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Site Selection for Suitable Water Harvesting Structure Using Remote Sensing and Gis

D.D. Sinha, S.N. Mohapatra, Gwalior and Padmini Pani, New Delhi

Abstract

Site selection for suitable water harvesting structures using modern techniques such as remote sensing and GIS has become inevitable for any water resources development planning work. In the present work suitable sites have been demarcated to develop a water resources development plan in Bilrai watershed of Shivpuri district Madhya Pradesh using geospatial techniques. The Indian remote sensing satellite data along with other collateral data sets and other existing maps have been utilized to extract information of various features such as lithological, geomorphological, structural, drainage, slope, land use/land cover and soil. These thematic maps have been generated using ARC GIS and ERDAS Imagine software. DEM has been generated from contours in order to obtain the slope percentage and slope aspect of the area. The major geomorphic units are alluvial plain, pediplain, valley fill, linear ridge, denudational hill and structural hill. Groundwater potential zones were delineated by weighted overlay analysis.As far as the groundwater potential zones are concerned 62.45% of the area falls in zones of good and very good category, where as the very poor, poor, and moderate category accounts for 37.55%. These are the areas of concern for further development in terms of ground water prospects. Finally a map showing suitable sites for the water harvesting structures has been prepared based on the IMSD criteria. The major water conservation structures recommended for the area are nala bunds, check dams, gabions and drought ponds. On the basis of the result obtained it was concluded that the water availability of the area is mainly controlled by topography, geology and geomorphology. Remote Sensing and GIS technology can be efficiently used to develop water resources development plan of semi arid regions of Shivpuri district, Madhya Pradesh.

Key Words: *Watershed, groundwater potential zone, DEM, weighted overlay, check dam*

Introduction

Water is one of the most noteworthy natural resources which support both human needs and economic development. Tremendous increase in the agricultural, industrial and domestic activities in the past couple of decades has increased the demand for good quality water to meet the growing needs. According to a World Bank report (Anonymous 2002) India will be in water stress zone by the year 2025 and water scarce zone by 2050.Groundwater is a major source of irrigation, drinking and other purposes of water requirements in several areas of India. More than 90% of rural and nearly30% of urban population depend on it for drinking water (NRSA 2008). Groundwater is mostly favored to meet the growing water demand because of its lower level of contamination and wider distribution. However, failure of monsoon in some years and overexploitation leads to depletion of groundwater level, which in turn tends to increase both the investment and the operational costs of water. In hard rock terrain, availability of groundwater is of limited extent. The occurrences of groundwater in such rocks are basically confined to fractured and weathered horizons. Remote Sensing technology has already been established as an effective complementary tool in natural resource mapping the world over. Extensive hydro-geological studies using remote sensing have been carried out by several workers in delineating groundwater potential zones in hard rock terrain (Agarwal and Mishra 1992; Krishnamurthy et al. 1992;Krishnamurthy and Srinivas 1995; Saraf and Jain1998; Rao et al. 2001; Dilip and Venkatesh 2004).Geographical Information System (GIS) had been used for integration and overlaying of lithological, geomorphological, slope and soil map for delineating groundwater potential/ prospective zones (Saraf and Choudhary 1998; Kumar et al. 2008).Satellite remote sensing provides reliable and accurate information on natural resources, which is pre-requisite for planned and balanced development at watershed level (Ravindran et al., 1992).Further, remote sensing technique along with collateral information gives a synoptic view of large areas, facilitating better and quicker assessment, development and management of water resources. The integration of remote sensing and GIS is an efficient tool in groundwater studies (Krishnamurthyet al. 1996; Krishnamurthy and Srinivas 1996; Sander1996; Saraf and Choudhury 1998), where remote sensing serves as the preliminary inventory method to understand the groundwater prospects/conditions and GIS enables integration and database management of multi-thematic data (Preeja et al. 2011). In addition, the advantage of using remote sensing techniques together with GPS in a single platform and integration of GIS techniques facilitated better spatial data analysis and their interpretations (Vijith 2007). Singh et al. (1996) and Behera and Mohapatra (1996) have carried out the studies on the application of remote sensing techniques for suggesting suitable sites for soil and water conservation measures in the various watersheds in the country. Chandra Sekharand Rao (1999) suggested suitable sites for various water harvesting structures, likes Farm Ponds, Check Dams, Bundies [‘or a sub-watershed of’ Song River in the Doon Valley of Uttaranchal. Thus, the integration of Remote Sensing and GIS Techniques is a powerful spin-off from space exploration and it has emerged as a powerful tool for watershed characterization, conservation planning and management in recent times (Saraf and Choudhary,1986).

