map of the study area has been generated through image interpretation. Geomorphologically, the area has special credential owing to the occurrence of multiple landforms, in which, each of the landform is unique in terms of groundwater situation as

well as potential. Similarly, each geomorphological unit is amenable to specific water conservation structure as per its runoff characters.

The geomorphological map of the study area shows a total of seven (7) geomorphic units, i.e., (a) dome type denudational hills (acts as runoff zone, unfavorable for groundwater occurrence; however, amenable to construction of water arresting structures such as gully plugs and loose boulder check dams); (b) outer fringe of upper Plateau (denudational slopes, acts as runoff zone, by virtue of steep slope the groundwater potential is expected to be poor; however, amenable to construction of water arresting structures such as gully plugs and loose boulder check dams); (c) MDP-A (exposed rock and thin soil cover, basically forms a recharge zone, amenable to construction of conservation structures such as percolation tanks and earthen check dams); (d) MDP-B (moderate soil cover, basically forms storage zone by virtue of its characters such as moderately thick weathered mantle and gentle slope, thus, amenable to structures such as earthen check dams and farm ponds); (e) plateau top (basically a residual basaltic plateau and, therefore, forms a runoff zone, amenable to farm ponds); (f) MDP-C (thick soil cover and thick weathered mantle, basically a storage zone and, therefore, most favorable for groundwater development, amenable to cement/masonry check dams, underground bandhara, etc.); (g) shallow alluvial plain (younger/lower) (storage zone, favorable for occurrence of groundwater, amenable to cement check dams, underground bandhara, etc., types of water conservation structures) (Fig. 6).

