



SPATIOTEMPORAL ASSESSMENT OF GROUNDWATER QUALITY FOR SUSTAINABLE WATER RESOURCE MANAGEMENT AT PAVAGADA TALUK, KARNATAKA, INDIA

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ABSTRACT

This study presents a comprehensive spatiotemporal analysis of groundwater resources in Pavagada Taluk, Tumakuru District, Karnataka to evaluate the suitability for sustainable management and public health. A total of 25 groundwater samples were collected during pre-monsoon and post-monsoon seasons. The analytical results were revealed generally stable, near-neutral pH and satisfactory levels for most parameters and are predominantly within BIS permissible limits. The findings indicate robust aerobic conditions and minimal contamination from agricultural or saline sources. The study identified critical concerns, that pervasive fluoride contamination was the significant issue, with concentrations ranged from 1.3 to 6.4 mg/L, exceeding the safe limit (1.0–1.5 mg/L) over 70% of samples. Geogenic origins, specifically the weathering of fluoride-bearing minerals in the local granitic-gneissic bedrock, are identified as the primary cause, exacerbated by semi-arid climatic conditions and localized spikes in turbidity and chlorides suggest minor anthropogenic influences. The spatiotemporal analytical results underscore a severe public health risk, notably endemic dental and skeletal fluorosis for the local population. The study showed groundwater is suitable for agricultural purposes, its direct consumption without treatment poses a significant health hazard. This study provides critical scientific baseline for policymakers to develop evidence-based interventions, ensuring water security and advancing public health.

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References: 31

Keywords: Spatiotemporal assessment, Groundwater, Health Hazards, Fluoride, Geogenic origin.

INTRODUCTION

Groundwater is a vital freshwater resource, especially in semi-arid regions, where surface water is scarce and seasonal [1], [2]; [3]; [4]. In India, it serves as the primary source of drinking water and irrigation for a significant portion of the population, particularly in rural areas [5]; [6]; [7]; [8], [9], [10]. However, the sustainability of ground water resource is increasingly threatened by both quantitative depletion and qualitative

degradation due to geogenic processes and anthropogenic activities. The intrinsic link between water quality and public health underscores the critical need for continuous monitoring and assessment, as contamination poses severe risks to community well-being ([11], [12], [13] [14], [15]; [16], [17], [18]. Pavagada Taluk, located in the drought-prone Tumakuru district of Karnataka, is emblematic of these challenges. The region's economy is

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predominantly agrarian, relying heavily on groundwater for irrigation and domestic use ([19], [20]). The local aquifer systems are primarily hosted within granitic and gneissic bedrock, which are known to be a natural source of ions, including fluoride, through water-rock interaction processes [10], [21], [22], [23]. This geogenic contamination, potentially exacerbated by agricultural practices and climatic factors, necessitates a detailed spatial evaluation of groundwater quality to inform sustainable management strategies [24], [25]. While previous studies have highlighted water scarcity issues in Karnataka, a comprehensive, spatially-representative analysis of hydro-chemical parameters in Pavagada Taluk, specifically targeting pre- and post-monsoon variations, remains limited. This study aims to fill this critical research gap by conducting a spatial analysis and quality assessment of groundwater resources across the taluk. The study aims to spatial assessment of ground water quality and its

suitability. By establishing a robust baseline dataset and identifying contamination hotspots, this research provides a scientific foundation for policymakers, water resource managers, and local communities to implement targeted interventions, thereby contributing to the achieve the Sustainable Development Goal 6 (Clean Water and Sanitation).

2. MATERIALS AND METHODS

2.1 Study Area

Pavagada Taluk is geographically located 13.92°N to 14.35°N, 76.78°E to 77.15°E in Tumakuru District of Karnataka, India is underlined by granitic-gneissic bedrock and has a semi-arid climate (Köppen, BSh) with a average annual rainfall of 650 mm [10] (Figure 1). The groundwater system of the area is sensitive to the geogenic mineralization as it has been exposed to the water-rock interaction processes for a longer period of time in fractured aquifers [26].

