International Journal of Environment and Climate Change

Volume 12, Issue 12, Page 351-362, 2022; Article no.IJECC.90203
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Remote Sensing and GIS-aided Land and Water Resources Management Plan for a Prioritized Sub-watershed of the Kotni Watershed, Chhattisgarh, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJECC/2022/v12i121471

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/90203

Original Research Article

Received: 19/09/2022
Accepted: 21/11/2022
Published: 28/11/2022

ABSTRACT

Land and water are the prime resources that support all forms of life through various processes. Integration of Remote Sensing and GIS is incredibly helpful in planning and management of this resources, it is superior to the limitation of typical land planning, causes it embraces the metaverse of planning and development of resources through modern technology. In the study area, these resources are in critical condition; approximately 6.5 % of land is agricultural fallow land, 3 % is

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barren land, and 50 % is current fallow in Rabi season caused by the majority of agricultural land being unproductive due to poor land and water resource management. This research makes prudent and effective use of the watershed resources to increase productivity and production in the study area. The runoff computation of the watershed was done using the SCS curve number approach for 11 years (2009-2019), it reveals average annual rainfall of 1329 mm, with 41% of runoff generation capacity, which is estimated as 483.95 Mm^3 of generated runoff. Methodology also includes Multi-Criteria Decision Analysis (MCDA) techniques and weighted overlay analysis (WOA) which effectively uses various thematic maps to delineate suitable zones for water storage and harvesting structures. Finally, suitable sites for 7 check dams, 10 percolation tanks for groundwater recharging and 20 check dams, 61 farm ponds for water harvesting were identified and proposed in the study area. The research findings will help to conserve water and soil resources and may increase the agricultural area as well as the production and productivity of the respected field.

Keywords: Remote sensing and GIS; SCS method; multi-criteria decision analysis; weighted overlay analysis; groundwater recharging structure; water harvesting; wartershed management.

1. INTRODUCTION

For millenniums, land and water resources have been benefiting both people and their economies [1]. However, in today's scenarios, resources are being depleted as a result of population expansion, and their consumption is increasing day by day, causing huge problems throughout the world [2]. Especially for a country like India, which have to sustain 17.7 percent of the world population on 2.42 % geographical area [3], the same situation has raised in the study area, where the use of various resources are dramatically increasing, resulting in the sacristy of primary resource. The annual average precipitation in the study area is 1,323 mm [4], with a high runoff conversion capability of 41% and due to lack of arrangements this high amount of runoff cannot be utilized in primary purposes such as agriculture.

In this research, land and water resources were studied for better management and sustainable utilization. It combines water availability analysis and structure planning at appropriate sites, assisting in enhancing the study area's water recharge and storage capacity and directly supporting farmers with sustainable agriculture. Various water recharging and harvesting structures, such as check dams, percolation tanks, and farm ponds, were proposed in the best feasible places. These will increase water availability, along with the production and productivity of the study area fields.

2. MATERIALS AND METHODS

2.1 Study Area

The study area (i.e., Kotni watershed) is located in the western part of Chhattisgarh state, within latitudes 20°52' to 21°15' N and longitudes 81°07' to 81°26'E and covers an area of 870 km^2. It is a part of the Seonath river sub-basin of the Mahanadi basin. Fig. 1 shows the boundary of the study area. The climate of the study area is tropical because of its proximity to the Tropic of Cancer and its dependence on the south-west monsoons for rains, which endures from late June to October. The study area exhibits average yearly precipitation and temperature as 1,323 millimeters 26.5°C [4] with 41% of runoff generation capacity which not being utilised due to inappropriate water conservation structures. It comprises four major groups of soil Entisol, Inceptisols, Alfisols, and Vertisols [5]. Major crops grown in the study area are rice, soybean, wheat, sugarcane and gram, etc. [6].

2.2 Methodology

2.2.1 Data acquisition

All the data required for the study were acquired from various sources, as mentioned in Table 1.

2.2.1.1 Spatial database building/ thematic map generation

Layers such as geomorphology, geology, and lineament obtained from various sources as mentioned above were clipped/ remoulded for the study area boundary. In the GIS context, the Shuttle Radar Topography Mission digital elevation model SRTM DEM (30 m) was utilised to create contour maps, slope maps, drainage maps, and drainage density maps. The land use and land cover map was created by Qgis software using semi-automatic categorization add-ins with the aid of sentinal-2 spatial data, of 25/Oct/2020 downloaded from the USGS website