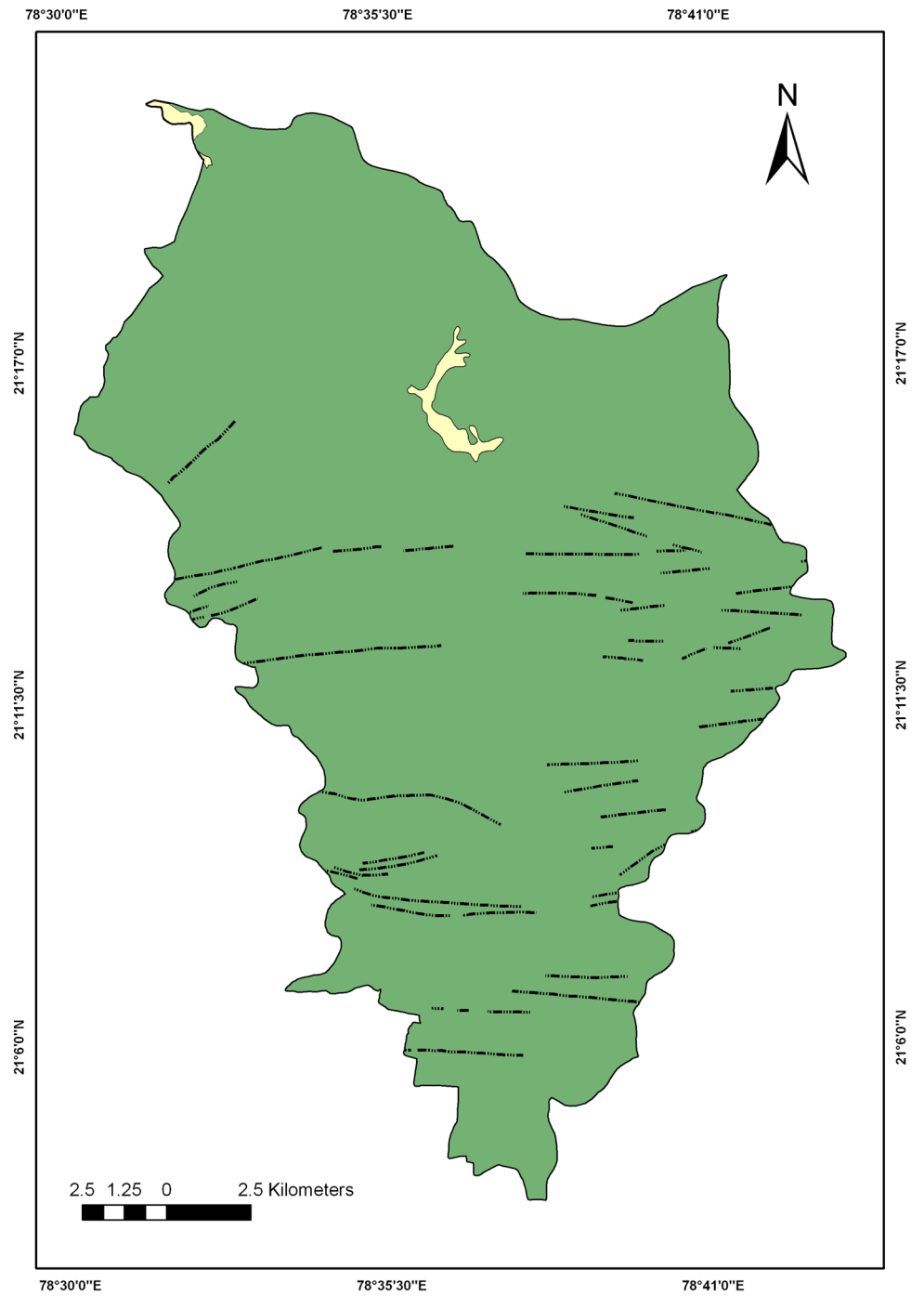
Land use/land cover

The land use/land cover directly reflects the physiographical and hydrological situation of any area and hence its knowledge is important to pinpoint the water conservation sites (Balachandar et al. 2010). The land use/land cover map shows various land use practices carried out on the earth surface and, therefore, it is also very significant in selection of water conservation sites (Varade et al. 2011b). By keeping the significance of this information, a map on land use theme for the study area has been prepared. The map reveals that the agriculture is the main land use (75%) in the area. Forest cover occupies 15% of the area and wasteland 5%, very less area has been occupied by water bodies and settlement (Fig. 7).

Integrated analysis

The ultimate objective of the current study is to evolve a site-specific action plan/model for the effective water conservation program. The selection of site is a multidisciplinary task and, therefore, an integrated study of all the

Fig. 4 Geology map of the study area



Legend

----- lineament

GEOLOGY

Alluvium

Basalt

Watershed Boundary

Table 2 Weightage for different classes of geomorphology map

Sr. no.	Classes	Hydromorphic zone	Characters	Weightage	Runoff characteristics	Feasible water conservation structure
1	(a) Dome type denudational hills (b) Outer fringe of upper Plateau (Denudational slopes)	Runoff	Slope >17% Shallow weathering Shallow soil <30 cm Forest cover/barren land	500	Runoff dominant	Water arresting structures Gully plugs Loose boulder structure
2	Moderately Dissected Plateau (MDP)-A	Upper recharge	Slope 5–10% Soil 15–30 cm Barren land/Scrub	400	Moderate runoff	Recharging structures Percolation tank Earthen check dams Compact contour trenches (CCT)
3	(a) Moderately Dissected Plateau (MDP)-B (b) Plateau Top	Recharge	Slope 3–5% Soil 30–45 cm Single crop (Kharif)	300	Low runoff	Recharging structures Earthen check dams
4	Moderately Dissected Plateau (MDP)-C	Storage	Slope <3% Soil 45 cm–1 m Intensive agriculture	200	Storage	Storage structures Cement nala bund Underground bandhara
5	Shallow alluvial plain (younger/lower)	Storage	Slope <1% Soil thick clayey Intensive agriculture	100	Storage	Storage structures Cement nala bund Underground bandhara

Table 3 Weightage for different classes of soil map

Sr. no.	Classes	Character	Weightage	Runoff characteristics
1	Sandy loam to Sandy clay	Runoff zone Slope >10% Soil thickness <30 cm Forest cover/barren land	30	Maximum
2	Sandy loam to loam	Recharge zone Slope 3–10% Soil thickness 30–45 cm Barren land/scrub	20	Moderate
3	(a) Clay loam (b) Clayey soil	Storage zone Slope <3% Soil thickness ~1 m Intensive agriculture Storage zone Slope <1% Soil thickness >1 m Intensive agriculture	10	Minimum

thematic layers is necessary to maximize the benefit of water conservation structures. This integrated approach helps in identification of polygons of unique characters in terms of geomorphology, soil and land use, which are amenable to specific water conservation structure. Such approach removes redundancy in the database and

facilitates to evolve an appropriate water conservation plan for any area.

Realizing the importance of this technique, an attempt has been made here to develop a GIS model that could help in identification of suitable sites for water conservation measures in the study area. In the process, initially, the