Shivpuri district in Madhya Pradesh is a drought prone area. Erratic rainfall, undulating topography and increasing use of groundwater in the district has led to declining watertable in several areas of the district. The objectives of present research are to find out suitable sites for various water harvesting structures for Bilrai watershed of Shivpuri district, M.P. Assessment of the potential sites for groundwater recharge zonation mapping and quantitative morphometric analysis of Bilarai watershed has been done by Sinha et al. 2012a and 2012b respectively. Mohapatra et al. 2009 carried out waste land inventory of the same area for watershed management. In the present study the suitable sites and structures for groundwater exploitation and for water harvesting are suggested in consideration with physical and cultural parameters of the area to fulfill the increasing demands of water for irrigation, drinking and other purposes. The study revealed that after the implementation of the proposed plan, peoples can make optimal use of water and farmers of the watershed will be able to take double crops.

Study Area

The Bilrai watershed area is drained by Bilrai River which is the tributary of the Mahaur River, which ultimately joins Sind River. The study area lies in the Survey of India topographical sheets 54 K/2, 54 K/3 and 54 K/7 on 1:50,000 scale. The proposed area is confined between 25^0 15’ 54” to 25^0 34’ 54”N latitude and 78^0 09’ 31” to 78^0 18’ E longitude covering an area of 294.167 sq. km.(Fig.1). Population density in the study area is more than the average of state of Madhya Pradesh. Hence, there is a necessity to increase agricultural activity/food grain production in the area for increasing population. Irrigation is an important resource for achieving higher productivity. Surface water sources for irrigation are limited in the watershed. Hence, groundwater use is increasing. The number of tube wells has also increased over the years. Water retains only in rainy season, mainly the month August to October. In this area major problem is lack of irrigation facility and there is no any preventive measure for soil erosion. Artificial recharge potential zones will helpful to check the soil erosion and other activities. The normal mean annual temperature of the area is around 250 C. The daily mean minimum temperature is about 5.10C. Sometimes, the individual day temperature comes down to as low as10C. The average rainfall of the area is around 764 mm.

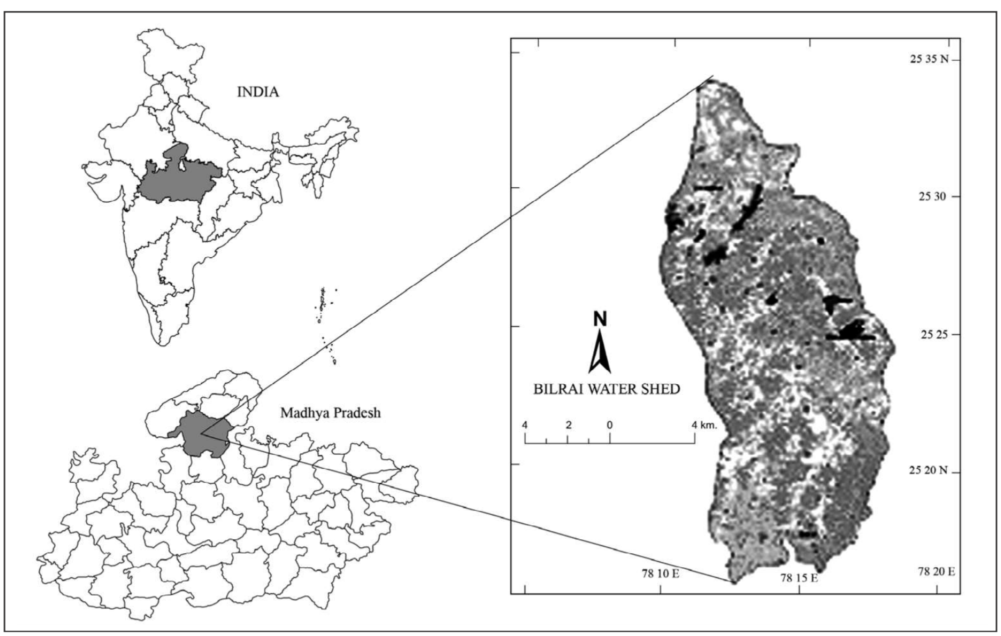

Fig. 1. Location map of the study area

Material and methods

Data Used

Three types of data sets have been used in the present study:

a. Remotely-sensed data: IRS 1D-LISS III data of January 2005, has been chosen as this is the peak time of growth of winter crops (Rabi season) and dry season vegetation helps to understand earth surface features as well as groundwater perspective. (fig.1b see page 233) It also facilitates better discrimination of lithologic character.

