

Remote sensing and GIS-aided Land and water resources management plan for a prioritized sub-watershed of the Kotni watershed, Chhattisgarh, India.

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 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 Mm³ 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, watershed management,

Introduction

For millenniums, land and water resources have been benefiting both people and their economies (Caughie & McBain 2018). 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 (Mittal, 2013). Especially for a country like India, which have to sustain 17.7 percent of the world population on 2.42 % geographical area (World Population Prospects 2019), 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

33 in the study area is 1,323 mm (Climate data, 2019), with a high runoff conversion capability of 41%
34 and due to lack of arrangements this high amount of runoff cannot be utilized in primary purposes such
35 as agriculture.

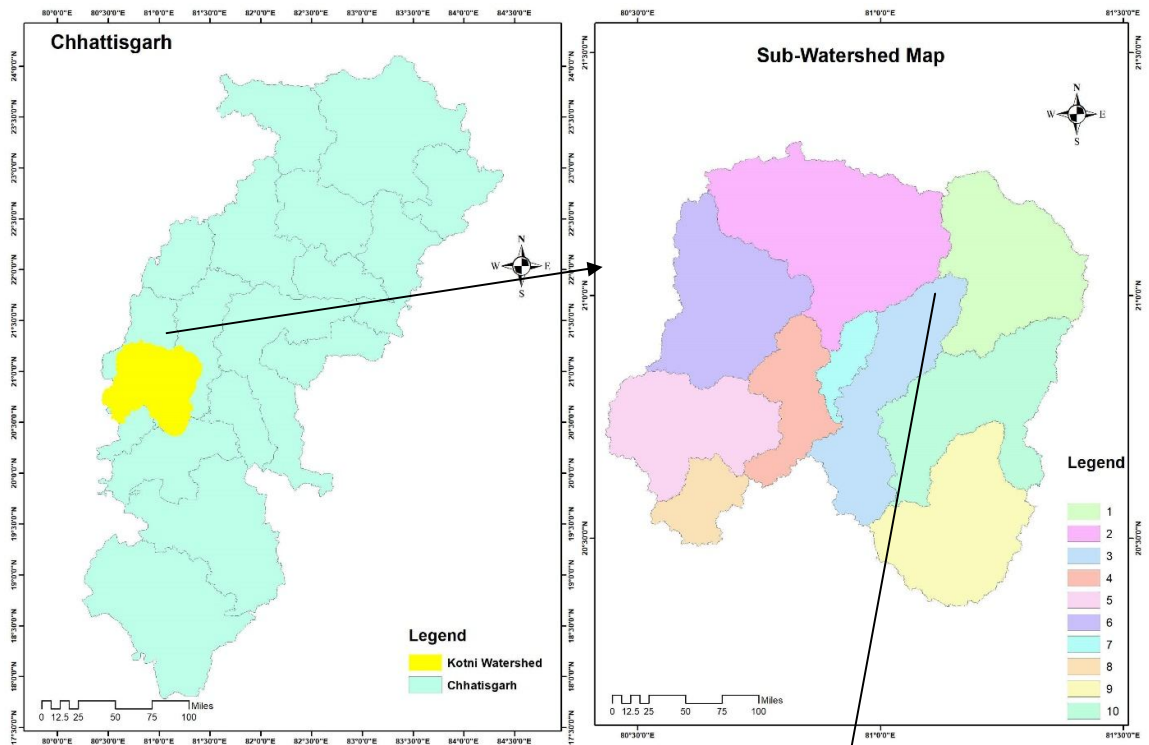
36 In this research, land and water resources were studied for better management and sustainable
37 utilization. It combines water availability analysis and structure planning at appropriate sites, assisting
38 in enhancing the study area's water recharge and storage capacity and directly supporting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