Fig. 5 Soil map of the study area

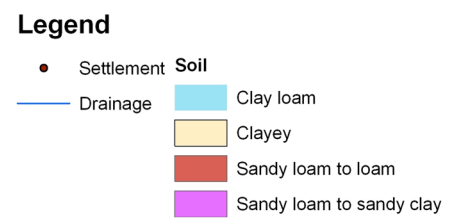
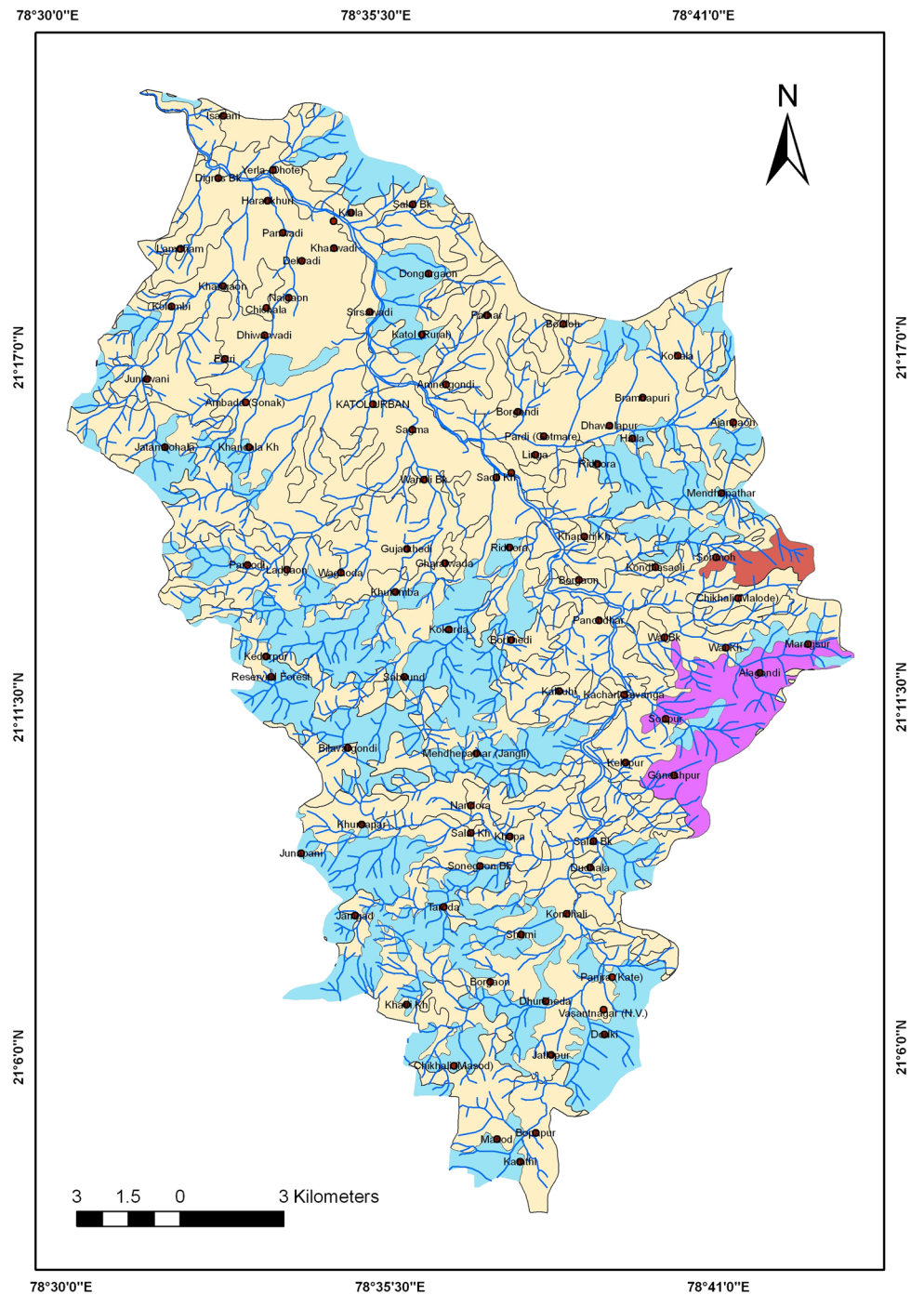
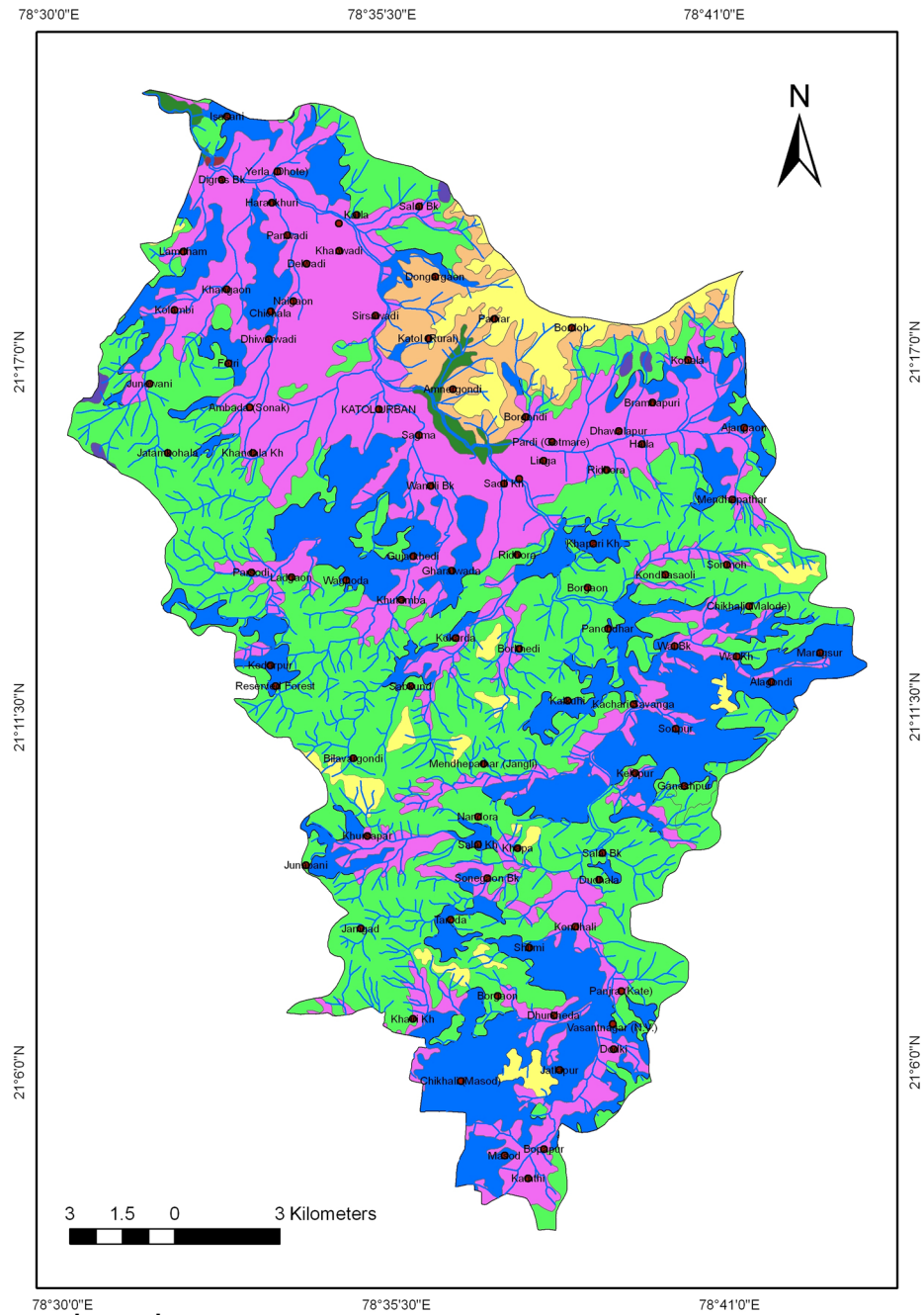


