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SITE SUITABILITY ANALYSIS FOR GROUNDWATER MANAGEMENT IN RIVER BASIN OF INDIA

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ABSTRACT

In this study, site suitability analysis for Groundwater management in river basin has been carried out by constructing runoff harvesting structures like percolation pond and check dam. The site suitability for different groundwater recharge is determined by considering spatially varying parameters like sub basin area, runoff potential, slope and fracture pattern. GIS tool used to store, analyse and integrate spatial and attribute information pertaining to drainage, runoff, slope and fracture. The SCS-CN method used to derive runoff potential in terms of runoff coefficient (ratio between the runoff and rainfall) which is classified into three classes, viz., high (>40%), moderate (20–40%) and low (<20%). IMSD specifications for water recharging /harvesting structures, parameters such as effective storage, and rock mass permeability are considered to augment effective groundwater storage. In GIS software,by using an overlay and decision tree concepts, potential water harvesting sites are identified. The derived sites are field investigated for suitability and implementation. The suitability map provides vision in selecting harvesting structures such as anicut, percolation ponds and check dams. In Luni river basin area 38 check dams and seven percolation ponds found were suitable for groundwater recharging and water harvesting.

KEY WORDS : Percolation pond, Check dam, RS and GIS, Site suitability, Groundwater, Recharge

INTRODUCTION

The groundwater table in most parts of Rajasthan is steadily going down due to over-exploitation and inadequate natural recharge, resulting from frequent drought conditions in a region where the erratic annual rainfall is below 50-60 cm in most parts. Water plays a vital role in fulfilling basic human need for life and health and socio-economic development. As the primary source of groundwater is rainfall, so it becomes necessary to recharge groundwater can be done by harvest of runoff water effectively, which can maximize the storage and minimize the wastage of rainwater.

In the Luni river basin there is a large variation between abstraction and resources. The basin falls under Thar desert of India. The Luni river basin receives very less rainfall. The groundwater potential can be augmented by artificial recharging of the depleted aquifers in ascientific and well-studied manner. The groundwater recharge requires applying water in surface and near-surface spreading basins, trenches and pits, using the unsaturated porous and permeable zones and fracture planes to store and transport water. The hydrogeology of unsaturated zones, particularly in vertical hydraulic conductivity of the land-cover steta, including the soils and sub-soil sediments, frequency of fractures and fault zones, lineaments etc., play a critical role in transporting and storing the recharged water (Machiwal, 2004).

Water harvesting structures are extremely important for conservation of precious natural resources. The groundwater in Luni river basin is depleting day by day at alarming rate. Water is essential for all life and is used in different ways such as drinking, food production, domestic, power generation, industrial and recreational use. Out of

2.5% global fresh water only1% is available for human consumption. According to the World Bank report (CGWR, 2008, Singh and Urmila, 2012a; Singh *et al*., 2019), India will be in water stress zone by the year 2025 and water scare zone by 2050. Due to the population growth land availability is shrinking day by day. The per capita land availability is reducing trend and it is estimated that by the end of 2025 per capita land will be available only 0.10 hectare (Kumar *et al.,* 2015). The water table is rapidly falling with unregulated over exploitation of groundwater. Statistics on water budget indicates that our country gets about 400 Mha.m of precipitation annually, out of which 200 Mha.m are lost in evapo-transpiration. About 135Mha.m is available on the surface and remaining portion of precipitation joins groundwater through percolation. As per estimate about 92 Mha.m of the available surface water ultimately goes to these as despite construction of large dams, reservoirs, check dams, water-harvesting structures etc. (Sharma and Paul, 1998; Singh and Urmila, 2012b; Srivalli 2019; Hirapara *et al.*, 2020). The precipitation in India is highly variable over time and space due to monsoon climate and land mountain topography. Spatially it ranges from l00 mm in Rajasthan to 11000 mm in Mausingram, Meghalya (Sharma and Paul, 1998; Dhoke *et al.,* 2018). Over time, about 80% of the annual rainfall is received within three monsoon months and the rest 20% in nine dry months with a highly scattered distribution. In order to conceptualize the runoff occurring from the humid regions, Zade *et al.* (2005) used the remote sensing images and Natural Resources Conservation Services (NRCS) curve number approach to estimate the annual runoff from 12 major river basins of India.

