Impact of mining activities on the water resources around Perambalur and Ariyalur district, southern India

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Submission Date : 10-Aug-2023

PROPOSAL DETAILS

(PDF/2023/002543)

Principal Investigator		Mentor & Host Institution	
Dr. Anbarasu Subramaniyan		**Balamurugan Guru**	
geoarasu.s@gmail.com		balamurugan.guru@gmail.com	
Researcher(Geology)		Associate Professor(Geology)	
Contact No	: +919585225524	**Central University of Tamil Nadu**	
Date of Birth	: 05-Jun-1988	Cutn bridge, neelakudy, Tiruvarur, Tamil nadu-610005	
Name of Father/Spouse :		**Contact No.**	: +919969050619
		Registrar Email	: balamurugan.guru@gmail.com
		No. of PHD Scholars	: 3
		No. Post-Doctoral Fellow	: 0

Details of Post Doctorate

Ph.D. (Geology)[Degree Awarded on : 13-Oct-2021]

Groundwater potential zonation, hydrogeochemical processes and numerical flow modelling in a part of Perambalur district, Tamil Nadu, India

Research Supervisor/Guide & Institution :

Dr. L. Elango

Anna University

Brief details of Thesis work :

The objective of this study is to identify groundwater potential zone, influence of rainwater recharge in groundwater, assess groundwater quality, role of hydrogeochemical processes and to simulate groundwater flow model. The study area is located in the western part of the hard rock terrain, Perambalur district, Tamil Nadu, southern India. The groundwater samples were collected every three months at once from September 2015 to September 2019 from 44 representative wells. Groundwater level, pH, EC, salinity, ORP, carbonate and bicarbonate were measured in the field while the major, minor ion and trace elements were measured the laboratory. Various thematic maps for the study area were prepared using ArcGIS 10.1. FEFLOW was used to develop groundwater flow model. About 85% of rainfall is received from the northeast and southwest monsoon. The groundwater level fluctuation is observed more in the upper river basin than lower and middle river basins because rainwater run off time has more and recharge also more in the lower and middle river basins. The rise of groundwater level was in the upper, middle and lower basins as 3.5, 1.2 and 1.7 m respectively. The weathered gneissic rock recharges more than charnockite rock. Most of the study area is covered medium lineament density, agriculture, gneissic rock, red soil, low slope and forest. Multi influencing factor method is used to derive weightage and rank for each layers based on the study area and literature review. Low drainage density, low slope, fissile hornblende biotite gneiss, black soil, pediment, pediplain, water body and agricultural have considered as high rank. Build up, waste land, higher slope, red soil, charnockite, low lineament density and forest area are considered as lower rank. The overlay analysis is used to derive the groundwater potential zones, which are classified as low, medium and high. 54% of the study regions are found as high groundwater potential zones. The good groundwater potential zones were mostly influenced by geology, land use and geomorphology whereas low groundwater potential zones were found in lineament, soil and drainage. The
groundwater potential zone was validated with groundwater level. The results indicate that the groundwater level fluctuation in the study region is found to be more in the low and medium groundwater potential zones. The groundwater is slightly acidic with alkaline nature and comprises fresh to brackish type. The order of dominance of ions present in the groundwater was followed such as Na > Ca > Mg > K for cations and HCO3 > Cl > SO4 for anions. Major hydrochemical facies of groundwater is identified as Ca-HCO3, Na-Cl, mixed Ca-Mg-Cl and mixed Ca-Na-HCO3 types. Rainwater recharge, ion exchange and irrigation return flow were found to be the reason for this composition of groundwater. The spatial variation of major ions in the groundwater indicates that high concentration was observed in southwest and eastern part due to less recharge and evaporation process. Low concentration of major ions was observed in northwest and central part and was due to high infiltration of rain water. Temporal
variation of major ion indicate major ion concentrations were increased due to weathering of rocks, dissolution of precipitate salts and use of fertilizer, which leaches from top soil to groundwater zone. During the summer period, major ion concentration was increased as groundwater level was deeper and which was due to evaporation processes and less recharge. The results indicate that variations in the major ion concentration were observed in most of the groundwater wells in the weathered rock zone. The evaporation process is the primary reason controlling the groundwater chemistry in the study area. Silicate weathering is a dominant process in the groundwater of hard rock terrain. The reverse ion exchange process was observed mostly during the monsoon and post monsoon. Ion exchange process was observed mostly during the pre monsoon. The saturation index of calcite and dolomite was
observed under-saturated when groundwater level was either increased or decreased in the upper river basin of the study area. In the middle river basin, the saturation index was always over-saturated but saturation index was increased when groundwater level was deeper in the middle river basin. The spatial variation of calcite and dolomite was observed mostly over-saturated in the study area. The sulphate concentration of the groundwater is reduced by the dissolution of minerals. The numerical flow modelling was used to simulate the groundwater head, groundwater recharge and discharge in the study area. The groundwater flow modelling was done using three dimensional finite element subsurface flow FEFLOW 7.0. A groundwater model of this region is carried out about 220 km2. The study area was divided into three layers such as top soil, weathered, fractured rock, and bottom hard rock based on geology and borehole lithology. Initial groundwater head was used as January 2006. The groundwater head was calibrated from January 2006 to August 2015, which was collected for 5 monitoring wells from CGWB, Chennai. The groundwater level was validated from September 2015 to June 2018 under transient state condition. The relationship between the observed and simulated groundwater level was showing good matching. To understand changes in groundwater recharge and discharge, the groundwater model was predicted from 2020 to 2030. The groundwater level will increase 4 m if rainwater recharge is increased by 10%. The groundwater level will decline up to 3 m if discharge rate is increase by 10%. The results show that model was predict the changes in future scenario of groundwater recharge and discharge.

Technical Details :

Research Area : Earth & Atmospheric Sciences (Earth & Atmospheric Sciences)

Project Summary :

A major source for drinking, agriculture and industrial is groundwater and surface water. Groundwater and surface water is mainly dependent on rainfall. Nowadays, around the mining region, water contamination is a major problem all over the world. Water contamination, land subsidence, reduce groundwater, degradation of water quality and fewer products are caused by industrialization, population growth, agriculture activities, irregular rainfall, mining activities and overexploitation. Water quality and quantity are influenced by geology, soil types, geomorphology and climate change factors. In order to provide good quality water for various purposes, it is necessary to analyze the hydrochemistry of major, minor, trace, and isotope elements in water. Mining activities can lead to environmental problems including erosion, dammed rivers, wastewater disposal, soil, groundwater and surface water contamination. Acid mine drainage could be a very dangerous threat to water resources. Mining activities can lower groundwater, reduce soil moisture, change climate and lead to contamination. While mining operations are closed in the mining industry, water resources may be affected by small or large-scale mining. While mining operations are closed in the mining industry, water resources may be affected by small or large-scale mining. Large amounts of soil waste and effluent from mining activities accumulate on the earth's surface, which could lead to contamination by the driving force of wind and rainfall. Contamination also occurs near water bodies when chemicals like sulfuric acid or cyanide leak, leach or spill from a separate target in the mining region. The future scenario of water contamination due to mining activities can be predicted using geochemical modelling. The Phreeqc model is one of the geochemical models used to study chemical reactions and geochemical processes in groundwater. In the field of water resources, the isotopic study can provide solutions to a variety of problems, such as the interactions between groundwater and surface water, the origin of water, and the determination of water age. Fieldwork and laboratory analyses are necessary to evaluate water quality around mining regions because water contamination harms human health and aquatic life directly or indirectly. In addition, drinking water containing high concentrations of major, minor and heavy metals for a long period of time could pose a high health risk, directly or indirectly through consumption, inhalation, and dermal contact. The primary objective of this study is to evaluate the impacts of mining activities on the water resources of Perambalur and Ariyalur district in Tamil Nadu, India by examining hydrochemistry of water and soil, and geochemical modelling.

Objectives :

- To determine water quality for drinking and agricultural purposes in and around the mining region of Perambalur and Ariyalur districts
- To identify groundwater and surface water contamination through hydrochemical studies
- To study hydrogeochemical processes and contamination of water on public health
- To evaluate soil major and trace element geochemistry
- To predict the water contamination around mining regions using geochemical modelling

Keywords :

Groundwater, surface water, contamination, mining, geochemical modelling, health risk assessment

Expected Output and Outcome of the proposal :

Mining activities create serious health problems for humans by using water. The study regions have a semiarid with less rainfall and limited supply of water. Before using water for drinking, water should be analyzed for hydrochemistry and trace elements. Regular hydrochemistry and groundwater level monitoring is necessary for drinking and irrigation purposes to understand sources of contamination. To assess water suitability for drinking, major, minor and trace elements will be measured. Hydrochemistry of water can be used to identify water types, water facies, the origin and source of water. Sources of water contamination can be determined from hydrochemistry, rock types and soil geochemistry. To determine water for irrigation purposes, hydrochemical parameters and indices will be applied. Soil geochemistry will be useful to study weathering and rock prevalence. Isotope studies in water will give clues to identify the origin, age and source. Hydrogeochemical processes can be used to determine the relationship between ground and surface water. Prediction of water contamination can be achieved using geochemical modelling through hydrochemical study. Health risk assessment will provide health risk effects on humans by drinking. Environment and human life can be saved from diseases and unsafe drinking water by identifying water contamination. This study will identify the causes of water contamination. As a result of this research, people will be aware of the problem of water.

Reference Details :

S.No	Reference Details
1	**Dr. L. Elango, Professor & Head, Department of Geology, Anna University, Chennai 600 025[+9444118629]** elango@34hotmail.com
2	**Dr. A. Ramachandran, Emeritus Professor, Centre for Climate Change and Disaster Management, Anna University, Chennai 600 025[+9443391990]** andimuthu.ramachandran@gamil.com

Concept of Proposal

Title of Project: Impact of mining activities on the water resources around Perambalur and Ariyalur district, southern India

Methodology:

First, hydrological studies are needed to identify study area details including geology, well type and purpose, hydrology, mining areas, groundwater, surface water and topography. For sampling, representative wells will be selected according to electrical conductivity, rock types and hydrology. Surface water and groundwater samples will be collected every four months for two years around the mining region. Samples will be stored in polyethene bottles for major, minor, trace element and isotope studies. Millipore filter paper (0.45 μm) will be used to filter water samples. To determine the geochemistry of major, minor and trace elements of groundwater and soil from selected representative wells. X-ray fluorescence will be used to analyse various elements including major from soil samples. During the sample collection, the following parameter will be measured; electrical conductivity, pH, oxidation redox potential (ORP), salt content, and groundwater level will be assessed in the field by a multi-parameters kit (Oakton Pcstestr 35). HCO_3 and CO_3 concentrations will be assessed by a titration method with an alkalinity kit in the field. Ca and Mg concentrations will be estimated by the volumetric titration method. A flame photometer will analyze sodium and potassium concentrations. Sulphate and nitrate concentration will be analysed by a UV-VIS spectrophotometer and Cl concentration will be analyzed using Metrohm titrando 905. F concentration will be assessed by a fluorimeter (Extech F700) which can be measured from 0.1 to 10 mg/l. Laser fluorimeters will be used to measure uranium ions, which can reach a range of 0.1 ppb to 1000 ppb. Total organic carbon, total inorganic carbon, and total nitrogen will be measured in the laboratory using the Total Organic Carbon (TOC) analyzer. Trace elements will be measured in the laboratory using ICP-MS. The study of the isotopes in water will be analyzed by Isotope Ratio Mass Spectrometry (IRMS). Sample analysis for hydrochemistry parameters will be done according to the "American Public Health Association standard methods (APHA, 1995)". Blanks and standards were used simultaneously to verify analysis efficiency. In addition, the analysis should be verified by an ion balance measurement error and which should be within ± 5%. Toposheet, Liss III image, and SRTM-DEM data are utilized to derive a base map, geology, geomorphology, soil and LULC of the study area. Various software like ArcGIS, Aquachem, Phreeqc, SPAA and IBM SPSS statistics can be used to determine groundwater quality, hydrogeochemistry and predict geochemical modelling. Analyses will be made in university laboratories, government research institutes and centres.

Year-wise work plan :

Sl. No.	Work plan	Year-I (months)			Year-II (months)		
		1-4	5-8	9-12	13-16	17-20	21-24
1.	Literature studies						
2.	**In phase-I**, Prepared various thematic maps to understand the research area						
3.	Surface water and groundwater samples collection (measured some parameters in the field)						
4.	Surface water and groundwater samples analyses (major and minor ions using Ion Chromatography)						
5.	Soi sample collection (major and trace element measure using X-ray fluorescence						
6.	Interpretation of measured parameters						
7.	Writing scientific research papers						
8.	**In phase-II,** Groundwater and surface water sampling (Major, isotope, TOC and Trace elements)						
9.	Groundwater and surface water analyses (Using Ion Chromatography, TOC, IRMS and ICP-MS)						
10.	Geochemical modelling (water contamination can be predicted using Phreeqc modelling through hydrochemical study)						
11.	Health risk will be assessed to human by hydrochemical study through ingestion, dermal and inhalation						
12.	All season measured parameters to be used for correlations						
13.	Identify major pollutants and resource (using combined all the measured data)						
14.	Writing scientific research papers						
15.	Conclusion report to SERB						

PROFORMA FOR BIO-DATA (to be uploaded)

1. Name and full correspondence address: Dr. S. Anbarasu,
S/O Subramaniyan,
5/290 West colony 5th Ward, Ladapuram (Po),
Perambalur (TK & DT), Tamil Nadu,
India, 621 101

2. Email(s) and contact number(s):geoarasu.s@gmail.com & +91 9585225524

3. Institution: Pondicherry University

4. Date of Birth: 05-06-1988

5. Gender (M/F/T): Male

6. Category Gen/SC/ST/OBC:SC

7. Whether differently abled (Yes/No): No

8. Academic Qualification (Undergraduate Onwards)

S. No	Degree	Year	Subject	University/Institution	% of marks
1.	B.Sc.	2011	Geology	National College, Trichy	74
2.	M.Sc.	2013	Applied Geology	Pondicherry University, Pondicherry	66
3.	Ph.D.	2021	Geology	Anna University, Chennai	80

9. Ph.D thesis title, Guide’s Name, Institute/Organization/University, Year of Award: Groundwater potential zone, hydrogeochemical processes and numerical flow modelling in a part of Perambalur district, Tamil Nadu, India, Dr. L. Elango, Professor, Department of Geology, Anna University, Chennai, October 2021.

10. Work experience (in chronological order).

S.No.	Positions held	Name of the Institute	From	To	Pay Scale
1.					

11. Professional Recognition/ Award/ Prize/ Certificate, Fellowship received by the applicant.

S.No	Name of Award	Awarding Agency	Year
1.	UGC-JRF-NET	CSIR-UGC	2012

12. Publications *(List of papers published in SCI Journals, in year wise descending order).*

S.No.	Author(s)	Title	Name of Journal	Volume	Page	Year
1.	**Anbarasu S**, Brindha K & Elango L	Geochemical evolution of fluoride and groundwater quality for drinking and irrigation purposes in a weathered gneissic rock aquifer of southern penisular India	Environmental Earth Sciences	81	273	2022
2.	RamyaPriya, R, Manoj, S, **Anbarasu, S,** Gowrisankar, G & Elango, L	Human health risk assessment using Monte Carlo simulations for groundwater with uranium in southern India	Ecotoxicology and Environmental Safety	226	112781	2021
3.	**Anbarasu S**, Brindha K & Elango L	Multi-influencing factor method for delineation of groundwater potential zones using remote sensing and GIS techniques in the western part of Perambalur district, southern India	Earth Science Informatics	13	317-332	2020
4.	**Anbarasu S** & Elango L	Assessment of Groundwater Quality in a part of Chinnar Watershed, Perambalur District, Tamil Nadu, India	International Journal of Earth Sciences and Engineering	09	2466-2471	2016

13. Detail of patents.

S.No	Patent Title	Name of Applicant(s)	Patent No.	Award Date	Agency/Country	Status

14. Books/Reports/Chapters/General articles etc.

S.No	Title	Author’s Name	Publisher	Year of Publication

15. Any other Information (maximum 500 words)

சி.ப.வு.எண் 125 / 2003

GCP-26-4-4,50,000 Cps.-18-6-98
நாள் 3-6-2003

R.Dis................./9 dt.

SC

சான்றிதழ் எண் :
Certificate No :

1783491

மாவட்டக் குறியீடு எண் / District Code	2	3	
வட்டக் குறியீடு எண் / Taluk Code	0	3	
கிராமக் குறியீடு எண் / Village Code	0	1	6

சாதிச் சான்றிதழ்
COMMUNITY CERTIFICATE

பெரம்பலூர் மாவட்டம் பெரம்பலூர் வட்டம்
லாடபுரம் கிழக்கு கிராமம்/நகரம், திரு. / திருமதி / செல்வி/
செல்வன் அன்பரசு தகப்பனார்/கணவர்
பெயர் சுப்ரமணியன்
இந்து பறையன்

வகுப்பைச் சார்ந்தவர், தாழ்த்தப்பட்டோர் மற்றும் பழங்குடியினர் உத்திரவுகள் (திருத்தப்பட்ட) சட்டம் 1976, வரிசை எண் 56 படி தாழ்த்தப்பட்ட பிரிவைச் சார்ந்தவர் எனச் சான்றளிக்கப்படுகிறது.

This is to certify that ANBARASU Son / Daughter of Thiru SUBRAMANIAN of LADAPURAM EAST Village / Town, PERAMBALUR Taluk ...., PERAMBALUR District of the State of Tamil Nadu belongs to HINDU PARAIYAN Community, which is recognised as a Scheduled Caste as per the Scheduled Castes and Scheduled Tribes Orders (Amendment) Act, 1976, vide Serial No.....................

2. திரு / திருமதி / செல்வன் / செல்வி அன்பரசு என்பவரும் அவருடைய குடும்பத்ினரும் தமிழ்நாட்டில் பெரம்பலூர் மாவட்டத்தில் பெரம்பலூர் வட்டத்தில் லாடபுரம் கிழக்கு கிராமத்தில் / நகரத்தில் வசித்து வருகிறார்கள் எனச் சான்றளிக்கப்படுகிறது.

2. It is certified that Thiru/Tmt./Selvan/Selvi ANBARASU .... and his/her family ordinarily reside(s) at LADAPURAM Village/Town PERAMBALUR Taluk PERAMBALUR District of Tamil Nadu.

முத்திரை.
Seal.