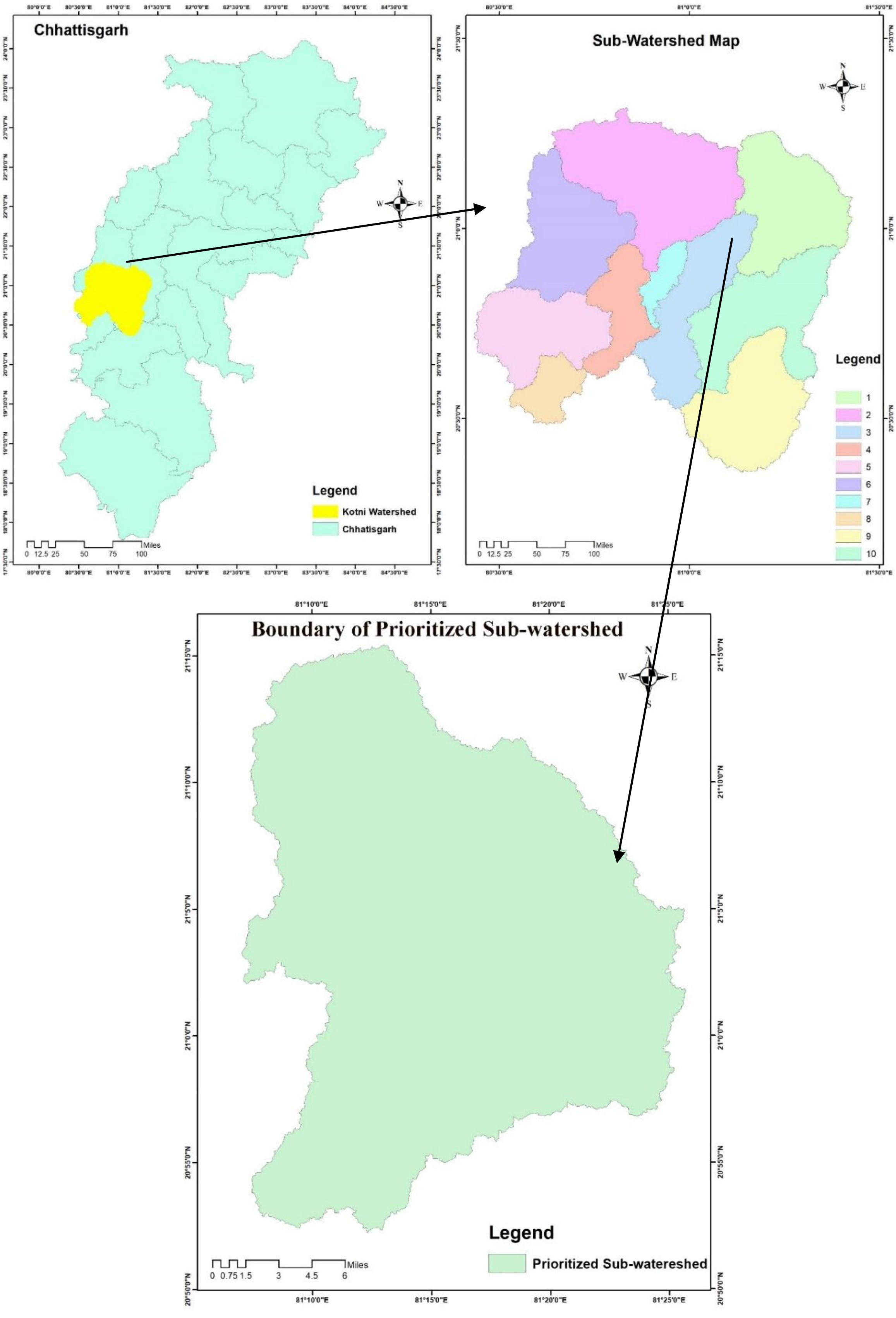


Fig. 1. Boundary of the study area

Table 1. Data acquisition

S. No.	Name	Type	Source
1	Meteorological and Hydrological Data	Daily Rainfall (2009-19)	Web Source: https://power.larc.nasa.gov/
2	Geology and Geomorphology	Shapefile	Central Ground Water Board (CGWB), NCCR, Raipur
3	Pre and Post monsoon water level map	Groundwater Level	Central Ground Water Board (CGWB), NCCR, Raipur Indiawris.com
4	Lineament Data	Shapefile	Chhattisgarh State Watershed Management Agency, Govt. of CG, Raipur.
5	Soil Data	Physiochemical properties	Chhattisgarh State Watershed Management Agency, Govt. of CG, Raipur.
6	Digital Elevation Model (D.E.M.) (30 m)	SRTM	Web Source: www.earthexplorer.usgs.gov.
7	Remote Sensing Data	Sentinal-2 (25-Oct-2020)	www.earthexplorer.usgs.gov., https://scihub.copernicus.eu/

(www.earthexplorer.usgs.gov.). The groundwater fluctuation and rainfall maps were created in ArcGIS 10.5 using Inverse Distance Weighting (IDW) interpolation technique. For groundwater fluctuation map, The fluctuation data from three locations inside the study area as Arjunda, Gunderdehi, and Durg were utilized. Likewise, average yearly rainfall data from three separate rainfall recorded sites were interpolated over the watershed for rainfall map. The rainfall-runoff estimation was done by the SCS curve number method developed by the United States Department of Agriculture (USDA) and the Natural Resources Conservation Service (NRCS).