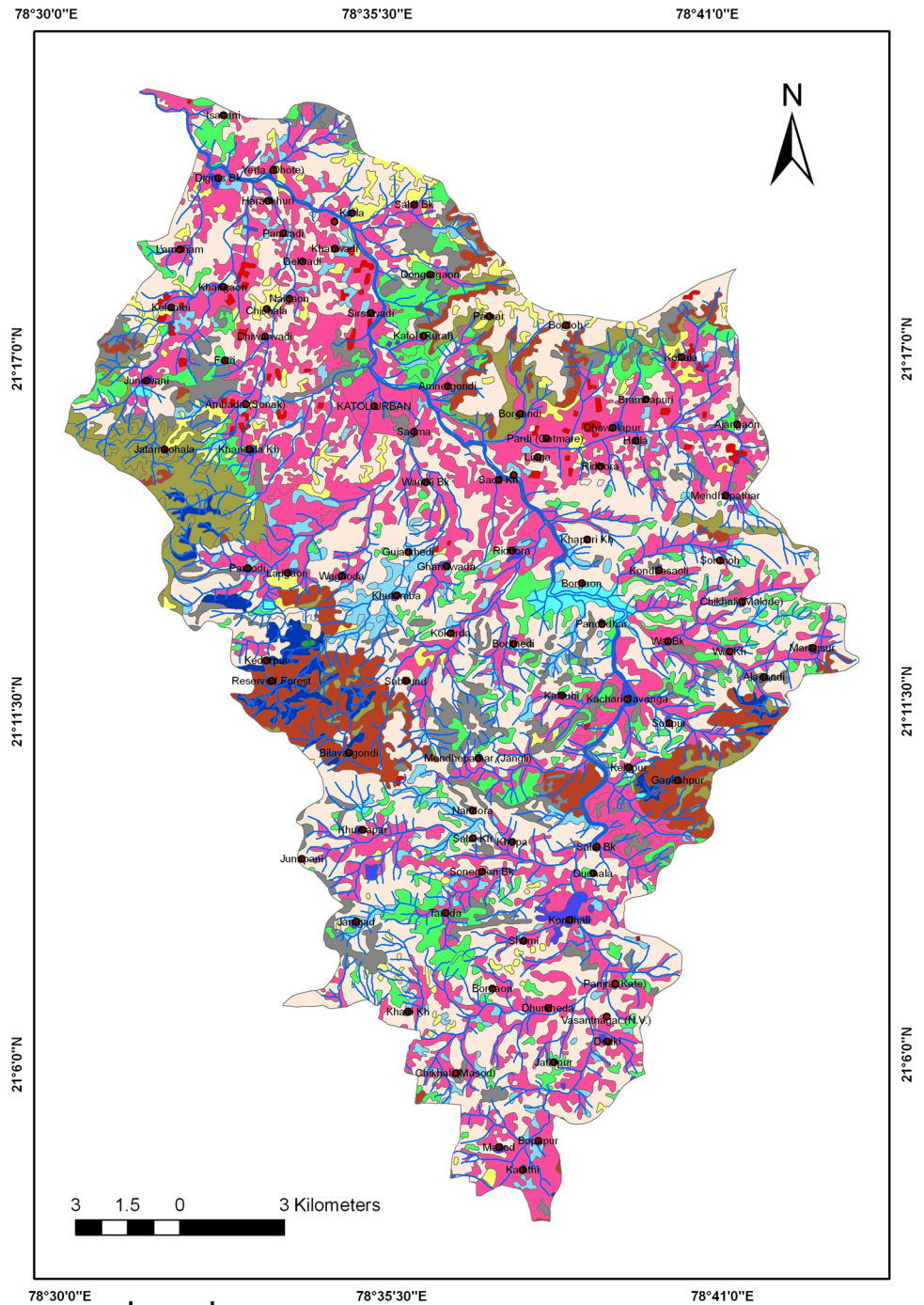
Fig. 6 Geomorphological set-up of the study area