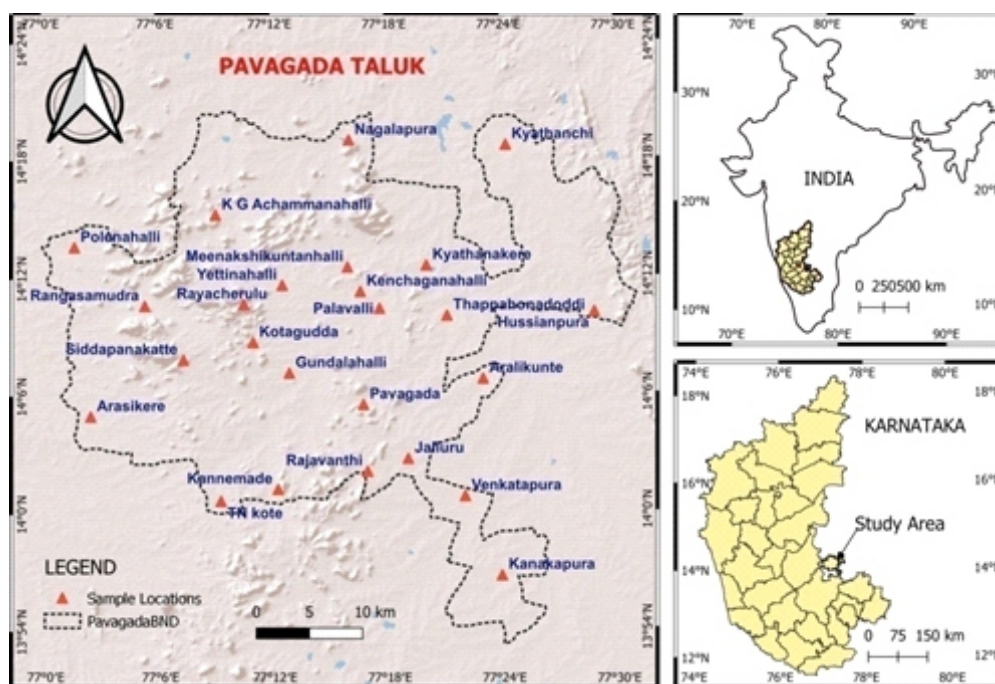


Fig.1: Location map of study area of Pavagada Taluk, Karnataka, India.

A representative Twenty-five ground water samples from borewell and handpump were collected both in pre-monsoon (May 2024) and post-monsoon (December 2024) seasons covering across the study area of hydrological units are shown in the Figure 2. Sampling proceeded in

accordance with BIS 10500:2012, where GPS-tagged samples were collected, the pH, EC, and temperature were measured on-site using calibrated with multiparameter probe (Hanna, HI98194).

Table 1: Sampling villages for groundwater in Pavagada taluk, Tumakuru district, Karnataka, India.

Site No	Name of the village
Site 1 (S1)	Kanakapura
Site 2 (S2)	Venkatapura
Site 3 (S3)	Rajavanthi
Site 4 (S4)	Pavagada
Site 5 (S5)	Aralikunte
Site 6 (S6)	Hussianpura
Site 7 (S7)	Rayacherulu
Site 8 (S8)	Kyathanchi
Site 9 (S9)	Nagalapura
Site 10 (S10)	Jalluru
Site 11 (S11)	K G Achammanahalli
Site 12 (S12)	Yettinahalli
Site 13 (S12)	Kenchaganahalli
Site 14 (S14)	Meenakshikuntanhalli
Site 15 (S15)	Kyathanakere
Site 16 (S16)	Thappahonadoddi
Site 17 (S17)	Palavalli
Site 18 (S18)	Gundalahalli
Site 19 (S19)	Kotagudda
Site 20 (S20)	Siddapanakatte
Site 21 (S21)	Rangasamudra
Site 22 (S22)	Polenahalli
Site 23 (S23)	Arasikere
Site 24 (S24)	TN kote
Site 25 (S25)	Kannemade

2.3. Analytical Methods

Sixteen parameters were measured as per the BIS and WHO standards (Table 2): pH, EC, TDS (Hanna HI98194) and analyzed as per APHA [27]. Titrimetry (APHA 2320), Total alkalinity, hardness (Ca^{2+} , Mg^{2+}), chlorides. Spectrophotometry (HACH DR3900): Nitrate (APHA 4500- NO_3), Sulphate (APHA 4500- SO_4^{2-}).

Fluoride ion-selective electrode (Thermo Scientific Orion Star A329). Fe and Cu are observed Atomic Absorption Spectroscopy (PerkinElmer PinAAcle 900T). Quality Assurance passes Triplicate analysis with certified reference materials (CRM, NIST 1640a) resulted in <5% RSD. Charge balance errors were $\pm 5\%$ for all samples ([28]).

2.4. Spatial Analysis

Mapping of contamination hotspots was achieved by inverse distance weighting (IDW) interpolation in QGIS, which was validated by kriging cross-validation (RMSE <0.8). Table 2 showing the BIS and WHO Standards for various analytical parameters.

Table 2. BIS and WHO Standards and Parameters.

S. No.	Parameter	Standard in mg/L
1.	pH	6.5-8.5
2.	TDS	500-2000
3.	Electrical Conductivity	u/s
4.	Total Alkalinity	200-600
5.	Total Hardness	200-600
6.	Ca Hardness	75-200
7.	Mg Hardness	30-100
8.	Chlorides	250-1000
9.	Dissolved Oxygen	>4.5
10.	Nitrate	45
11.	Fluoride	1-1.5
12.	Iron	0.3
13.	Copper	<1.5
14.	Colour	5-15 hz
15.	Turbidity	1-5 NTU
16.	Sulphate	200-400

3. Results

The comprehensive analysis of 25 groundwater samples from Pavagada Taluk revealed a complex hydro chemical profile (Table 3 and Fig 3),