2.2.1.2 Delineation of suitable zones for of water storage and harvesting structures

The Multi-Criteria Decision Analysis (MCDA) method provides the optimal solution with which the uncertainties are associated [7]. GIS-based MCDA approach incorporates and transforms spatial data (input) into the decision (output), where qualitative information on individual themes and characteristics is transformed into quantitative values using Saaty's scale [8]. Through the pairwise comparison matrix the weights were assigned to the themes and features which based on the views of expert hydrologists and hydrogeologists, along with local experience. The rasterisation and reclassification tool in ArcMap 10.5 was utilized to transform all layers into raster format, and to allocate weightages to the layer and their feature.

2.2.1.3 Identification of suitable locations for storage and water harvesting structures

To identify the best suitable structure and its locations, the water storage and harvesting structures suitability zones layer was integrated with LULC, lineament, contour map (1 m), and google satellite image in the QGIS software. it helps for better visual interpretation for selecting the best-engaged points for structures. Table 2 shows the criteria for site interpretation and structure recommendation, developed by Indian National Committee on Hydrology (INCOH) [9].

Table 2. Site selection criteria for artificial recharge structures

Type of structure	Slope (%)	Soil texture	Rainfall (in mm)	Land use	Drainage
Check Dam	<15%	Sandy Clay Loam	<1000 mm	Barren, Scrubland	Higher-order, i.e., >3rd order
Percolation Tank	<10%	Silt loam, Clay loam	<1000 mm	Barren, Scrubland	2nd to 3rd order
Farm Pond	<5%	Sandy clay loam, Silt loam	>200 mm	Scrubland, Moderately cultivated	1st order

Elevation data from Google Earth can be used for low-cost exploration and early research [10]. Thus, it was merged with the 1 m contour line created with the SRTM DEM in the ArcGIS environment to estimate the capacity of the proposed structures. The length, width, and depth of stagnated water were determined in google earth pro, and by multiplying these parameters, the volume of water stored in the structure was estimated.

3. RESULTS AND DISCUSSION

3.1 Generation of Thematic Map

3.1.1 Land use/cover map (LULC)

The LULC was created using cloud-free geocoded digital data from Sentinal-2 dated 25/Oct/2020. The principal LULC classes were determined based on the results of image classification of *Kharif* season, includes agricultural (80.65 %), current fellow (6.36 %), barren land (2.73%), settlement (7.21 %), and water body (3.05 %). As shown in Fig. 2.

3.1.2 Geology and geomorphology

The major formation discovered in the study area were mesoproterozoic - neoproteozoic. consists of structural plains of Gondwana rocks with active flood plain, pediment pedi plain complex, younger alluvial plain and waterbody as geomorphology. Fig. 3 depicts the research area's geology and geomorphology map.

3.1.3 Lineament map

Fractures in the strata of a specific location are referred to as lineament [11]. Lineament map of study area was obtained from the Central Ground Water Board, Raipur (C.G.). In the GIS context, a 100 m buffer was created around the lineaments. The lineament in the research region was estimated to be 256 km long.

3.1.4 Slope map and contour map

The elevation of the study area ranges between 268 to 354 metres above mean sea level (MSL). The slope map exhibited a range of 0 to 49%. It categorised into five ranges flat (0%), mild slope (0-2%), low (2-4%), moderate (4-6%), and high slope zones (>6%). Most of the catchment area has a mild slope zone making it ideal for water harvesting, recharge structures and farming. Fig. 4 shows a slope map and a contour map with a 10 m interval.