42 **Materials and methods**

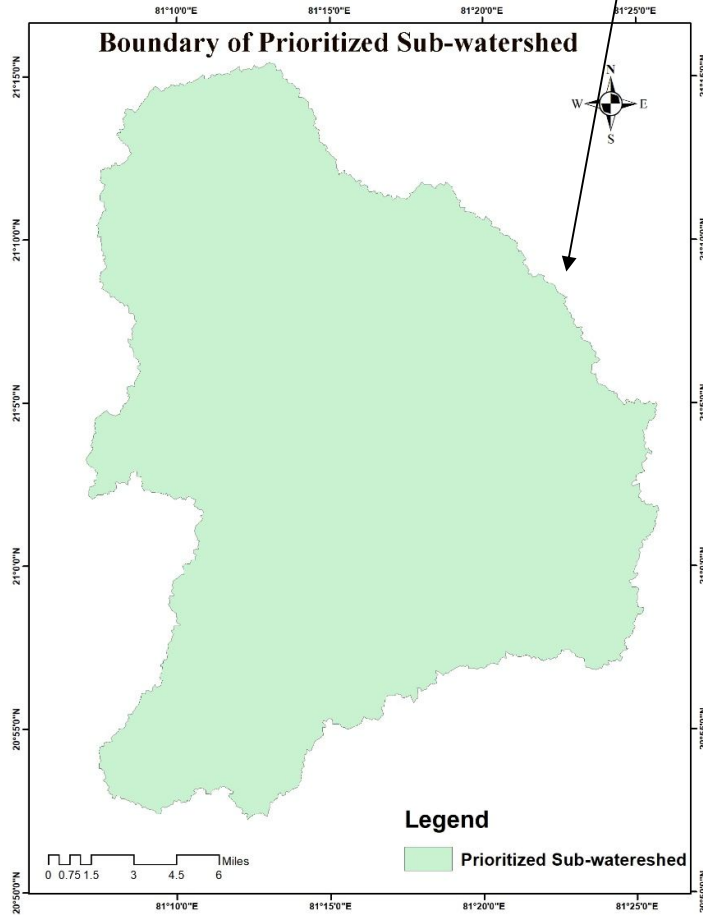
43 **Study Area**

44 The study area (i.e., Kotni watershed) is located in the western part of Chhattisgarh state,
45 within latitudes 20°52' to 21°15' N and longitudes 81°07' to 81°26'E and covers an area of 870 km². It
46 is a part of the Seonath river sub-basin of the Mahanadi basin. Fig. 1 shows the boundary of the study
47 area. The climate of the study area is tropical because of its proximity to the Tropic of Cancer and its
48 dependence on the south-west monsoons for rains, which endures from late June to October. The study
49 area exhibits average yearly precipitation and temperature as 1,323 millimeters 26.5°C (Climate data,
50 2019) with 41% of runoff generation capacity which not being utilised due to inappropriate water
51 conservation structures. It comprises four major groups of soil Entisol, Inceptisols, Alfisols, and
52 Vertisols (Mandal, 2018). Major crops grown in the study area are rice, soybean, wheat, sugarcane and
53 gram, etc. (Agriculture Contingency Plan, C.G., 2013).

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Fig 1: Boundary of the study area

57 **Methodology**

58 **Data Acquisition**

59 All the data required for the study were acquired from various sources, as mentioned in Table
60 1.

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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/

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63 **Spatial database building/ thematic map generation**

64 Layers such as geomorphology, geology, and lineament obtained from various sources as
65 mentioned above were clipped/ remoulded for the study area boundary . In the GIS context, the Shuttle
66 Radar Topography Mission digital elevation model SRTM DEM (30 m) was utilised to create contour
67 maps, slope maps, drainage maps, and drainage density maps. The land use and land cover map was
68 created by Qgis software using semi-automatic categorization add-ins with the aid of sentinal-2 spatial
69 data, of 25/Oct/2020 downloaded from the USGS website ([www.earthexplorer.usgs.gov.](http://www.earthexplorer.usgs.gov)). The
70 groundwater fluctuation and rainfall maps were created in ArcGIS 10.5 using Inverse Distance
71 Weighting (IDW) interpolation technique. For groundwater fluctuation map, The fluctuation data from
72 three locations inside the study area as Arjunda, Gunderdehi, and Durg were utilized. Likewise,
73 average yearly rainfall data from three separate rainfall recorded sites were interpolated over the
74 watershed for rainfall map. The rainfall-runoff estimation was done by the SCS curve number method
75 developed by the United States Department of Agriculture (USDA) and the Natural Resources
76 Conservation Service (NRCS).

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79 **Delineation of suitable zones for of water storage and harvesting structures**

80 The Multi-Criteria Decision Analysis (MCDA) method provides the optimal solution with
81 which the uncertainties are associated (Durbach & Stewart 2012). GIS-based MCDA approach
82 incorporates and transforms spatial data (input) into the decision (output), where qualitative
83 information on individual themes and characteristics is transformed into quantitative values using
84 Saaty's scale (Kumar T. et al, 2014). Through the pairwise comparison matrix the weights were
85 assigned to the themes and features which based on the views of expert hydrologists and
86 hydrogeologists, along with local experience. The rasterisation and reclassification tool in ArcMap
87 10.5 was utilized to transform all layers into raster format, and to allocate weightages to the layer and
88 and their feature.

89 **Identification of suitable locations for storage and water harvesting structures**

90 To identify the best suitable structure and its locations, the water storage and harvesting
91 structures suitability zones layer was integrated with LULC, lineament, contour map (1 m), and google
92 satellite image in the QGIS software. it helps for better visual interpretation for selecting the best-
93 engaged points for structures. Table 2 shows the criteria for site interpretation and structure
94 recommendation, developed by Indian National Committee on Hydrology (INCOH) (Nigam & Tripathi
95 2019)

96 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., >3 rd order
Percolation Tank	<10%	Silt loam, Clay loam	<1000 mm	Barren, Scrubland	2 nd to 3 rd order
Farm Pond	<5%	Sandy clay loam, Silt loam	>200 mm	Moderately cultivated	1 st order

97 Elevation data from Google Earth can be used for low-cost exploration and early research.
98 Ashmawy (2016). Thus, it was merged with the 1 m contour line created with the SRTM DEM in the
99 ArcGIS environment to estimate the capacity of the proposed structures. The length, width, and depth

100 of stagnated water were determined in google earth pro, and by multiplying these parameters, the
101 volume of water stored in the structure was estimated.

