Standalone Open-Source GIS-Based Tools for Land and Water Resource Development Plan Generation

Arati Paul, V.M. Chowdary, Dibyendu Dutta and J.R. Sharma

Abstract Land and water which are extremely important natural resources are depleting at a fast rate. This has triggered the need to conserve these resources and utilise them optimally. Proper planning that involves strategies for achieving a desired set of goals, and management of these resources are required for sustainable development of any geographical area at watershed scale. Remote sensing and Geographic Information System (GIS)-based techniques have the potential to generate as well as to analyse geospatial data that serve as key inputs for generation of land and water resource development plans at the watershed level. However, planning authorities are adopting conventional methods for planning due to lack of GIS knowledge which is time consuming. Thus, the proposed customised open-source GIS tools not only help in bridging the knowledge gap but also help in generation of land and water resource development plans in short time. MapWindowGIS is a unique standalone open-source GIS component that can be customised through dot net programming. In the present study, MapWinGIS is used to develop Land Resource Development (LRD) and Water Resource Development (WRD) plan generation tools. These tools employ a set of logical conditions over a set of input layers to produce WRD and LRD action plans for a chosen area. A spatial database, pertaining to the Kuchai block of Saraikela district, Jharkhand India is used for generation of land and water resources development plan. These plans involve the generation of alternate land use and demarcation of areas suitable for artificial recharge. Thus, the tool enables to integrate together spatial data from diversified sources in order to analyse and produce meaningful information for decision makers to support their planning activity.

Keywords LRD · WRD · Natural resources · Open source · GIS

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1 Introduction

Sustainable development of land and water resources is necessary to maintain and improve land productivity as well as to conserve soil and water resources. Soil degradation and high surface runoff can be caused by a variety of factors including inadequate forest cover and uncontrolled grazing. Moreover, accelerated soil erosion has an adverse effect on the productivity of land. Hence an alternate land-use plan, in addition to water resource development plan, is sometimes necessary for the optimum use of a watershed.

Most of the studies carried out at the watershed level in India involve site-specific techniques based on intuition, experience and thumb rules, which may have serious environmental implications (Bali and Karale 1977; Singh et al. 1990). However, geospatial technologies such as remote sensing and geographic information systems (GIS) have shown their proven potential for generating sustainable LRD and WRD plans (Krishnamurthy et al. 2000; Anbazhagan et al. 2005; Shankar and Mohan 2005; Chowdary et al. 2009). The critical analysis of thematic maps derived from satellite data interpretation and socio-economic parameters are extremely crucial in this regard. It helps to identify problems as well as potential of the thematic information in terms of availability, sensitivity, severity, and criticality of resources. This facilitates optimum utilisation of resources and transfers the benefits to people in the watershed area.

Particularly, land-use information obtained from satellite images allowed decision-makers to devise plans for sustainable natural resource management (Joerin et al. 2001; Jansen and Di 2004). Integrated water resource development plan that involves identifying suitable zones for artificial recharge using GIS is extremely important as it makes watershed management not only simpler but also more effective. Multi-criteria analysis at spatial context was carried out in GIS by several researchers in solving conflict situations that arose during planning (Janssen and Rietveld 1990; Joerin et al. 2001; Chowdary et al. 2009; Rout et al. 2012).

For the past few years, the world of GIS has experienced many free and open-source GIS software tools, which helped GIS to reach out to a large number of people and created a significant impact on the society. Customised GIS applications were developed in many fields, viz. civil engineering projects (Jabbar 2011), potential risk assessment of water resources due to contaminants (Marchant et al. 2013), ground water quality assessment (Rabah et al. 2013) and natural resource management (Paul et al. 2014). Hence in the present study, customised tools are developed using open-source GIS component in order to generate LRD and WRD plans for any chosen area that might bridge the knowledge gap between policy makers and GIS professionals. The LRD Plan generation tool generates alternate land-use plan while the WRD plan generation tool demarcates the suitable zones for taking up location-specific activities such as check dam, percolation tank, underground barrier, etc., for artificial recharge in a natural boundary like a watershed.