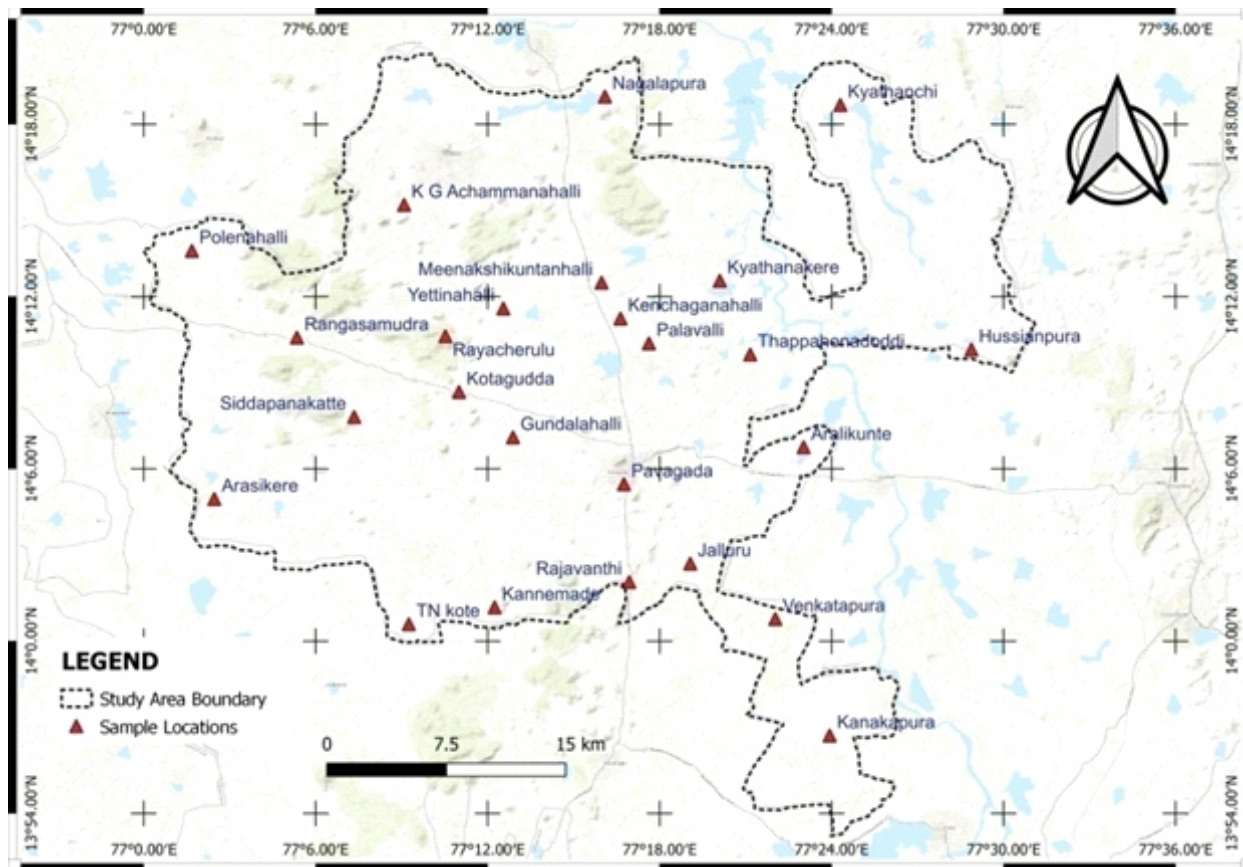


Fig. 1: Hydrological units of the study area, Pavagada Taluk, Karnataka, India.

parameters largely conforming to Bureau of Indian Standards (BIS 10500:2012) limits, except for one critical exception. The pH values were ranged from 6.7 to 7.5 pre-monsoon and 7.2 to 8.1 post-monsoon season.

Total Dissolved Solids (TDS) values exhibited a moderate variability (642–1125 mg/L pre-monsoon; 626–912 mg/L post-monsoon), remaining all values were remains within the permissible limit (<2000 mg/L).

Table 3: Groundwater Quality during Pre monsoon (May-2024).

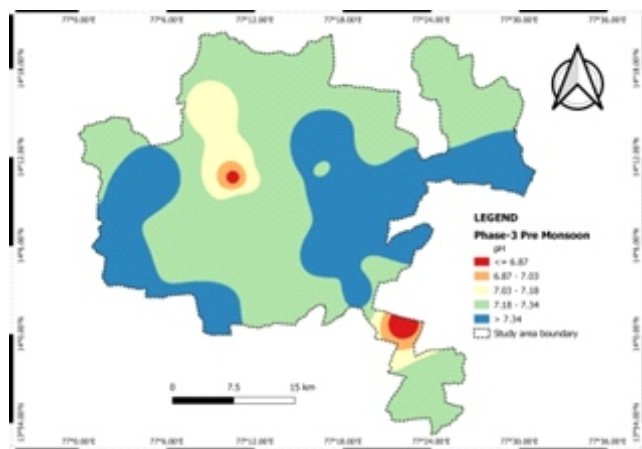
Parameter	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25
pH	7.3	6.7	7.3	7.4	7.5	7.4	6.8	7.2	7.3	7.4	7.1	7.2	7.3	7.5	7.3	7.4	7.5	7.3	7.3	7.3	7.5	7.3	7.4	7.5	7.3
TDS	82	94	83	73	95	115	93	82	75	82	86	76	72	68	82	86	76	62	82	96	115	93	75	62	68
EC	164	188	166	136	180	230	186	164	150	164	162	142	144	130	106	148	88	108	104	130	156	86	102	134	128
Alkalinity	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25
Hardness	127	131	112	129	133	142	113	161	126	145	123	128	142	47	115	116	154	146	45	136	142	115	125	136	121
Calcium hardness	182	162	142	112	146	102	148	162	172	149	181	145	134	112	126	102	135	108	136	112	136	142	112	126	102
Magnesium hardness	31	24	13	32	53	29	17	56	24	25	39	45	32	29	17	48	42	53	57	49	18	25	26	24	22
Iron					Notable																				
Copper					Notable																				
Chlor					Clouss																				
Turbidity	14	07	12	13	06	04	63	13	06	04	41	04	12	19	7	07	1	18	23	15	12	31	18	12	14

Table 4: Groundwater Quality during Post monsoon (December-2024).