The need and importance of water harvesting and water conservation has been stressed in national water policy and national agricultural policy of the Government of India. Thevarious rainwater-harvesting structures viz., check dams, farm ponds, tanka, Khadin, nalla bunds, percolation ponds etc. are constructed at an appropriate site that checks flood and provides irrigation downstream. This holistic approach within a basin in conserving soil and water resources by selecting the suitable site-specific soil and water conservation structures will conserve soil and water resources and enhance the crop yield. Thiruvenkatasamy (1982) has reported the effect of contour bunding on ground water recharge and observed 14.3% increase in water yield in the wells due to contour banding. Sarangi *et al.*(2004) have developed a Decision Support System (DSS) for soil and water conservation methods on agricultural watersheds, which generates alternative scenarios for selecting and targeting different vegetative and mechanical measures for conservation of soil, water, and reduction of sediment loss. Similar data also reported by Singh 2005; Singh *et al*., 2014; Machiwal *et al*., 2017 and Singh *et al.,* 2018. The salt concentration is higher in groundwater of basin area. In local language salt is known as "Lun" so this river name is Luni river. Groundwater recharging is the only solution to improve the groundwater quality of the basin area (Singh *et al.,* 2021). Therefore, this study was under taken for find out suitable sites for groundwater recharge in the Luni river basin.

LOCATION OF STUDY AREA

The Luni River Basin is located between 25°0′0" N to 26°56′45′′ N latitude and 72°04′64′′ E to 74°44′01′′ E longitudes and having total area of 34,442.2 km^2 (Fig. 1). The climate is semi-arid and very hot in summer and extremely cold in winter. The whole basin have monsoon of very short duration. Almost 90% of total annual rainfall is received during southwest monsoon, which enters the basin in first week of July and withdraws in mid of September. The temperature varies from 49 degree in summer to 1 degree in winter. Atmosphere is generally dry except during monsoon period. Humidity is at its highest in August with mean daily relative humidity of 43%. The annual maximum potential evapotranspiration in the basin is 1850 mm and it is highest (260 mm) in month of May and lowest (77 mm) in month of December. Geographically, the Luni River Basin as a whole form a part of the Indian Great Thar Desert. The Luni River represents sandy plain dotted with bold hills. The Luni River Basin elevation varies from 70 above mean sea level (m amsl) at Sindhari to 457 m amsl at Ghonia village. The river is ephemeral, flowing only in response to heavy precipitation. In the year of drought there is no run off.

Data Used

Cartosat-1 stereo datasets are proved in high accuracy compared to SRTM and ASTERDEM (Muralikrishnan *et al.*, 2013). The extracted data of basin are projected to the regional projection

(WGS_1984_UTM_Zone_43 N). The different data used for this study and their acquisition are given below:

DEM Cartosat-1(www.bhuvan.nrsc.gov.in)

Name of the dataset	:	C1_DEM_16b_2005-2014_V3R1
Theme	:	Terrain
Spheroid/datum	:	GCS, WGS-1984
Original source	:	Cartosat-1 PAN (2.5 m) stereo data
Resolution	:	1 arc s (32 m)
Sensor	:	PAN (2.5 m) stereo data
File format	:	Geotiff
Bits per pixel	:	16 bit

Soil Maphttp://www.nbsslup.in

Satellite Images Lands at 8 OLI/TIRS (http://earthexplorer.usgs.gov) DATES- 29/11/14 (3 TILES), 22/11/14(3 TILES)

Land Use/ Land Cover ISRO GBP -2005 (Scale1:250000)

Rainfall Data TRMM (2013-2015), Resolution- 25 km (http://mirador.gsfc.nasa.gov)

METHODOLOGY

The methodology followed for the preparation of various thematic maps, i.e. land use map, soil map, slope map, hydrological soil group map, stream order map, CN_2 map, drainage map etc. of Luni river basin is shown in Fig. 2 and briefly described in this section.