2 Study Area and Spatial Data Used

In the present study, spatial database pertaining to the Kuchai block of Saraikela district, Jharkhand (Fig. 1) is used for the generation of land and water resource development plans. The geographical extent of the study area lies between 85° 30′ 40″ E, 22° 56′ 36″ N and 85° 50′ 28″ E, 22° 43′ 37″ N. Remote sensing and GIS techniques were utilised for generation of various thematic resource maps in conjunction with collateral data. Data integration and generation of development plans were carried out in GIS environment. The data acquired from multi-spectral sensors, viz. LISS-III (23 m resolution), LISS-IV (5.6 m resolution), panchromatic sensor, viz. CARTOSAT-1 (2.5 m resolution) of the Indian Remote Sensing Satellite (IRS) series were extensively used for generating spatial databases under different national projects coordinated by the National Remote Sensing Center, India and were used in the present study.

Multi-date satellite data covering the area under study is considered necessary to guard against any information loss and improve data sensitivity. Inputting the spatial data generated from various sources is the fore most step for GIS analysis. Spatial layers such as land use/land cover (LU/LC), soil, drainage order, slope, geology (structural layer), runoff potential layer and ground water potential (GWP) layers are used in the present study. For WRD plan generation, spatial layers such as LU/LC, soil, slope and drainage order (buffer layer) are considered as requisite layers while runoff potential layer and geology (structural layer) are considered as optional. Information on existing LU/LC and its spatial distribution forms the basis for any developmental planning. In the present study, LU/LC mapped using three season LISS-III data of 2005–2006 by Jharkhand Space Application Centre (JSAC) as part of NRSC sponsored NR-CENSUS project was considered. Major portion of the study area is upland and devoid of natural vegetation. Paddy is the main crop during *kharif* season.

Hydro-geomorphological maps depict major geomorphic units, landforms and provide an understanding of the processes relating to groundwater occurrence as

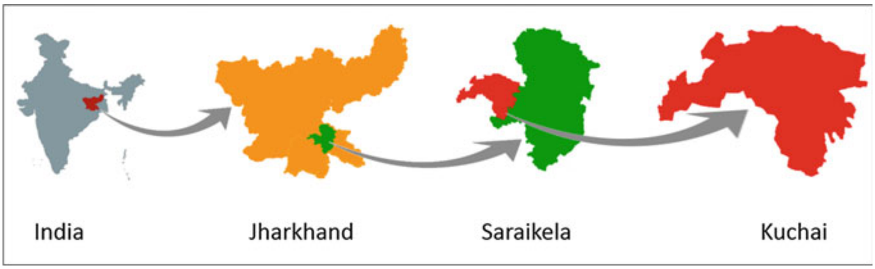

Fig. 1 Index map of the study area

well as groundwater prospects. Such maps depicting prospective zones for groundwater targeting are essential as a basis for land-use planning. Based on the morphological expressions in the satellite data, geomorphological map prepared at 1:50000 scale is used. Digital elevation model (DEM) is one of the important parameters for developmental activities and was derived from CARTOSAT-1 stereo pair. The elevation data is very much essential for generating slope map, which is an essential parameter for generating land and water resources development plan. CARTOSAT-1 stereo pair, supplied with Rational Polynomial Coefficients (RPC) were used for generation of DEM at 10 m resolution. That subsequently is used for generation of slope map in the area under study using standard procedures available in the Erdas Imagine software. Slope map of the study area, categorised into eight classes as per Integrated Mission for Sustainable Development guidelines (IMSD 1995), was derived using DEM. Satellite images are ortho-rectified first to remove effects of image perspective and relief. This ortho-rectified image (i.e. planimetrically correct image) enables accurate measurement of distances, angles and areas and was used as an input to produce drainage network. Strahler's method was adopted for stream ordering as it is an important parameter in planning of artificial recharge structures (Strahler 1964). These natural resource (NR) maps were used to produce the utilitarian type of maps to serve planning decisions. They were derived in some cases by the direct translation of single thematic map (Table 1) and in others either by the combination of two or more thematic maps, or chosen parameters of different themes, particularly as in case of the runoff potential map and the ground water potential maps (Table 2).