b. Survey of India (SOI) Topographic sheets at 1:50,000 scale (54K/2, 3 &7), published geological map and soil map at 1:250,000.

c. Ground data like pre and post monsoon water fluctuation, water sampling, GPS observation, etc. obtained during the field visits and study related published data form district statistical office, Shivpuri district, M.P.

Methodology

The methodology adopted (Fig. 2) for the present study consists of three distinct stages. In the first stage, all the data have been converted to digital format, by digitization of existing maps. Remote sensing data are already in digital format. The second stage involves generation of thematic layers of information from different sources. It involves digital image processing of remote

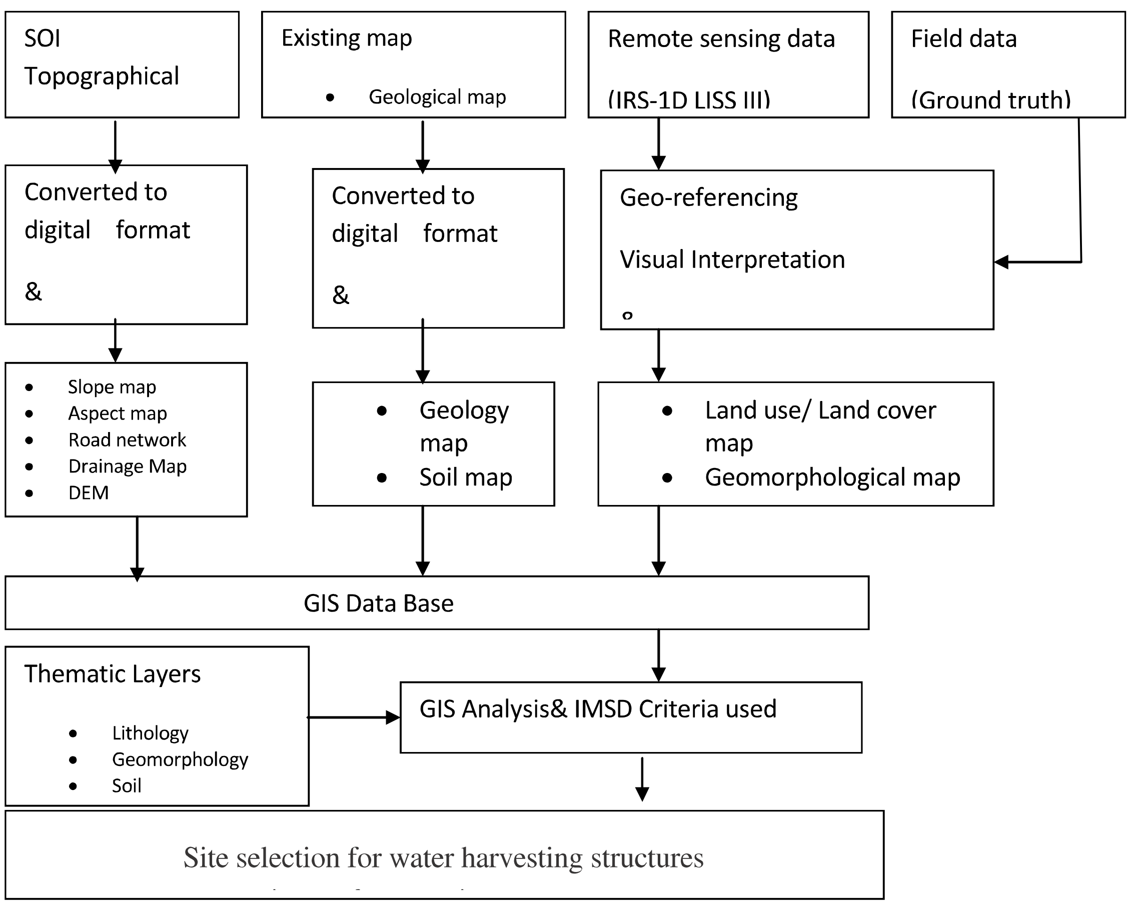

Fig. 2. Depicts the methodology adopted in this study

sensing data and further processing of existing maps and field data for extraction of pertinent information. The third stage involves the integration and generation of the data in a GIS environment. The various processes involved in the study include geo-referencing, FCC generation, digitizing, unsupervised classification, and ground truth validation, supervised classification for land use and land cover. The ERDAS Imagine and ARC GIS software were used in different stages of the work.

Geographic Information System (Arc GIS 9.1) was used for the preparation of various thematic layers. The weightages of individual themes (lithological, geomorphological, slope and soil)and feature score were fixed and added to each layers depending on their suitability to hold groundwater potential (Tab.1). This process involves raster overlay analysis and is known as multi criteria evaluation techniques (MCE). Of several methods available for determining interclass/

Table 1. Weightage criteria for groundwater prospect in the study area

Criteria	Class	Weightage for Groundwater Prospect
Geology	Alluvium	5
	Quartzite	1
	Bundelkhand Granite Gniess with Soil cover	3
	Bundelkhand Granite Gniess Outcrop	2
Geopmor-phology	Younger Alluvium Plain	4
	Valley Fills	4
	Burried Pediplain	3
	Undulating Pediplain	2
	Linear Ridge	1
	Denudational Hill	1
	Residual Hill	1
Slope	Nearly level to very gentle slopping (0-5%)	5
	Moderate slopping (5-10%)	4
	Steep slopping (10-20%)	2