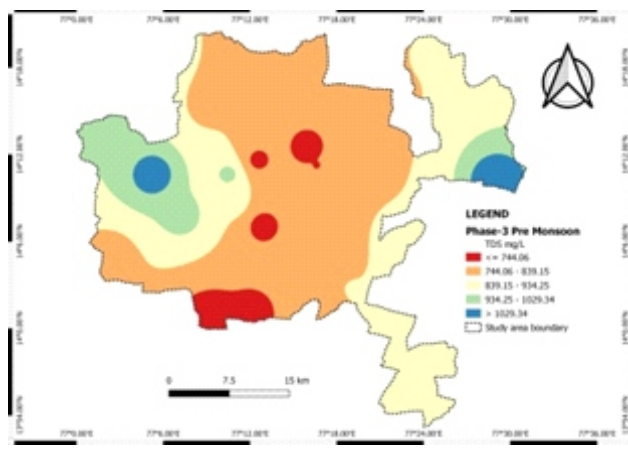
S. No	Parameter	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25
1	pH	7.6	7.5	7.2	7.7	7.8	7.9	7.8	7.8	7.7	7.7	7.7	7.8	7.7	7.6	7.8	8.1	7.8	7.8	8.1	7.7	8.0	7.9	8.0	8.1	8.0
2	TDS	742	875	776	804	875	891	876	784	716	756	811	690	714	726	792	841	766	672	826	856	886	912	751	662	626
3	EC	1480	1755	1553	1606	1751	1780	1750	1561	1430	1510	1620	1383	1420	1450	1581	1682	1532	1339	1653	1710	1765	1820	1492	1320	1255
4	Alkalinity	85	78	72	85	76	91	84	81	72	69	81	88	68	71	88	86	61	74	79	57	60	72	89	81	65
5	Hardness	168	185	165	171	182	179	192	232	181	159	175	215	195	180	165	171	165	172	175	161	160	170	155	165	211
6	Ca Hardness	105	123	115	128	135	142	151	175	132	118	126	172	158	138	138	141	128	126	131	126	123	132	115	118	162
7	Mg Hardness	63	62	50	43	47	37	41	57	49	41	49	43	37	42	27	30	37	46	44	35	37	38	40	47	49
8	Chlorides	82	72	84	86	102	95	90	112	110	103	95	101	79	72	81	76	82	83	75	81	69	81	76	72	70
9	Fluoride	12.3	11.2	13.6	12.1	11.2	12.6	10.2	11.2	12.6	10.2	13.7	10.4	10.3	12.1	11.6	13.5	10.3	11.3	14.7	13.6	10.8	11.8	13.2	11.0	12.2
10	Nitrate	2.8	2.6	2.1	2.8	5.7	2.4	1.5	6.4	2.5	3.2	3.1	5.2	3.3	2.7	1.5	5.4	5.7	6.1	5.8	5.1	2.4	3.1	3	2.6	2.8
11	Iron	Nil (Average of 0.02)																								
12	Copper	Nil (Average of 0.01)																								
13	Colour	Normal																								
14	Turbidity	Clear and transparent , No turbidity																								

Total Hardness (152–222 mg/L as CaCO) and Calcium Hardness were predominantly within acceptable limits, suitable for irrigation and notably, low Total Alkalinity was shown from 52–91 mg/L range. There was a pervasive fluoride contamination and it was ranged from 1.3 to 5.7 mg/L pre-monsoon and 1.5 to 6.4 mg/L post-monsoon, exceeds the BIS safe limit of 1.0–1.5 mg/L. The study area is enriched and is

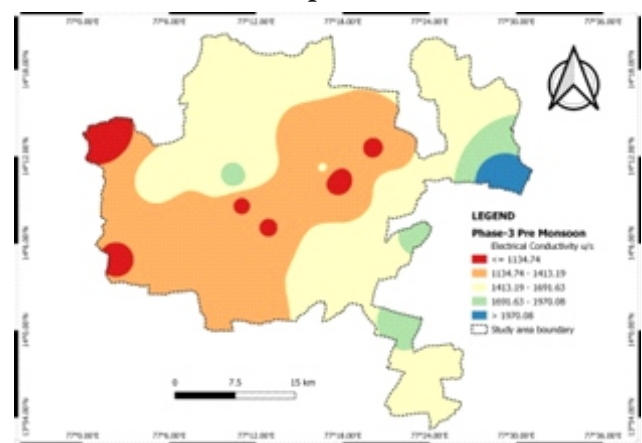
unequivocally geogenic, attributable to the dissolution of fluoride-bearing minerals (e.g., fluorite, apatite) present in the local granite-gneiss aquifers. Figure 3 and 4 showed the spatial persistence of these hotspots underscores the necessity of targeted intervention strategies over generalized approaches, prioritizing these high-risk villages for immediate remedial action.