கையொப்பம்
Signature
நாள்
Date
தனி எழுத்துக்களில் பெயர்
Name in Capital Letters
பதவிப் பெயர்
Designation

TAHSILDAR
PERAMBALUR

13603

Endorsement Certificate from the Mentor & Host Institute

This is to certify that:

I. The applicant, Dr **S. Anbarasu**, will assume full responsibility for implementing the project.

II. The fellowship will start from the date on which the fellow joins University/Institute where he implements the fellowship. The mentor will send the joining report to the SERB. SERB will release the funds on receipt of the joining report.

III. The applicant, if selected as SERB-N PDF, will be governed by the rules and regulations of the University/ Institute and will be under the administrative control of the University/ Institute for the duration of the Fellowship.

IV. The grant-in-aid by the Science & Engineering Research Board (SERB) will be used to meet the expenditure on the project and for the period for which the project has been sanctioned as indicated in the sanction letter/ order.

V. No administrative or other liability will be attached to the Science & Engineering Research Board (SERB) at the end of the Fellowship.

VI. The University/ Institute will provide basic infrastructure and other required facilities to the fellow for undertaking the research objectives.

VII. The University/ Institute will take into its books all assets received under this sanction and its disposal would be at the discretion of the Science & Engineering Research Board (SERB).

VIII. University/ Institute assume to undertake the financial and other management responsibilities of the project.

IX. The University/ Institute shall settle the financial accounts to the SERB as per the prescribed guidelines within three months from the date of termination of the Fellowship.

Dated: 04/Aug/2023

Signature of the Mentor:

Name & Designation: Dr Guru Balamurugan, Associate Professor & Head, Department of Geology, School of Earth Sciences, Central University of Tamil Nadu, Thiruvarur.

Dated: 9/8/23.

Signature of the Registrar of the University:

Seal of the Institution:

Undertaking by the Fellow

I, Dr. S. Anbarasu, Son/ of S. Subramaniyan resident of 5/290 West Colony, Ladapuram, Perambalur District, Tamil Nadu agree to undertake the following, If I am offered the SERBN-PDF
`

1. **I shall abide by the rules and regulations of SERB during the entire tenure of the fellowship.**
2. **I shall also abide by the rules, discipline of the institution where I will be implementing my fellowship**
3. **I shall devote full time to research work during the tenure of the fellowship**
4. **I shall prepare the progress report at the end of each year and communicate the same to SERB through the mentor**
5. **I shall send two copies of the consolidated progress report at the end of the fellowship period.**
6. **I further state that I shall have no claim whatsoever for regular/permanent absorption on expiry of the fellowship.**

Date: 22-07-2023 **Signature**

Mentor: Brief CV

1.	**Mentor Personal Information**	
	a] Name	Dr. Guru Balamurugan
	b] Present Designation	Associate Professor
	c] Age as on today	45
	d] Workplace and its affiliation	Central University of Tamil Nadu
	e] Whether your workplace is a UGC recognized research centre	Yes
2.	**Post doctoral Fellows**	
	a] No of Currently working postdoctoral Fellows (along with name/s)	Nil
	b] No of consent/s given for whom result is awaited (along with name/s)	Nil
3.	**Number of Ph.D. students guided so far**	
	a] Degree awarded	5
	b] Currently working	3
4.	**Publications**	
	a] Total Number of International publications	40
	b] List of publications in the last five years (Title of the paper, Authors, Volume No, Page No/DOI No, Publication Year, Journal)	Refer Annexure- I for more details.
5.	**Laboratory Facilities**	
	a] Whether the infrastructure and equipment needed for the proposed postdoctoral work for SERB-NPDF is available at laboratory	Yes. Advanced analytical facilities like IC is available. This laboratory also has other minor equipment like Furnace, Electronic balance, Spectrophotometer, Flame photometer, Conductivity meter, pH meter, MilliQ Water Purifier etc.
	b] In case the mentor is a retired Professor/ Scientist, a letter from the concerned Head of the Department permitting to avail the facilities to the SERB-NPDF fellow under the mentorship of the mentor must be enclosed.	Yes/ No/ **Not applicable** *(Highlight your choice)*

Dr. Guru Balamurugan

Name

09/Aug/2023

signature of mentor

Dr. Guru Balamurugan
Associate Professor and Head
Department of Geology
School of Earth Sciences
Central University of Tamil Nadu
Neelakudi, Thiruvarur-610...

Annexure – I

Kindly furnish the information in following specified format.

Sr. No.	Author List	Year	Title of the paper	Full Journal Name	Vol. No. Page No./ DOI No.
1	Bera S, Gnyawali K, Dahal K, Melo R, Li-Juan M, Guru B & Ramana G	2023	Assessment of shelter location-allocation for multi-hazard emergency evacuation	International Journal of Disaster Risk Reduction	Vol.84, 103435
2	Kodag S, Mani SK, Balamurugan G & Bera S	2022	Earthquake and flood resilience through spatial planning in the complex urban system	Progress in disaster science	Vol.14, 100219
3	Pradhan RM, Guru B, Pradhan B & Biswal TK	2021	Integraded multi-criteria analysis for groundwater potential mapping in Precambrian hardrock terranes (North Gujarat) India	Hydrological Sciences Journal	Vol. 66, 961-978
4	Bera S, Upadhyay VK, Guru B & Oommen T	2021	Landslide inventory and susceptibility models considering the landslide typology using deep learning: Himalayas, India	Natural Hazards	Vol.108(1), 1257-1289
5	Barik G, Guru B & Sangma F	2021	Shoreline changes analysis and forecast using Digital Shoreline Assessment System 5.0: Evidences from parts of east coast of India	Journal of the Indian Society of Remote sensing	Vol. 49, 2815-2830
6	Damle S, Mani SK & Balamurugan G	2021	Natech guide words: A new approach to assess and manage natech risk to ensure business continuity	Journal of Loss Prevention in the Process Industries	Vol. 72, 104564
7	Bera S, Melo R & Guru B	2021	Assessment of exposed elements in a changing built environment by using an integrade model of debris flow ignition and runout (Kalimpong region, Himalaya)	Bulletin of Engineering Geology and the Enviroment	Vol. 80(9), 7131-7152
8	Hirwe RR, Bera S, Roy SS & Guru B	2021	A study on solar and green house gas mitigation potential in India by using AHP method and geospatial technology	International Journal of Renewable Energy Research	Vol. 11(1), 295-307
9	Hirwe RR & Guru B	2021	Assessing rooftop solar capacities for green house gas mitigation potential in India	Disaster Advances	Vol. 14(4), 50-58
10	Rajaram HR, Krishnan B & Guru B	2021	Leveraging on repowering of wind sites for potential wind-solar hybrid capacities: a case study	International Energy Journal	Vol.21(1)
11	Sachin D, Mani Shibu K & Guru B	2021	Risk management of technological accidents triggered by natural hazards (Natech): Review of relevant Indian legislation	Disaster Advances	Vol.14(4), 95-106

12	Kannan E, Guru B & Narayanan S	2021	Spatial economic analysis of agricultural land use changes a case of peri-urban Bangalore, India	Journal of the Asia Pacific Economy	Vol. 26(1), 34-50
13	Andrad R & Guru B	2020	Recharge site delineation through integraded geophysical hydrological and GIS approach- A basic understanding with case studies from Indian sub-continent	Groundwater for Sustainable Development	Vol. 10, 100343
14	Sangma F & Guru B	2020	Watersheds characteristics and prioritization using morphometric parameters and fuzzy analytical hierarchal process: a part of lower Subansiri sub-basin	Journal of the Indian Society of Remote Sensing	Vol. 48, 473-496
15	Bera S, Guru B & Oomen T	2020	Indicator-based approach for assigning physical vulnerability of the houses to landslides hazard in the Himalayan region of India	International Journal of Disaster Risk Reduction	Vol. 50, 101891
16	Guru B, George A, Kushma K. N & Kapoor V	2020	Artificial recharge and its impact on groundwater sustainability and socioeconomic status in parts of Kumudvathi river basin	Journal of the Geological Society of India	doi.org/10.17491/cgsi/2020/156159
17	Bera S, Guru B, Chatterjee R & Shaw R	2020	Geographic variation of resilence landslide hazard: A household-based comparative studies in Kalimpong hilly region, India	International Journal of Disaster Risk Reduction	Vol. 46, 101456
18	Hirwe R. R & Guru B	2019	Study of renewable energy certificate market in India	International Journal of Earth Science and Engineering	Vol. 12 (02), 86-90
19	Bera S, Guru B & Ramesh V	2019	Evaluation of landslide susceptibility models: a comparative study on the part of Western Ghat region, India	Remote Sensing Application: Society and Environment	Vol. 13, 39-52
20	Lakshmi Ram Prasath H, Kushma K. N, Chaitanya S & Guru B	2019	Frequency ratio modelling using geospatial data to predict Kimberlite clan of rock emplacement zones in Dharwar craton, India	International Journal of Applied Earth Observrations and Geoinformation	Vol.74, 191-208

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RESEARCH ARTICLE

Multi-influencing factor method for delineation of groundwater potential zones using remote sensing and GIS techniques in the western part of Perambalur district, southern India

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Abstract
Identification of groundwater recharge zones in an area is important to properly utilize and safeguard the groundwater resources. The objective of this study is to delineate the groundwater potential zones in the Chinnar River basin of Perambalur district, southern India, using remote sensing and GIS methods. Toposheets and satellite imageries were used to prepare various thematic maps such as geology, soil, drainage density, slope, lineament density, geomorphology, and land use. These data were combined with the weighted overlay method to demarcate the groundwater potential zones. Multi-influencing factor (MIF) method was used to derive the weights for the seven layers, and ranks were assigned to the features within the layers based on local knowledge and from literature. The study suggests that the geology, slope, land use, and geomorphology features play a major role in determining the availability of groundwater in the study area. The groundwater potential was high in 54%, medium in 21%, and low in 25% of the study area. The groundwater level fluctuation that varies based on the rainfall and different rock types was used to validate the groundwater potential map. Areas with high groundwater potential had the lowest groundwater fluctuation compared with the medium and low groundwater potential areas. Sensitivity analysis showed that excluding the land use and geomorphology features will have the highest impact on identifying the groundwater potential zones. Determination of effective weights indicated that land use, geomorphology, and slope have higher weights than the assigned weights. The results show that the delineated groundwater potential zones can be used in the future for groundwater resource management in the study area.

Keywords Multi-criteria analysis · Multi-influencing factor · Recharge areas · Rainfall · Water resources management · Sensitivity analysis · Perambalur · Tamil Nadu

Introduction

Groundwater forms an important source of water for sustaining livelihood in most parts of India. In the recent years, groundwater is continuously declining in some places and the major reasons for this are over exploitation, population growth, industrialization, intensification of agriculture, and climate change. The annual replenishable groundwater resources of the country has been estimated as 431 km^3, and the estimated net annual groundwater availability is 396 km^3 (as of March 2009) (CGWB 2011). The groundwater development in India is not uniform and some regions of the country have declining groundwater level due to excessive pumping. The annual average rainfall contribution to the groundwater resources in the country is about 68%, and other resources such as tanks, ponds, irrigation return flow, and water storage structures contribute to about 32% (GEC 2017). However, due to uneven distribution of rainfall events over space and time, there is large variation in the groundwater availability and extraction. Of the 5842 assessment units in the country, 802 units are over-exploited, 523 are semi-critical, and 169 are critical (CGWB 2011). Hence, the sustainable management of this limited freshwater resource requires detailed assessment, proper planning, and stringent

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implementation measures. For this, as a first step, it is essential to identify the potential zones for groundwater recharge.

Traditional hydrogeological approaches of groundwater exploration through visual, geological, geophysical, and drilling methods are expensive, time-consuming, and requires skilled staff (Jha et al. 2010; Mahato and Pal 2018). Geospatial methods have been used as an effective tool for a long period of time for assessment, monitoring, and sustainable management of the groundwater resources (Fagbohun 2018; Mokadem et al. 2018; Rajaveni et al. 2015; Suganthi et al. 2014). Remote sensing data that can be used in a geographic information systems (GIS) platform is nowadays inexpensive and in many cases hosted in an open-access portal for public use. Hence, these data provide valuable information on the groundwater resources, and on the factors influencing the groundwater occurrence and distribution. Key advantages of remote sensing and GIS are the spatial, spectral, and temporal availability of the data, and the ability to produce quick results (Jha et al. 2010; Misi et al. 2018). Large and inaccessible areas can also be examined through satellite imageries.

Common practice for identification of the groundwater potential zones is to combine the different surface features derived from satellite imagery and toposheets using weighted overlay analysis (Jha et al. 2006; Preeja et al. 2011; Sener et al. 2004). Studies have adopted this basic idea and have improvised by combining with other techniques to obtain reliable results. Researchers have integrated geophysical data with remote sensing and GIS resources (Anbazhagan and Jothibasu 2016; Jha et al. 2010; Oladunjoye et al. 2019). Multiple-criteria decision-making/analysis (Das and Mukhopadhyay 2018; Machiwal et al. 2011; Pradhan 2009), analytic hierarchy process (Andualem and Demeke 2019; Murmu et al. 2019), fuzzy logic (Aouragh et al. 2017; Mohamed and Elmahdy 2017), artificial neural network (Lee et al. 2018), principal component analysis (Mahato and Pal 2018), bivariate statistical methods (Falah et al. 2017), weights-of-evidence (Ghorbani Nejad et al. 2017; Lee et al. 2012), evidential belief function (Mogaji et al. 2016; Pourghasemi and Beheshtirad 2015), frequency ratio (Oh et al. 2011; Razandi et al. 2015), and weighted linear combination (Senanayake et al. 2016) are some of the wide array of methods integrated with GIS for groundwater potential mapping. Among these methods, multi-influencing factor (MIF) method has gained more attention recently as it is comparatively simple and reliable (Etikala et al. 2019; Fagbohun 2018). A comparison of the existing approaches have also been carried out to determine the consistency of the results from various methods (Arabameri et al. 2019; Cui et al. 2017; Pham et al. 2019).

In Perambalur district located in Tamil Nadu, southern India, agriculture is intensively practiced, and groundwater is the main source for irrigation, drinking, and domestic purposes. Nearly 60% of the extracted groundwater is used for agriculture (CGWB 2009). Perambalur district experienced 71% deficit in rainfall in December 2016 (CGWB 2017), and 79% of the monitored wells showed decline in water table between May 2016 and January 2017. Decline in groundwater level in comparison with the decadal mean (2006 to 2015) was recorded in 20%, 93%, and 90% of the monitoring wells in May 2016, November 2016, and January 2017, respectively. As per Central Ground Water Board (CGWB), the entire district was categorized as over-exploited on March 2011. In view of these reports, it is necessary to demarcate the groundwater potential zones for proper planning and for safeguarding the resource for future water supply. Previous studies in this region are restricted to the assessment of groundwater quality and identification of the hydrogeochemical processes (Ahamed et al. 2013; Anbarasu and Elango 2016). A clear understanding and delineation of the groundwater recharge areas that should be protected are not available. Therefore, the present study aims at demarcating the groundwater potential zones in the western part of Perambalur district using modern techniques of remote sensing and GIS and identifying the areas that require more focused management during water crisis.

Study area

The study region covers an areal extent of ~ 220 km^2 and is located in the Chinnar River basin, Perambalur district, Tamil Nadu, India (Fig. 1). Most part of the study area is covered by the Eastern Ghats (Pachamalai). This area experiences an arid to semi-arid climate and has high humidity. The maximum temperature is about 40 °C during the summer (April to June), and the minimum temperature is 22 °C during winter (December to February). Annual average rainfall is about 950 mm. Most of the rainfall occurs during the northeast monsoon (October to December) and the southwest monsoon (July to September) contributes to a lesser extent. This region is comprised of weathered and fractured gneissic rocks along with charnockite which is mostly covered by agricultural lands. The major water-bearing formations are the weathered gneiss (CGWB 2009). The water-yielding capacities of the rock formations in the

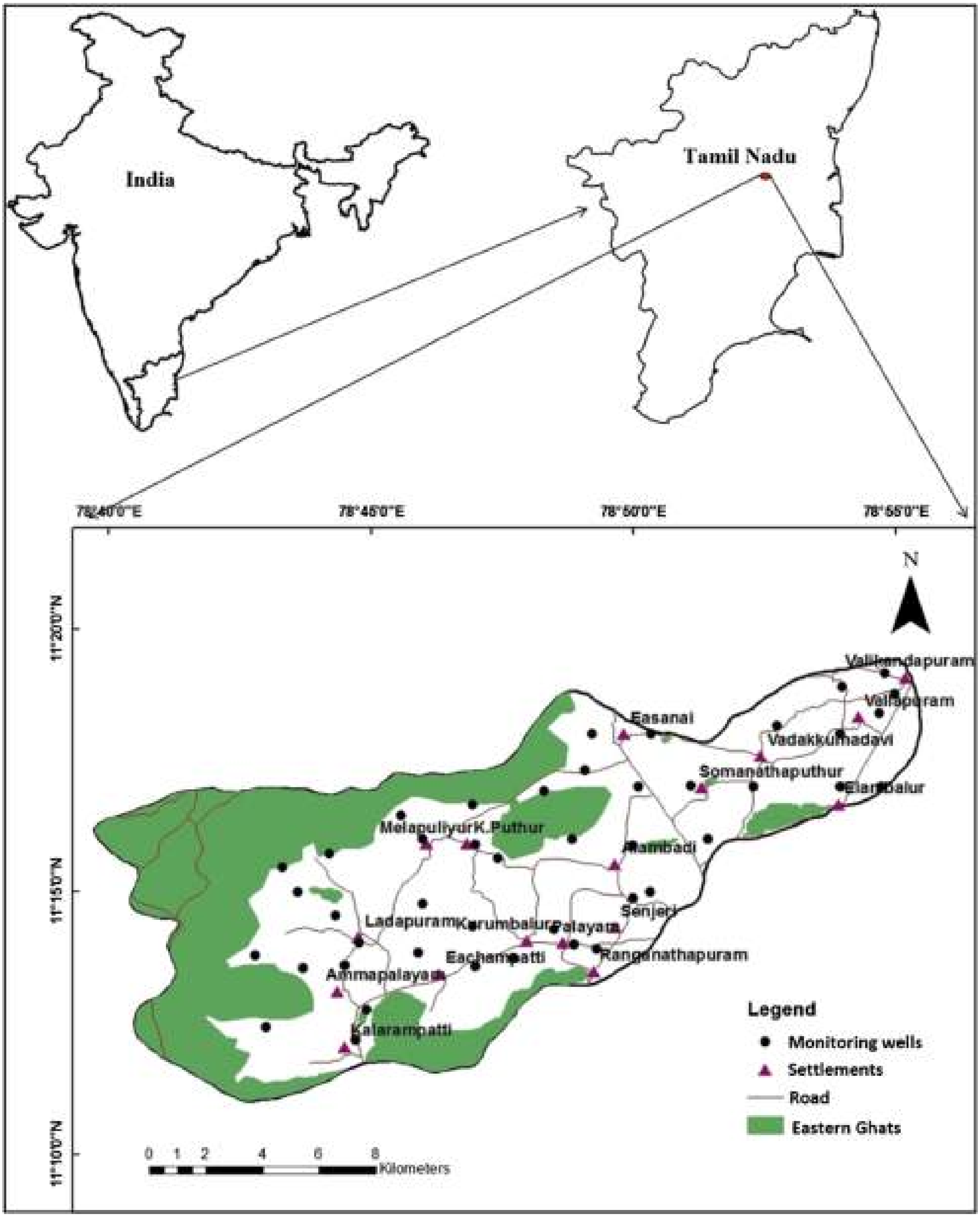

Fig. 1 Location of the study area with monitoring wells

Table 1 Water yielding capacities (specific yield %) of the rock formations in the study area