	Very steep slopping (>20%)	1
Soil	Loamy, kaolinitic, hyperthermic, Typic Ustorthents	3
	Loamy, kaolinitic, hyperthermic, Lithic Ustorthents	3
	Loamy, kaolinitic, hyperthermic, Typic Haplustalfs	3
	Fine-loamy, mixed, (Cal.), hyperthermic, Typic Ustochrepts	2
	Fine-loamy, kaolinitic, hyperthermic, Typic Haplustalfs	2
	Fine-loamy, kaolinitic, hyperthermic, Typic Ustochrepts	2

inter-map dependency, a probability weighted approach has been adopted that allows a linear combination of probability weights of each thematic map and different categories of derived thematic maps have been assigned scores, by assessing the importance of it in groundwater occurrence and role in artificial recharge. The maximum value is given to the feature with highest groundwater potentiality and the minimum being to the lowest potential feature and the same process is repeated to artificial recharge potential. The procedure of weighted linear combination dominants in raster based GIS software systems. After assigning the weightages and scores to the themes and features, all the themes were converted to raster format using 'Spatial Analyst', extension of Arc-Info Arc GIS software. While converting to raster the scores assigned to individual features were taken in the value field. Then, the individual themes were normalized by dividing themes weightages has been assigned on the basis of knowledge-based hierarchy of ranking from 1 to 5 point scale (5 was the highest weightage order and 1 was the lowest weightage order) depending on their perspective role, their characteristics and their spatial distribution in the study area in groundwater as well as artificial recharge. The 'Raster Calculator option of Spatial Analyst was used to prepare the integrated final groundwater potential map of the study area., Water harvesting structures have been suggested by using the criteria laid by Integrated Mission for the Sustainable Development (IMSD), for making water resources development plan. The recommendations and suggestions from the above mentioned organizations are refined and perfected for use in the agro climatic and socioeconomic situation appropriate for the Bilrai watershed using Remote Sensing and GIS approach. The decision criteria for selecting sites for soil & water conservation structures is given in Table2.