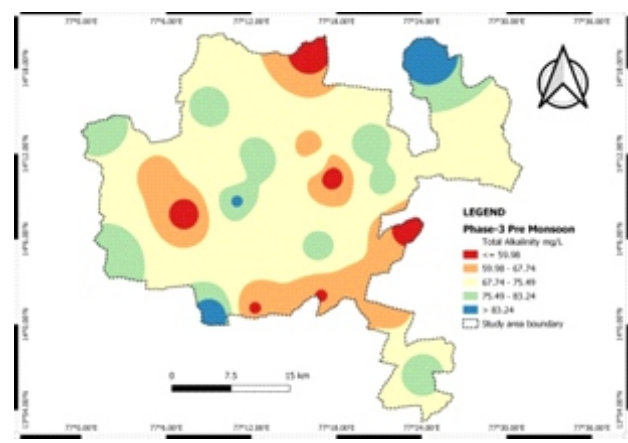
pH



TDS



Electrical Conductivity



Total Alkalinity

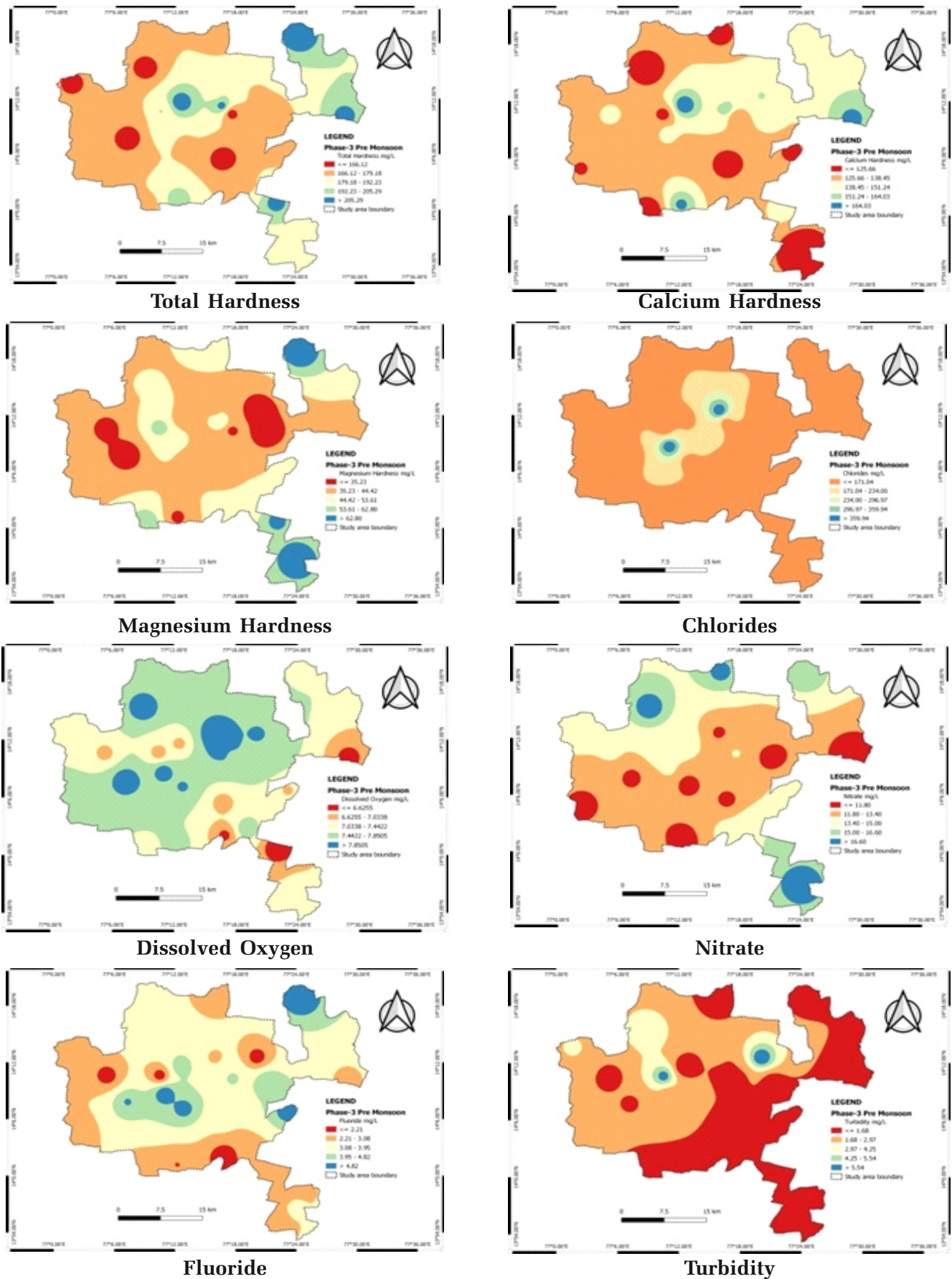
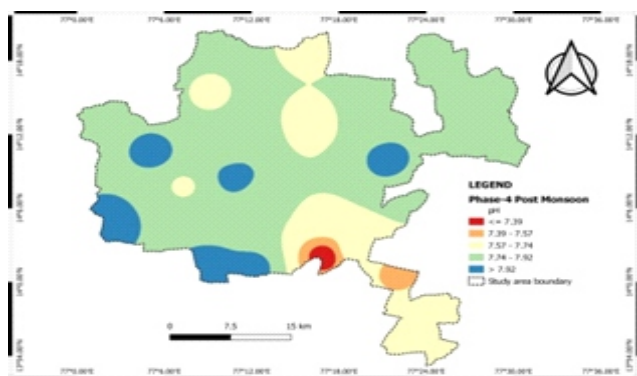