resource maps of geomorphology, soil and land use/land cover are digitized into the GIS environment in the form of thematic layers using Arc-Info 9.0 software on the scale of

1:50,000. The weightage values to all the classes of respective themes are assigned in descending order as per their runoff characteristics (Tables 2, 3, 4).

Fig. 7 Land use/land cover map of the study area



Legend

- Settlement
- Drainage
- Current Fallow
- Dense/Closed
- Forest Blanks
- Horticulture
- Kharif
- Kharif+Rabi (Double Cropped)
- Land with scrub
- Land without scrub
- Open
- Rabi
- Reservoirs
- River
- Scrub Forest
- Villages (Rural)

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

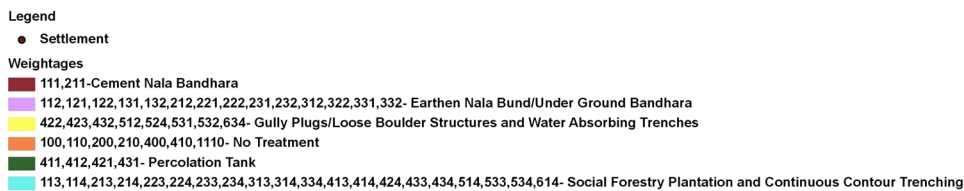
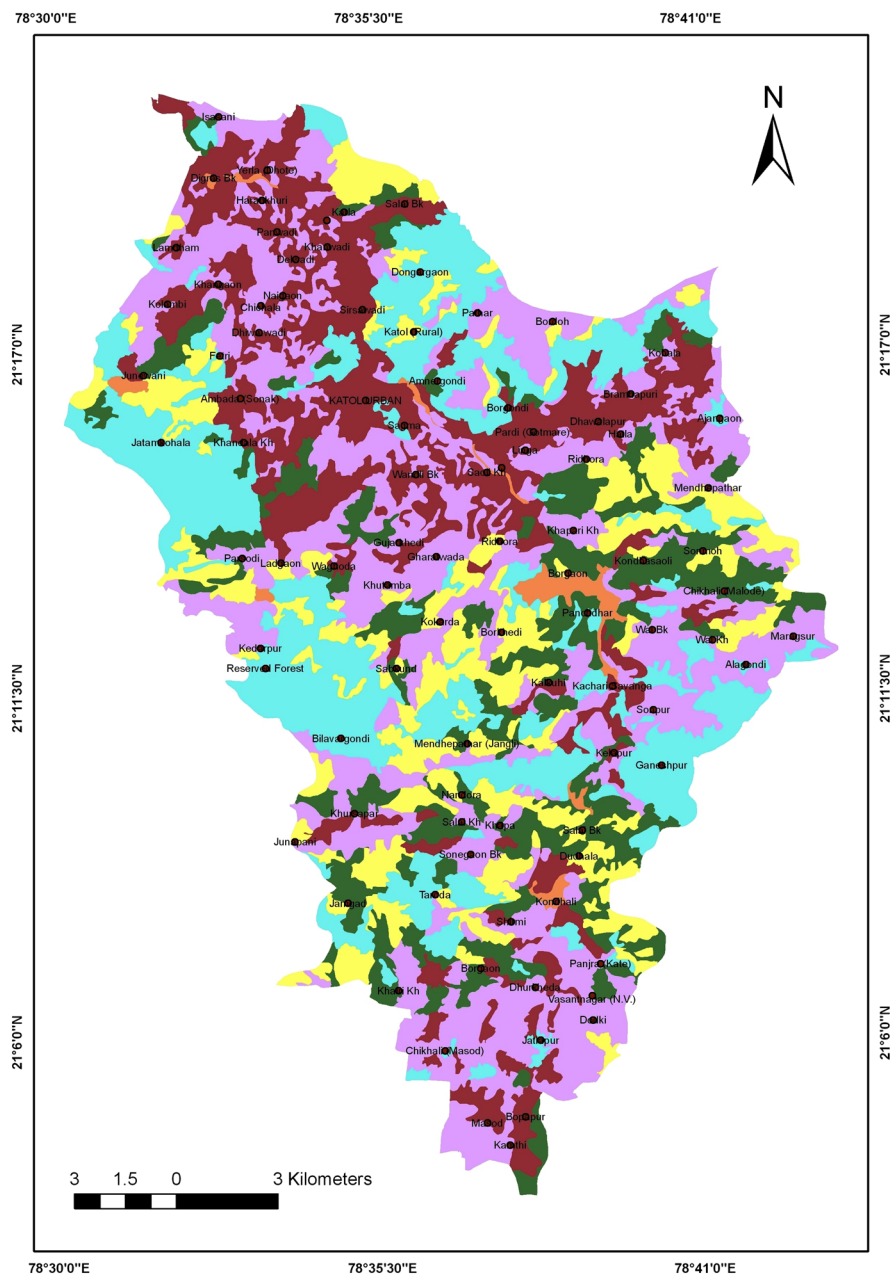
Sr. no.	Class	Character	Weightage
1	Scrub forest Land without scrub Land with scrub Open land	Runoff zone	3
2	Forest Dense/closed Forest blank	Recharge	2
3	Double crop (Kharif + Rabi) Horticulture land Rabi Kharif Current fallow land	Storage	1
4	Built up land/settlement	–	1000
5	Reservoir/river	–	0