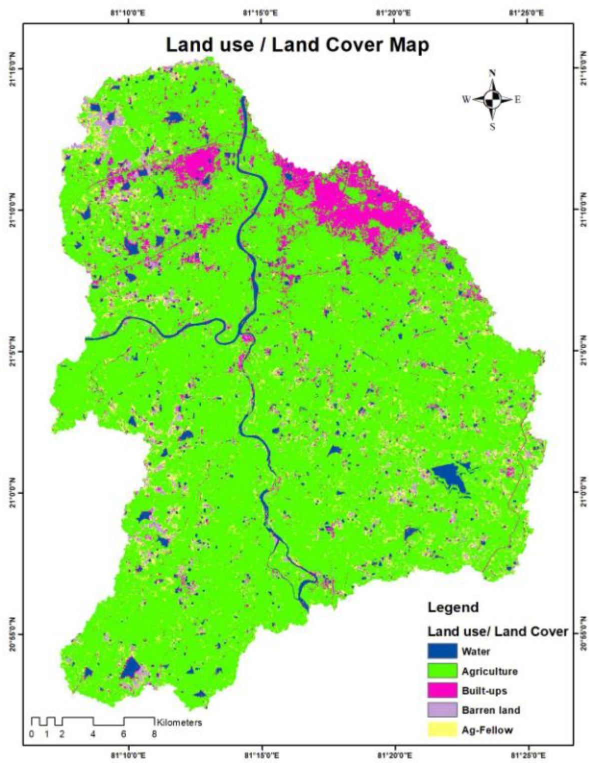


Fig. 2. Land use/cover map

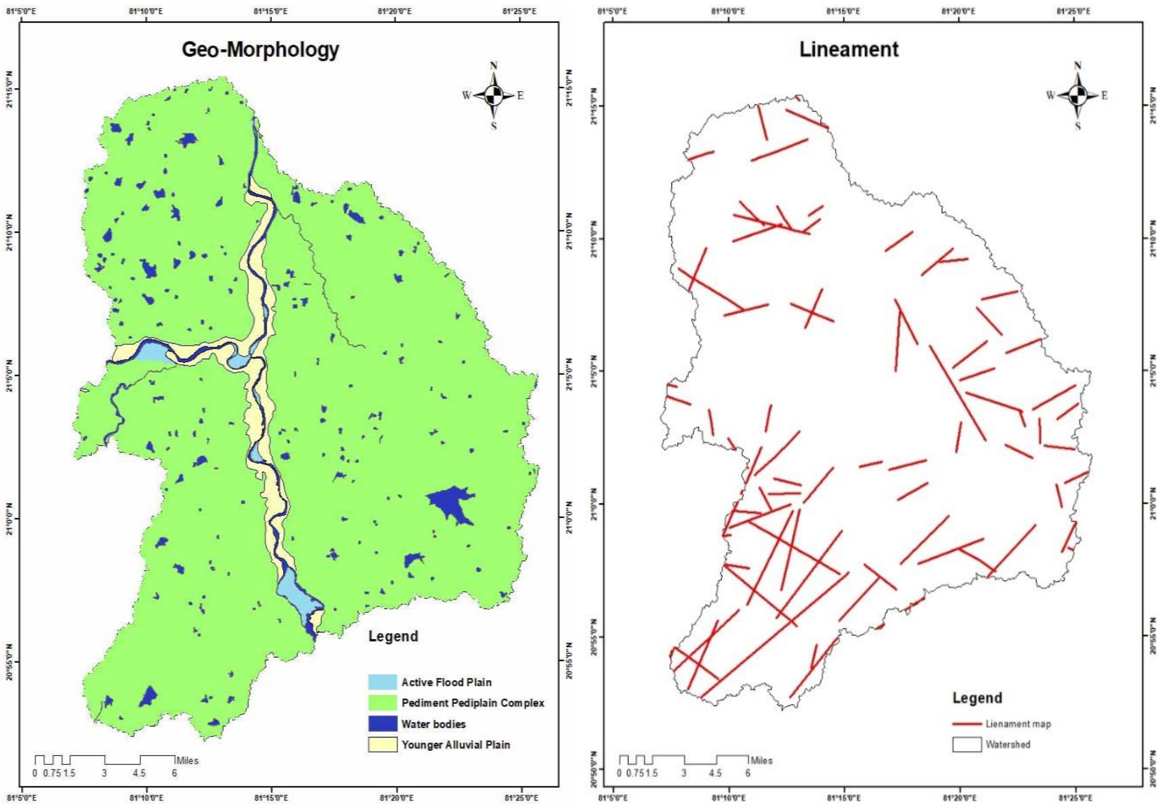


Fig. 3. Geomorphology and lineament map

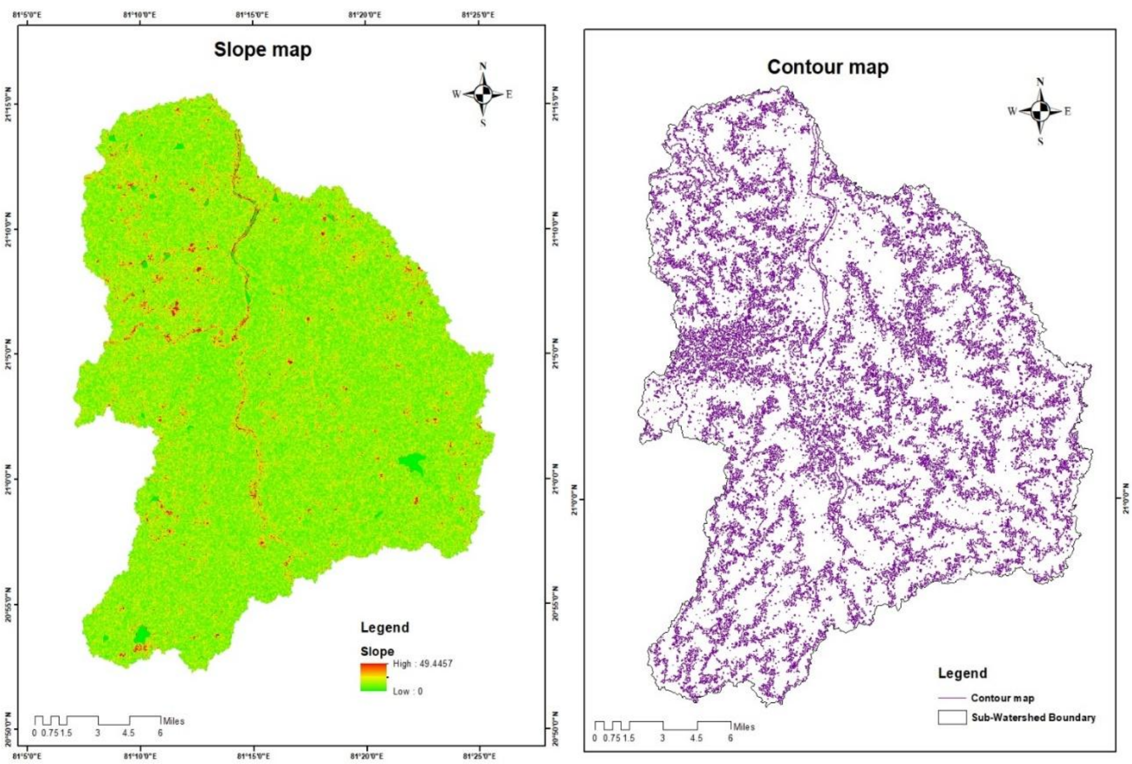


Fig. 4. Slope map and contour map

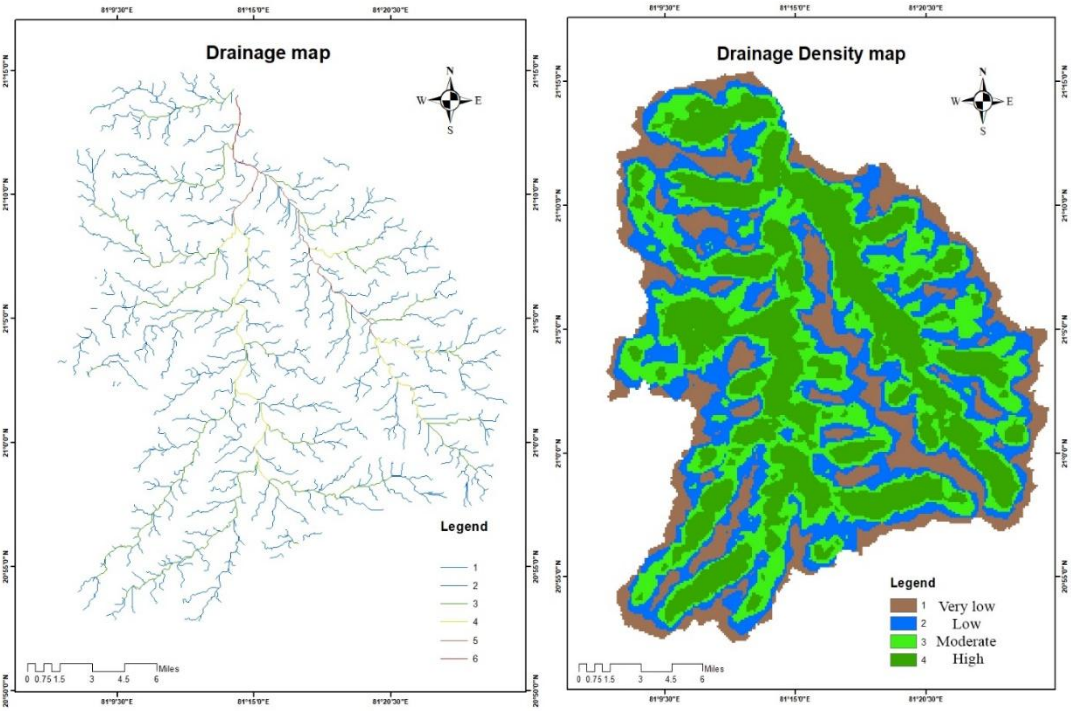


Fig. 5. Drainage & drainage density map

3.1.5 Drainage and drainage density map

In ArcMap 10.5, an SRTM DEM (30 m) was utilized to create the drainage map. There were total 1152 streams in the study area, comprising of 586 1^{st} order, 277 2^{nd}, 187 3^{rd}, 60 4^{th}, 34 5^{th}, and 8 number of sixth-order streams. The total length of streams was calculated as 973.60 km and drainage density is calculated by dividing the total length of channels (km) by the basin area (km^2). The study area is categorized into very low, low, moderate and high drainage density zones.

3.1.6 Soil texture map

The Central Groundwater Board, Raipur,(C.G.) provided the study area's soil texture/type map. Table 3 and Fig. 6 summarise various soil textures found in the study area.

3.1.7 Rainfall map and groundwater fluctuation map

In study area rainfall and groundwater fluctuation maps were separated into three zones: low, medium, and high. While yearly groundwater fluctuation of Durg block was obtained as 3.35 m, Arjunda block as 1.573 m and Gunderdehi block as 3.926 m. Fig. 7 shows the rainfall and groundwater fluctuation map of the study area.

3.1.8 Surface runoff assessment

Graph 1 shows the annual rainfall and runoff trend for the study area from 2009 to 2019. Data reveled that the average daily rainfall over the last eleven years was 1329 mm. The hydrological soil group of the watershed allows to generate about 41% runoff; thus, the average annual runoff estimated from eleven years was 483.95 Mm^3.