102 **Results And Discussion**

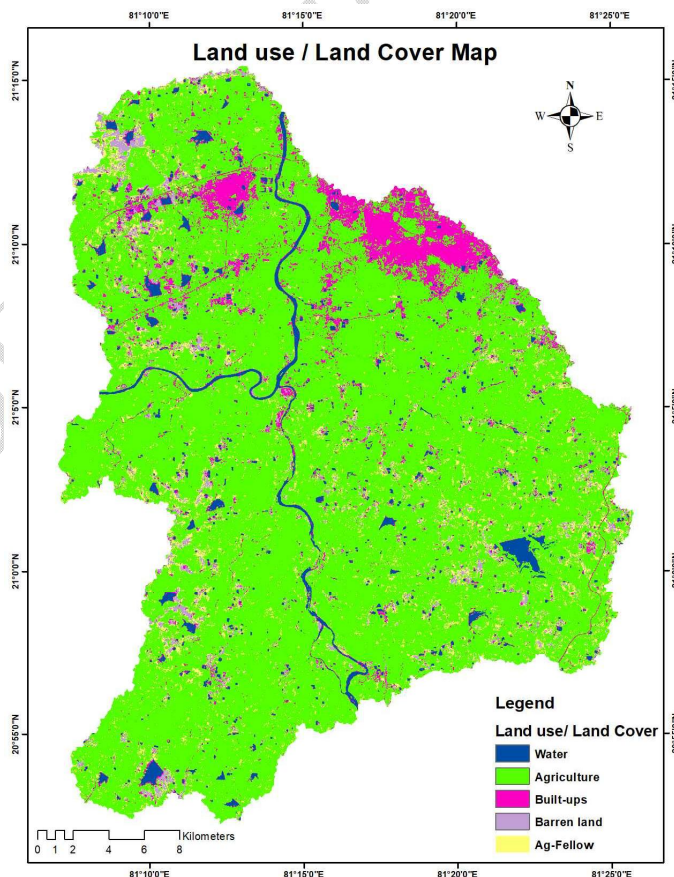
103 **Generation of thematic map**

104 **A. Land use/cover map (LULC)**

105 The LULC was created using cloud-free geocoded digital data from Sentinel-2 dated
106 25/Oct/2020. The principal LULC classes were determined based on the results of image classification
107 of *Kharif* season, includes agricultural (80.65 %), current fellow (6.36 %), barren land (2.73 %),
108 settlement (7.21 %), and water body (3.05 %). As shown in Fig 2.

109 **B. Geology and geomorphology**

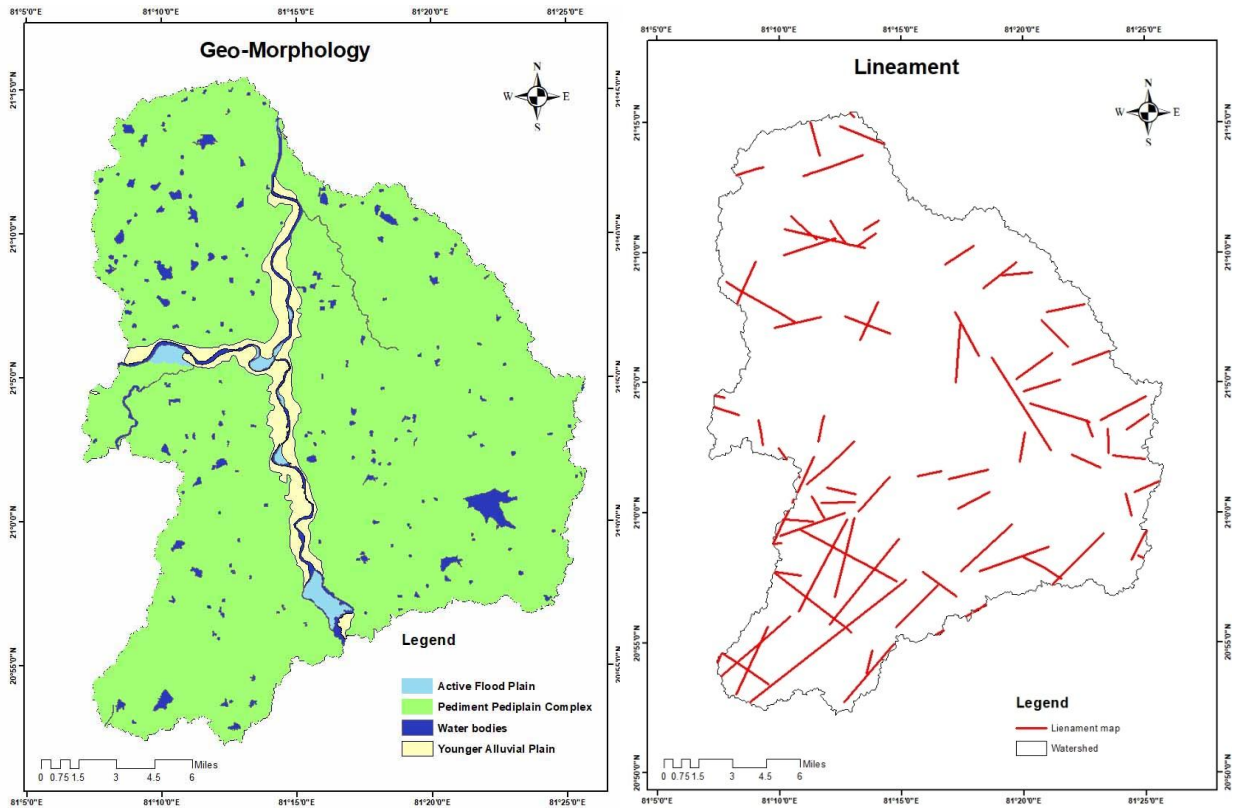
110 The major formation discovered in the study area were mesoproterozoic - neoproterozoic.
111 consists of structural plains of Gondwana rocks with active flood plain, pediment pedi plain complex,
112 younger alluvial plain and waterbody as geomorphology. Fig. 3 depicts the research area's geology and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



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Fig. 2: Land use/cover map



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Fig. 3: Geomorphology and lineament map

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C. Lineament map

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Fractures in the strata of a specific location are referred to as lineament (Soro *et al.* 2017). 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.