Table 1 Information sources for land and water resources planning

Data/map	Source	Spatial/non-spatial
Digital elevation model	CARTOSAT-1 stereo data	Spatial
Geological map	Rajiv Gandhi National Drinking Water Mission	Spatial
Geomorphological map		Spatial
Structures/lineaments		Spatial
Soil	NBSS & LUP, India	Spatial
Land use/cover	NR census	Spatial
Drainage map	IRS LISS IV	Spatial
Surface water bodies		Spatial
Watershed map	CARTO-DEM	Spatial
Meteorological data	Indian Met. Dept. (IMD)	Spatial
Settlement location	IRS LISS IV/CARTOSAT	Spatial
Transport network		Spatial
Village boundaries	Census directorate	Spatial
Population		Non-spatial

Table 2 Derived spatial databases required LRD and WRD planning

Derived map	Theme map	Remarks
Slope	Digital elevation model	Derived from DEM
Land capability map	Soil, slope and climate maps	Digital aggregation
Land irrigability	Soil, slope, landform, groundwater	Digital aggregation
Groundwater potential	Geology, geomorphology, bore well litholog and yield data	Integration of thematic maps and point database
Drainage density	Drainage network	Strahler method
Surface water potential	Slope, soil map, land use, rainfall and micro-watershed boundary	Natural Resources Conservation Service-Curve Number (NRCS-CN) technique through integration of layers

3 Methodology for Development of LRD and WRD Tools

LRD and WRD plans are generated by integrating different thematic layers according to the set of logical conditions highlighting suitability of a particular land-use or artificial recharge activity in the area under study. The logical conditions for integrating spatial layers in the GIS environment are presented in Tables 3 and 4 respectively. GIS is an analytical tool capable of performing storing, spatial

Table 3 Land resources plan development generation—conditions

Existing land use	Soil Perm.	GWP (m^3/h)	Slope (%)	Geomorphic units	Proposed LU
Single crop	Low/moderate	12–24	0–1	Pediplain/valley fills/buried pediplain	Intensive agriculture
Single crop, fallow	Low/moderate/high	3-12	0–3	Pediplain/dissected plateau/buried pediment/pediment	Agro-horticulture
Single crop, fallow wasteland	Low/moderate/high	3–12	3–10		Agro-forestry
Land with/without scrub, gullied land, stony waste	Moderate/high	<3–6	0–5		Silvopasture
Land with/without scrub, mining waste areas, barren land	High	<3–6	5–35	Pediment	Fuel and fodder plantation

operations, spatial queries, data linkages, data matching and output generation. A GIS can perform all these operations because it uses geography or space as a common key between the databases. The data sets are linked only if they relate to the same geographical area. Further, the important purpose of a GIS is to combine together spatial data from diversified sources. This helps in describing and analysing data to make predictions with models and in providing support for decision makers. Thus, a GIS model is a process of combining a set of input themes with a function to produce an output theme:

$$\text{Output} = f(\text{two or more input themes}) \tag{1}$$

MapWindowGIS is a standalone open-source GIS component that is customised through dot net programming in the present study to develop LRD and WRD plan generation tools. LRD and WRD plans have been generated through respective tools by inputting the requisite thematic layers. Hence, for integration of the layers, attributes in the thematic layers need to be in a specific format failing which tools generate suitable error messages. Subsequently, thematic layers are integrated to generate a new union layer having the attributes of all the themes where logical conditions are applied. This union layer is extremely important as this layer helps in evaluating the suitability of the particular area for a specific action plan. Further, the dissolve operation of GIS tool is performed on the respective LRD and WRD action plans as shown in the map area of respective tools. A provision is also made in the tool for storing initial output and dissolved output at the prescribed location. The overall methodology for generation of LRD and WRD tools is shown as a flowchart in Fig. 2.

4 Customised GIS Tools for Generation of Developmental Plans

4.1 LRD Plan Generation Tool

For the generation of LRDP, thematic layers pertaining to LU/LC, soil, slope, and GWP are mandatory. These layers with specific attributes are selected and executed through the input module of LRDP tool (Fig. 3). The LRDP layer with or without the dissolve operation is generated and stored in a particular location. The path of the generated layers is displayed on the tool's screen while the dissolved layer is shown in the map area of the tool (Fig. 3). The background process of the LRDP generation tool is depicted in Fig. 4. The tool checks the availability of the required attribute in a specific format for each layer, in the absence of which it generates a suitable message (Fig. 5) and the system prompts for the correct input. The 'HELP' document attached along with the tool provides the details of each input layer and its format.