Rock type	Intensity of weathering	Water yielding capacities (specific yield %)
Charnockite	Highly weathered (soil)	4–8
	Medium weathered	2–4
	Fractured	3–6
Gneissic rock	Highly weathered (soil)	10–12
	Medium weathered	4–7
	Fractured	5–10

area are given in Table 1 (GEC 2017; Ministry of Environment Forest and Climate Change 2018). The depth of groundwater level ranges from 3 to 15 m bgl (TWAD 2018). Groundwater recharge occurs mostly by rainfall, surface water bodies (river and ponds), and irrigation return flow during the monsoon period. The yield of

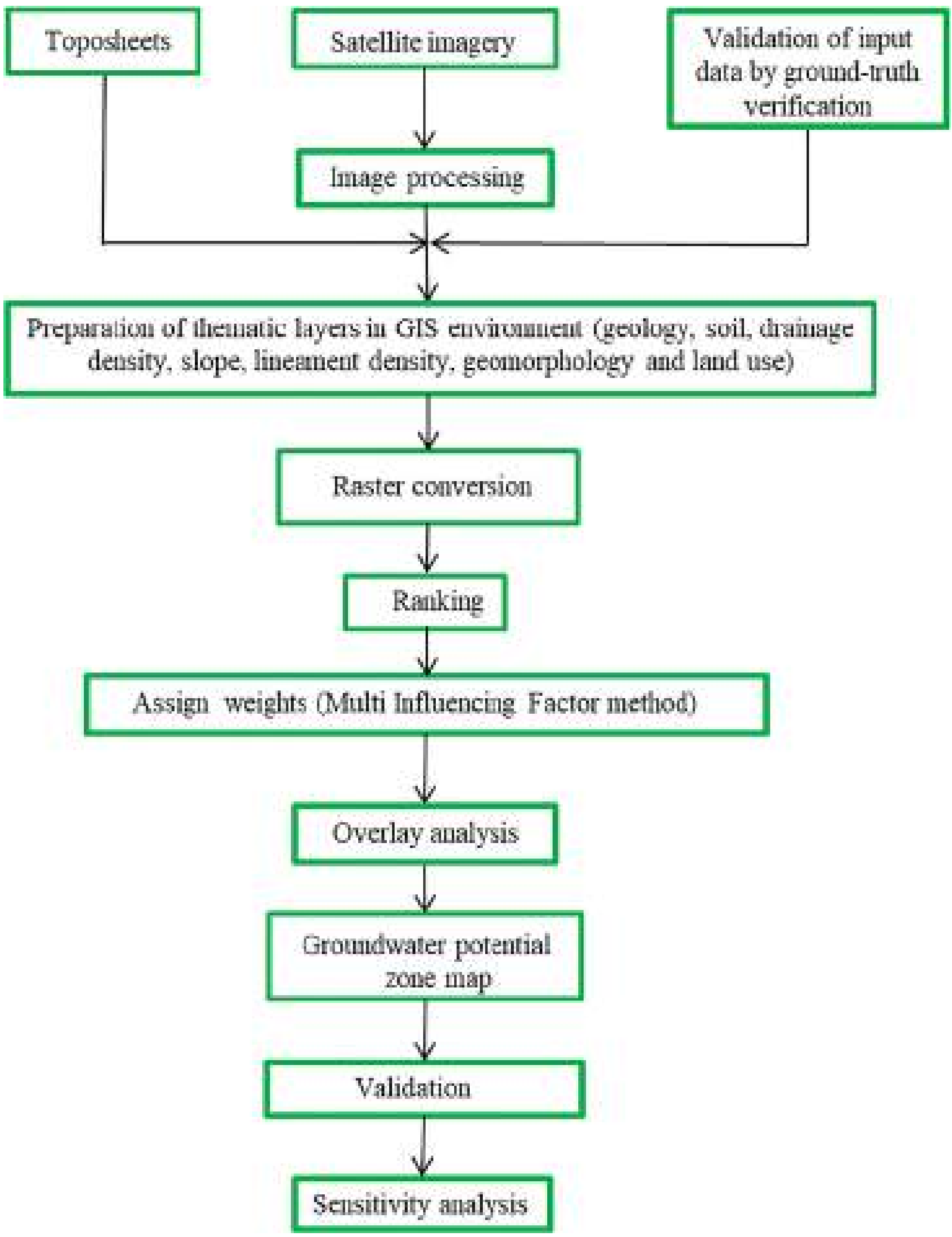

Fig. 2 Methodology adopted in the present study

wells range from 80 to 120 lpm in the hard rock formations (TWAD 2018). As the pumping rate is increasing in the recent years, the groundwater table is going very deep, and there are instances wherein the wells get dried-up because of the high rate of evaporation and very less rainfall (CGWB 2017; TWAD 2018). Irrigation is the chief activity in the region.

Methodology

Preparation of input data

The methodology adopted is given as a flow chart in Fig. 2. Base map of the western part of Perambalur district and the drainage pattern in the area was demarcated from the Survey of India toposheets (1:50,000 scale) (Survey of India 1995). Slope was derived for the year 2014 from the Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) with 30 m spatial resolution. Geology, soil, lineaments, geomorphology, and land use were generated from the Indian Remote Sensing satellite P6 (Resourcesat-1) Linear Imaging Self-Scanning Sensor III (IRS P6 LISS III) images of the year 2014 with a spatial resolution of 24 m (1:50,000 scale geocoded with UTM projection, WGS 84 and North zone 44). Geology map was verified with the map from the Geological Survey of India (1:50,000 scale) (GSI 1995). The prepared thematic layers were cross-checked with the data collected during the field work for ground-truth verification. Processing the data, generating the thematic layers, and analyzing the data through MIF method was carried out in a GIS environment using the ArcMap 10.4 program. For the validation of the groundwater potential map, the groundwater level was measured in selected monitoring wells (44 wells) in the study area for the period from 2015 to 2018.

Weightage from multi-influencing factor method

Geology, soil, drainage, slope, lineament, geomorphology, and land use, considered as the influencing factors in facilitating groundwater recharge are combined to delineate the potential zones. The weightage of each factor is computed by the MIF method where the strong and weak relationship between the influencial factors are considered to assign the weight. Figure 3 shows that the interrelationship and interdependency between these factors and their effects. Major effect represents direct influence of one factor over another, and minor effect represents indirect influence. The major and minor effects are classified based on their holding capacity and the characteristics of the surface and subsurface features. The major factor is assigned a value of 1 and minor factor is given 0.5 value. These values are combined to calculate the MIF weight of each layer using the following equation:

$$\mathrm{MIF} = \frac{(A+B)}{\sum(A+B)} \times 100 \tag{1}$$

where A is the major effect between the two factors, and B is the minor effect between the two factors.

Overlay analysis

Seven factors influencing the groundwater occurrence in the study area were used to delineate the groundwater

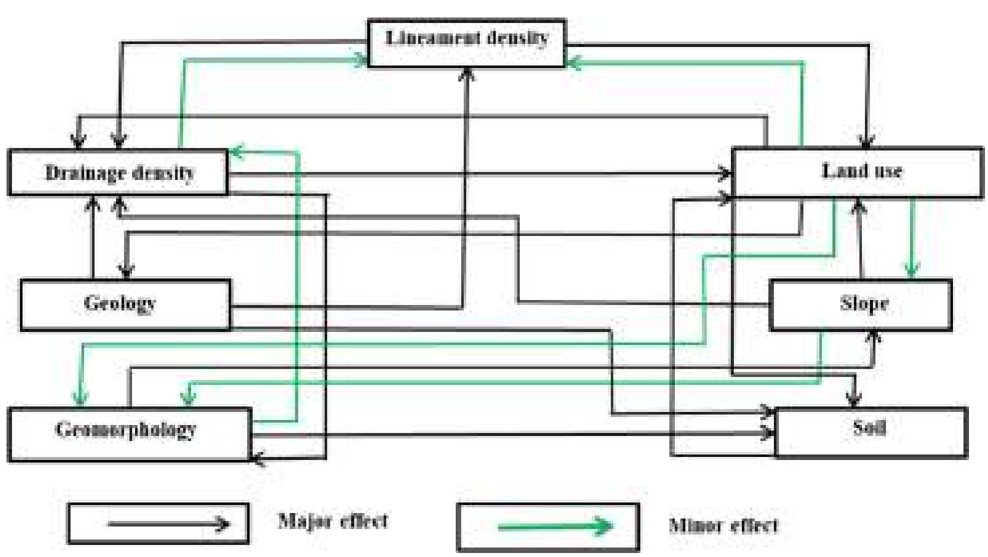

Fig. 3 Interrelationship between the multi-influencing factors that are considered in mapping the groundwater potential

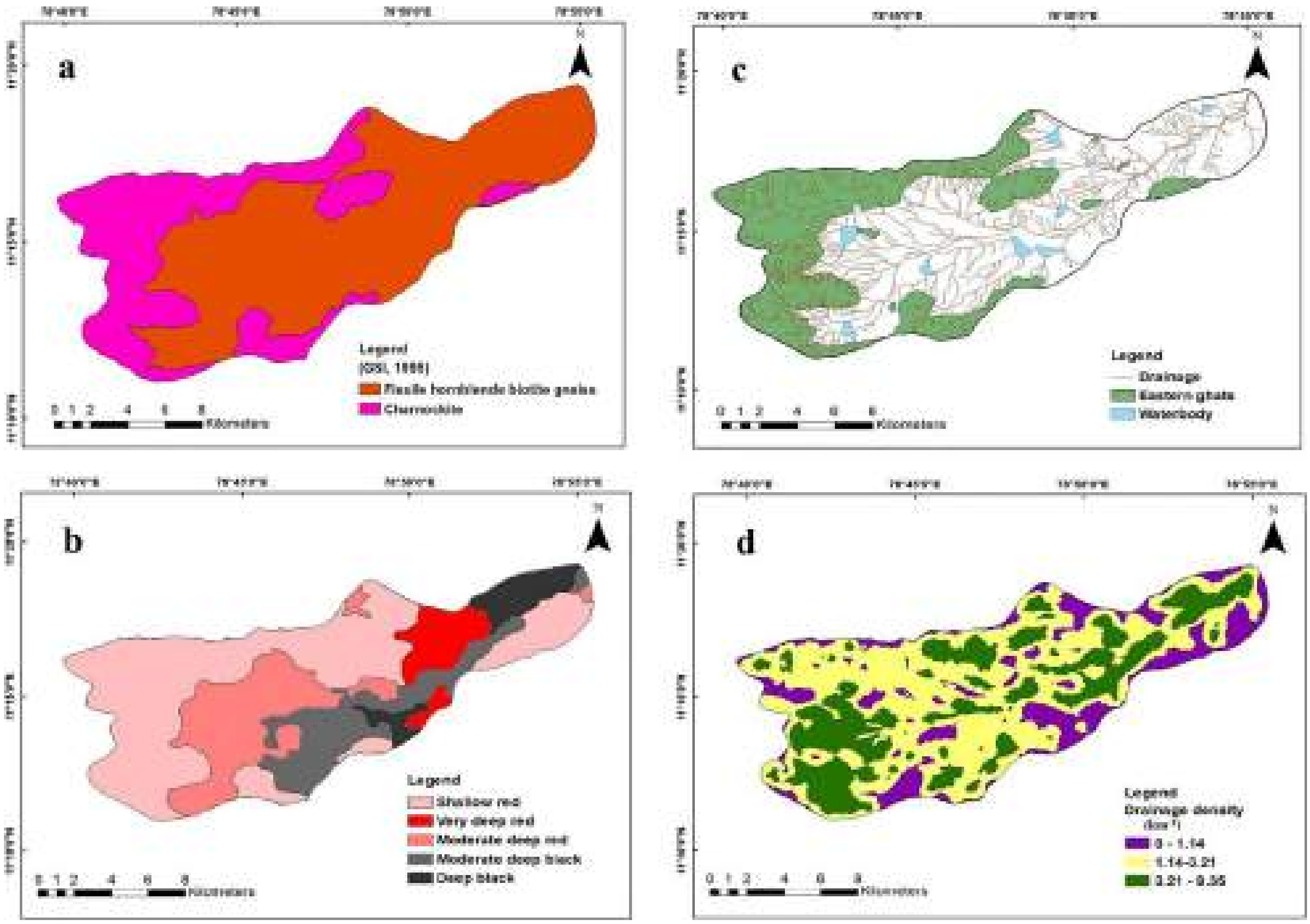

Fig. 4 Features of the study area. **a** Geology. **b** Soil. **c** Drainage. **d** Drainage density

potential zones. These potential zones were generated by the weighted overlay analysis method. The weights for the layers were derived from MIF method as described earlier. The features within each layer were assigned ranks based on local knowledge about the area and from literature (Avtar et al. 2010; Chaudhary and Kumar 2018; Gnanachandrasamy et al. 2018; Jasmin and Mallikarjuna 2011; Patra et al. 2018; Rajaveni et al. 2015). The layers assigned with the ranks and weights were integrated using the equation given below to arrive at the groundwater potential index.

$$\begin{aligned}\text{Groundwater potential index} &= (G_w \times G_r) + (SO_w \times SO_r) + (DD_w \times DD_r) \\ &\quad + (SL_w \times SL_r) + (LD_w \times LD_r) + (GM_w \times GM_r) \\ &\quad + (LU_w \times LU_r) \qquad (2)\end{aligned}$$

where G represents the geology, SO represents the soil, DD represents the drainage density, SL represents the slope, LD represents the lineament density, GM represents the geomorphology, LU represents the land use, r represents the feature rank within a layer, and w represents the layer weight calculated using MIF method.

Sensitivity analysis

Sensitivity of the parameters used in the groundwater potential index calculation can be analysed using the map removal analysis and single parameter analysis. Map removal sensitivity analysis is carried out by removing one parameter or multiple parameter at a time from the index (Lodwick et al. 1990). This is calculated using

$$S = \frac{|(\mathrm{GWPI}/N)-(\mathrm{gwpi}/n)|}{\mathrm{GWPI}} \times 100 \qquad (3)$$

where S is the sensitivity measure, GWPI is the unperturbed groundwater potential index computed with all the parameters, gwpi is the perturbed groundwater potential index computed by removing one or more layers, N is the number of layers used to compute GWPI, and n is the number of layers used to compute gwpi.

Single parameter sensitivity measure also helps to identify the influence of the layers on the groundwater potential index. This is used to compare the theoretical weights assigned to the input layers with actual or effective weights (Babiker et al. 2005). This can be calculated using the following equation given by Napolitano and Fabbri (1996).

$$W = \frac{(P_r P_w)}{GWPI} \times 100 \quad (4)$$

where, W is the effective weight of a parameter, P_r is the rank of the feature within a layer, P_w is the weight of each layer, and GWPI is the groundwater potential index.

Results and discussion

Groundwater availability depends on several surface and subsurface features. Accuracy of predicting the groundwater potential zone depends on the quality of the thematic layers and the number of features considered in the study.

Geology

Geological formations play an important role in determining the quality, occurrence, and movement of groundwater. Geological map was prepared with the help of the GSI map and LISS III images (Fig. 4a). The study area is largely covered by fissile hornblende biotite gneiss especially in the plains (65%), and remaining part of the area is covered by charnockite rock in the mountainous region (Table 2). The hard rock formation of fissile hornblende biotite gneissic rock is comprised of amphibolite, granulite, granite, hornblende, granodiorite, garnetiferous gneiss, gneiss, weathered biotite, weathered granite, and weathered garnetiferous gneiss with coarse to medium texture, melano- and mesocratic color. The fissile hornblende biotite gneiss

Table 2 Areal extend of each feature in the study area

Layer	Range/ Feature	Area in km^2	Percentage
Geology	Charnockite	77.2	35
	Fissile hornblende biotite gneiss	142.7	65
Soil	Moderately black	31.5	14
	Deep black	15.1	7
	Shallow red	111.5	51
	Moderately red	45.6	21
	Very deep red	16.2	7
Drainage density (km^{-1})	Low density	34.8	16
	Medium density	116.7	53
	High density	68.4	31
Slope (°)	Low slope (< 8)	158.4	72
	Medium slope (8–20)	35.8	16
	High slope (> 20)	25.7	12
Lineament density (km^{-1})	< 0.49	161.2	73
	0.49–1.32	52	24
	1.32–1.96	3.5	2
	> 1.96	3.1	1
Geomorphology	Structural origin low dissected hills and valleys	0.1	0
	Structural origin moderately dissected lower plateau	9.9	5
	Denudational origin lower dissected hills and valleys	6.7	3
	Denudational origin pediment and pediplain complex	149.3	68
	Structural origin moderately dissected hills and valleys	53.8	24
Land use	Wetland and water bodies	13.7	6
	Waste land, scrub land and barren land	19.7	9
	Forest	66.4	30
	Built-up	3.5	2
	Agriculture	116.6	53

is comparatively more weathered than the charnockites. Hence, the rainfall recharge in the gneissic rocks is more than the charnockites. Thus, the fissile hornblende biotite gneiss are assigned a higher rank and charnockites have lower rank (Table 3).

Soil

Soil controls the infiltration of water in an area and depends on several characteristics such as grain size, grain shape, soil texture, porosity, and bulk density. Soils in the study area have formed from the weathering of the parent rock. Black soil and red soil are major soil types in this region (Fig. 4b). Black soils found at a depth of 30–200 cm, are deep gray to black in color and clayey loam in texture. These soils have high water holding capacity with medium infiltration, exchangeable bases and alkaline soil pH. Black soil covers 21% of the study region (Table 2), which is considered suitable for groundwater development. Red soils have shallow to medium depth and light texture. These soils have low water holding capacity, thus unsuitable as a groundwater potential zone, and 79% of the study area is covered by red soil. Black soils were allotted a higher rank and red soils were given lower rank (Table 3).