Drainage Map

The drainage map of study area has been derived from DEM of the Basin and verified from the toposheet of the Basin. The Luni river Basin having up to fourth order stream as shown in Fig. 3. Drainage ordering of the basin represent the number of streams presents in each order defined, i.e. 1, 2,3 and 4 stream orders. 2nd, 3rd and 4th order streams are suitable for Check dams. 2nd and3rd order streams are suitable for Percolation ponds and nala bunds.

Land Use Map

Land use map (Fig. 4) was obtained from ISRO GBP-2005 considering eleven different classes of land use. Water body, built-up area, plantation, crop Land, fallow land, mixed forest, shrub land, waste land, grass land, deciduous broad leaf forest. Land use map was further classified based on suitability for different water conservation structures.

Soil Map

Soil map (Fig. 5) which is collected from National Bureau of Soil Survey and Land use Planning, Nagpur. Four types of soil are present in the study area viz. sandy soil, clayey soil, loamy soil and loamy skeletal soil.

Slope Map

The slope map was prepared from Digital Elevation Model map (Fig. 6). The slope designated in value domain was prepared using filtering technique. The slope map was further classified for exploring

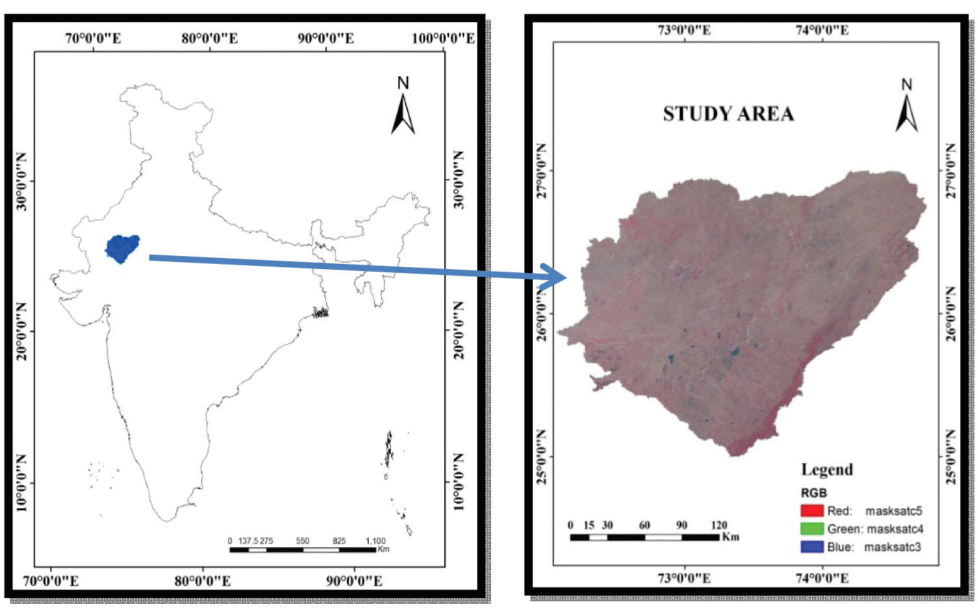

Fig. 1. Location of study area

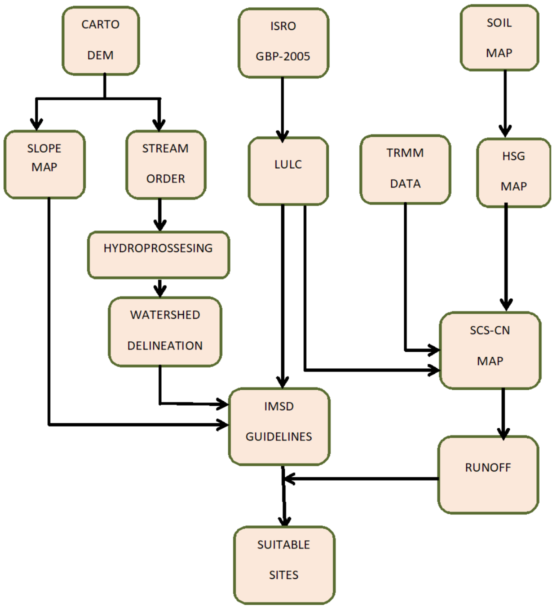

Fig. 2. Methodology Flow Chart

potential suitable sites for several water conservation structures.