Table 4 Water resources development plan generation—conditions

Drain order	Soil Perm.	Slope (%)	Land use	Runoff potential	Structure	Action plan
Second/third	Moderate to high	<10	Agricultural areas	Medium/low		Check dam (in agricultural areas)
Second/third	Moderate to high	<10	Forest areas	Medium/low		Check dam (in forest areas)
Second/third	High	<3	Waste lands	Medium/low	Lineament and fractures preferred	Percolation tank (across streams)
	High	<3	waste lands	Medium/Low	Same as above	Percolation tank (in wasteland areas)
	Low	0–3	Agricultural areas	Medium/low	Lineament and fractures should be avoided	Farm pond (without seepage control)
	Moderate to high	0–3	Agricultural areas	Medium/low	Same as above	Farm pond (with seepage control)
Fourth–seventh	Sandy/gravel river bed	0–3				Subsurface dykes (underground barrier)

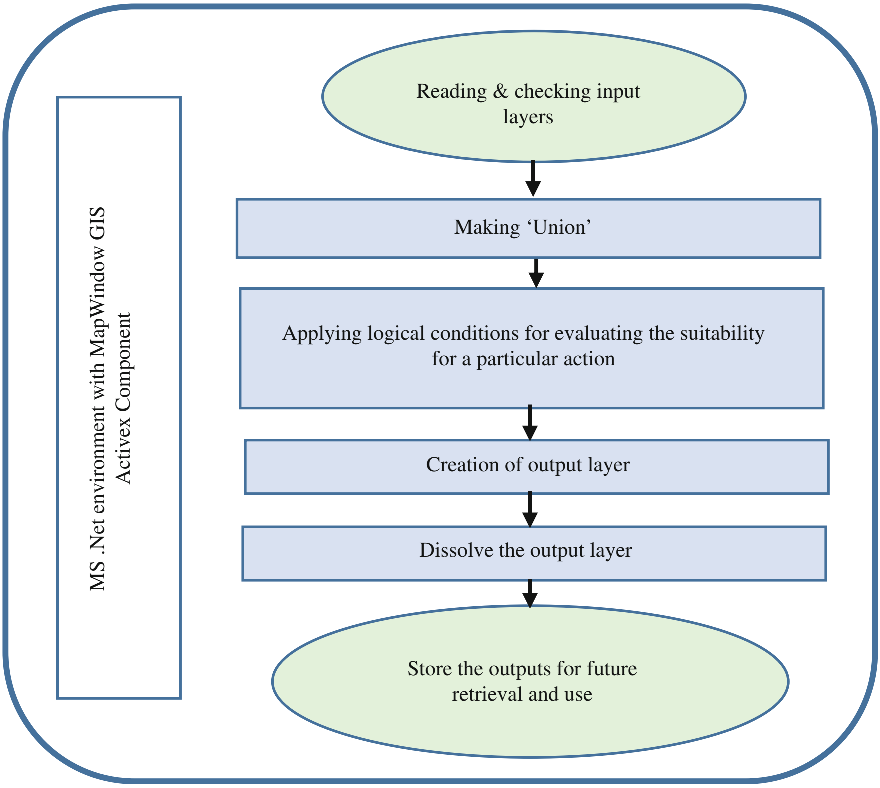

Fig. 2 Schematic representation of methodology

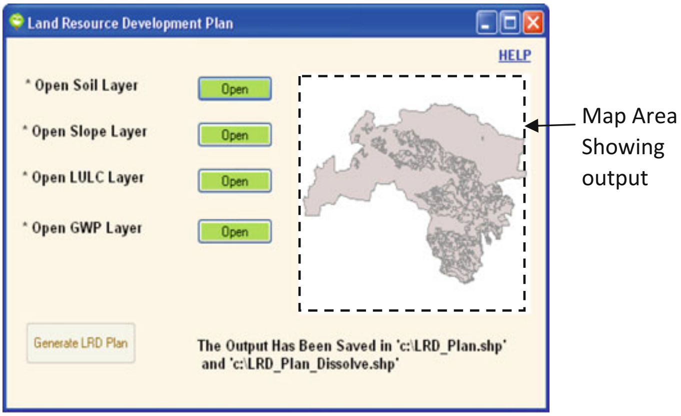

Fig. 3 LRD plan generation tool

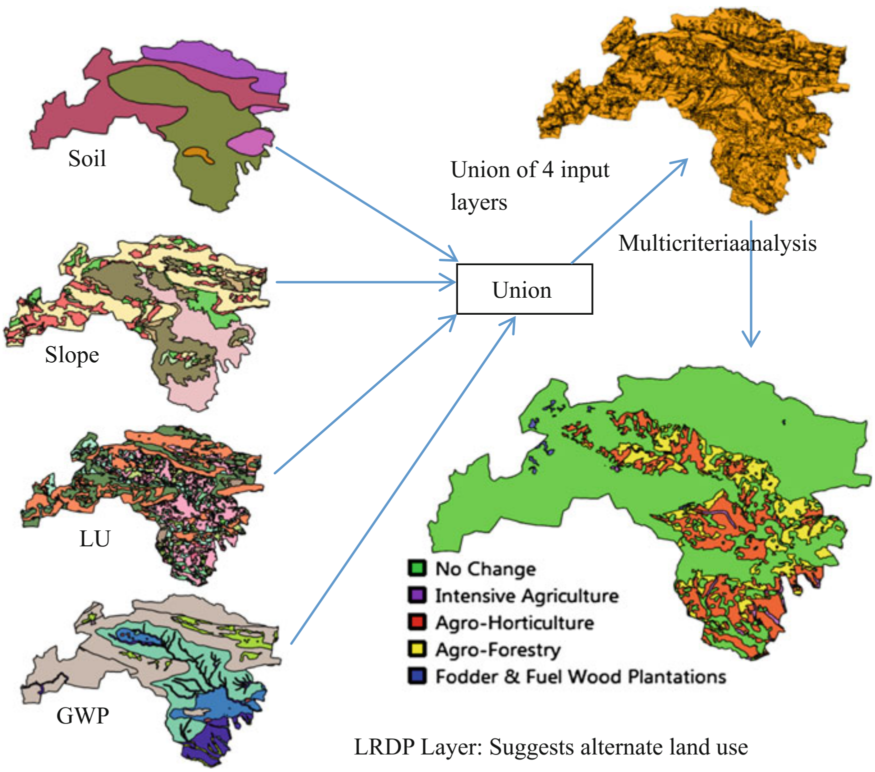

Fig. 4 LRDP generation process

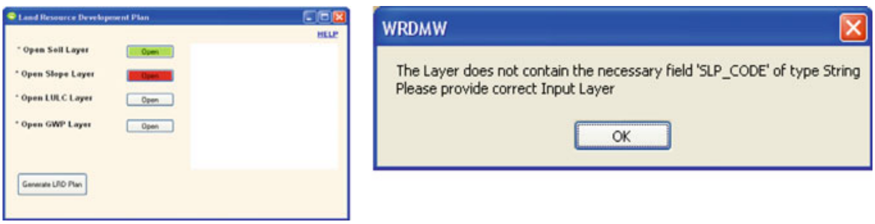

Fig. 5 LRD plan generation tool shows prompts for the correct input layer

4.2 WRD Plan Generation Tool

For the WRD plan generation, spatial layers such as LU/LC, soil, slope, drainage order (Buffer layer) are considered to be the requisite layers, while the runoff potential layer and geology (structural layer) are considered to be optional. Once the required input layers are selected from the tool (Fig. 6), validation of input