Drainage density

Drainage density is the total length of streams and rivers per unit area in a drainage basin. This feature is an indirect function of permeability and surface runoff. Drainage was initially digitized from the toposheets (Fig. 4c), and the drainage density map was generated using the line density tool (Fig. 4d). A small stream is found in this area, where water flows only during the rainy season (from October to December). Most of the study region is covered by dendritic drainage pattern, and the remaining area is covered by sub-trellis drainage pattern (Fig. 4c). Based on the drainage density, the study area has been classified into three types: low drainage density (< 1.14 km^{-1}) (16%), medium drainage density (1.14 to 3.21 km^{-1}) (53%), and high drainage density (> 3.21 km^{-1}) (31%) (Table 2, 3). Low drainage density has good potential for groundwater augmentation, since this area is usually flat and slow surface runoff facilitates more recharge. Whereas, high drainage density areas have a steeper slope, and infiltration is low due to fast runoff, thus offering poor chances for

Table 3 Rank assigned for each feature within a thematic layer

Layer	Range/ Feature	Rank
Geology	Charnockite	1
	Fissile hornblende biotite gneiss	2
Soil	Moderate deep black, deep black	3
	Moderate black, shallow red	2
	Moderate red, very deep red	1
Drainage density (km^{-1})	< 1.14	3
	1.14–3.21	2
	3.21–8.35	2
Slope (°)	0–8	3
	8–20	2
	20–38	1
Lineament density (km^{-1})	< 1.32	1
	1.32–1.96	2
	> 1.96	3
Geomorphology	Structural lower dissected hills and valleys	1
	Denudational lower dissected hills and valleys	2
	Structural moderate dissected lower plateau	3
	Denudational pediment and pediplain complex	4
Land use	Waste land, built-up land	1
	Forest	2
	Wetlands and water body	3
	Agricultural area	4

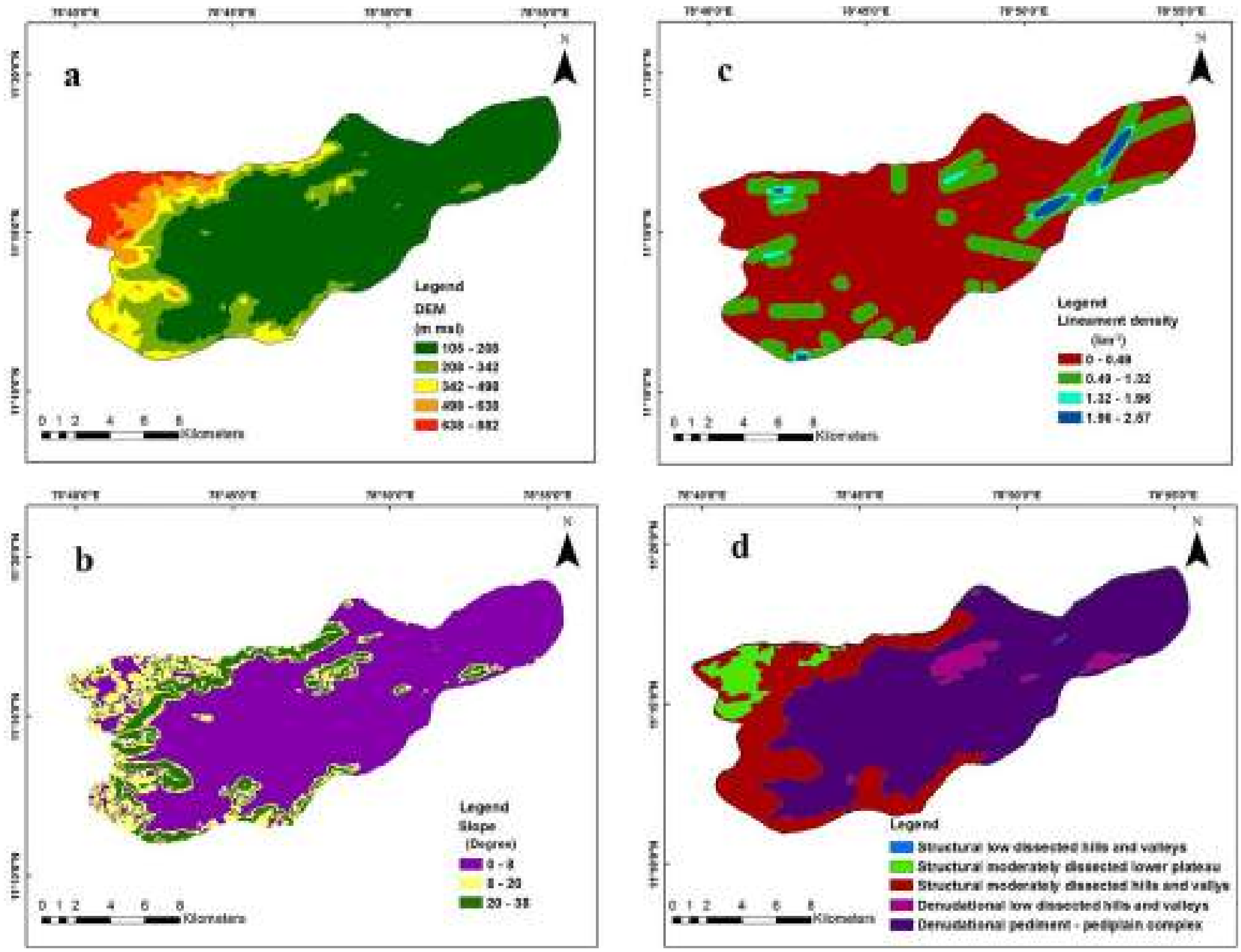

Fig. 5 Features of the study area. **a** Topography. **b** Slope. **c** Lineament density. **d** Geomorphology

groundwater development. Low drainage and high drainage areas were assigned a high and low rank, respectively (Table 3).

Slope

Topography plays an important role in understanding the runoff and occurrence of groundwater resources. Slope of a region is derived from the topography. So, the topography was first prepared from the satellite imageries (Fig. 5a). Major part of the study region is covered by gentle slope, moderate undulating discontinuous hills, and flat land (Fig. 5b). Steep slope implies low groundwater potential, because of faster runoff, whereas the gentle slope has high groundwater potential. Areas with lesser gradient favor infiltration of rainfall by offering more time. Based on the slope degree, the groundwater potential is classified into three classes: < 8° (low slope), 8 to 20° (medium slope), and > 20° (higher slope) (Table 2). The study region comprised largely of flat area (72%), gentle slope (16%), and steep slope (12%). Higher ranks were given to flat and gentle slope and lower ranks for higher slope (Table 3).

Lineament density

A lineament is a linear feature on the earth, which is an indirect evidence for geological structures such as faults and fractures. These features indicate increase in secondary porosity and permeability and are main conduits for transit and storage of groundwater. Thus, lineaments represent the faulting and fracturing zones, which are also indicators for the groundwater potential zones. Lineament density map was prepared from the line density tool in GIS platform (Fig. 5c). Lineament length in the study region ranges from 0 to 2.57 km^{-1}, trending in the SSW-NNE direction. Based on the

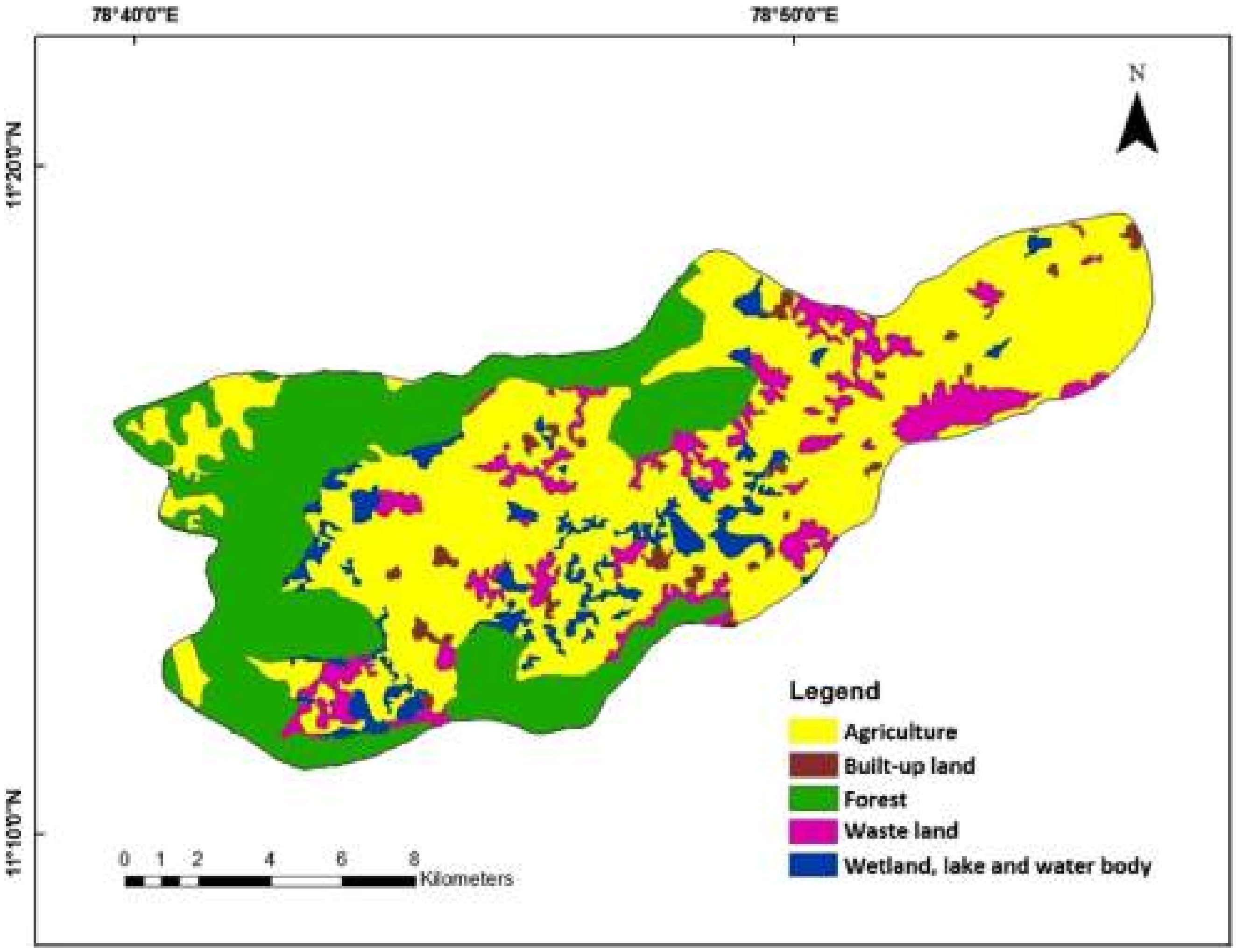

Fig. 6 Land use in the study area

lineament density, the study area was classified into four classes: low (< 0.49 km^{-1}), medium (0.49–1.32 km^{-1}), high (1.32–1.96 km^{-1}), and very high (> 1.96 km^{-1}). About 73% of the study area fall in low lineament density (Table 2), which is considered as poor groundwater potential, and these areas are assigned a lower rank (Table 3). Nearly 3% of area fall in the high lineament density zone, and these areas occur mostly in the middle and lower part of the study region (Fig. 5c).

Table 4 Relative rates and score for each influencing factor calculated using the MIF technique

Influencing factor	Major effect (*A*)	Minor effect (*B*)	Proposed relative rates (*A* + *B*)	Proposed score of each influencing factor
Drainage density	1	0.5	1.5	9
Slope	1 + 1	0.5	2.5	14
Lineament density	1 + 1	0	2	12
Soil	1	0	1	6
Geology	1 + 1 + 1	0	3	18
Geomorphology	1 + 1	0.5 + 0.5	3	18
Land use	1 + 1 + 1	0.5 + 0.5	4	23
			∑17	∑100

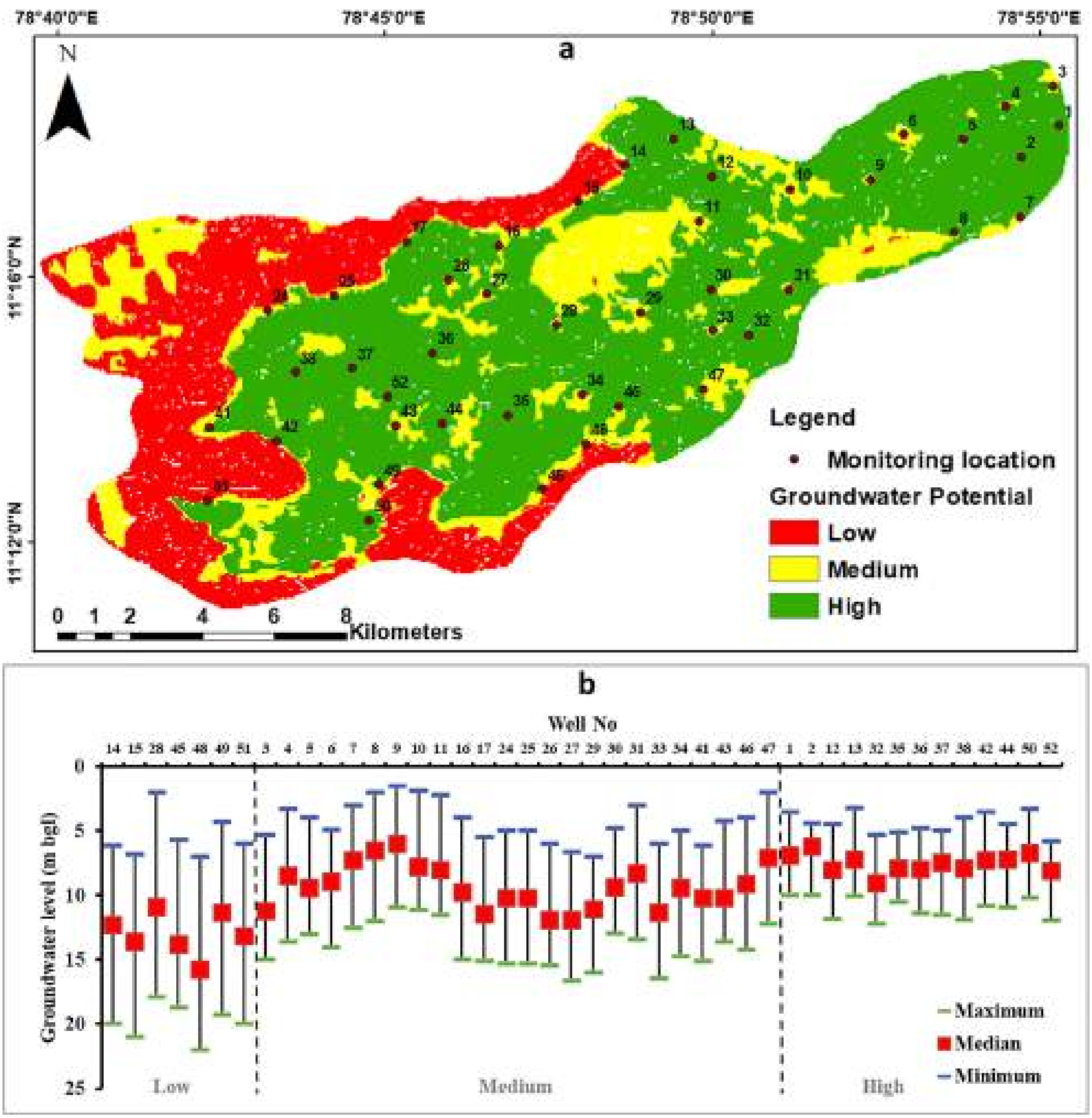

Fig. 7 **a** Groundwater potential zones identified through the MIF method. **b** Groundwater level fluctuation in different groundwater potential zones

Geomorphology

Various geomorphic features of the earth are formed by different processes such as the action of waves, wind, chemical reaction, groundwater movement, surface water flow, tectonism, and glacial action. The geomorphological features controlling the movement of groundwater was derived from LISS III image. Various features identified in the study area are structural, denudational dissected hills and valleys, lower plateau, pediment and pediplain (Fig. 5d). The study area comprises mostly of pediment and pediplain (68%) followed by structurally dissected hills with valleys (24%), moderately dissected lower plateau (5%), and lower dissected hills with valleys (3%) (Table 2). Pediplain is covered by an extensive plain of agricultural land with water bodies and is naturally suitable for groundwater development due to the high recharge rates. Moderately dissected lower plateau has slow runoff with moderate groundwater potential. Structurally dissected hills and valleys are considered as low groundwater potential zones due to the high elevation, steep

Table 5 Water holding capacity of various surface and subsurface features based on the groundwater potential zones

Layer	High	Medium	Low
Drainage density	< 1.14 km^{-1}	1.14–3.21 km^{-1}	> 3.21 km^{-1}
Slope	< 8°	8–20°	> 20°
Lineament density	> 1.96 km^{-1}	0.49–1.96 km^{-1}	< 0.49 km^{-1}
Soil	Deep black, moderately black	Moderately black, shallow red	Moderately red, very deep red
Geology	Fissile hornblende biotite gneiss	Fissile hornblende biotite gneiss, charnockite	Charnockite
Geomorphology	Pediplain, pediment	Dissected lower plateau	Dissected hills and valleys
Land use	Agriculture, water bodies	Forest	Wasteland, built-up area
Groundwater range measured in the monitoring wells	1.9–12.4 m	1.5–16.4 m	2–22.5 m
Groundwater potential values based on the 7 layers	248 to 311	185 to 247	120 to 184
Total area	118.9 km^2	46.1 km^2	54.7 km^2

topography, faster runoff, and subsequently low infiltration rate. Therefore, pediplain is assigned a higher rank, and the structural dissected hills and valleys are assigned a lower rank (Table 3).

Land use

Land use is one of the key features that control groundwater recharge. LISS III satellite imagery was used to derive the various land use patterns in this region. The study area had diverse land use, such as agricultural land, water bodies, forest, waste land, and built-up areas (Fig. 6). Agriculture is the major activity in this region, with 53% of the land being used for cultivation (Table 2). Paddy, shallots, groundnut, maize, sweet corn, cotton, sunflower, fruits, vegetables, and flowers are cultivated as major crops in this region. Agricultural lands and water bodies function as good groundwater potential areas because of more recharge in the flat areas. Wetland and water body contains 6% of the study area; these are considered as having good groundwater potential. Forest occupies 30% of the study area, even though there is recharge in these areas, it is comparatively less and hence is considered to have medium groundwater potential (Table 3). Wasteland (9%) and built-up area (2%) have low recharge due to non-availability of space to infiltrate the rainwater, and thus have the lowest groundwater potential.