Table 2. Decision Rules Used in Generation of WRDP

Sl. No.	Conservation Structures	Criteria
1.	Check Dams	i. Slope must be gentle (1-10%) ii. Drainage 1-3rd order iii. Loamy Soil iv. Human population should be less in upstream region, Land Use: forest/scrub land
2.	Dugout Ponds	v. Slope gentle 1-10%. Close to ephemeral streams vi. Low soil permeability,
3.	Nala Bundh	vii. Slope not more than 5% viii. Soil with adequate permeability ix. Land use: forest/scrub land
4.	Gully Plug	x. Slope more than 35% xi. Constructed in open forest with soil depth 50 cm
5.	Gabions	xii. Slope 10-15% xiii. Soil depth 50cm xiv. In degraded forest area

6.	Spur	xv. xvi. xvii. xviii.	River bed slope 1-10% Stream: Upstream of meander sections Proximity to agricultural or habitation Availability of construction material

Result

Water Harvesting Structures for artificial recharge and other uses:

In north-eastern part of study area (Narwar and Karera blocks) are facing the problem of high fluoride content in the groundwater, therefore it is required to dilute the groundwater by means of construction of artificial recharge and pouring in fresh surface water to groundwater which may reduce the fluoride content (CGWB, 2000). Suitable sites for the following water harvesting structures have been demarcated (Fig. 3 see page 233) by using the thematic layers geology, geomorphology, slope, soil, land use / land cover, and the groundwater potential zones as per the IMSD guide lines.

Check Dam

These are low height structures which have to be built where the river/nallahs are in plain country. The gorges like features are not suitable for such structures. An ideal location would be where the stream emerges from a gorge into the plain so that it will have plain area under its command and will also have some storage behind it in the gorge. Depending on the command area available the height of the structure could be varied up to a limit when the backwater does not submerge land upstream so as to avoid problems of rehabilitation and resettlement. A location where exposed rock is visible and the reach is narrow should be preferred to reduce construction costs. From such structures irrigation could be done on both sides subject to availability of land. Command of plain land has to be preferred over that of sloping land from considerations of retention of soil moisture from rains, which will reduce the need for irrigation water.

Drought Pond

A drought pond for water storage is called storage pond when it is done on the scrubland and farm pond when it is done of the field or farm. The tank when excavated in the open or scrub forest is referred to as forest tank. The prerequisite for the structures is availability of good catchments which can feed the depression, low point of runoff to prevent excessive water accumulation in the pond and favorable spill out for overflow of water. If the spillway conditions are not proper then artificial ones are necessary.

Nala Bund

Nala Bunds are basically of two types, first is Earthen Nala Bunds (ENB) and second is Cement Nala Bunds (CNB).Water conservation works are basically small dams with height not exceeding 3-5 meters. The objective of constructing ENB and CNB structures is to create a barrier to the flow of water and to impound water against this barrier. This impounded water can be used through the wells on the down streamside. The use of such structures is to provide water for drinking, domestic use and agriculture etc. These water conservation structures are divided only on the basis of construction material used and the related strength factor. A little variation of the nala bunding is the cement bag structure, where the nala bunding material used are cement bags filled with local material like sand and stones.

Gabion Structure

Gabion structure is a bund constructed by stones wrapped in galvanized mesh. These structures are basically meant for impounding the rainfall in the channels thereby adding to the ground water recharge and also provide water to the nearby fields for extending the cropping season. These structures break runoff velocity, conserve soil and recharge groundwater. The recommended location sites are in the upper and middle catchments of the watershed. Construction is recommended on nala with high velocity of runoff and where the stream flows are straight. The area where the cement nala bunds are uneconomical, the gabion structures can be constructed.

Including the water harvesting structures some renovation activities like conversion of village tanks into percolation tanks, de-silting and cementing of silted and damaged recharge structures, deepening of drinking water source and modification of irrigation technology are necessary in the watershed area.

Conclusion

The remote sensing and Geographic Information System (GIS) technique plays important role in groundwater potential zone mapping. The study has done on the effectiveness of remote sensing and GIS in the identification and delineation of groundwater potential zones of Bilrai watershed. In the present study groundwater potential zones are categorized into five zones viz., very good, good, moderate, poor and very poor. Finally, using ISMD guidelines water harvesting structures have been recommended for artificial recharge. The suitable sites and structures for groundwater exploitation and for water harvesting are suggested in consideration with physical and cultural parameters of the area to fulfill the increasing demands of water for irrigation, drinking and other purposes. Remote sensing and GIS tools are less time consuming and cost effective, which provides sufficient support in groundwater studies mainly where the region lacks previous hydrogeological investigations and data. The overall results demonstrate that remote sensing and GIS provides potentially powerful tools for studying groundwater resources and make a suitable exploration plan for different purposes of uses. The integrated map could be useful for various purpose such as sustainable development of groundwater as well as identification of priority areas for implementation of water conservation projects and programmes at micro-level.