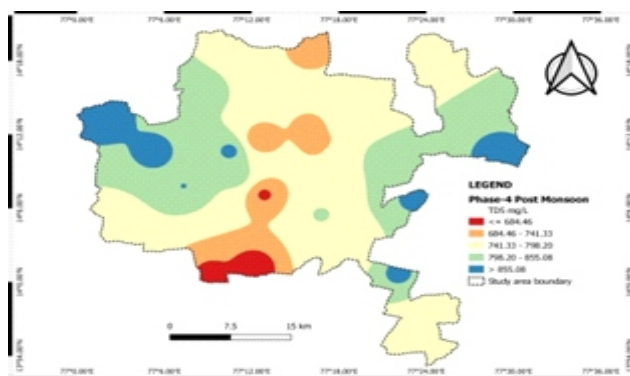
Fig. 3: Pre monsoon (May-2024) spatial distribution of groundwater quality of the study area.

Pre monsoon (May-2024) spatial distribution of groundwater quality of the study area is shown in Table 4 and Figure 4.

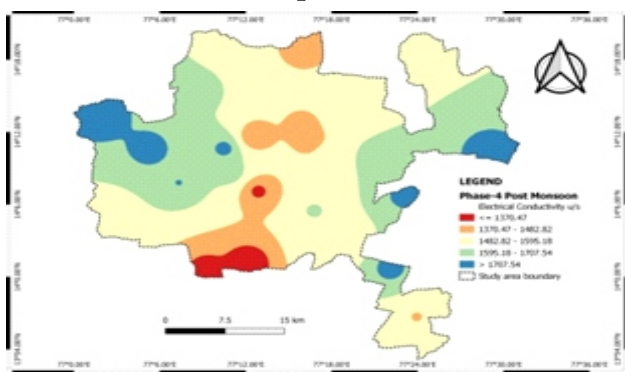
Spatial variation of physicochemical characteristics is shown in Figure 4.