Table 6 Groundwater potential areas in different land use

Land use	Low (km^2)	Medium (km^2)	High (km^2)
Wetland and water body	0.0	2.0	11.7
Wasteland	0.4	19.3	0.0
Forest	56.2	10.2	0.0
Built-up land	0.0	3.1	0.5
Agriculture	0.0	6.4	110.2

Delineation of groundwater potential zones

The weightage of each factor is computed by the MIF method. The minor and major effects of one influencing factor over another was calculated and is given in Table 4. The groundwater potential map indicating its spatial variation is given in Fig. 7a. High groundwater potential occurs in the plains as it comprises mostly of agricultural land, low slope, low drainage density, and pediplain (Table 5). About 54% of the study region was covered by high groundwater potential. Geology, slope, land use, and geomorphology have played an important role in the high groundwater potential zone. The medium groundwater potential occurs around the forest areas with medium drainage and medium slope, black and red soils. Geological formation in the high groundwater potential area is mostly coarse sand, amphibolite, and garnetiferous gneiss. About 21% of the study area is covered by the medium groundwater potential. Low groundwater potential was found out in the low, medium dissected hills and valleys with high slope, high drainage density, and low lineament feature (Table 5). Infiltration of this area is very low due to fast runoff with steep slopes, waste land, and built-up area that were reducing recharge of the water into the subsurface. Low groundwater potential was noticed in 25% of the study area. The groundwater potential in the study area compared with the different land use is given in Table 6.

Validation

The groundwater potential zone of low, medium, and high was validated with groundwater level data in the study area to understand the recharge of rainwater into the aquifers. The groundwater level was monitored every 3 months in 44 wells

Table 7 Single parameter sensitivity measure

Removed influencing layer	Minimum	Maximum	Average	Standard deviation
Land use	0.0	6.4	2.2	1.2
Geomorphology	0.0	5.1	1.7	1.1
Soil	0.1	2.0	1.4	0.3
Lineament density	0.0	1.7	1.0	0.5
Drainage density	0.0	1.9	1.0	0.5
Slope	0.0	2.8	0.6	0.5
Geology	0.0	2.2	0.5	0.3

from 2015 to 2018 (Fig. 7a). This groundwater level information was used to validate the groundwater potential map. The groundwater level fluctuation in low groundwater potential zones ranged from 2 to 22.5 m with an average value of 7.5 m, in medium groundwater potential zones from 1.5 to 16.4 m with an average value of 4.85 m, and in high groundwater potential zones from 1.9 to 12.4 m with an average value of 3.1 m (Fig. 7b). The results show that groundwater level fluctuation was very shallow in the high groundwater potential zone than in the medium and low groundwater potential zones in the study region. Thus, the delineated groundwater potential map is validated with the measured groundwater levels from the study area.

Sensitivity analysis

All the parameters used for the groundwater potential index are inter-related, and removing one or more parameters will indicate the sensitivity of the removed parameters in demarcating the potential zones. Table 7 indicates the sensitivity of the index when one layer is removed during the index calculation, and Table 8 indicates the sensitivity when one or more layers are removed at the same time of index calculation. Most influence on the groundwater potential index is exerted by the land use parameter. This is followed by geomorphology, soil, lineament density, drainage density, slope, and geology. Though geology and geomorphology layers have the same weight assigned using the MIF method (i.e., 18), geomorphology has a higher influence on the groundwater potential index than the geology. Table 8 indicates that removing more layers increases the variation in the potential index. The removal of layers were carried out based on the influence of the layers identified in Table 7. Removal of any one of the layers has a great impact on the identified groundwater recharge areas. This shows the importance of including these parameters in the delineation of groundwater potential areas.

The effective weights identified through the sensitivity analysis is compared with the theoretical weights assigned through the MIF method (Table 9). It is clear that the effective weights do not make a perfect match with the assigned weights for few parameters. Land use, geomorphology, and slope have higher average effective weights than the assigned weights. Drainage density and soil have the same average effective weights and assigned weights. All other parameters have lower effective weights. This shows the importance of assigning weights to the layers in overlay and index studies such as this for identifying the groundwater potential zones. These weights cannot be universally applied to these layers and should be combined with knowledge of the study region. This study also shows that these layers cannot be excluded in any

Table 8 Single or more parameter removal sensitivity measure

Influencing layer(s) used	Minimum	Maximum	Average	Standard deviation
LU, GM, S, LD, DD, SL, G	0	0	0	0
LU, GM, S, LD, DD, SL	0.0	2.2	0.5	0.3
LU, GM, S, LD, DD	0.0	5.0	0.8	0.7
LU, GM, S, LD	0.0	6.2	1.9	1.1
LU, GM, S	0.0	11.3	4.1	2.3
LU, GM	0.0	21.5	10.2	4.0
LU	0.1	38.3	13.1	7.0

LU land use, *GM* geomorphology, *S* soil, *LD* lineament density, *DD* drainage density, *SL* slope, *G* geology

Table 9 Statistical summary of single parameter sensitivity measure by calculating the effective weight

Influencing layer	Theoretical weight (%)	Effective weight (%)			
		Minimum	Maximum	Average	Standard deviation
Drainage density	9	3.0	21.8	8.6	3.7
Slope	14	5.2	31.3	15.5	4.2
Lineament density	12	4.0	24.5	8.7	4.1
Soil	6	2.0	13.8	5.8	2.1
Geology	18	6.0	27.7	12.4	3.3
Geomorphology	18	7.2	45.0	22.8	8.9
Land use	23	9.1	52.6	26.2	8.9

groundwater potential studies, and sensitivity analysis should be included to identify the influence of these layers in a region.

Conclusion

The groundwater potential zones were identified using remote sensing and GIS methods in the western part of Perambalur district, Tamil Nadu. The various thematic layers like geology, soil, geomorphology, drainage density, slope, lineament density, and land use were prepared using satellite imagery, toposheets, and conventional data. The various thematic layers were assigned a weightage based on the MIF method, and ranks were assigned to features within the layers based on the local knowledge about the region. The high groundwater potential zone is found around the agricultural land, low slope, and pediplain areas. Medium groundwater potential was found in wetland areas, medium slope, plateau, and soils, whereas the low groundwater potential zones occurred in hills, valleys, waste land, and built-up areas. High groundwater potential zone occurs in 54% of this region; 21% is in the medium groundwater potential zone, and 25% falls in the low groundwater potential zone. Weathered gneissic rock, low slope, pediplain, high lineament, and water body played an important role in increasing the groundwater recharge in this region. The groundwater level data was used to validate the groundwater potential areas in the study region, which indicated that groundwater level fluctuation was more at low and medium groundwater potential zones than the high groundwater potential zone. This was due to the low recharge rate in the low and medium groundwater potential zones and high recharge in the high groundwater potential zone. Sensitivity analysis was carried out to analyse the importance of one layer over another. Land use was the significant parameter that influenced the delineation of the groundwater potential areas. This study shows that the groundwater potential areas identified by integrating features of the various layers can be used to identify the locations for exploration of groundwater. This groundwater potential zone map may assist stakeholders and decision-makers in groundwater development activities in the region.

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THEMATIC ISSUE

Geochemical evaluation of fluoride and groundwater quality for drinking and irrigation purposes in a weathered gneissic rock aquifer of southern penisular India

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Abstract
Assessment of groundwater chemistry of a region is important to determine its usability. The objective of this study is to understand the hydrochemistry and groundwater quality especially with respect to fluoride in the Perambalur District, Tamil Nadu, India where groundwater is used without treatment for drinking and agricultural purposes. Groundwater samples were collected from 44 locations once every three months between September 2015 and July 2018. Mixed Ca–Mg–Cl, Ca–HCO_3, Na–Cl and mixed Ca–Na–HCO_3 types were the predominant hydrochemical facies. Fissile hornblende biotite gneissic rocks had more fluoride concentration than the charnockite rocks in the study area. These weathered rocks leach high concentration of fluoride to groundwater. Ion exchange processes played a major role in fluoride dynamics in groundwater. Fluoride concentration was comparatively high in the wells where the groundwater level fluctuation is at deeper levels. Groundwater in most of the wells were suitable for drinking purpose based on the ions analysed, but few wells were unsuitable for drinking and irrigation purposes. Based on health risk assessment, children are likely to be more affected than infants and adults through intake of high fluoride groundwater from the study area.

Keywords Groundwater · Drinking · Irrigation · Fluoride · Health risk · Perambalur · Southern India

Introduction

Groundwater quality varies due to rainfall, geology, hydrogeochemical processes, rock-sediment–water interaction, influence of anthropogenic sources, and from the impact of climate change. Understanding the variation in the concentration of dissolved constitutents in groundwater provides information on the origin, flow path, recharge mechanisms, geochemical reactions and also it helps to determine its suitability for specific purposes. Over-exploitation of groundwater can lead to negative impact on the groundwater quality, especially in the shallow aquifers (Khan et al. 2016; Pophare et al. 2014; Salameh 2008). Managing the groundwater resources from potential pollutants and contaminants is a difficult task and it requires long-term systematic monitoring of the water levels and quality as well as studying the stages of groundwater development in relation to the rate of replenishment. Though contamination of groundwater from human activities can be curtailed to a larger extent, geogenic contamination poses severe peril to freshwater demand and supply worldwide (Eawag 2015).

India, the world's largest groundwater user is facing crisis due to uncontrolled exploitation of the resource established by drying of wells and rapid lowering of water levels. Groundwater use is largely in the agricultural sector (89%), followed by the domestic (9%) and industrial sectors (2%) (World Bank 2010). About 50% of urban and 85% rural water requirements are met by groundwater (CGWB 2011). Common anthropogenic pollutants causing problems in

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Indian groundwaters are salinity (Manivannan and Elango 2019; Gopal et al. 2020; Biplab et al. 2021), nitrate (Karunanithi et al. 2020; Abdur et al. 2021), chromium (Kanagaraj and Elango 2019; Christina et al. 2021), lead, cadmium and other trace metals (Sharma et al. 2019; Monika et al. 2021). Key geogenic pollutants are arsenic (Sridharan and Nathan 2018; Sumant et al. 2021), fluoride (Jagadeshan et al. 2015a; Raju 2017; Chetan and Surindra 2019), iron and salinity (Kumar et al. 2019; Paul et al. 2019; Gopal et al. 2020; Dinesh Kumar et al. 2022). Among these natural contaminants, arsenic and fluoride are global threat to human health (Eawag 2015). Arsenic is more common contaminant in groundwater of the north eastern part of India and in the alluvial plains of the Ganges and Brahmaputra river basins (Chakraborti et al. 2017a, b; Jain et al. 2018). Fluoride contamination is more prominent throughout the nation (Brindha et al. 2011, 2016; Kalpana et al. 2018; Kanagaraj and Elango 2019; Ajaykumar et al. 2020).

Since adequate drinking water is not supplied through pipes to home in rural parts of India, the large rural population use groundwater without treatment. Hence, the periodical assessment of groundwater quality and hydrogeochemistry of major ions is necessary. One such region is located in the western part of Perambalur district, Tamil Nadu, India. Based on the groundwater availability and the gross groundwater pumped for various uses this region is categorised as over-exploited (CGWB 2017). Of the 11 administrative revenue blocks in Perambalur district, 6 are over-exploited, 3 are semi-critical and 2 are safe based on the current groundwater extraction practises (TWAD 2018)**.** Thus, it is well-established that groundwater forms the major source of water for the rural population of this area for domestic use including drinking and agricultural needs.

Compared to the available literature on the hydrogeochemistry of other parts of Tamil Nadu, this region has not been throughly investigated till now. Previously, only the general groundwater quality assessment (Kasthuri et al. 2007) and the suitability for agricultural use (Ahamed et al. 2013) has been carried out. The excessive groundwater abstraction together with decifit in rainfall, reduced recharge and subsequent decline in groundwater level led to the identification and demarcation of the groundwater potential zones in the area for future groundwater development activities (Anbarasu et al. 2019). Uranium in the groundwater was used the health risk assessment to understand the presence of uranium and distribution based on rock types (RamyaPriya et al. 2021). These studies however did not draw out an understanding of the hydrogeochemistry, and the presence of fluoride and its dynamics in groundwater. Considering that groundwater is used for drinking and irrgation uses, it is necessary to assess the possible impact of groundwater use on the human health and plant growth. Hence, the present study aims at quantifying the fluoride abundance in groundwater, understanding the sources, factors controlling its occurrence, release meachanisms and its movement in groundwater in the hard rock aquifers of upper part of the Chinnar river basin which forms a part of the Perambalur district, Tamil Nadu, India. Health risk assessment is also carried out to understand the potential health hazards due to ingestion of groundwater on the rural population. This study also assesses the general hydrogeochemistry and the suitablity of groundwater for drinking and agricultural uses based on the major ions.

Methodology

Field work

Initially, a detailed hydrogeological field investigation was carried out and information on the geological outcrop, depth of the wells, its dimensions, purpose of use etc. were noted. The electrical conductivity (EC) and groundwater level in the wells were also measured in the field. Based on these information, forty-four representative wells (Fig. 1) which were spread uniformly throughout the study area were selected for long-term monitoring. Totally 436 samples were collected from the 44 open wells (diameter from 4 to

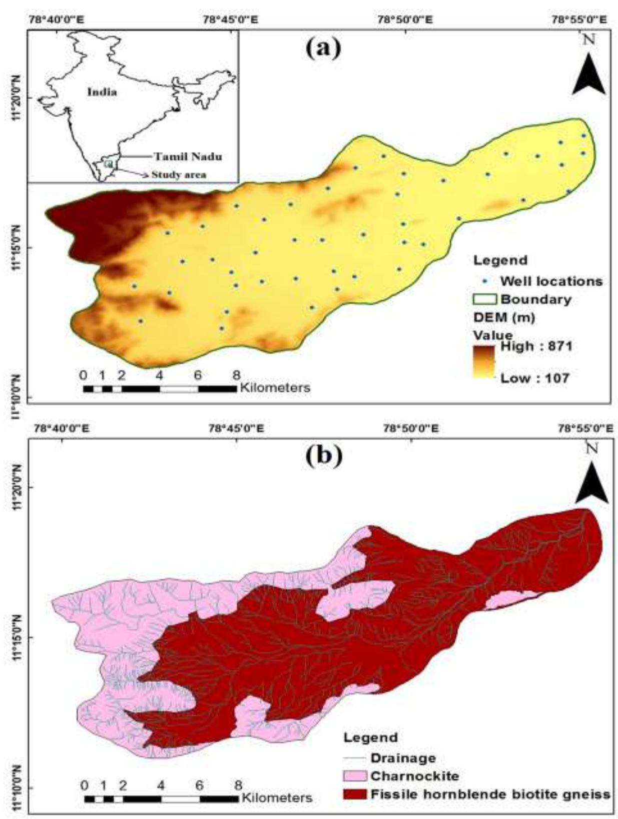

Fig. 1 **a** Study area, **b** geology and drainage map of study area

10 m) once every three months between September 2015 and July 2018. Water level indicator (Solinist101) was used to measure the water levels. Temperature, pH and EC were measured in situ using a portable meter (Oakton Pcstestr 35). Sampling bottles were cleaned with dilute HCl and then washed thoroughly with distilled water before sample collection. Groundwater samples were filtered using millipore filter paper (0.45 μm) and filled in the sample collection bottles without air bubbles, properly labelled, stored in a cooler and brought to the laboratory for further analysis.

Laboratory methods

Carbonate and bicarbonate concentrations were measured immediately after sample collection by volumetric titration against diluted H_2SO_4 using the Aquamerck test kit (1.11009.0001). Calcium and magnesium were measured by volumetric titration. Sodium, potassium and nitrate concentrations were determined by a flame photometer. Sulphate concentration was measured by UV–VIS spectrophotometer (Systronics UV–VIS 118). Chloride concentration was measured by using titrando 905. Fluoride in groundwater was measured by a fluorimeter (Extech F700) which can measure from 0.1 to 10 mg/l. All analytical methods were followed as per standard procedures (APHA 2012). Verification of efficiency of the analysis was done by testing blanks and standards. Ion balance error was calculated and was within the ± 5%.

Exposure dose of fluoride

Fluoride intake water was calculated by using the given formula (USEPA 2011).

$$\text{Exposure dose} = \frac{C \times \text{WI}}{\text{BW}}, \tag{1}$$

where, C is the measured fluoride concentration (mg/l), WI is the daily water intake (l/day) and BW is the body weight (kg). The water intake and body weight varies based on the different age groups. The water amount adopted for infants was 250 ml/day, for children was 1.5 l/day and for adults was 3 l/day (Planning Commission 2011). Infants, children and adult's body weight were considered as 6.9, 18.7 and 57.5 kg, respectively (ICMR 2009).

Description of the study area

The study area is located in the hard rock terrain of Perambalur district, Tamil Nadu, India (Fig. 1a) and it covers about 220 km^2. This region extends between the latitudes of 11° 8′ 16″ N and 11° 21′ 14″ N and longitudes of 78° 38′ 45″ E and 78° 57′ 35″ E. This region experiences semi-arid climate with temperature ranging from 20 to 42 °C. The average annual rainfall is about 900 mm with rainfall in the northeast monsoon, southwest monsoon and summer accounting for 60%, 25% and 15% of the rainfall respectively. The region is surrounded by the mountains of Eastern Ghats (Pachamalai) in the north, west and south, except for the eastern part. This area is characterized by discontinuous small with gentle uplands and the elevation ranges from 400 to 900 m msl. Subdendritic with trellis is the drainage pattern in this area (Fig. 1a). Agriculture is the primary activity in this area.

Geology and hydrology

The geology of the study area was demarcated based on the geological map obtained from the Geological Survey of India (GSI 1995) (Fig. 1b). This region comprises of fissile hornblende biotite gneisses and charnockite rocks. The gneissic and chanockite rocks are fractured over a thickness ranging mostly between 20 and 31 m and 18 and 25 m, respectively. The sand and silt occur in small quantity along the river course. Groundwater occurs in unconfined conditions in the weathered and fractured rocks. The aquifer thickness ranges between 15 and 35 m. Specific yield is between 80 and 210 lpm (litre per minute) and top soil thickness is from 0 to 6 m. Long-term fluctuation in groundwater table during the period from 1998 to 2007 indicates that there is no major change in its annual trend (CGWB, 2009).

Results and discussion

Statistical summary of the parameters analysed in groundwater are given in Table 1. The suitability of the groundwater for drinking purpose based on its properties are presented in Table 2.