The weightage indicates the relative runoff character of an individual unit and is merely qualitative and not quantitative. The most favorable unit of an individual theme with respect to its runoff potential is assigned with maximum weightage and vice versa. The overlay analysis for the thematic map in GIS environment is carried out for identification of the suitable sites for water conservation structures. Accordingly, the classes of geomorphology, soil and land use/land cover are assigned with three, two and single digits, respectively. Integration of these layers has given rise to different polygons with a value in three (3) digits. These 3-digit polygons are important for the identification of specific type of structures. Each digit of the polygon is indicative of its characters in the form of land use, soil and geomorphology. Accordingly, a final map is evolved which shows different polygons with unique integrated values amenable to specific structures, since each polygon possess a unique hydromorphic character. The polygons of runoff characters are identified as a suitable area for the construction of runoff arresting structures; polygons of recharge characters are recognized as a suitable area for construction of recharge structures; the polygons of storage characters are recognized as suitable for construction of storage structures. This principle is adopted to select the site-specific structures in the study area. Finally, a model is built up with polygons of unique characters in terms of hydromorphic zones, viz., runoff zone, recharge zone and storage zone, amenable to specific water conservation structures (Fig. 8).

Evolution of water conservation plan for the study area

Since groundwater is the major source for irrigation, it is being indiscriminately exploited in the study area for Orange Orchard, which has resulted in depleting of water table at faster rate. If the present trend of exploitation continued, there is a possibility of drying up of unconfined aquifers resulting into chaotic situation in the event of drought. Under this situation, it is necessary to implement water conservation measures on large scale. Thus, it is required to conserve the water flowing out as runoff from the area which needs to be arrested at various places by constructing different types of water conservation structures on the drainage lines by adopting the ridge to valley development concept, i.e., runoff arresting structures are taken on hilly region, while the recharge structure such as earthen check dams are generally constructed in recharge zone or middle reaches, and storage structures and masonry check dams are constructed in storage zone of the watershed area (Bhattacharya 2010; Varade et al. 2012). Therefore, for implementation of water conservation program, identification and delineation of three zones such as runoff zone, recharge zone and storage zone are essential. The integrated analysis by applying weightages to different layers has created number of polygons with total weight value in three digits. The digit in the unit place indicates the land use of that polygon, while digit in tenth's place shows soil characteristics and the digit in the hundredth's place reflects the geomorphic character. For example, polygon number 422 indicates that it is a moderately dissected plateau with sandy loam to loam type of soil and forest cover. This has helped in forming a decision support system (DSS) for deciding specific water conservation structure to particular polygon. Based on this logic, following water conservation structure plan is derived and recommended for the study area, i.e., watershed WRJ-4. The various recommended water conservation structures are in vogue in Maharashtra state of Central India and are being implemented on a large scale using 'Ridge to Valley' approach, e.g., each watershed has three distinct units (ridge, middle reaches and valleys). Each unit is amenable to specific water conservation structure, i.e., ridges amenable to prevention of runoff structures; middle reaches, i.e., recharge zone is amenable to construction of large storages such as percolation tanks which allows infiltration; valleys, i.e., storage zones amenable to water storage structures, i.e., cement nala bund. The recommended structures need to be constructed on drainage lines which are exposed with hard rocks. The various recommended water conservation structures and its relation with hydromorphic zones are provided in Table 5.