Table 3. Area under different soil types

S. no	Soil type	Soil code	Area	Percentage area
1	Clay Loam	CYLM	153.17	17.61
2	Sandy Clay Loam	SCLM	0.04	0.00
3	Silty Clay	SYCY	676.97	77.82
4	Very Gravel Sandy Loam	VGSL	28.89	3.32
5	Water	WATER	10.82	1.24
	Total		869.89	100.00

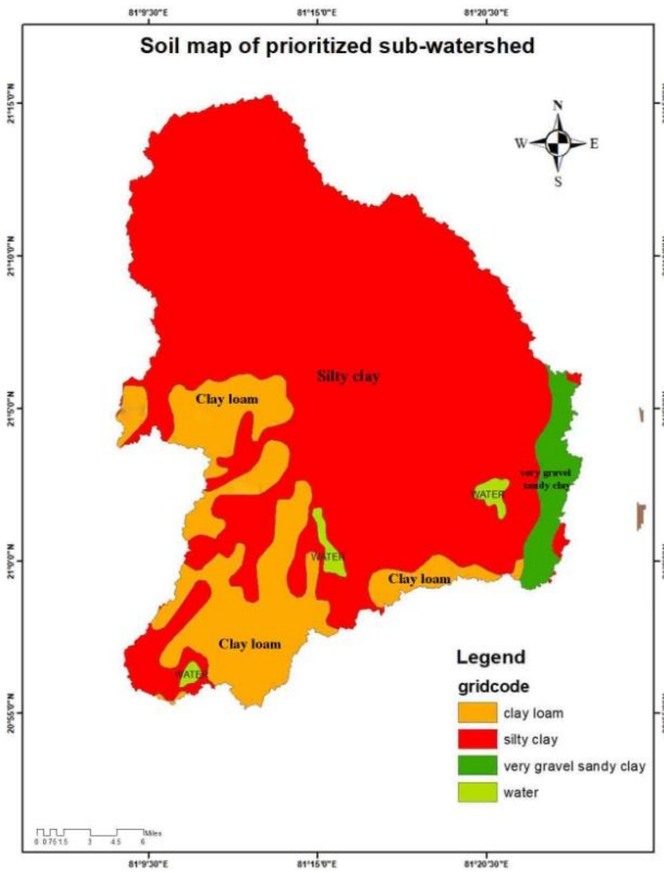


Fig. 6. Soil texture map of the study area

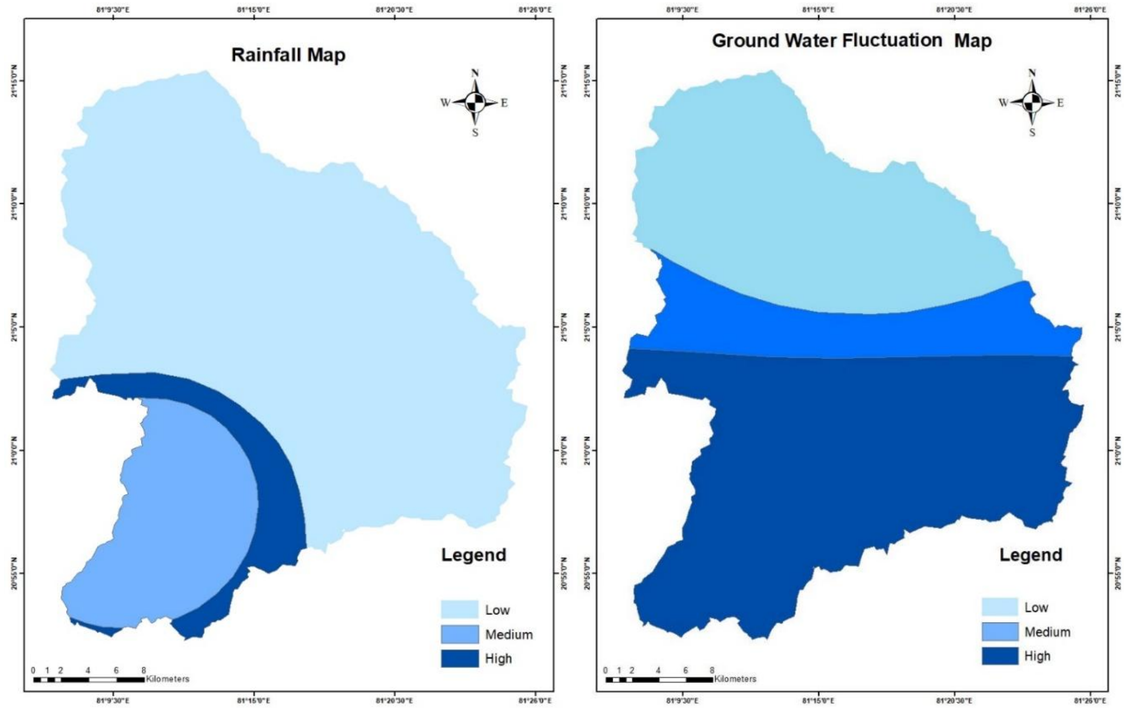
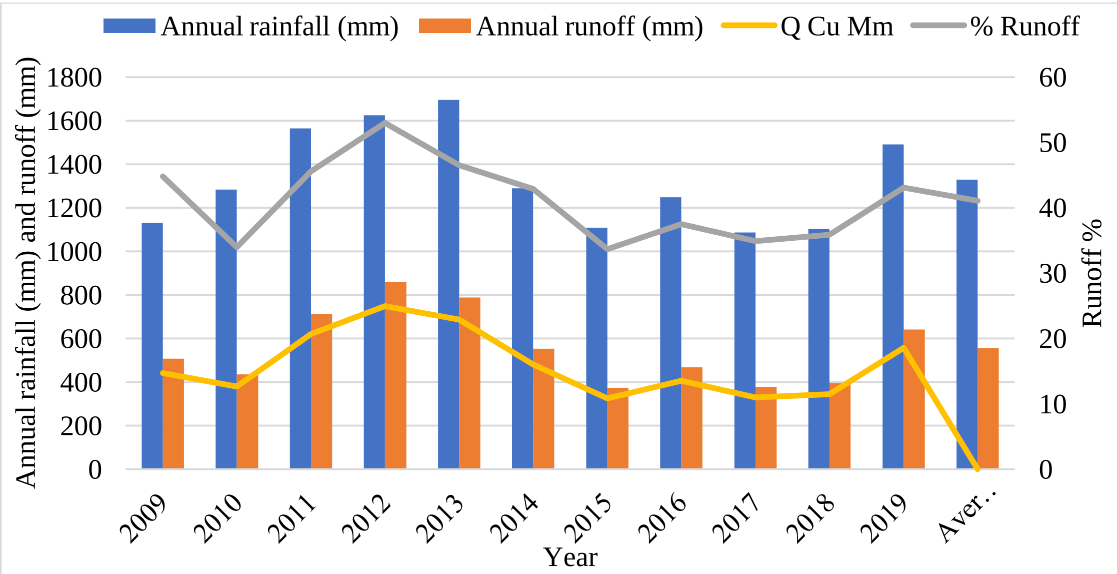