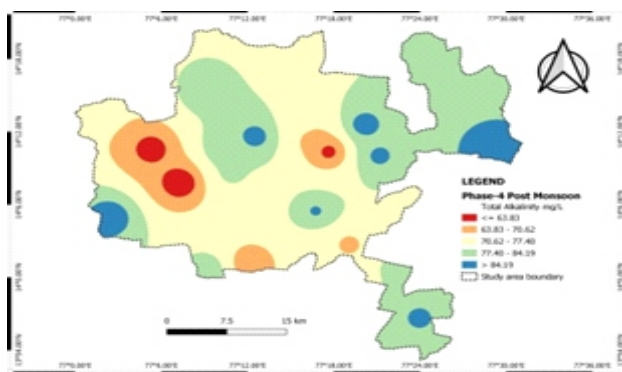
pH



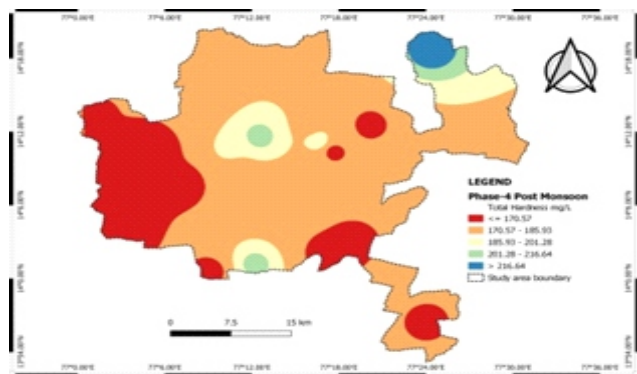
TDS



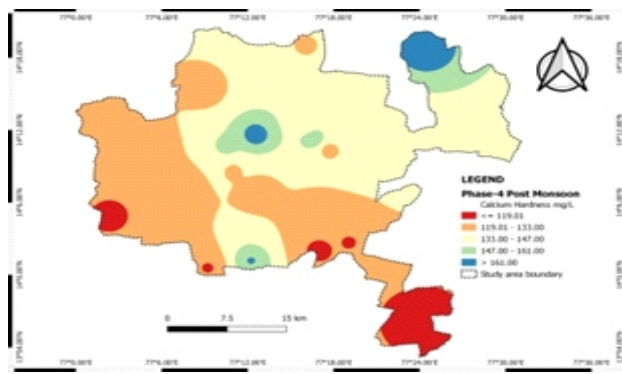
Electrical Conductivity



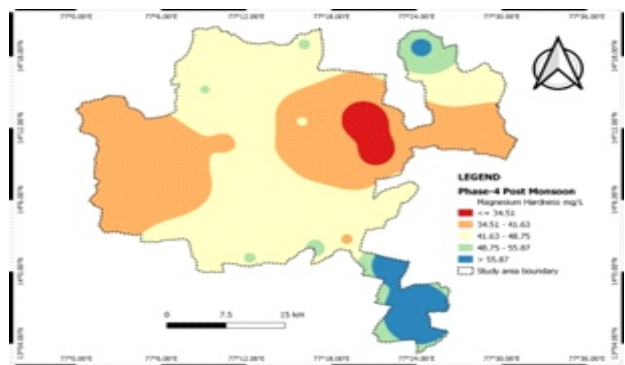
Total Alkalinity



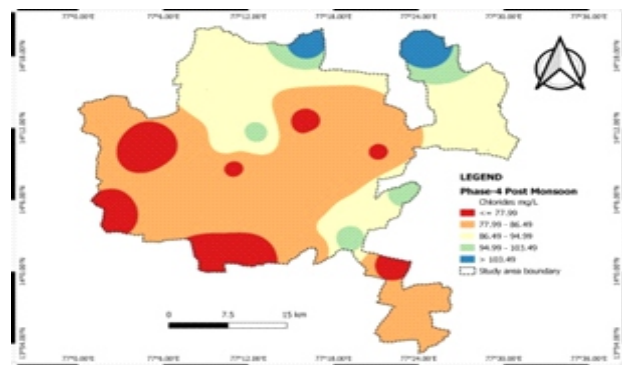
Total Hardness



Calcium Hardness



Magnesium Hardness



Chlorides

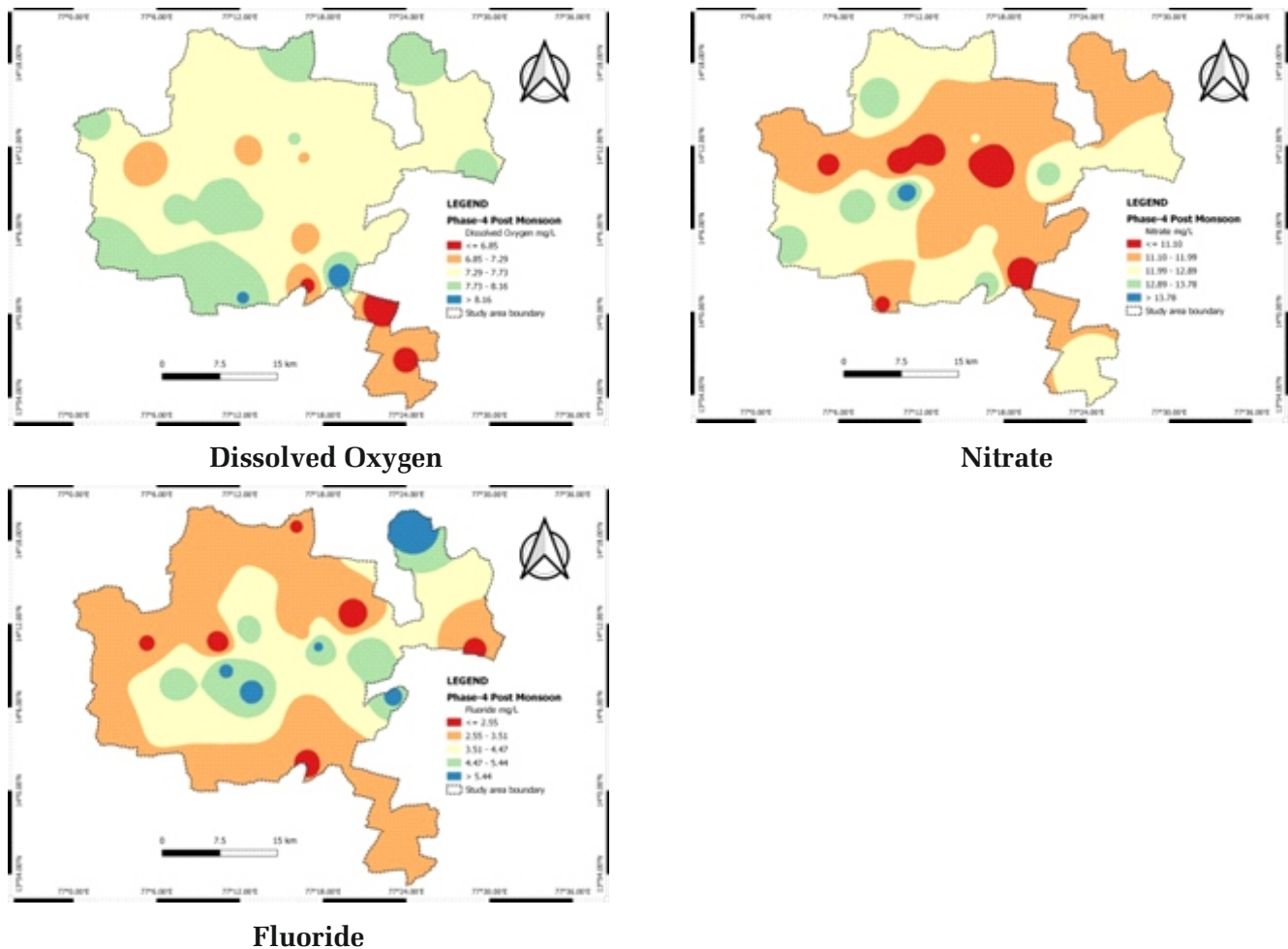


Fig. 4: Post monsoon (December-2024) spatial distribution of groundwater quality of the study area.