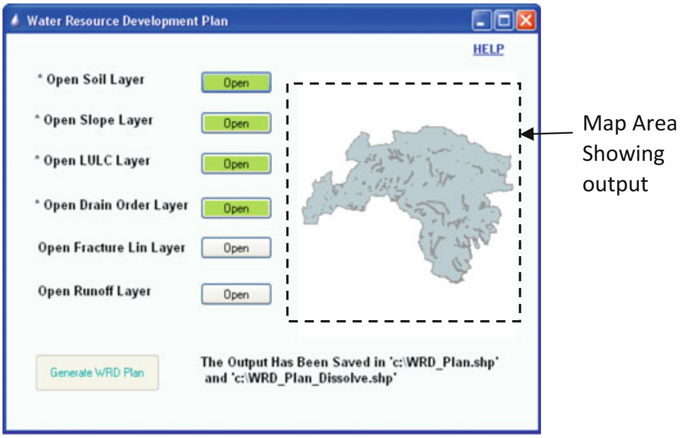

Fig. 6 WRD plan generation tool

parameters is performed. In case wrong input layers are selected, suitable error messages will be generated. The 'HELP' document contains details of the input data formats. If input layer selection is correct, the tool generates WRDP as well as dissolved WRDP layers and stores them as in case of the LRDP tool. The background process of the WRDP generation is depicted in Fig. 7.

All the required layers are integrated one by one through the 'Union' operation for both LRDP and WRDP generation tools, which is a computationally complex process. Hence, it is advisable to use these tools only for a small geographical area such as micro-watershed, block or village level to avoid long processing time. Generation of development plans through conventional methods is a tedious process as many controlling parameters must be independently derived and integrated. Hence, in the present study, standalone open-source GIS based tools is proposed for land and water resources development planning, which involves generation of alternate land-use and demarcation of areas suitable for artificial recharge.

Although, these specific action plans involve application of a set of criteria resulting from the GIS analysis of scientific factors, they need to be integrated with social factors as well. This associational analysis not only helps in a better understanding of the cause and effect related to problems or limitations, but also helps in assessing the potential for betterment that exists in the area under study. An attempt has been made for the generation of a water resource development plan through an integrated analysis by combining the different thematic layers using the Boolean logics in GIS. Detailed field inspection while implementation of plans at micro level, however, is likely to improve results of this analysis.