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D. Slope map and contour map

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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. Figure 4 shows a slope map and a contour map with a 10 m interval.

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E. Drainage and drainage density map

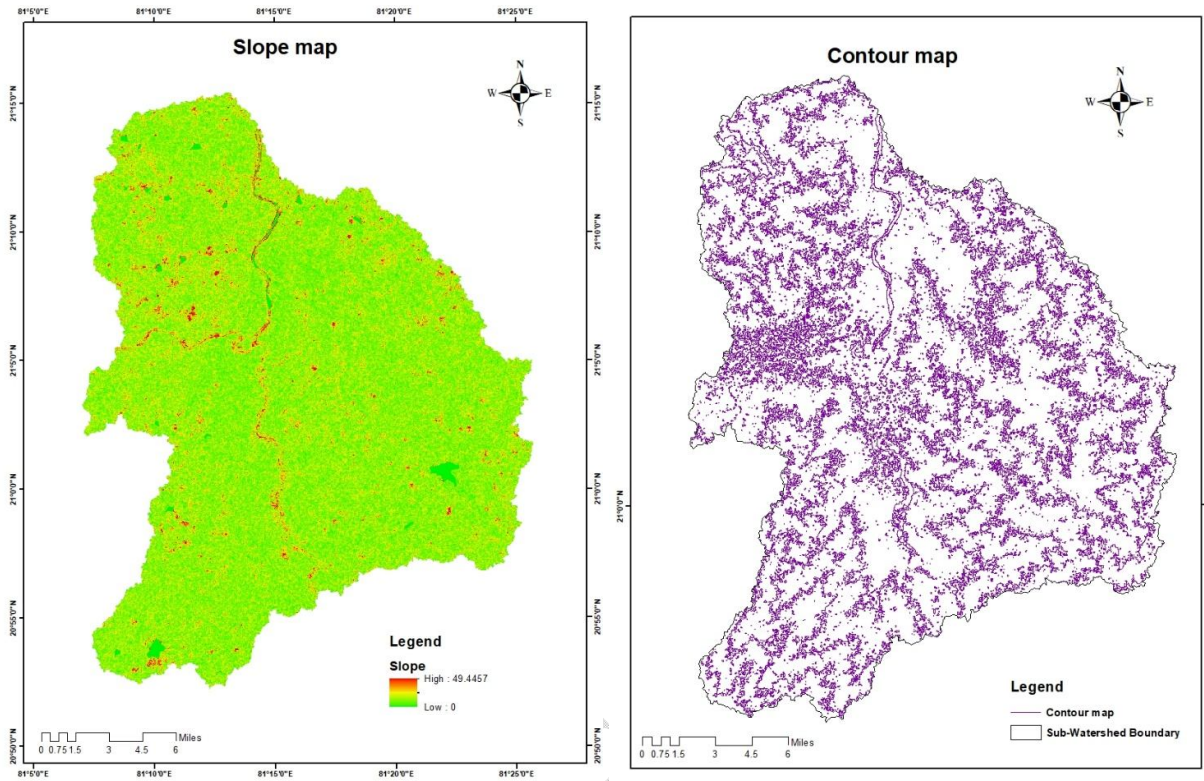
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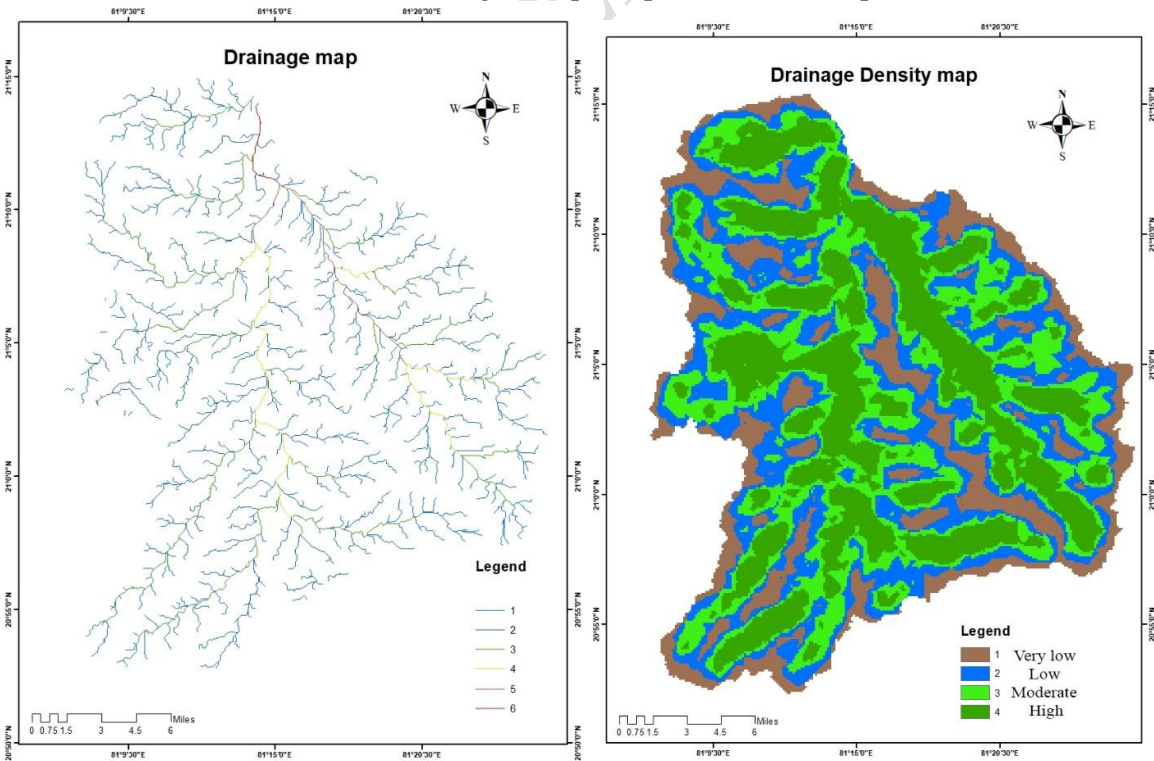
In ArcMap 10.5, an SRTM DEM (30 m) was utilized to create the drainage map. There were total 1152 streams in the study area, a comprising of 586 1st order, 277 2nd, 187 3rd, 60 4th, 34 5th, and 8 number of sixth-order streams. The total length of streams was calculated as 973.60 km and drainage