4. Discussion

In this study it indicates a stable, near-neutral to alkaline conditions conducive for domestic and agricultural use [29], [30]. The study showed a the groundwater quality with spatial distribution of TDS and Electrical Conductivity (EC) underscores the predominance of ionic constituents like Na^+ , Ca^{2+} , Mg^{2+} , and Cl^- , derived primarily from the weathering of the region's granitic-gneissic bedrock, a common phenomenon in peninsular India [12]. It also indicates a limited buffering capacity, rendering the aquifer vulnerable to acidification from potential anthropogenic inputs. Chloride and Nitrate concentrations were largely within safe limits, effectively ruling out widespread saline intrusion or significant contamination from agricultural runoff and sewage shows aerobic conditions. The spatial analysis reveals severe

hotspots in Kotagudda, Kyathanchi and Aralikunte study sites.

This enrichment is unequivocally geogenic, attributable to the dissolution of fluoride-bearing minerals (e.g., fluorite, apatite) present in the local granite-gneiss aquifers, a process exacerbated by ion exchange and evaporative concentration under semi-arid conditions [11], [13]. The post-monsoon increases in fluoride levels in some locations, contrary to the expected dilution effect, suggests a complex recharge dynamics and potential leaching from the unsaturated zone. This pervasive fluoride contamination presents a dire public health risk, including endemic dental and skeletal fluorosis for the local population reliant on groundwater [23], [31]. The spatial persistence (Fig 3 and 4) of these hotspots underscores the necessity of

targeted intervention strategies over generalized approaches, prioritizing these high-risk villages for immediate remedial action.

Based on findings, the following multi-pronged recommendations are proposed for sustainable groundwater management in Pavagada Taluk - *Immediate Public Health Intervention*: The pervasive fluoride contamination need to be addressed and immediate deployment of decentralized, community-managed defluoridation units using cost-effective adsorbents like activated alumina or bone char in the hotspot villages are Kotagudda, Kyathanchi, and Aralikunte. Concurrently, robust public health campaigns must be launched to educate communities on the severe health risks of fluorosis and the proper use and maintenance of treatment units. *Diversification of Water Sources*: Alternatively, the government and non-governmental agencies should promote and subsidize rainwater harvesting structures at both household and community levels. Furthermore, exploring the feasibility of sourcing and treating surface water from nearby sources should be prioritized to provide a sustainable, safe drinking water alternative.

Enhanced Monitoring and Research

The outcome of the study would serve as a baseline for a long-term, systematic groundwater quality monitoring network. A comprehensive cost-benefit analysis of various remediation technologies is also recommended. *Policy Integration and Sustainable Practice*: The spatial hydrochemical data must be integrated into local water security plans and watershed management programs. Policies should incentivize sustainable agricultural practices to prevent future nitrate and chloride pollution, to protect the water quality from anthropogenic degradation.

5. Conclusions

The physicochemical parameters of groundwater in Pavagada Taluk are found within permissible limits for domestic and agricultural use, the resource is critically compromised by pervasive fluoride contamination. The spatial analysis was

identifying the severe geogenic fluoride enrichment, with concentrations reaching up to 5.7 mg/L, exceeds the BIS safety limit. This presents an immediate and severe public health risk, including endemic dental and skeletal fluorosis for the dependent population. The findings underscore a clear disconnect: the water is otherwise chemically suitable but is rendered unsafe for direct consumption due to this single parameter. Therefore, conventional water quality management approaches are insufficient. The sustainable water resource management is contingent upon addressing this specific contaminant through a multi-pronged strategy. This must include the immediate deployment of decentralized defluoridation units in hotspot villages, coupled with the development of alternative water sources like rainwater harvesting to reduce dependency on contaminated groundwater. The long-term sustainability hinges on integrating these technical interventions with robust community awareness programs and establishment of continuous groundwater quality monitoring network. This research provides a critical evidence base for policymakers to prioritize public health and implement targeted, sustainable water security measures in Pavagada Taluk and similar fluoride-endemic regions.

Abbreviations

APHA: American Public Health Association
BIS: Bureau of Indian Standards
CGWB: Central Groundwater Board
DO: Dissolved Oxygen
EC: Electrical Conductivity
NITI: (National Institution for Transforming India)
TDS: Total Dissolved Solids
TH: Total Hardness
WHO: World Health Organization

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Author Contributions

V.D. Shivanna Vaddarahalli Dasappa: Conceptualized the Research area, collected resources and carried out formal analysis and writing original draft.

J.S. Chandrashekar: The author supervised the entire work, provided the methodology and edited and validated final manuscript.

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Data Availability Statement

1. The data supporting the outcome of this research work has been reported in this manuscript.

Conflicts of Interest

“The authors declare no conflicts of interest.”

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