Fig. 7. Rainfall and groundwater map of the study area



Graph 1. Rainfall-Runoff trend of study area (2009-2019)

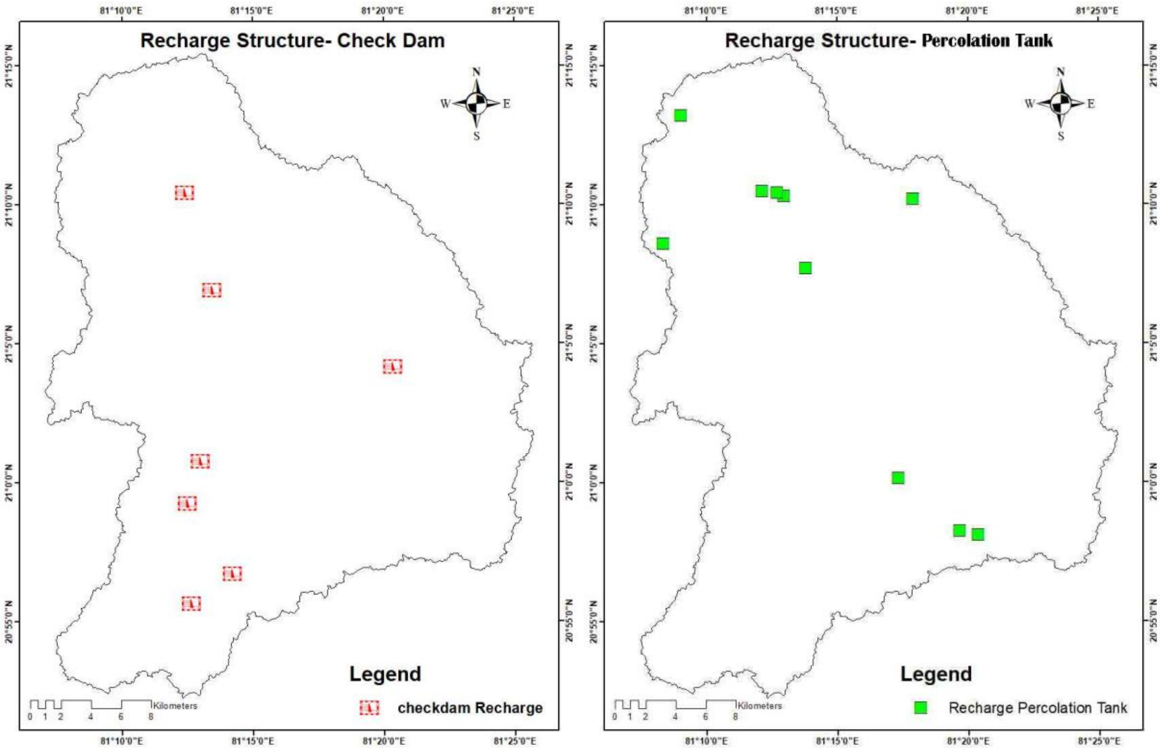


Fig. 8. Proposed sites for water recharge structures

3.1.9 Water resources development plan

A water resource development plan was developed by integrating information on surface water availability, land use/land cover, drainage, the current condition of groundwater utilisation, and the study area's present and long-term water demands As described in the methodology, the eight parameters were chosen to identify recharging and harvesting structure's locations [12-15]. Percentage influence and scale value of individual themes were estimated through Satty's analytical hierarchical process. The suitability map for the water recharge and storage structure sites is shown in Figs. 8 and 9. For recharge