133 density is calculated by dividing the total length of channels (km) by the basin area (km²). The study
 134 area is categorized into very low, low, moderate and high drainage density zones.



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Fig 4: Slope map and Contour map



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Fig 5: Drainage & drainage density map

139 **Soil texture map**

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

142 **Rainfall map and groundwater fluctuation map**

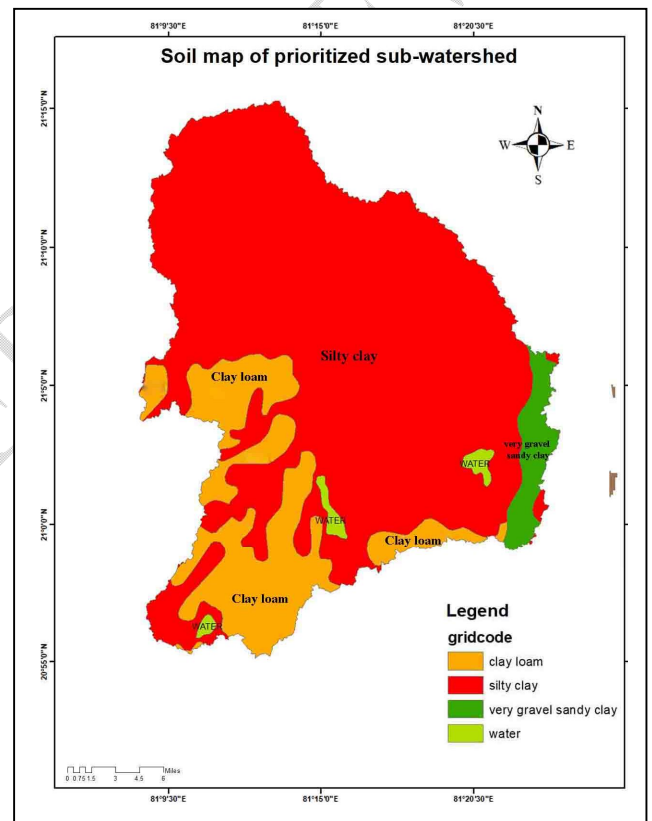
143 In study area rainfall and groundwater fluctuation maps were separated into three zones: low,
 144 medium, and high. While yearly groundwater fluctuation of Durg block was obtained as 3.35 m,
 145 Arjunda block as 1.573 m and Gunderdehi block as 3.926 m. Fig 7 shows the rainfall and groundwater
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

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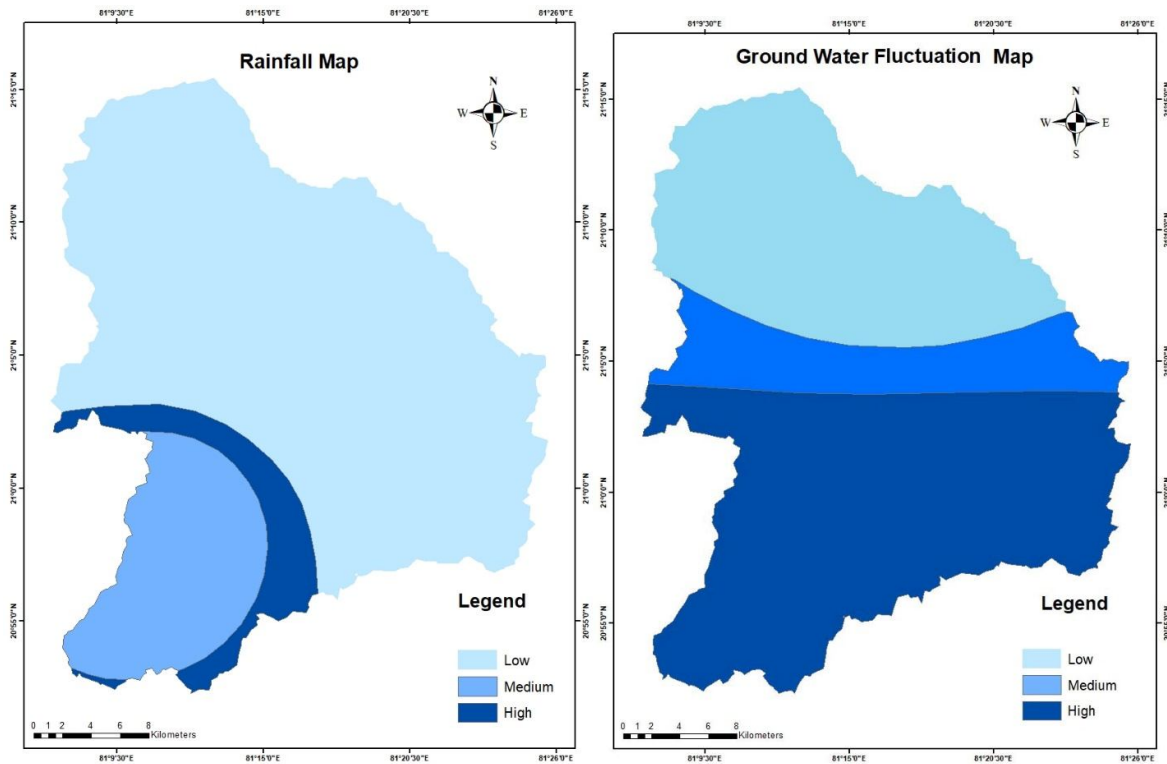
148 **Table 3: Area under different soil types**