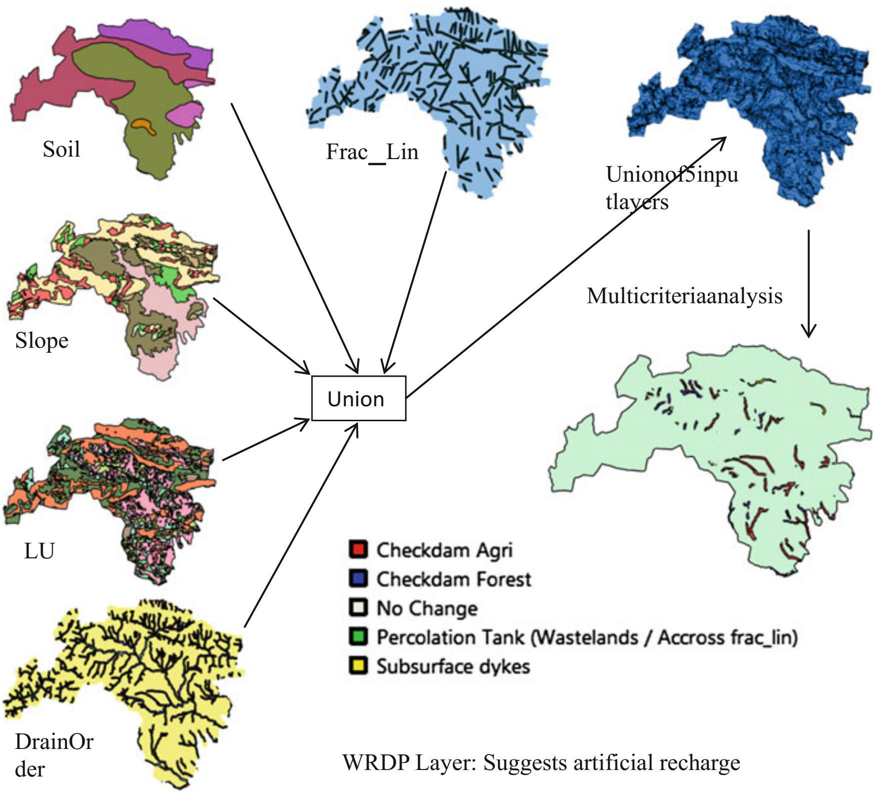

Fig. 7 WRDP generation process

5 Conclusion

Land and water resources planning is usually done by various government agencies through conventional methods, and are limited when it comes to GIS expertise. The full version of GIS software is not always desirable for decision-makers due to technical and financial constraints. Development of customised GIS tools and its access to the planners may address these issues to a greater extent. In the recent past, geospatial technologies have become effective tools by either substituting or supplementing the conventional technology with reasonably faster and efficient methods of survey and inventory in the domain of land and water resources planning, conservation, development, management and utilisation. Further, efforts are continued to develop customised tools to use remotely sensed data in a more optimal and efficient way for as many applications as possible to ensure that these techniques are used as powerful and inevitable tools for integration of the diverse spatial database. Customised tools developed in the present study are useful for generation of action plans at the watershed, or administrative (*panchayat* or the block) level. Persons with a limited GIS background can also use these tools for effective planning of natural resources.

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References

Anbazhagan S, Ramasamy SM, Das Gupta S (2005) Remote sensing and GIS for artificial recharge study, runoff estimation and planning in Ayyar basin, Tamil Nadu, India. Environ Geol 48:158–170

Bali YP, Karale RL (1977) A sediment yield index for choosing priority basins. IAHS-AISH Publ 222:180

Chowdary VM, Ramakrishnan D, Srivastava YK, Chandra V, Jeyaram A (2009) Integrated water resources development plan for sustainable management of Mayurakshi Watershed, India using remote sensing and GIS. Water Resour Manag 23:1581–1602

IMSD (1995) Integrated mission for sustainable development (IMSD) technical guidelines. NRSA, Hyderabad

Jabbar A (2011) Using geographic information system (GIS) to manage civil engineering projects. Eng Technol J 29(7):1276–1289

Jansen LJM, Di GA (2004) Obtaining land-use information from a remotely sensed land cover map: results from a case study in Lebanon. Int J Appl Earth Obs Geoinf 5:141–157

Janssen R, Rietveld P (1990) Multicriteria analysis and geographical information systems: an application to agriculture land-use in Netherlands. In: Scholten HJ, Stillwell JCH (eds) Geographical information systems for urban and regional planning. Kluwer Academic Publishers, Dorchecht, pp 129–139

Joerin F, Thériault M, Musy A (2001) Using GIS and outranking multicriteria analysis for land-use suitability assessment. Int J Geogr Inf Sci 15(2):153–174

Krishnamurthy J, Mani A, Jayaraman V, Manivel M (2000) Groundwater resources development in hard rock terrain—an approach using remote sensing and GIS techniques. J Appl Geol 2 (3/4):204–215

Marchant P, Banks VJ, Royse KR, Quig-ley SP (2013) The developed of aGIS methodology to assess the potential for water resource contamination due to new development in the 2012 Olympic Park Site, London. Comput Geosci 51:206–215

Paul A, Chowdary VM, Chakraborty D, Dutta D, Sharma JR (2014) Customization of freeware GIS software for management of natural resources data for developmental planning a case study. Int J Open Inf Technol 2(4):25–29. ISSN: 2307-8162

Rabah F, Budwan AE, Ghabayen S (2013) Customized standalone GIS-based tool for ground water quality assessment: Gaza Strip as a case study. J Softw Eng Appl 6(5):243–250

Rout J, Ojha A, Pradhan S, Samal RN (2012) GIS for rural development and spatial planning system. Geospatial World, Application (Utilities)

Shankar MNR, Mohan G (2005) A GIS based hydrogeomorphic approach for identification of site-specific artificial-recharge techniques in the Deccan Volcanic Province. J Earth Syst Sci 114(5):505–514

Singh G, Venkataramanan C, Sastry G, Joshi BP (1990) Text book on manual of soil and water conservation practices. Oxford & IBH publishing Co. Pvt. Ltd., New Delhi, p 387

Strahler AN (1964). Quantitative geomorphology of drainage basins and channel networks. In: Chow VT (ed) Hand book of applied hydrology Sections 4–11. McGraw Hill, New York

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