Hydrological Soil Group Map

The soil map consist of four classes viz., clayey, silty, loamy and loamy skeletal. (Fig. 7) shows the hydrologic soil group (HSG) map was prepared from soil map taking into account the infiltration rates of various soil textures. Accordingly the soil classes were grouped under three categories viz. A,C and D. The classified HSG map was further grouped for the suitability of check dam, percolation ponds and water harvesting structures.

CN2 Map

This map (Fig. 8) was prepared by joining the land use / land cover map and soil map and thereafter assigning CN_2 values to each combination of land use / land cover and soil map. The output raster dataset was obtained to be CN_2 map.

SCS-CN Method of Estimating Runoff

The SCS-CN method used to runoff estimation of the Luni river Basin. This method is a simple, stable and predictable conceptual method which estimate the direct runoff depth based on storm the rainfall depth. It is a widely used and versatile procedure for the runoff estimation. The SCS approach involves use of simple empirical formulas and readily available as tables and curves, developed by Soil Conservation Service (SCS, 1985). The curve numbers are varied for different land use/land cover, soil,and hydrologic conditions. Although this method is designed for a single rainfall event, it can be scaled to find average runoff (Srivalli, 2017; Upadhyay et at, 2019 and Singh et al, 2021). The SCS runoff can be expressed in unit depth spread over the basin as

$$Q=\frac{(P-0.2S)^2}{P+0.8S}$$

Where, Q = direct flow volume expressed in depth

S = potential maximum soil retention

P = total rainfall

CN = curve number value which is used to estimate potential maximum soil retention (S)

$$S=\frac{25400}{\mathrm{CN}}-25$$

The CN values are tabulated according to the NRSC TR 55 for various land covers and soil textures. These values were developed from annual

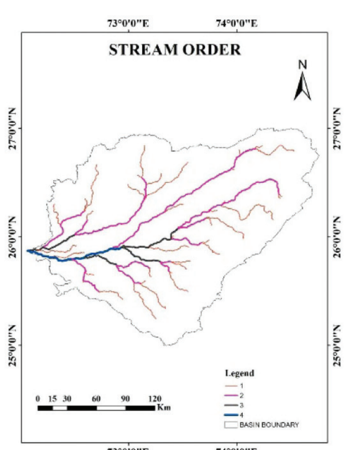

Fig. 4. Drainage map

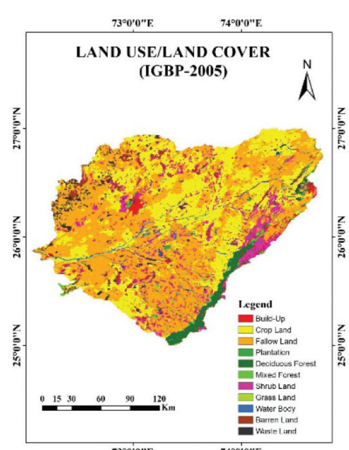

Fig. 5. Land use map

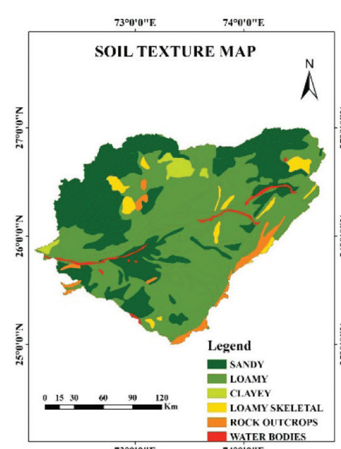

Fig. 6. Soil map

flood rainfall–runoff data from the literature for a variety of basins generally less than one square km area *(USDA-SCS, 1985)*. For runoff estimation in Luni river basin, the curve number (CN), initial abstraction (IA), potential maximum soil retention (S) and antecedent moisture condition is required.