Drinking water quality

Groundwater in this area is used for drinking and domestic purposes. Hence, the various hydrochemical parameters measured were compared with the prescribed values proposed for drinking water quality by the Bureau of Indian Standards (BIS 2012) and World Health Organisation (WHO 2011) (Table 2). Evaluation of water for drinking and domestic purposes depends on the parameters mentioned in the following sections.

Total dissolved salts and total hardness

The total dissolved salts (TDS) is the total amount of salts dissolved in water and comprises of major, minor ions and trace elements. TDS was calculated from the EC using the formula,

Table 1 Statistical summary of physicochemical parameters in the groundwater

Parameters	Unit	Pre-monsoon ($N=216$)			Post-monsoon ($N=220$)		
		Minimum	Maximum	Mean	Minimum	Maximum	Mean
pH	No unit	6.9	8.5	–	6.6	9.5	–
EC	µS/cm	446	3920	1449	232	3370	1442
TDS	mg/l	285	2508	927	148.5	2156.8	920
TH	mg/l	64.7	789.1	240	30	710	275
Calcium	mg/l	19	245.8	70	9	199	84
Magnesium	mg/l	4.2	66.6	17.5	1.8	68	23
Sodium	mg/l	21.5	470	107.6	13.1	537	108
Potassium	mg/l	0.4	5.7	2.6	1.1	15.1	5.1
Carbonate	mg/l	0	0	0	10	12.2	10.4
Bicarbonate	mg/l	158	597	282	55	647	312
Chloride	mg/l	17.6	589	170.5	16	579	184
Sulphate	mg/l	20	190	89	8	238	88
Nitrate	mg/l	6.9	37	15.7	0	24.8	8.6
Fluoride	mg/l	0.1	1.5	0.4	0.2	2.7	0.7
Na %	%	14.1	89	43.4	7	81.7	38
SAR	meq/l	0.4	31	3.1	0.3	17.4	3.8
RSC	meq/l	− 9.4	6.7	− 0.58	− 10.4	4.7	− 1.1
KR	meq/l	0.1	7.5	0.9	0.1	4.3	0.8
MH	meq/l	13.4	48.8	29.1	13.5	47.4	29.3
PI	%	21.2	120.7	69.4	21.7	124.3	64.2

EC electrical conductivity, *TDS* total dissolved salt, *TH* total hardness, *Na%* sodium percentage, *SAR* sodium adsorption ratio, *RSC* residual sodium carbonate, *KR* Kelly's ratio, *MH* magnesium hazard, *PI* Permeability Index

Table 2 Groundwater suitability for drinking purposes according to BIS (2012) and WHO (2011)

Parameters	Unit	References	Acceptable limit	Permissible limit	Number of samples exceeding acceptable limit	Number of samples exceeding permissible limit
pH	No unit	BIS (2012)	6.5–8.5	No relaxation	5	–
TDS	mg/l	BIS (2012)	500	2000	361	17
TH	mg/l	BIS (2012)	200	600	314	10
Ca	mg/l	BIS (2012)	75	200	232	2
Mg	mg/l	BIS (2012)	30	100	58	Nil
Na	mg/l	WHO (2011)	–	200	–	52
K	mg/l	WHO (2011)	–	12	–	8
CO_3	mg/l		–	–	–	–
HCO_3	mg/l		–	–	–	–
Cl	mg/l	BIS (2012)	250	1000	105	Nil
SO_4	mg/l	BIS (2012)	200	400	8	Nil
NO_3	mg/l	BIS (2012)	45	No relaxation	Nil	–
F	mg/l	BIS (2012)	1	1.5	44	28

$$\text{TDS in mg/l} = \text{EC in } \mu\text{S/cm} \times 0.64. \tag{2}$$

TDS was ranging between 148.5 and 2508 mg/l with an average of 959.3 mg/l (Table 1). Groundwater in this area was fresh based on the classification proposed by Freeze and Cherry (1979). BIS (2012) has proposed 500 mg/l and 2000 mg/l of TDS as the acceptable and permissible limit in drinking water. Groundwater in this area exceeds the maximum permissible limits for drinking water quality in

4% of the groundwater samples (Table 2). TDS decreases after the monsoon period due to dilution effect.

Calcium, magnesium and carbonate ions are the essential components determining the total hardness (TH) of groundwater. The TH in water was calculated from the given formula,

$$\text{Total hardness}\left(CaCO_3\right) = 2.5\left(Ca^{2+}\right) + 4.1\left(Mg^{2+}\right). \quad (3)$$

All values are expressed in mg/l. TH ranges from 30 to 789.1 mg/l with an average of 291 mg/l (Table 1). Groundwater of this area can be classified as moderately hard, hard and very hard water for drinking uses (Sawyer and McCarty 1978) (Fig. 2). About 16% wells were moderately hard, 34% wells were hard and 50% wells were very hard. About 71% of the samples exceed the acceptable limit and 2% of the samples exceed the permisbble limit (Table 2).

Cations and anions

In the study area, 52% of the samples exceeded the accepted limit for calcium (Table 2). The acceptable limit of magnesium is 30 mg/l in drinking water (BIS 2012) and its 13% of the groundwater samples exceeded the magnesium concentration in groundwater. Concentration of sodium exceeded the permissible limit (WHO 2011) in 12% of the samples and potassium exceeded the permissible limit (WHO 2011) in 2% of the groundwater samples. Carbonate content was low in groundwater. There were prescribed limits for carbonate and bicarbonate in drinking water. Chloride and sulphate also did not pose any threat to groundwater quality. About 24% of the groundwater samples exceeded the acceptable limit for chloride, but still were within the permissible limits. Sulphate in groundwater exceeded the acceptable limit in 2% samples (Table 2). However, it was within the permissible limit.

Minor ions

Nitrate concentration ranged up to 37 mg/l with an average of 10.8 mg/l in groundwater. There was no threat to groundwater quality and for drinking use based on nitrate (Tables 1, 2). Concentration of fluoride was ranging from 0.1 to 2.7 mg/l with average of 0.6 mg/l in the study area (Table 1). Table 3 shows that the fluoride concentration varied seasonally in the sampling locations.

The suitability of groundwater for drinking purpose in terms of TDS, TH, cations and anions was assessed as a combination of all these parameters. If all the parameters

Table 3 The temporal variation in the suitability fluoride for drinking

Month	Percentage of samples		
	< 1 mg/l	1–1.5 mg/l (permissible range)	> 1.5 mg/l
Sep-15	88	12	0
Jan-16	83	5	12
Jul-16	90	10	0
Oct-16	70	16	14
Jan-17	67	19	14
Apr-17	88	10	2
Jul-17	90	10	0
Oct-17	86	4	10
Jan-18	81	7	12
Jul-18	88	12	0
Total	83	10	7

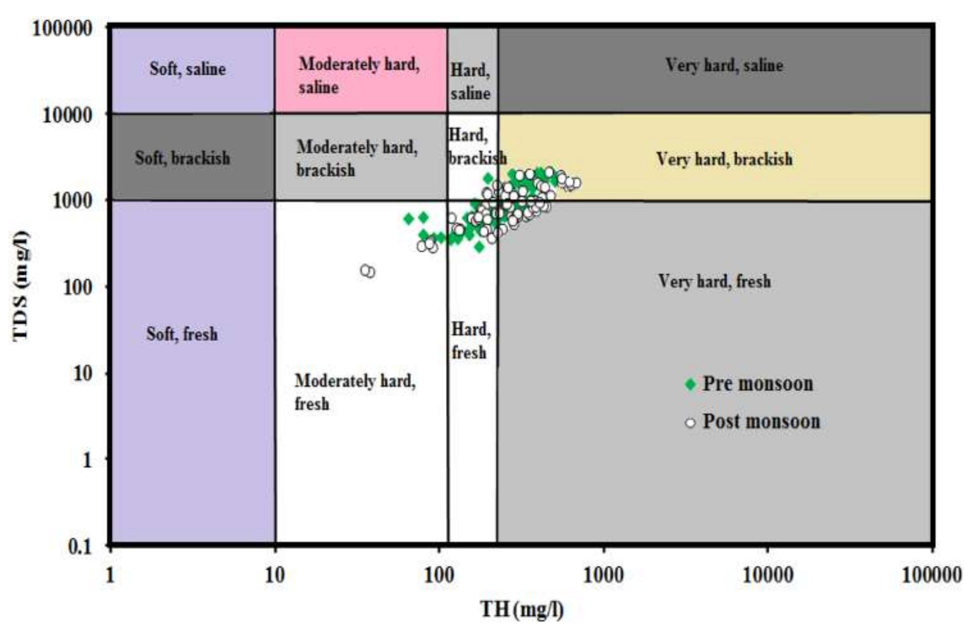

Fig. 2 Groundwater types based on total dissolved solids and total hardness

were within the permissible limits during three times of the four sampling times in a year, then the groundwater is considered as suitable for drinking. Based on the integration of all the parameters considered for drinking water quality analysis, 84% of the study area is suitable (Fig. 3).

Irrigation water quality

Groundwater in this area is widely used for irrigation purpose. Quality of groundwater for irrigation purpose was determined by various paramters as listed in following sections (Table 4).

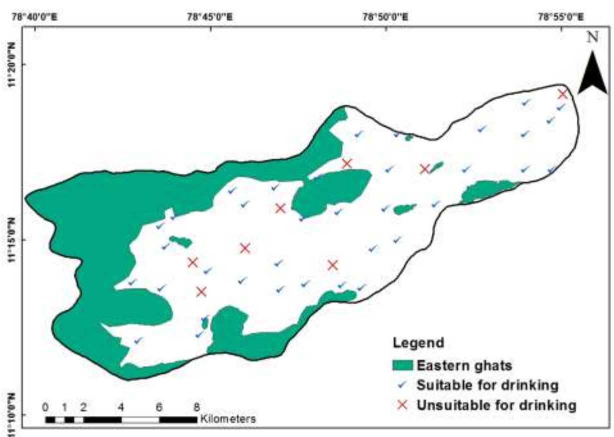

Fig. 3 Sampling locations indicate suitability for drinking use

Salinity and alkalinity hazard

High concentration of dissolved salts in groundwater can hinder soil permeability and may decrease the crop yield. The United States Salinity Laboratory (USSL) diagram (Richards 1954) classifies groundwater suitability for irrigation as two types: salinity hazard and sodium hazard. The salinity hazard is determined based on the EC and the sodium hazard is determined by using SAR equation. SAR determines the relative amount of sodium with respect of calcium and magnesium and is given as

$$\mathrm{SAR} = \frac{\mathrm{Na}^{+}}{\sqrt{\frac{\mathrm{Ca}^{2+}+\mathrm{Mg}^{2+}}{2}}}, \quad (4)$$

where the values are expressed in meq/l. Salinity hazard is further classified into four classes: C1, C2, C3, C4 and sodium hazard i.e. SAR is classified into S1, S2, S3, S4. SAR is plotted against EC in the USSL diagram. EC ranged up to 3920 µS/cm and classification based on EC show 16% of the samples were good, 70% were suitable and 14% were doubtful in the study area (Fig. 4a, Table 4). SAR values were between 0.3 and 31 meq/l with average of 3.5 meq/l (Table 1). Based on SAR, 93% of the locations were excellent and 7% of the locations were good for irrigation purpose (Fig. 4a).

Table 4 Classification of groundwater for irrigation uses

Parameters	Range	Classification	Percentage of wells exceeding the permissible limit
Na% (Wilcox 1955)	0–20	Excellent	07
	20–40	Good	47
	40–60	Suitable	36
	60–80	Doubtful	10
	> 80	Unsuitable	Nil
SAR (Richards 1954)	0–10	Excellent	93
	10–18	Good	07
	18–26	suitable	Nil
	> 26	Poor	Nil
RSC (Richards 1954)	< 1.25	Good	86
	1.25–2.5	Permissible	07
	> 2.5	Unsuitable	07
EC (Richards 1954)	< 250	Low salinity hazard	02
	250–750	Medium salinity hazard	14
	750–2250	High salinity hazard	70
	> 2250	Very high hazard	14
Kelley's ratio (Kelley 1957)	< 1	Suitable	82
	> 1	Unsuitable	18
MH (Szaboles and Darab 1964)	< 50	Suitable	100
	> 50	Unsuitable	Nil
PI (Donean 1964)	Class I	Max. permeability	77
	Class II	75% of Max. permeability	18
	Class III	25% of Max. permeability	05

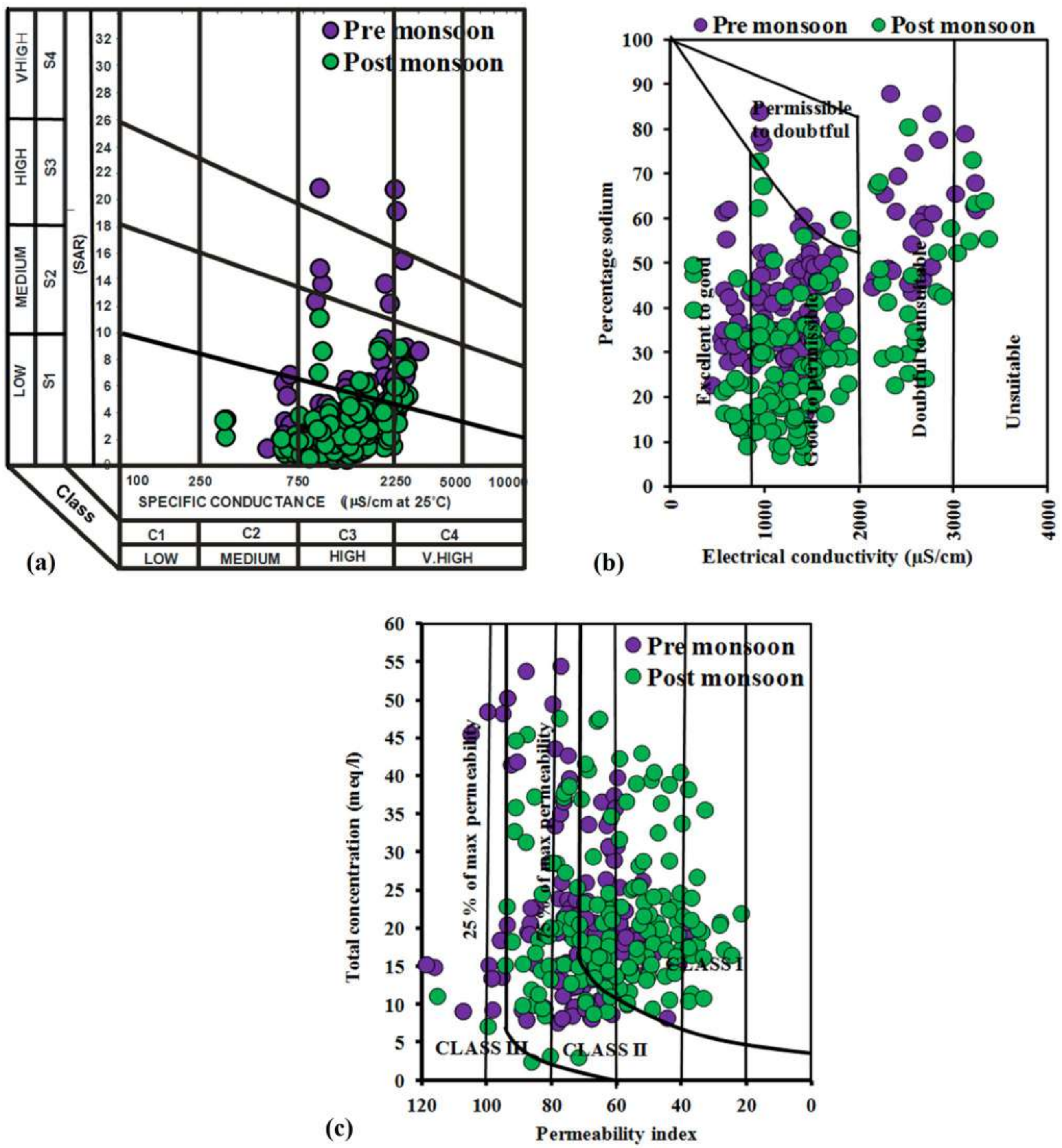

Fig. 4 Groundwater suitability for irrigation purpose based on **a** sodium and salinity hazard, **b** EC and sodium percent and **c** permeability index

Sodium percent

Sodium is an essential component in groundwater, which at high concentrations is not favorable for plant growth. If sodium is excess in groundwater, it will reduce the permeability of the soil and can clog the soil layer. Based the sodium content, Wilcox (1955) proposed an index known as the sodium percentage (Na%) for classifying the water quality for irrigation use. It is given as,

$$\text{Na\%} = \frac{\left(\text{Na}^+ + \text{K}^+\right)}{\left(\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+ + \text{K}^+\right)} \times 100. \tag{5}$$

All concentrations given in meq/l. Na% was found to range from 7 to 89 meq/l with an average of 40.7 meq/l. Wilcox plot between EC and Na% (Fig. 4b) indicates that 54% of the groundwater samples had excellent to good quality, 36% were good to suitable and 10% of the samples has doubtful to unacceptable water quality for irrigation (Table 4). Figure 4b shows that most of the groundwater in the area is suitable for irrigation purposes.

Residual sodium carbonate

Alkalinity hazard in groundwater can be understood from the residual sodium carbonate (RSC). When sodium concentration is high in groundwater, calcium and magnesium will precipitate more in the soil and cause soil infiltration problems. RSC is calculated as (Ragunath 1987),

$$\text{RSC} = \left(\text{CO}_3^{2-} + \text{HCO}_3^-\right) - \left(\text{Ca}^{2+} + \text{Mg}^{2+}\right). \tag{6}$$

All concentrations given in meq/l. RSC of groundwater was between − 10.4 and 6.7 meq/l with average of − 0.8 meq/l (Table 1). Based on RSC, 86% of the groundwater samples were good, 7% were suitable and 7% were unacceptable for irrigation purpose (Table 4).

Permeability index

Calcium, sodium, magnesium, and bicarbonate ions affect the soil permeability. Hence, based on the concentration of these ions, the permeability index (PI) was proposed by Doneen (1964) to determine the quality of water for irrigation and. PI is calculated based on the formula given below

$$\text{PI} = \frac{\text{Na}^+ + \sqrt{\text{HCO}_3^-}}{\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+} \times 100. \tag{7}$$

All concentrations given in meq/l. PI in groundwater was ranging from 21.2 to 124.3 meq/l with average of 66.8 meq/l. The relation between PI and total concentration of ions in groundwater is plotted in Fig. 4c. The results show that 77% wells were good, 18% wells were within permissible limit, 5% wells were unsuitable for irrigation purpose (Table 4).