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

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160 **Fig 6: Soil texture map of the study area**



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Fig 7: Rainfall and groundwater map of the study area

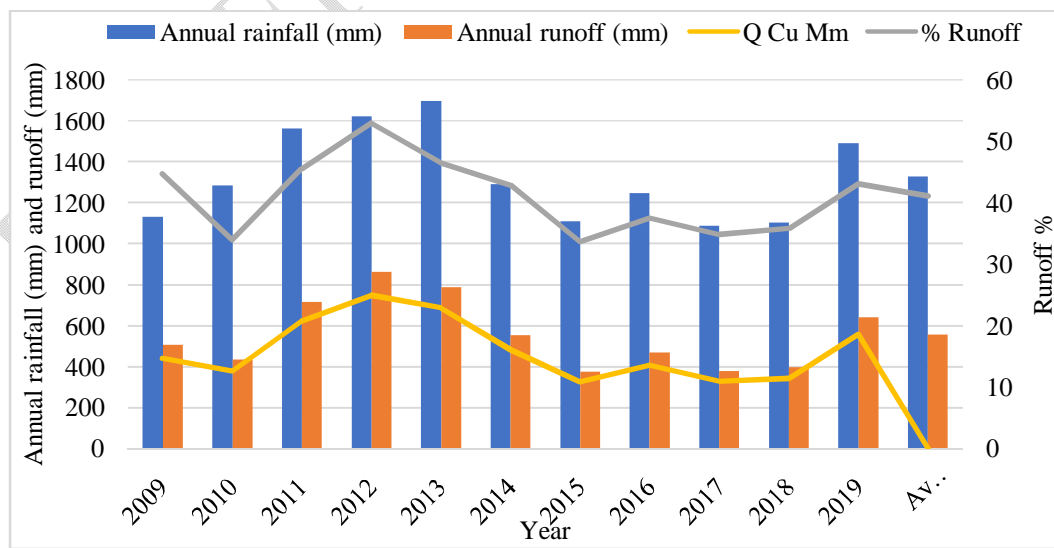
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Surface runoff assessment

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Graph 1 shows the annual rainfall and runoff trend for the study area from 2009 to 2019. Data revealed 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 Mm³.

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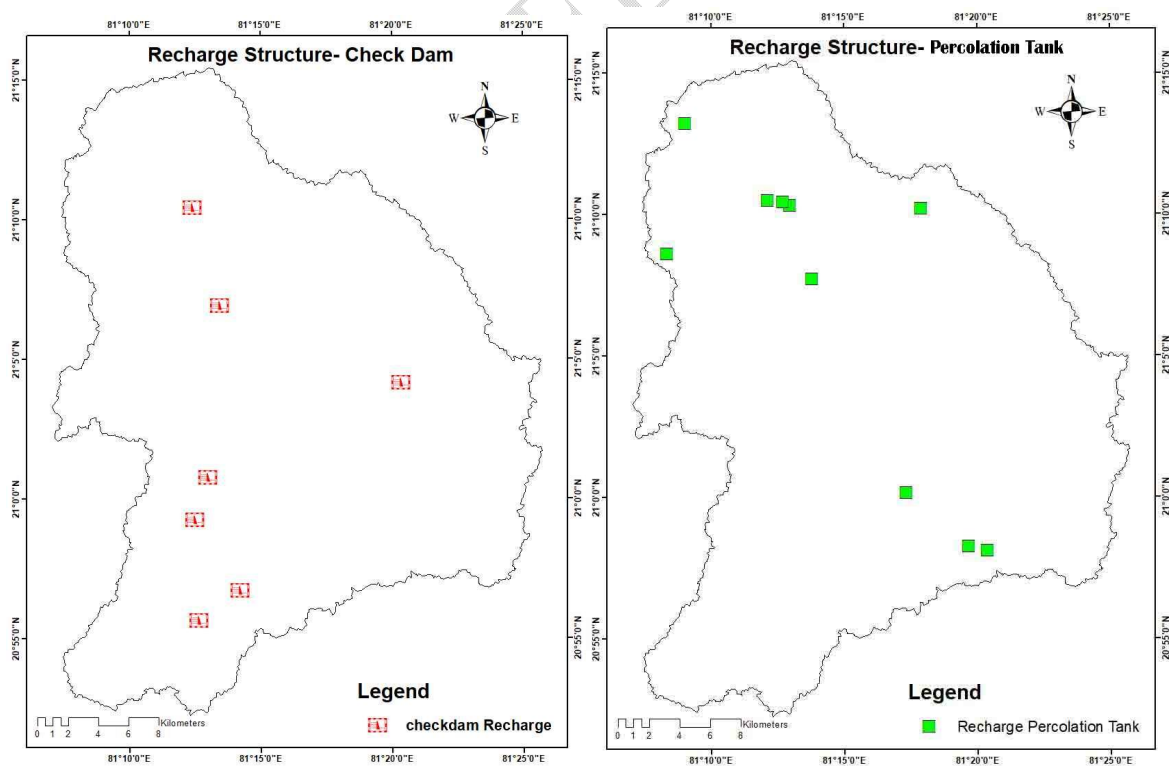
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Graph 1: Rainfall-Runoff trend of study area (2009-2019)