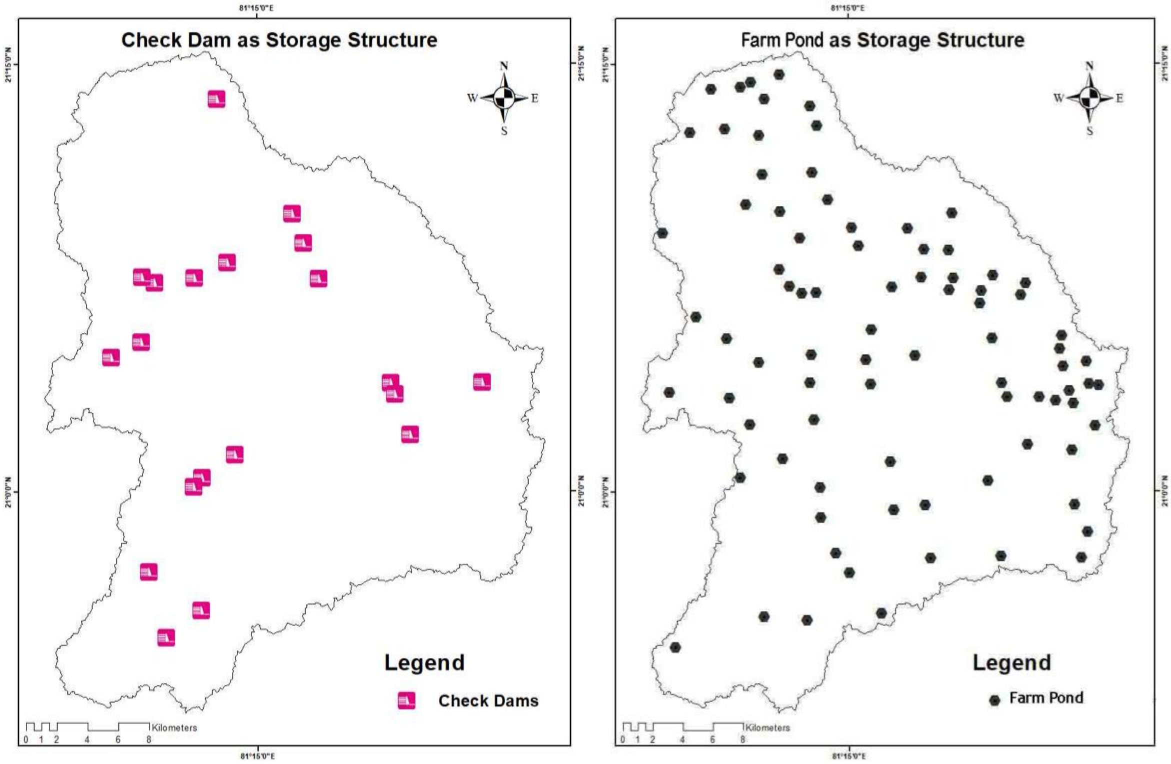


Fig. 9. Proposed sites for water storage structures

structures, 07 check dams and 10 percolation tank sites were identified, while 30 check dams and 61 farm pond sites were estimated to be extremely appropriate for water storage structures. The harvested water and recharged groundwater will be aided by the structures may offer the farmers to expand their agricultures even in the summer season when there is sacristy of water and Assist to raise the production and productivity by enhancing water supplies [16-20]. Agricultural yield might be improved because of the additional harvested and recharged water [21-23].

Table 4. Capacity of proposed structures

Proposed structure	Capacity (Mm^3)
Recharge structure	
Check Dam	0.246
Percolation tank	0.027
Storage structure	
Check Dam	0.78
Farm pond	1.26
total capacity	2.313

After assessing the best suitability of these sites, the proposed structure's location were also ground-truthed and validated. It was determined that the total capacity of stagnated water in different recharge and storage structures was 2.313 Mm^3. Table 4 shows the results.

4. CONCLUSIONS

The standard process was used to create thematic maps such as the base map, LULC, slope, contour, drainage, drainage density, groundwater fluctuation and a rainfall map, etc. These maps aid in understanding the study area's behaviour and water resource planning. The appropriate sites for 7 check dams and 10 percolation tanks for groundwater recharging and 20 check dams and 61 farm ponds for water harvesting were identified and proposed in the study area. The water stagnation capacity of the proposed structures was calculated as 2.31 Mm^3. Due to a lack of water and improper management, only 30% of the area is under agriculture in the summer/rabi season, and about 50% of the area is under current fallow. This output of the result will help to increase the productivity within the watershed along with conserving the crucial resources.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/90203