Weighted Curve Number

$$= \frac{\sum(CN1 * A1 + CN2 * A2 + \cdots CNn * An)}{\sum A}$$

Where, CN1 curve number for the particular land unit 1, A1 area for that particular land unit1,"A sum of total area. After calculating weighted curve number, potential maximum soil retention (S) was calculated for each sub-basin by using the following formula

$$S = \frac{25400}{CN} - 25$$

The potential maximum soil retention estimation of basin, initial abstractions (IA) are calculated. Initial abstractions in water losses, e.g.infiltration, plant interceptions and surface storage which occur prior to the runoff and are then subtracted from total runoff *(USDA-SCS 1985)*. The standard assumption are

$I_A = 0.2S$

If rainfall is greater than 0.2 S, then there is a possibility for runoff. If rainfall is less than 0.2S, there will be no runoff. Hence, the every rainfall events, which is more than 0.2S, will be considered for further runoff estimation.

Antecedent Moisture Conditions (AMC)

The antecedent moisture condition refers to the water content present in the soil at a given time. It is determined by total rainfall in 5-day period preceding a rainfall event (SCS, 1986). There are three antecedent soil-moisture conditions (I, II and III) according to different soil conditions and rainfall limits for dormant and growing seasons (Table 1). The AMC-I, indicates the lowest runoff potential because the soils are dry enough, AMC-II indicates the average soil moisture condition and AMC-III indicates highest runoff potential of the soil, which practically happens when areas of basin are saturated from antecedent rains. The value of CN for different land use conditions and hydrologic soil group are given in standard curve number tables 2 (SCS, 1986). These values are applied only to AMC-II and in order to derive curve number values for AMC-I and III, the following correction factors need to be applied (Rao *et al.*, 2004). If the antecedent moisture condition is I (dry), the curve number is adjusted down by using the following formula

$$CN_1 = \frac{CN2}{2.334 - 0.01334CN2}$$

And if the antecedent moisture condition is III (wet), the curve number is adjusted up by using the following equation.

$$CN_3 = \frac{CN2}{0.427 + 0.00573CN2}$$

The antecedent moisture condition is II, the same weighted curve number is used for runoff estimation.

Table 1. Classification of antecedent moisture conditions (SCS, 1986)

AMC CLASS	Dormant Season	Growing Season
I	<12.5	<35
II	12.5 to 27.5	35 to 52.5
III	>27.5	>52.5