Kelly's ratio

Kelle's ratio (KR) to evaluate water quality for irrigation purposes was suggested by Kelly (1957) and is calculated as given below

$$\text{KR} = \frac{\text{Na}^+}{\text{Ca}^{2+} + \text{Mg}^{2+}}. \tag{8}$$

All concentrations given in meq/l. When sodium concentration is higher than the concentration of calcium and mangensium, it will affect the soil sailinity and is unsuitable for irrigation. So, if the KR is < 1, it is good for irrigation purposes. When KR is beyond 1, water is unacceptable for irrigation purpose. KR was found to range from 0.1 to 7.5 meq/l with an average of 0.9 meq/l (Table 1). About 18% of the groundwater samples were unsuitable for irrigation in the study area. Therefore, the results show that most of the groundwater wells were suitable for irrigation purpose.

Magnesium hazard

When exchangeable magnesium concentration is high in groundwater, it may cause infiltration issues. Szabolcs and Darab (1964) have proposed the following magnesium hazard (MH) index for irrigation purposes

$$\text{MH}(\%) = \frac{\text{Mg}^{2+}}{\text{Ca}^{2+} + \text{Mg}^{2+}} \times 100. \tag{9}$$

All concentrations given in meq/l. If MH is greater than 50%, it is considerd as harmful and unsuitable for irrigation purpose. MH ranges from 13.4 to 48.8 meq/l with an average of 28.6 meq/l in groundwater (Table 1). Based on MH, all sampling locations are within the maximum permissible limit. Hence, groundwater can be used for irrigation purpose with respect to MH.

The above indices determine the irrigation water quality based on each index at a particular point in time. An overall irrigation water quality map was prepared based on the EC, SAR, Na%, RSC, PI, KR and MH. If the groundwater quality based on these indices were suitable three times out of the

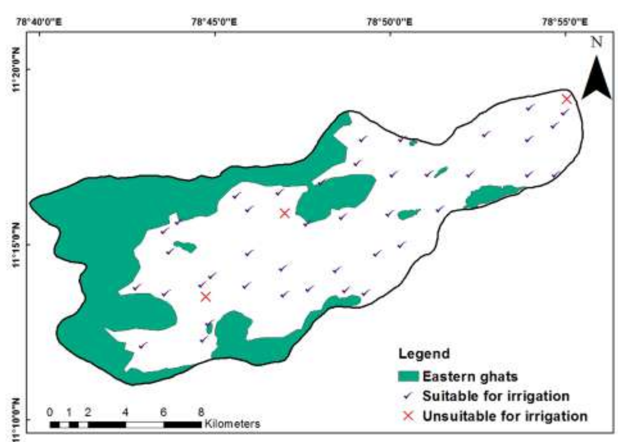

Fig. 5 Suitability of groundwater for irrigation use

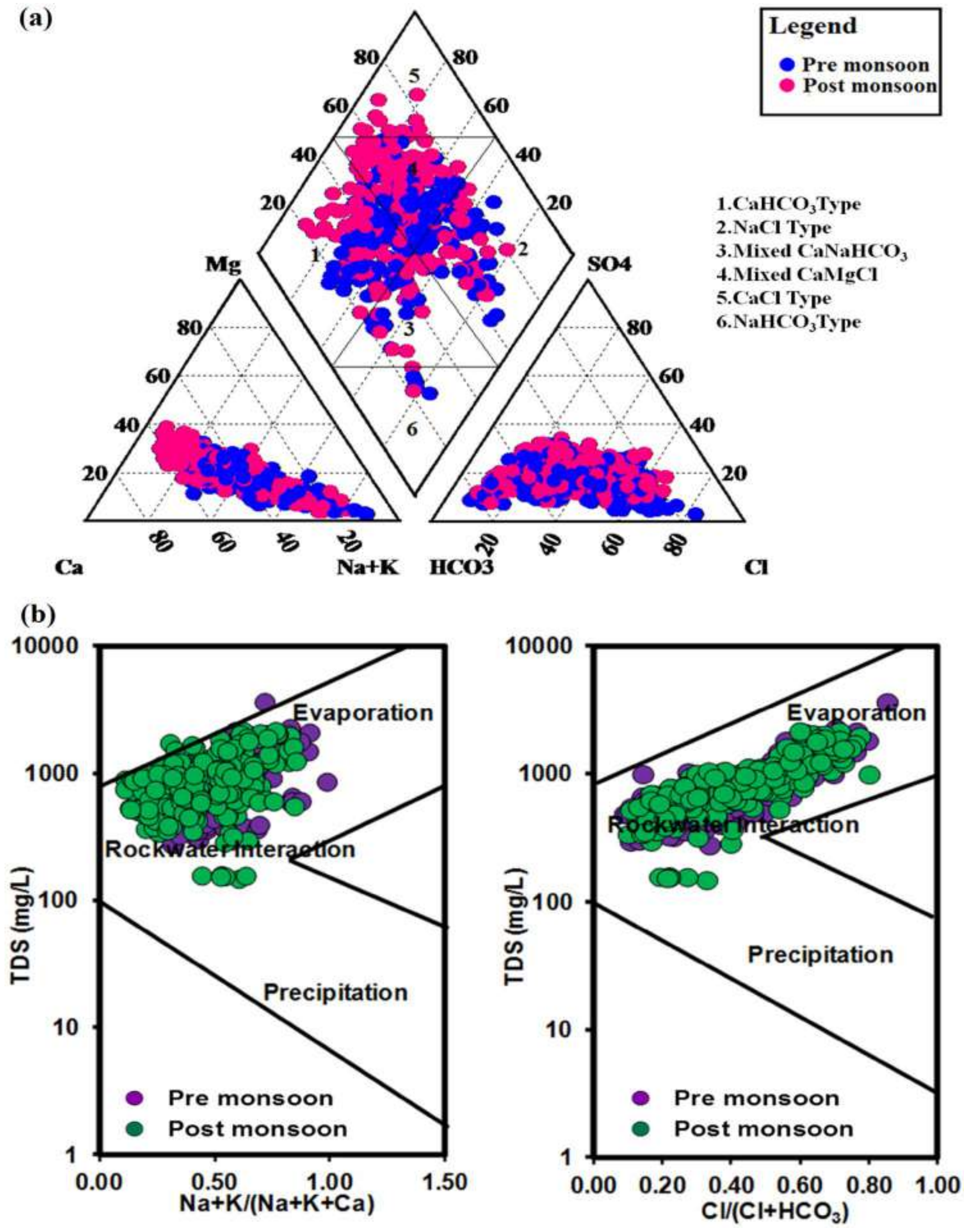

Fig. 6 **a** Major hydrochemical facies of groundwater, **b** major hydrological processes controlled the chemistry of groundwater

four sampling times in a year, the groundwater is considered suitable for irrigation. The irrigation water quality map prepared using this method is shown in Fig. 5. Based on the integration of all the irrigation water quality parameters, it was found that 93% of the study area has groundwater that can be utilised for irrigational purposes.

Hydrogeochemical facies

The pH of the groundwater was ranging between 6.6 and 9.5, which shows that it is slightly acidic to alkaline. EC in groundwater ranges from 232 to 3920 µS/cm with average of 1499 µS/cm (Table 1). Major ions of cations and anions in groundwater were in the order of sodium, calcium, magnesium and potassium, and bicarbonate, chloride and sulphate, respectively. Most of the groundwater samples exhibited mixed Ca–Mg–Cl, Ca–HCO_3 type and Na–Cl type (Fig. 6a). Key processes contributing to groundwater geochemistry were identified using Gibbs plot (Gibbs 1970). Figure 6b shows that rock water interaction and evaportaion are the domiant processes controlling the chemical composition of the groundwater.

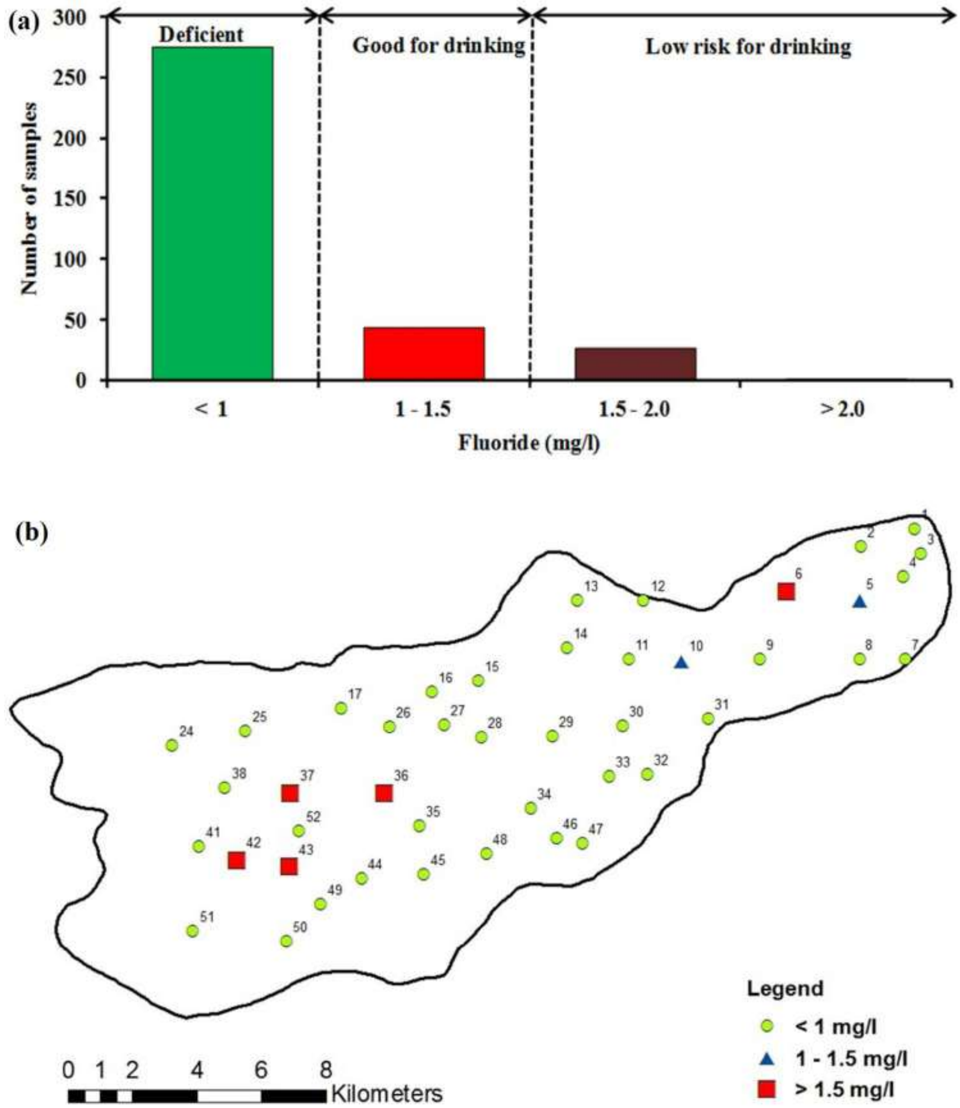

Fig. 7 **a** Fluoride concentration in groundwater in different range, **b** average fluoride concentration in groundwater

Sources of fluoride

Figure 7a indicates that about 10% of wells exceeded the permissible limit of 1.5 mg/l, 18% of groundwater wells were within the permissible range of 1–1.5 mg/l which are good for drinking purpose and 72% of groundwater wells were below the permissible limit of (< 1 mg/l) in the study area. The average concentration of fluoride in the groundwater at different locations is shown in Fig. 7b. The percentage of samples exceeding fluoride concentration during this study is given in Table 3. The fluoride concentration exceeds 1.5 mg/l in many wells during October and January months i.e. post-monsoon. After monsoon, the concentration of ions increases in specific regions due to dissolution and leaching of minerals by the groundwater.

The sampling wells were differentiated based on the geology in which they were located. Groundwater samples collected from wells located in the fissile hornblende biotite gneiss had higher fluoride concentration in comparison with the wells located in the charnockite. Table 5 shows the range of fluoride concentration in the samples located in the two different geology. Fluoride concentration from wells in the fissile hornblende biotite gneissic rock ranges between 0.1 and 2.7 with average of 0.6 mg/l. The concentration of fluoride from samples located in charnockite areas range from 0.1 to 1.3 mg/l with an average of 0.35 mg/l. The key source of fluoride is mainly from the biotite, hornblende and amphibole minerals from the granite, gneissic and charnockite rocks of this area. The mobilization of these minerals by hydrogeological processes had led to high fluoride in groundwater. Jagadeshan et al. (2015b) reported maximum fluoride concentration in charnockite and epidote hornblende biotite gneiss as 68 mg/kg and 97 mg/l in a nearby region. The interaction

Table 5 Fluoride concentration in groundwater samples located in different rock types (10 times)

Sample no	Rock type	Minimum	Maximum	Average	Sample no	Rock type	Minimum	Maximum	Average
1	Fissile hornblende biotite gneiss	0.1	1.1	0.41	29	Fissile hornblende biotite gneiss	0.1	0.6	0.28
2	Fissile hornblende biotite gneiss	0.1	0.8	0.39	30	Fissile hornblende biotite gneiss	0.1	0.8	0.42
3	Fissile hornblende biotite gneiss	0.2	1	0.53	31	Charnockite	0.1	0.5	0.32
4	Fissile hornblende biotite gneiss	0.1	0.4	0.22	32	Fissile hornblende biotite gneiss	0.1	1	0.51
5	Fissile hornblende biotite gneiss	0.4	1.6	1.01	33	Fissile hornblende biotite gneiss	0.1	0.5	0.24
6	Fissile hornblende biotite gneiss	1.3	1.9	1.51	34	Fissile hornblende biotite gneiss	0.1	0.8	0.39
7	Charnockite	0.1	0.5	0.28	35	Fissile hornblende biotite gneiss	0.4	1.3	0.83
8	Fissile hornblende biotite gneiss	0.1	0.6	0.36	36	Fissile hornblende biotite gneiss	1.2	1.9	1.52
9	Fissile hornblende biotite gneiss	0.1	0.4	0.22	37	Fissile hornblende biotite gneiss	1.1	1.8	1.51
10	Fissile hornblende biotite gneiss	0.5	2.7	1.05	38	Fissile hornblende biotite gneiss	0.1	1.3	0.5
11	Fissile hornblende biotite gneiss	0.1	0.4	0.2	41	Charnockite	0.2	1.3	0.47
12	Fissile hornblende biotite gneiss	0.2	1.1	0.5	42	Fissile hornblende biotite gneiss	1	2	1.52
13	Fissile hornblende biotite gneiss	0.1	0.7	0.31	43	Fissile hornblende biotite gneiss	1	2	1.53
14	Charnockite	0.1	0.6	0.3	44	Fissile hornblende biotite gneiss	0.1	0.6	0.25
15	Charnockite	0.1	0.5	0.3	45	Fissile hornblende biotite gneiss	0.1	1	0.39
16	Fissile hornblende biotite gneiss	0.1	0.8	0.27	46	Fissile hornblende biotite gneiss	0.1	0.7	0.27
17	Fissile hornblende biotite gneiss	0.1	0.6	0.27	47	Fissile hornblende biotite gneiss	0.1	0.6	0.32
24	Charnockite	0.1	1.1	0.28	48	Fissile hornblende biotite gneiss	0.2	0.8	0.39
25	Charnockite	0.1	0.6	0.32	49	Charnockite	0.3	1.3	0.65
26	Fissile hornblende biotite gneiss	0.1	0.9	0.49	50	Charnockite	0.1	0.7	0.35
27	Fissile hornblende biotite gneiss	0.3	1.3	0.86	51	Fissile hornblende biotite gneiss	0.2	1	0.46
28	Charnockite	0.1	0.8	0.3	52	Fissile hornblende biotite gneiss	0.2	1.1	0.6

between groundwater and these fluoride bearing minerals over longer time period lead to the leaching and dissolution of these minerals in groundwater. About 2.9 and 1.1% of fluoride is present in hornblende and biotite minerals respectively (Jagadeshan et al. 2015a). The fissile hornblende gneissic rock is comparatively more weathered than the charnockites (Anbarasu et al. 2019) and hence the concentration of fluoride is higher in the former regions. Equations governing the weathering of these fluoride bearing minerals are given below

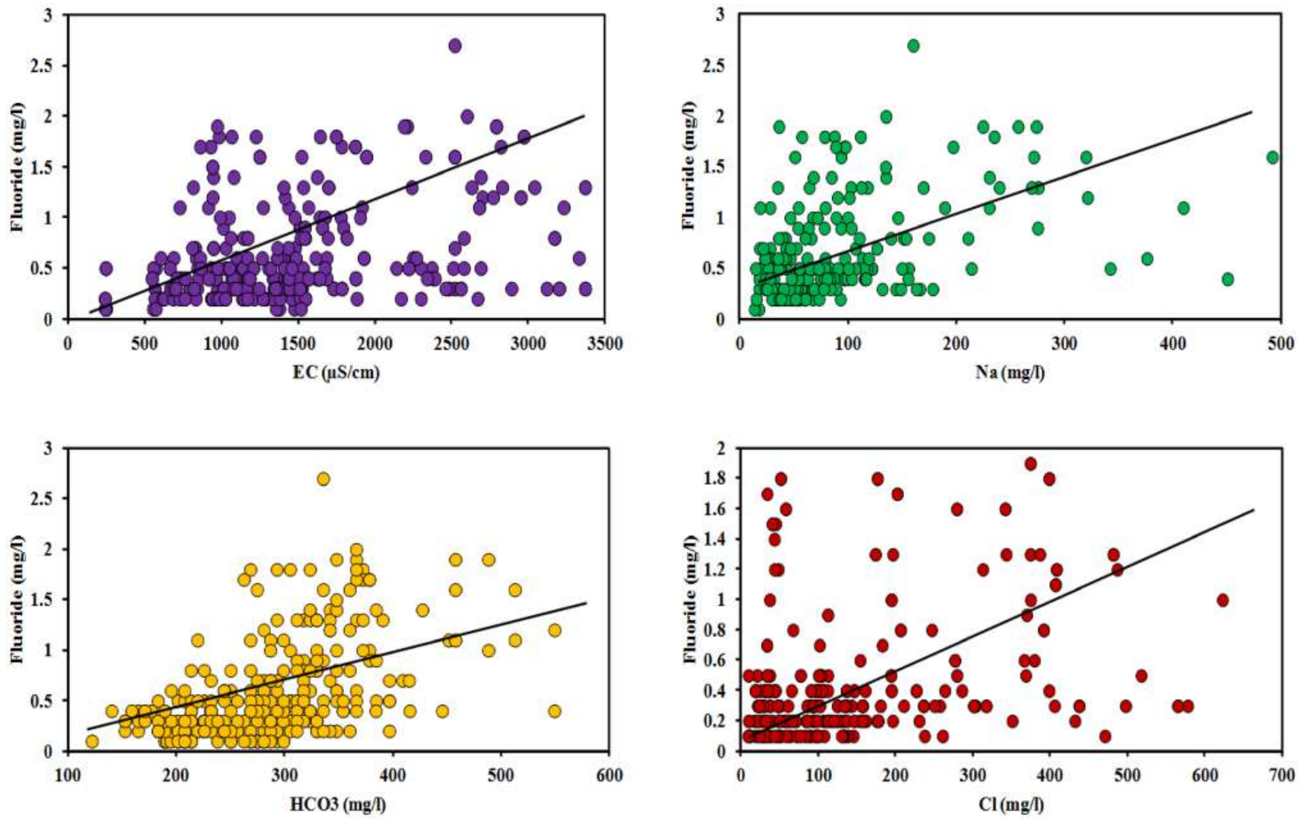

Fig. 8 The correlation between fluoride, EC and major ions shows that positive

$$CaNa_2(Mg)5\left(Si_8O_{22}\right)F_2(\text{Hornblende}) + 2OH^- = Na(CaNa)\ Mg_5\left(Si_8O_{22}\right)\left(OH^-\right)_2 + 2F^-, \quad (10)$$

$$K(Mg)_3\left(AlSi_3O_{10}\right)F_2(\text{Biotite}) + 2OH^- = KMg_3\left(Al_2Si_3O_{10}\right)\left(OH^-\right)_2 + 2F^-. \quad (11)$$