170 Graph shows the annual rainfall- runoff trend for the study area from 2009 to 2019. Data
171 reveled that the average daily rainfall over the last eleven years was 1329 mm. The hydrological soil
172 group of the watershed allows to generate about 41% runoff; thus, the average annual runoff estimated
173 from eleven years was 483.95 Mm³.

174 **Water resources development plan**

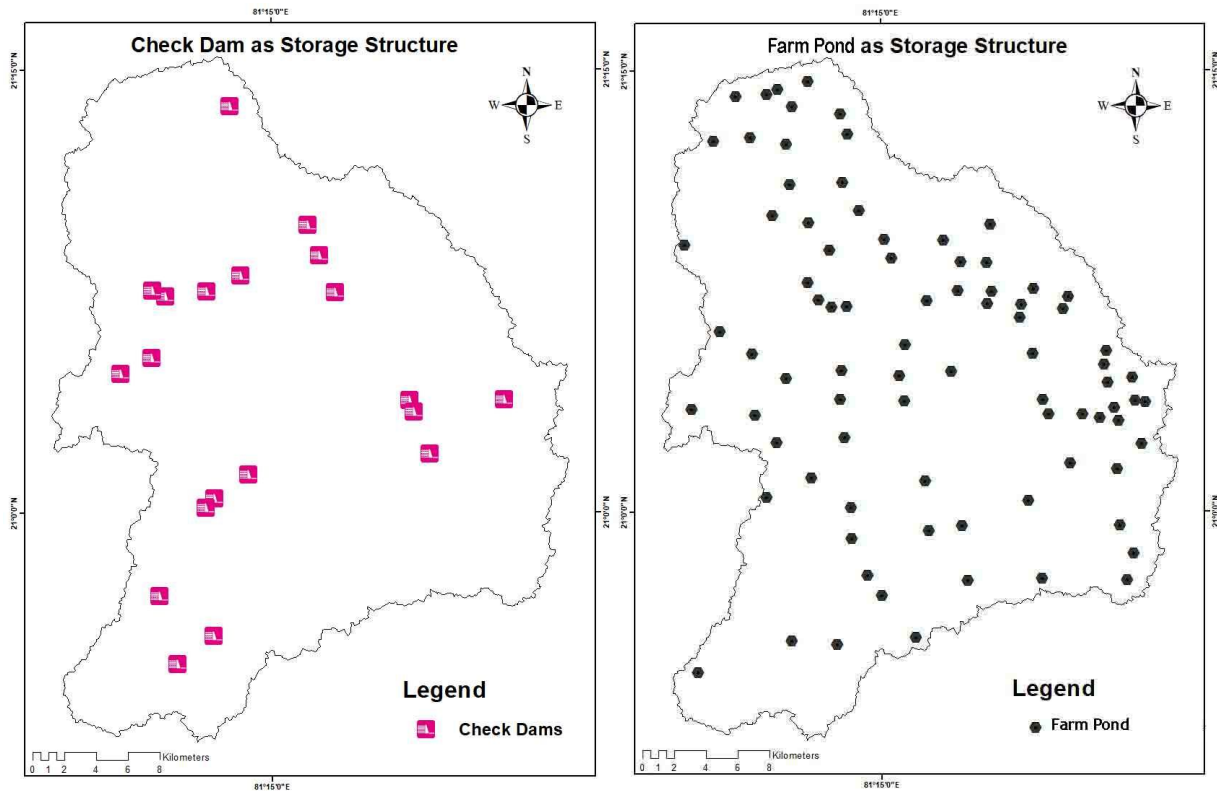
175 A water resource development plan was developed by integrating information on surface water
176 availability, land use/land cover, drainage, the current condition of groundwater utilisation, and the
177 study area's present and long-term water demands As described in the methodology, the eight
178 parameters were chosen to identify recharging and harvesting structure's locations. Percentage
179 influence and scale value of individual themes were estimated through Satty's analytical hierarchical
180 process. The suitability map for the water recharge and storage structure sites is shown in Fig 8 and 9.
181 For recharge structures, 07 check dams and 10 percolation tank sites were identified, while 30 check
182 dams and 61 farm pond sites were estimated to be extremely appropriate for water storage structures.
183 The harvested water and recharged groundwater will be aided by the structures may offer the farmers
184 to expand their agricultures even in the summer season when there is sacristry of water and Assist to
185 raise the production and productivity by enhancing water supplies. Agricultural yield might be
186 improved because of the additional harvested and recharged water.



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Fig 8: Proposed sites for water recharge structures



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Fig 9: Proposed sites for water storage structures

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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 Mm³. Table 4 shows the results.