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D.D.Sinha & S.N.Mohapatra
Centre of Remote Sensing & GIS, SOS in Earth Science, Jiwaji University, Gwalior

Padmini Pani
Centre for the Study of Regional Development, JNU, New Delhi

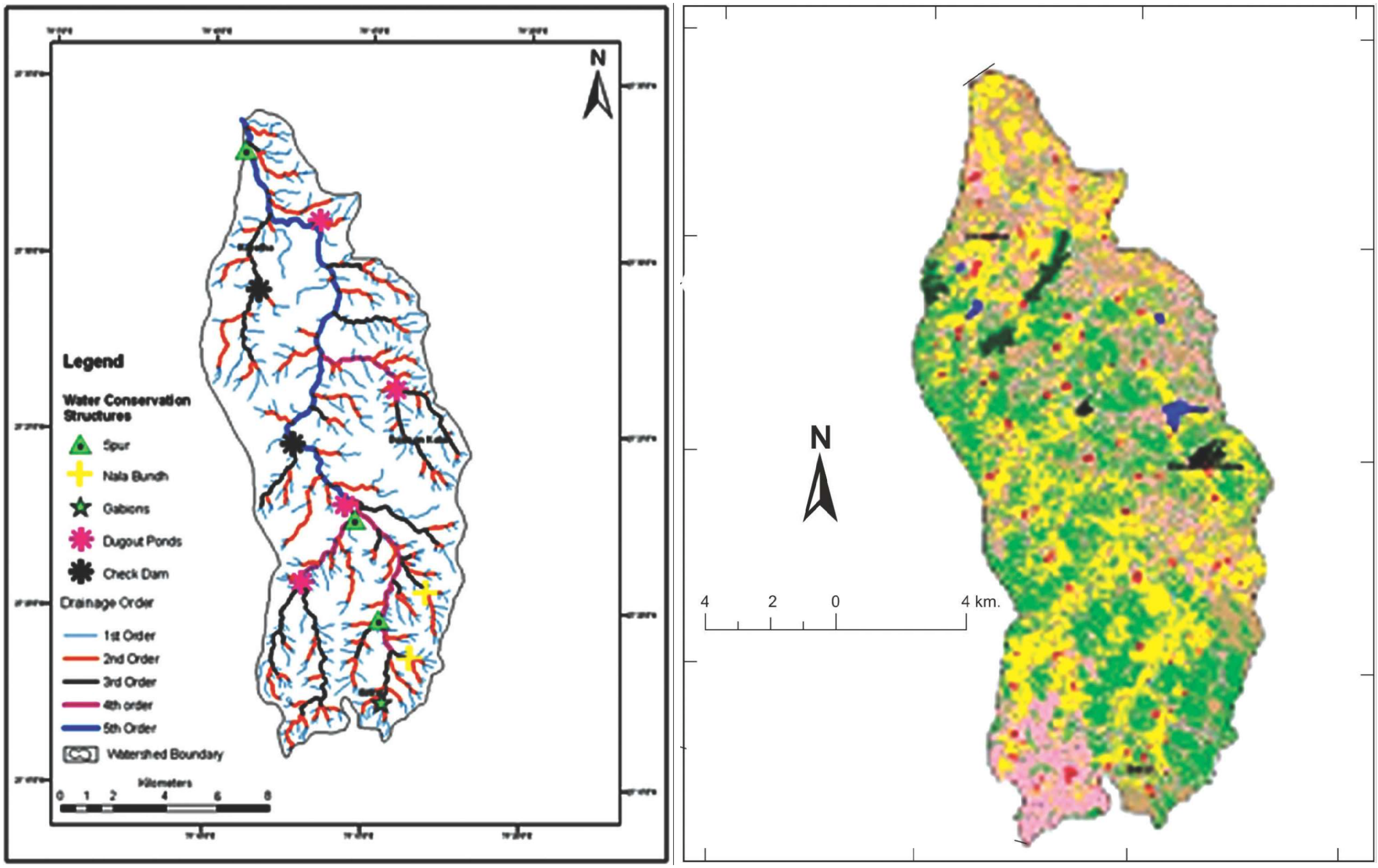

Fig. 3. Shows the specific suitable sites for water harvesting structures in the study area. (see page 229 for the text)