Fig. 8 Water conservation map of the study area



Conclusions and recommendation

The selection of water conservation site is a multidisciplinary task and, therefore, it is essential to integrate the entire interrelated database to arrive at specific conclusion in relation to specific water conservation structure. The sites

so selected are the most suitable for specific set of hydrological situation as it adopts holistic approach. Similarly, it also helps in removing the subjectivity as well as ambiguity in selection of appropriate sites. In a process, it takes care of each individual thematic database which is directly or indirectly responsible for particular set of hydrological

Table 5 Recommended water conservation treatment in integrated polygons of the study area

Sr. no.	Total integrated weightage values	Polygon characters	Geomorphic zone	Feasible water conservation treatment
1	111, 211	(a) Thick weathered mantle (b) Thick soil cover (c) Predominantly agricultural activity	Storage	Cement Nala Bandhara (i.e., Masonry dam)
2	112, 121, 122, 131, 132, 212, 221, 222, 231, 232, 312, 322, 331, 332	(a) Moderate weathered mantle (b) Moderately thick soil cover (c) Predominantly single crop area	Upper storage	Earthen nala bund Underground bandhara
3	422, 423, 432, 512, 524, 531, 532	(a) Shallow soil thickness (b) Rocky exposures (c) Steep to highly sloping areas (d) Wasteland and forest cover	Runoff	Gully plug Loose boulder structure Water absorbing trenches
4	113, 114, 213, 214, 223, 224, 233, 234, 313, 314, 334, 413, 414, 424, 433, 434, 514, 533	(a) Predominantly waste land (b) Sand and clayey loam soil confined to hilly areas	Upper recharge	Social forestry plantation Continuous contour trenches (CCT)
5	411, 412, 421, 431	(a) Moderately sloping (b) Sandy soil (c) Predominantly single crop area	Recharge	Percolation tank

situation. The present study has demonstrated efficacy of integrated analysis to evolve a model for selection of sites for construction of water conservation structures. The designed methodology is found to be universal and, therefore, applicable to any type of hydro-geological terrain with appropriate modifications by considering the local conditions. The approach also helps in adoption of ridge to valley concept as it considers each component of watershed for selection of water and soil conservation sites to derive the maximum benefits. Additionally, the concept is cost effective because it reduces the manpower for fieldwork studies. Based on the present work, following conclusions are drawn:

1. The integration of various thematic layers in a GIS environment has proved to be very useful in identifying potential areas for water conservation programs as each individual polygon is discrete in character in terms of geomorphology, soil and land use. Therefore, each polygon is amenable to specific conservation practice.
2. The evolved water conservation plan is found to be realistic since it considers all the correlated thematic layers thus reflecting the actual terrain characters. Accordingly, for the effective water conservation plans in the study area (WRJ-4), the water conservation treatment structures, viz., cement nala bandhara (masonry dam), earthen nala bund (ENB)/underground bandhara, gully plugs/loose boulder structure and water absorbing trenches, percolation tanks, social forestry plantation/continuous contour trenches (CCT) are recommended. Implementation of such water conservation plan will definitely help to enhance the groundwater condition in the area.

The present work has successfully demonstrated the efficacy of GIS technique for building up a model for selection of sites for water conservation structures. The model so designed has a universal acceptance; however, the weightage system may differ with respect to terrain situation and, therefore, it forms a unique decision support system by itself. However, there is a scope to further refine the model by addition of more interrelated layers. Presently a large groundwater database is being generated in India under the Rajiv Gandhi National Drinking Water Mission (NRSA 2008). In this context, it is felt that the generated database will prove significance 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.

Acknowledgements The authors are thankful to the Director, Maharashtra remote Sensing Centre, Nagpur for providing the necessary facilities to carry out the work at their esteemed laboratory. The help and suggestions provided by the expertise available at MRSAC office are also gratefully acknowledged here.

References

- Agashe RM (1990) Scope for artificial groundwater recharge on Deccan trap areas-an overview. In: Proceedings of all India seminars on modern techniques of rain water harvesting, water conservation and artificial recharge for drinking water, afforestation, horticulture and agriculture, Maharashtra, Pune, pp 121–129
- Anbazhagan S, Ramasamy SM (2001) Remote sensing based artificial recharge studies-a case study from Precambrian terrain, India. In: Dillon PJ (ed) Management of aquifer recharge for sustainability, ISAR-4, Adelaide. Balkema, Lisse, pp 553–556