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Table 4: Capacity of proposed structures

Proposed structure	Capacity (Mm³)
Recharge structure	
Check Dam	0.246
Percolation tank	0.027
Storage structure	
Check Dam	0.78
Farm pond	1.26
total capacity	2.313

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CONCLUSIONS: -

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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 Mm³. Due to a lack of water and improper

202 management, only 30% of the area is under agriculture in the summer/rabi season, and about 50% of
203 the area is under current fallow. This output of the result will help to increase the productivity within
204 the watershed along with conserving the crucial resources.

205 **References**

- 206 Mishra, N., Khare, D., Gupta, K. K., & Shukla, R. (2014). Impact of land use change on
207 groundwater—a review. *Advances in Water Resource and Protection*, 2(28), 28-41.
- 208 Agriculture Contingency Plan for District: Durg State: Chhattisgarh 2013 accessed January
209 2021 <https://www.agricoop.gov.in/sites/default/files/Durg.pdf>
- 210 Anonymous, 2019, UN fund for population activities (unfpa), United Nations, accessed January 2021,
211 < <https://www.unfpa.org/swop-2019> >
- 212 Caughie, J., & J McBain, J. (2018). Local Films for Local People: HAVE YOU BEEN
213 CINEMATOGRAPHED,
- 214 Climate data, 2019, Climate-Data.org / AM OP / OpenStreetMap contributors, accessed January 2021,
215 < <https://en.climate-data.org/asia/india/chhattisgarh/durg-6282>.
- 216 Daily, G. C., & Ehrlich, P. R. (1994). Population, sustainability, and Earth's carrying capacity.
217 In *Ecosystem Management* (pp. 435-450). Springer, New York, NY.
- 218 Durbach, I. N., & Stewart, T. J. (2012). Modeling uncertainty in multi-criteria decision
219 analysis. *European journal of operational research*, 223(1), 1-14.
- 220 Edinburgh University Press doi = 10.3366/edinburgh/9781474420341.003.0008
- 221 El-Ashmawy, K. L. (2016). Investigation of the accuracy of google earth elevation data. *Artificial*
222 *Satellites*, 51(3), 89.
- 223 Falkenmark, M. (2006). Shift in thinking to address the 21st century hunger gap. In *Integrated*
224 *Assessment of Water Resources and Global Change* (pp. 3-18). Springer, Dordrecht.
- 225 Hao, Y., Cao, B., Zhang, P., Wang, Q., Li, Z., & Yeh, T. C. J. (2012). Differences in karst processes
226 between northern and southern China. *Carbonates and Evaporites*, 27(3), 331-342.
- 227 Khokhar, 2017, World bank blogs March 22, 2017, accessed January 2021, <
228 <https://blogs.worldbank.org/opendata/chart-globally-70-freshwater-used-agriculture> >

- 229 Kumar, S. S., Land Accounting in India, 2012, Issues and concerns. Central Statistics Office, Ministry
230 of Statistics & Programme Implementation, New Delhi, India. The views expressed in this
231 article are personal to the author.
- 232 Kumar, T., & Gautam A. K., Kumar, T., Appraising the accuracy of GIS-based Multi-criteria decision
233 making technique for delineation of Groundwater potential zones, *Water Resour Manage*
234 (2014) 28:4449–4466, DOI 10.1007/s11269-014-0663-6.
- 235 Mandal, S., Khalkho, D., Tripathi, M. P., & Kushwaha, L. K. S. (2018). Characterization and
236 delineation of farming situations of Durg district. *Journal of Pharmacognosy and*
237 *Phytochemistry*, 7(4), 2208-2214.
- 238 Mittal, R., (2013). IMPACT OF POPULATION EXPLOSION ON ENVIRONMENT, WeSchool
239 "Knowledge Builder" -The National Journal Volume -1 | Issue -1 | 2013 | ISBN 978-1-62840-
240 737-2
- 241 Nigam, G. K and Tripathi, M. P. 2019. Generation of Groundwater Zones for Selection of Prospective
242 Suitable Water Harvesting Structure Sites for Sustainable Water Supply Towards the
243 Agricultural Development. *Agricultural Research*, 9: 148-160.
- 244 Saaty, T.L. 1980. *The Analytic Hierarchy Process*, McGraw-Hill, New York, NY.
- 245 Soro, D. D., Koïta, M., Biao, C. A., Outoumbe, E., Vouillamoz, J. M., Yacouba, H., & Guérin, R.
246 (2017). Geophysical demonstration of the absence of correlation between lineaments and
247 hydrogeologically usefull fractures: case study of the Sanon hard rock aquifer (central northern
248 Burkina Faso). *Journal of African Earth Sciences*, 129, 842-852.
- 249 Subramanya, K. 2013. *Engineering Hydrology*, 4e. Tata McGraw-Hill Education.
- 250 Subramanya, K., 2008, *Engineering Hydrology* 3rd edition Engineering Hydrology, McGraw-Hill
251 publishing company limited new Delhi 110032.
- 252 UN, *World Population Prospects 2019*, 09 Dec 2021, Ministry of Statistics and Programme
253 Implementation < <https://population.un.org/wpp/Download/Standard/Population/> >
- 254 United States Department of Agriculture 1999, *Soil Taxonomy A Basic System of Soil Classification*
255 *for Making and Interpreting Soil Surveys* Second Edition, 1999 U.S. Government Printing
256 Office Washington, DC 20402.
- 257