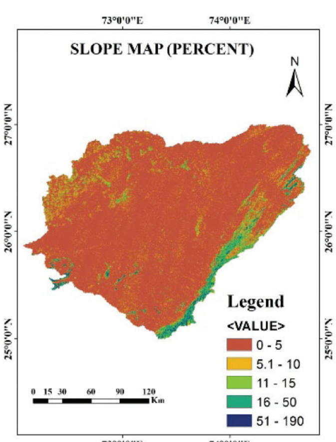

Fig. 7. Slope Map

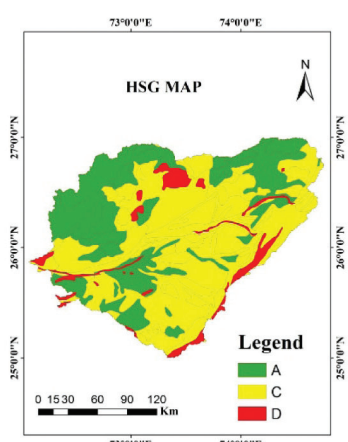

Fig. 8. Hydrologic Soil Group Map

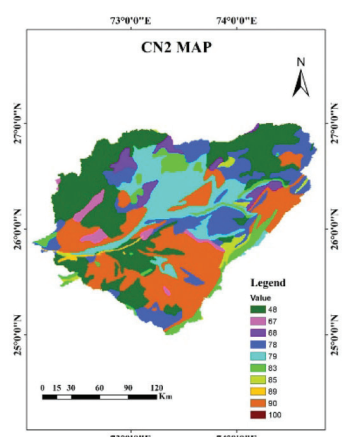

Fig. 9. CN2 Map

Evaluating Curve Number

The curve number method is used to characterize the runoff properties of Luni river basin for a certain soil and land use/ land cover. The SCS runoff equation uses curve number value as input parameter. The CN is evaluated for the study area on pixel basis using the soil and land cover/land use maps, that are reclassified to hydrologic conditions and hydrologic soil group (Table 3). Infiltration depends on soil property which effects relation between rainfall and runoff. The SCS model divides all soils into four HS groups according to the USGS classification system of land use and land cover (A, B, C and D) (Table 2). This is classification of soil to HS group depends on infiltration rates and soil texture composition. Only three classes A, B and D were found in the Luni river basin.

The high runoff potential was found in the west of Luni river basin because mostly area lies in wasteland and open land. Hydrologic condition refers to the effect of land cover and represents the surface conditions in Luni river basin in relation to infiltration and runoff. The land cover that is present in Fig. 5 was used together with a map of HS group in ERDAS model maker to match the hydrologic soil group and land cover of the basin. Table 2 presents the values of curve number based on the USGS classification system (A, B, C and D). In the next iteration suitable land use and infiltration rate, suitable soil feature and suitable stream order are intersected and overlaid on slope map for locating suitable sites for water harvesting structures. The IMSD guidelines have been followed as discussed previously and therefore suitable sites were located.

RESULTS AND DISCUSSION

The multi-layer integration through slope, land use/ cover drainage, flow direction, road and settlement gave the suitability units for identifying rain water harvesting sites for check dams and percolation ponds. Factor layers (maps) were incorporated in ArcMap. The suitability map was developed for potential sites for different rain water harvesting sites / groundwater recharging in Luni river basin. The suitability maps for the different rainwater harvesting show that there are multiple areas suitable for each technique, as shows in Fig. 10 the suitability maps for location of check dams and percolation ponds.

The suitable sites for water harvesting structures were identified with the application of remote sensing and GIS. The basin boundary map, drainage map, land use map, soil map and DEM were prepared using satellite imagery of Luni River Basin. The eleven classes of land use/land cover and hydrological soil map were prepared. The overlay operation of land use map, hydrologic soil group map, stream order map and slope map were carried out for water harvesting structures and presented through site suitability map.

Check Dams

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 structure’s irrigation could be done on both sides subjectto 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.

Check dams are small structure constructed of rock, sediment retention, gravel bags, sandbags,

Table 2. Soil group and corresponding soil texture

Soil Group	Runoff Description	Soil Texture
A	Low runoff potential and high infiltration rates	Sand, loamy sand and sandy loam type
B	Moderately infiltration rates and runoff potential	Silty loam and loam type
C	High/moderate runoff potential and slow infiltration	Sandy clay loam type
D	High runoff potential with very low infiltration	Clay loam, silty clay loam, clay, sandy clay, and silty clay

Table 3. CN values for LU/LC classes adopted in this study (SCS, 1986)

Land cover/Land use	Hydrologic Soil Group			
	A	B	C	D
Forest (Dense)	48	67	77	83
Forest (Open)	68	79	86	89
Settlement	48	66	78	83
Agriculture	67	78	85	89
Plantation	65	73	79	81
Fallow	76	85	90	93
Scrub	48	67	77	83
Barren Land	64	75	83	85
Water	90	94	98	100

fibre rolls or other proprietary product placed across the natural or manmade channel or drainage ditch. Itreduces scour and channel erosion by reducing flow velocity and encouraging sediment settlement.

In the study of Luni River Basin having very gentle slope and 1st, 2nd, 3rd and 4th order stream are proposed for check dams. Thirty-one sites (Fig. 10) for construction of check dam are suggested in the Luni River Basin.