The correlation between fluoride, EC and major ions is used to understand the source i.e. the weathering of rocks (Fig. 8). In general, fluoride shows a positive correlation with EC, sodium and bicarbonate. The relationship between the concentration of fluoride and well depth is shown in the Fig. 9a. When the groundwater level in wells was in top soil (0.1–6 m bgl) and fractured rock (18.1–22 m bgl), the concentration of fluoride in most of the wells was less than 1 mg/l. When the groundwater level in wells was in the weathered zone (6.1–18 m bgl), the concentration of fluoride was more than 1.5 mg/l in most of the wells. As the leaching of weathered gneissic rock is contributing more fluoride to groundwater, the wells in this area have high concentration of fluoride in groundwater. Comparison of the fluoride concentration with the groundwater level in different rock types is shown in Fig. 9b. This figure also confirms that groundwater in the fissile hornblende gneissic areas have high fluoride. Also, the fluoride concentration, irrespective of shallow or deep groundwater table was low in the charnockite areas. However, in fissile hornblende gneiss such differentiation could not be made as both shallow and deep water levels showed fluoride concentrations at all ranges. A clear understanding of the relationship between fluoride concentration and groundwater level could not be made from Fig. 9b as they were collectively plotted. The concentration of fluoride in groundwater varies temporally in the different rock types. It is evident that the groundwater fluctuation depth plays an important role in determining the fluoride concentration (Brindha et al. 2011, 2016; Fantong et al. 2009; Jagadeshan et al. 2015b). Hence, all the sampling wells were individually plotted to identify the relationship.

The temporal relationship between fluoride and groundwater level is classified as type I wells and type II wells. The shallow groundwater table increases during the rainy season, decreasing the fluoride concentration in groundwater due to dilution. During summer, fluoride concentration increases as the groundwater level declines due to evaporation and no natural recharge. This is the characteristic if

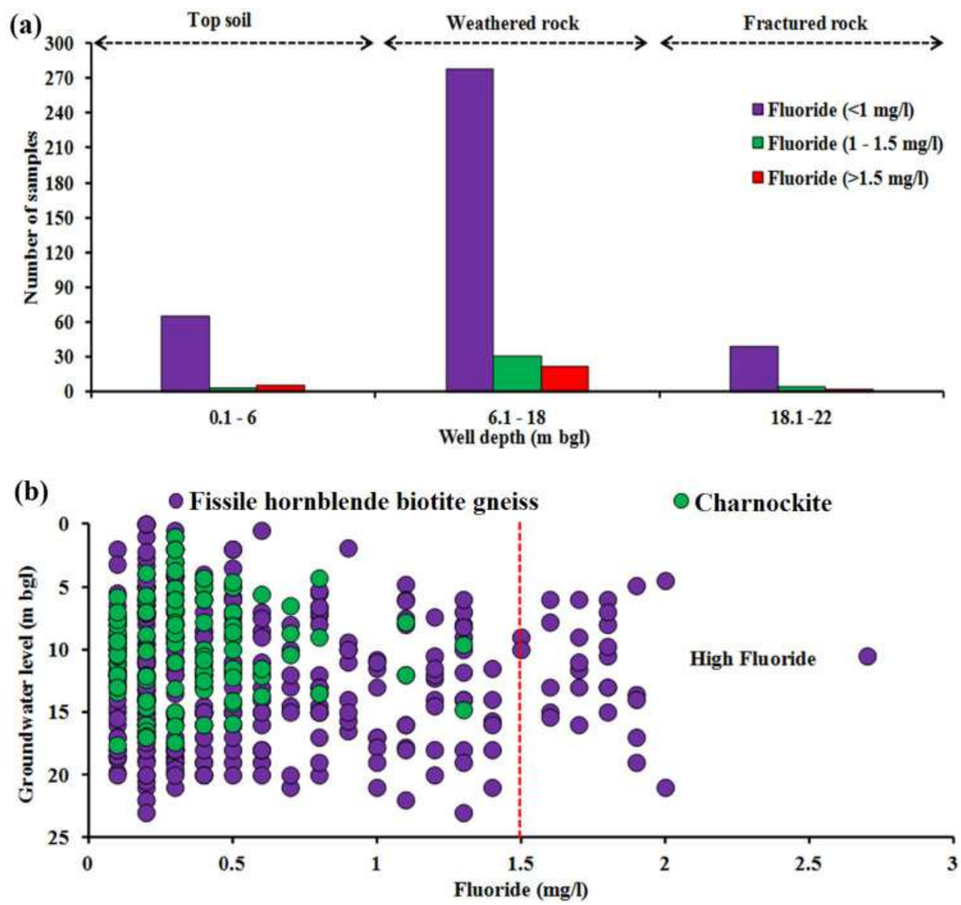

Fig. 9 Variation in fluoride concentration in groundwater **a** well depth, **b** groundwater level

type I wells (Fig. 10a). In type II wells, during the rainy season, infiltration of rainwater flushes the precipitated fluoride salts from the unsaturated zone and hence increase in groundwater levels also increases the fluoride concentration. With prolonged infiltration, the fluoride concentration will decrease in the deep wells too (Fig. 10b). This relationship has been reported in several regions with high fluoride concentrations (Brindha et al. 2011, 2016).

Health risk analysis

Groundwater with fluoride concentration between 1 and 1.5 mg/l as suggested by BIS (2012) is considered to be permissible for drinking use. When fluoride concentration in drinking water was deficient (< 1 mg/l), it can cause dental caries, especially in children (Raju 2017). Fluoride concentration above 1.5 mg/l in drinking water cause dental and skeletal fluorosis (Mandinic et al. 2010; Perumal et al. 2013). Fluoride exposure dose for infants ranges from 0 to 0.1 mg/kg/day, for children it ranges from 0.01 to 0.22 mg/kg/day and for adults, it ranges from 0 to 0.14 mg/kg/day. The results show that fluoride exposure dose was minimum risk for infants and adults but maximum risk for children (Fig. 11). The minimal risk level from oral ingestion based on chronic-duration studies is given as 0.05 mg fluoride/kg/day (ATSDR 2003). About 9% of the groundwater samples exceed the minimum risk level for infants, 21% of the samples exceeded for children and 13% of the samples exceed for adults. The fluoride exposure dose calculated for infants, children and adults shows that children have a high exposure dose than infants and adults.

Conclusion

The present study focused on the fluoride contamination, its sources and the associated human health risk due to the ingestion of contaminated groundwater. Mixed Ca–Mg–Cl, Ca–HCO_3, Na–Cl and mixed Ca–Na–HCO_3 types were the dominant groundwater facies. Groundwater is generally slightly acidic to alkaline nature. The suitability of groundwater for drinking purpose was estimated by TDS, TH, major and minor ions, and 84% of the study area wells

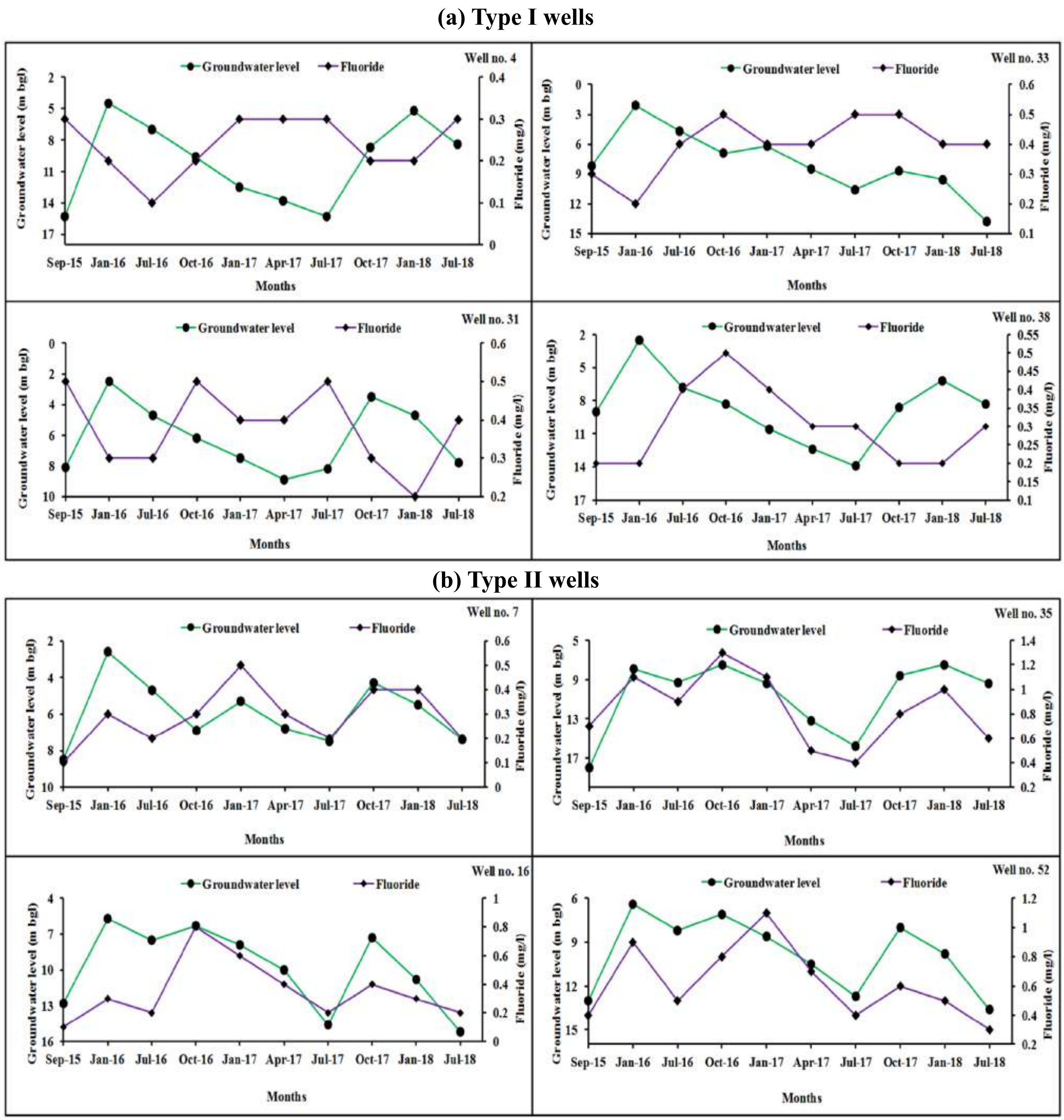

Fig. 10 The temporal variation of groundwater level and fluoride **a** type I wells, **b** type II wells

were good for drinking purpose. Except a few of well, about 93% of the groundwater wells were good for irrigation purpose based on integrating of Na%, SAR, RSC, KR, MH and PI values. 10% of groundwater samples were exceeding the permissible limit of fluoride and 31% of groundwater samples were within the permissible limit for drinking purposes based on BIS and WHO. Fluoride concentration was released more to groundwater due to recharge of rainwater and weathering processes during the monsoon and post-monsoon. Fluoride was showing positively good relation with EC, sodium and bicarbonate ion. Weathering of minerals, dissolution, evaporation and dilution were the major hydrogeochemical processes controlling high fluoride in groundwater. High fluoride

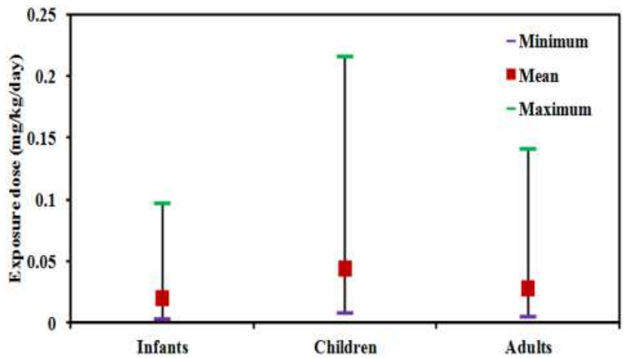

Fig. 11 Fluoride exposure dose for infants, children and adults

concentration occurred mostly in regions with weathered fissile hornblende biotite gneissic rocks than in charnockite rocks. The health risk assessment indicates that children are affected more than infants and adults through intake of high fluoride groundwater. Suitable management of water resources especially to overcome fluoride contamination is required in this area.

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Declarations

Conflict of interest All authors declare that they have no conflicts of interest.

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05/03

சான்றிதழ் வ.எண்/ CERTIFICATE S. No. SEC. 0363549

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இடைநிலைக் கல்வி பள்ளி இறுதி வகுப்புச் சான்றிதழ்
SECONDARY SCHOOL LEAVING CERTIFICATE

பத்தாம் வகுப்பு
X STANDARD

தமிழ்நாடு அரசின் அதிகாரத்திற்கு உட்பட்டு வழங்கப்படுகிறது
ISSUED UNDER THE AUTHORITY OF THE GOVERNMENT OF TAMILNADU

தேர்வர் ANBARASU S MAR.2003 இல் பத்தாம் வகுப்புப் பொதுத் தேர்வெழுதிக் கீழ்க்காணும் விழுக்காட்டு மதிப்பெண்களைப் பெற்றுள்ளார் என்று சான்றளிக்கப்படுகிறது.

Certified that the above mentioned Candidate appeared for the SSLC Public Examination and obtained the following percentage of marks :

பாடம் SUBJECT	மதிப்பெண் MARKS
மொழி LANGUAGE TAMIL	86 EIGHT SIX
ஆங்கிலம் ENGLISH	55 FIVE FIVE
கணிதம் MATHEMATICS	77 SEVEN SEVEN
அறிவியல் SCIENCE	93 NINE THREE
சமூக அறிவியல் SOCIAL SCIENCE	88 EIGHT EIGHT
மொத்தம் TOTAL	399 THREE NINE NINE

பிறந்த நாள் / DATE OF BIRTH	பதிவெண் / REGISTER NO.	ம.அ.ப.குறியீட்டெண் & நாள் TMR CODE NO. & DATE
05.06.1988	387289	A345573 30.05.2003

பள்ளியின் பெயர் / SCHOOL
GOVT HSS AMMAPALAYAM

பத்தாம் வகுப்புத் தேர்வில் தேர்ச்சி பெற ஒவ்வொரு பாடத்திலும், 100க்குக் குறும அளவு முப்பத்தைந்து விழுக்காடு மதிப்பெண் பெறுதல் வேண்டும். இது பகுதி முறையில் தேர்வு எழுதித் தேர்ச்சி பெறுவதற்கும் பொருந்தும்.

A PASS IN THE SSLC (X STD.) EXAMINATION REQUIRES A MINIMUM OF THIRTY FIVE PERCENT OF MARKS IN EACH ONE OF THE FIVE SUBJECTS. THIS INCLUDES PASSING UNDER THE COMPARTMENTAL SYSTEM ALSO.

சு. அன்பரசு
தேர்வரின் ஒப்பம்
Candidate's Signature

செயலாளர்
மாநிலப் பள்ளித்தேர்வுகள் குழுமம், தமிழ்நாடு
SECRETARY
STATE BOARD OF SCHOOL EXAMINATIONS, TAMILNADU

Undertaking by the Principal Investigator

To

The Secretary
SERB, New Delhi

Sir

I Dr. **S. Anbarasu** hereby certify that the research proposal titled **Impact of mining activities on the water resources around Perambalur and Ariyalur district, southern India** submitted for possible funding by SERB, New Delhi is my original idea and has not been copied/taken verbatim from anyone or from any other sources. I further certify that this proposal has been checked for plagiarism through a plagiarism detection tool i.e. **Urkund software** approved by the Institute and the contents are original and not copied/taken from any one or many other sources. I am aware of the UGCs Regulations on prevention of Plagiarism i.e. University Grant Commission (Promotion of Academic Integrity and Prevention of Plagiarism in Higher Educational Institutions) Regulation, 2018. I also declare that there are no plagiarism charges established or pending against me in the last five years. If the funding agency notices any plagiarism or any other discrepancies in the above proposal of mine, I would abide by whatsoever action taken against me by SERB, as deemed necessary.

S. Anbarasu 10/8/23

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S Anbarasu

Name/ designation

Anna University

PROGRESS THROUGH KNOWLEDGE

Reg.No. 1512719214/RG

The Syndicate of the Anna University hereby makes known that **ANBARASU S** *has been admitted to the* **DEGREE OF DOCTOR OF PHILOSOPHY** *under the* ***Faculty of Science and Humanities,*** *having been certified by the duly appointed examiners to be qualified to receive the same in the year* **2021.** *The degree has been awarded in compliance with the* ***"University Grants Commission, Regulations 2009".***

Title of the Thesis:

GROUNDWATER POTENTIAL ZONATION, HYDROGEOCHEMICAL PROCESSES AND NUMERICAL FLOW MODELING IN A PART OF PERAMBALUR DISTRICT, TAMIL NADU, INDIA

Given under the Seal of the University

Chennai 600 025
India
July 2022
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Controller of Examinations

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Registrar

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