- Anbazzhagan S, Ramasamy M, Dasgupta S (2005) Remote sensing and GIS for artificial recharge study, runoff estimation and planning in Ayyar basin, Tamilnadu India. *Environ Geol* 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. *Int J Geom Geosci* 11:84–97
- Bhattacharya AK (2010) Artificial ground water recharge with a special reference to India. *Int J Res Rev Appl Sci* 4(2):214–221
- Carver SJ (1991) Integrating multi-criteria evaluation with geographical information systems. *Int J Geogr Inf Syst* 5(3):321–339
- CGWB (2003) Ground water resources and development potential of Nagpur District, Maharashtra, and annual action programme 1999–2000 Central Region, Nagpur, Central Groundwater Board, pp 1–11
- Deshpande GG (1998) Geology of Maharashtra. Geological Society of India, Bangalore, pp 1–223
- Dhokariker BG (1991) Groundwater resource development in Basaltic rock terrains of Maharashtra. Water Industry Publication, Pune, p 277
- Durbude DG, Venkatesh B (2004) Site suitability analysis for soil and water conservation structures. *J Indian Soc Remote Sens* 32(4):399–405
- Duriaswami RA (2005) Dykes as potential groundwater reservoirs in semi-arid areas of Sakri Taluka, Dhule district, Maharashtra. *Gond Geol Mag* 20(1):1–9
- GSDA (2004) Estimation of groundwater resources in Maharashtra (as per GEC 1997), Groundwater Surveys and Development Agency, Government of Maharashtra
- GSDA (2008) Groundwater surveys and development agency annual report for the year 2008. District Office, Nagpur
- Gurugnanam B, Prabhakaran N, Suvetha M, Vasudevan S, Gobu B (2008) Geographic information technologies for hydrogeomorphological mapping in parts of Vellar Basin, Central Tamil Nadu. *J Geol Soc Ind* 72:471–478
- Jafar G, Ghermezcheshme B, Feiznia S, Noroozi AA (2005) Integrating GIS and DSS for identification of suitable areas for artificial recharge—case study Meimeh Basin, Isfahan, Iran. *Environ Geol* 47:493–500
- Jankowski P (2006) Integrating geographical information systems and multiple criteria decision-making methods. *Class IJGIS: Twenty Years Int J Geogr Inf Sci Syst* 9(3):265–296
- Malczewski J (2006) GIS-based multi-criteria decision analysis: a survey of the literature. *Int J Geogr Inf Sci* 20(7):703–726
- Natarajan D, John Britto S, Balaguru B, Nagamurugan N, Soosairaj S, Arockiasamy DI (2004) Identification of conservation priority sites using remote sensing and GIS—a case study from Chitteri hills, Eastern Ghats, Tamil Nadu. *Curr Sci* 86(9):1316–1323
- NRSA (2008) Groundwater prospects mapping for Rajiv Gandhi National Drinking Water Mission. National Remote Sensing Agency (NRSA), pp 3–7
- Pandey A, Chowdary VM, Mal BC, Dabral PP (2011) Remote sensing and GIS for identification of suitable sites for soil and water conservation structures. *Land Degrad Dev* 22(3):359–372
- Paul JC, Mishra JN, Pradhan PL, Sharma SD (2008) Remote Sensing and GIS aided land and water management plan preparation of watershed—a case study. *J Agric Eng* 45(3):27–33
- Preeja KR, Joseph S, Thomas J, Vijith H (2011) Identification of groundwater potential zones of a tropical river basin (Kerala, India) using remote sensing and GIS techniques. *J Ind Soc Remote Sens* 39(1):83–94
- Ramaswamy SM, Anbazzhagan S (1997) Criteria and techniques of detecting site specific mechanism for artificial recharge—a case study from Ayyar basin, India. *J Geol Soc Ind* 50:449–456
- Ravi Shankar MN, Mohan G (2005) A GIS based hydro-geomorphic approach for identification of sites specific artificial recharge technique in the Deccan volcanic provenance. *J Earth Syst Sci* 114(5):505–514
- Saptarshi PG, Raghvendra RK (2009) GIS-based evaluation of micro-watersheds to ascertain site suitability for water conservation structures. *J Ind Soc Remote Sens* 37:693–704
- Saraf AK, Choudhury PR (1998) Integrated remote sensing and GIS for groundwater exploration and identification of artificial recharge sites. *Int J Remote Sens* 19(10):1825–1841
- Sarma SK (1992) Remote sensing techniques to locate areas suitable for artificial recharge of groundwater in granitic terrain. In: Proceedings of the workshop on artificial recharge of groundwater granitic terrain, Bangalore, pp 14–44
- Todd DK (1959) Annotated bibliography on artificial recharge of groundwater through 1954. U.S.G.S. Water Supply Paper, 1477-115
- Varade AM, Wath P, Dongre K, Khare YD, Khandare H (2011a) Integrated approach using remote sensing & GIS for assessment of groundwater situation in parts of Chandrapur and Gadchiroli Districts of Maharashtra. *J Ind Geophys Union* 15(4):195–206
- Varade AM, Wadwekar M, Kolte D, Dongre KP, Khare YD (2011b) Identification of groundwater potential zones in and around Nagpur city, Maharashtra using remote sensing and GIS. *Gond Geol Mag* 26(2):129–138
- Varade AM, Khare YD, Mondal NC, Muley S, Wankawar P, Raut PD (2012) Identification of water conservation sites in a watershed (WRJ-2) of Nagpur District, Maharashtra using geographical information system (GIS) technique. *J Ind Soc Remote Sens* 41(3):619–630. doi:10.1007/s12524-012-0232-5
- Walsh MR (1992) Towards spatial decision support systems in water resources. *J Water Resour Manag* 109(2):158–169
- Weerasinghe H, Schneider UA, Low A (2011) Water harvest-and storage-location assessment model using GIS and remote sensing. *Hydrol Earth Syst Sci Discuss* 8:3353–3381