Percolation ponds

The percolation ponds are the structures for groundwater/ aquifer recharging. These are generally constructed across streams and in bigger gullies to impound a part of the run-off water. In the Luni River Basin which are under land with scrub, moderate slope, basalt, 2nd, 3rdand 4th order stream and high density of lineaments is proposed for percolation pond. Eight sites for the construction of percolation ponds are suggested (Fig. 10).

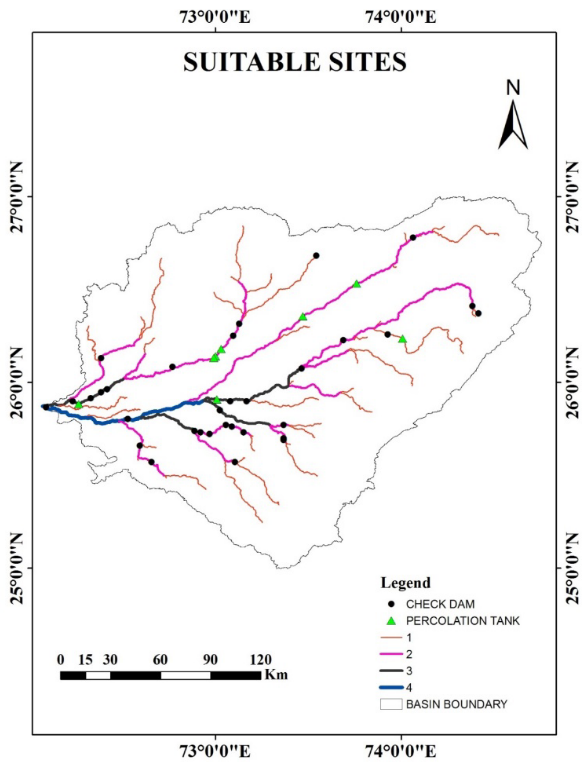

Fig. 10. Suitable Sites for Water Conservation Structures

CONCLUSION

Site Suitability Analysis for Groundwater Management in river basins of India is carried out by overlying the soil, slope, land use/land cover & stream order maps. The Luni river basin has full scope for check dams and percolation ponds. GIS technique will help in the selection of the suitable location of harvesting structures and groundwater recharge in water depleted areas. The site suitability thematic layers such as HSG map and land use/land cover features, basically the physical properties of the basin were generated from the remote sensing data and integrated with soil, drainage, and slope maps under GIS environment, which helps to prepare geodatabase for identifying water conservation structures in Luni River Basin of Rajasthan. The locations suitable for the construction of check dams and percolation ponds were identified by using the IMSD guidelines. In Luni river basin 38 check dams and seven percolation ponds were found suitable for groundwater recharging and water harvesting.

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REFERENCES

Dhoke, Shailja, Singh, M., Singh, P.K. and Yadav, K.K.

2018. Estimation of soil loss and sediment yield in small watershed under humid condition of Rajasthan. *International Journal of Chemical Studies*. 6 : 1209-1214.

Hirapara, J.G., Singh, P.K., Singh, M. and Patel, C.D. 2020. Analysis of rainfall characteristics for crop planning in north and south Saurashtra region of Gujarat. *Journal of Agricultural Engineering*. 57: 162-171

Kumar, M., Kumar, R., Singh, P.K., Singh, M., Yadav, K.K. and Mittal, H.K. 2015. Catchment delineation and morphometric analysis using geographical information system. *Water Science Technol.* 72: 1168-1175. https://doi.org/10.2166/wst.2015.303

Machiwal, D., Singh, P.K. and Yadav, K.K. 2017. Estimating aquifer properties and distributed groundwater recharge in a hard-rock catchment of Udaipur, India. *Appl Water Sci.* 7 : 3157-3172. https://doi.org/10.1007/s13201-016-0462-8

Muralikrishnan, S., Pillai, A. and Narender, B. 2013. Validation of Indian National DEM from Cartosat-1 Data. *J Indian Soc Remote Sens*. 41 : 1-13. https://doi.org/10.1007/s12524-012-0212-9

Sarangi, A., Madramooto, C.A. and Cox, C. 2004. A decision support system (DSS) for soil and water conservation measures on Agricultural watershed. *Journal of Land Degradation and Development*. 15(1) : 46-63

SCS, 1985, 1986. *Hydrology', National Engineering Handbook,* Supplement A, Section 4, Chapter 10, Soil Conservation Service, USDA, Washington, D.C.

Sharma, B.R. and Paul, D.K. 1998. Water resources of India. In : 50 years of natural resources management research (GB Singh and BR Sharma). Division of Natural Resources Management, Krishi Bhavan, ICAR, New Delhi, pp 31-48.

Singh, D., Singh, P.K., Patil, P.R. and Singh, M. 2019. Morphometric analysis of Mewado Ka Math Micro-Watershed using remote sensing and GIS. *Green Farming.* 10 : 354-359.

Singh, M. and Urmila, 2012a. Sustainable development through watershed management: a case study. *Ecology, Environment and Conservation.* 18 (04): 1041-1044.

Singh, M. and Urmila, 2012b. Assessment of soil and water conservation measures: a case study of the district Banswara, Rajasthan, India. *Ecology, Environment and Conservation.*18 (04) : 1045-1049.

Singh, M. 2005. Planning and designing of appropriate soil and water conservation measures in Kadmal watershed (*Master dissertation, MPUAT, Udaipur*). pp 1-112 http://krishikosh.egranth.ac.in/handle/1/5810020273.

Singh, M., Jat, S.C., Singh, P.K. and Yadav, K.K. 2021. Estimation of Aquifer Parameters in Upper Berach River Basin Area of Rajasthan, India. *La Pensée.* 51 (1) : 547-552.

Singh, Manjeet, Singh, P.K., Yadav, K.K., Kothari, M. and Bhakar, S.R. 2021. Fluoride Distribution in the Groundwater of Upper Banas River Basin, Rajasthan, India. *International Research Journal of Humanities and Interdisciplinary Studies*. 2(6) : 74-85. http://doi-ds.org/doilink/06.2021-85348761/IRJHIS2106011

Singh, P.K, Singh, M. and Yadav, K.K. 2014. Assessment of Surface Water Potential and Land Degradation of Wakal River Basin Using RS & GIS. *American Society of Agricultural and Biological Engineers,* pp. 1-12. https://doi:10.13031/wtcw.2014-034.

Singh, P.K., Dahiphale, P., Yadav, K.K. and Singh, M. 2018. Delineation of groundwater potential zones in Jaisamand basin of Udaipur district. *Groundwater, Water Science and Technology Library, Springer: Singapore*, pp. 3-20. https://doi.org/10.1007/978-981-10-5789-2_1.

Srivalli, C.R. and Singh, M. 2019. Identification of potential sites for water harvesting structures in Gadela watershed using remote sensing and GIS. *Environment Conservation Journal*. 20 (3) : 125-130. DOI: https://doi.org/10.36953/ECJ.2019.20316

Thiruvenkatasamy, K.R. 1982. Engineering and economic aspects of soil and water conservation. Soil and Water Conservation in southern hill regions of India. *Proc. Working Meeting of Soil Conservationists from Southern Hill Regions, CSWCRTI, Dehradun,* pp 264.

Upadhyay, H., Mittal, H.K., Singh, M. and Hirapara, J.G. 2019. Application of SWAT Model for Estimation of Runoff in Pindwara Watershed and Assessment of its Feasibility. *Int. J. Curr. Microbiol. App. Sci*. 8 (06): 3056-3065. doi: https://doi.org/10.20546/ijcmas.2019.806.364.

Zade, M., Ray, S.S., Dutta, S. and Panigrahy, S. 2005. Analysis of Runoff pattern for all major basins of India derived using remote sensing data. *Current Science*. 88 (8): 1301-1305.