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Impact of 2018 Climate Extreme on Groundwater Quality: Assessment of Environmental Pollution and Health in Periyar Basin, Southern Western Ghats, India

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ABSTRACT

The increasing frequency and intensity of climate extremes such as heavy rainfall, tropical cyclones, and large-scale flooding are key manifestations of Anthropocene-driven climate change, with profound impacts on Earth system processes. These disruptions have heightened the prevalence of climate-sensitive diseases and intensified environmental contamination, particularly in tropical regions. This study examines the influence of the 2018 Kerala floods on groundwater quality and associated public health risks in the Periyar River Basin (PRB), a low-lying region with a shallow water table vulnerable to rapid floodwater infiltration. Groundwater samples (n = 47) were collected across four hydrological phases: pre-flood, flood, and post-flood periods of 2018, and a non-flood period in 2021. Analysis revealed that 69% of wells experienced improved water quality post-flood, 19% showed deterioration during the flood compared to pre-flood conditions, and 12% exhibited negligible change. In 2021, degraded water quality was observed in 15% of samples during the pre-monsoon and in 11% during the post-monsoon period. Health data analysis indicated a peak in diarrheal illnesses prior to the flood, correlating with *Escherichia coli* concentrations reaching 760 CFU/mL likely due to infiltration from septic systems or compromised sewage infrastructure. Following flood response measures such as systematic well disinfection and chlorination, *E. coli* levels declined to 280 CFU/mL. The findings highlight the vulnerability of shallow aquifers to climate-induced flooding and emphasize the critical need for integrated water quality monitoring and post-disaster sanitation interventions to mitigate microbial and chemical contamination in groundwater.

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1. Introduction

Assessing groundwater quality and its suitability for various uses is crucial for sustainable groundwater management, particularly in a country like India, characterized by diverse geographical and socio-economic conditions (IPCC, 2021). India is among one of the most vulnerable countries to the impacts of climate change, with the Indian subcontinent frequently experiencing hydrometeorological disasters that are increasingly exacerbated by the ongoing climate crisis (Mukherjee et al., 2020; Shah et al., 2003).

In recent years, there has been a significant rise in the occurrence of natural disasters, leading to loss of life, property damage, and environmental devastation (Singh et al., 2022). Floods, a natural phenomenon inherent to Earth's biophysical processes, can escalate to catastrophic levels due to human activities such as land-cover clearance, alteration of natural drainage systems, deforestation, and ongoing construction in wetland areas along riverbanks (Charles et al., 2020).

These events also exert profound impacts on human health and spread of infectious diseases (Hoque, 2016). Elevated precipitation creates profuse breeding grounds for vectors (Aedes aegypti) while, extreme drought conditions enhance container usage for rainwater storage, fostering their growth and lifecycle. Water-related infectious diseases like malaria, dengue fever, chikungunya, along with their causative agents and the mode of transmission of these diseases have been affected by climate variability. Similarly, waterborne diseases like typhoid and cholera are influenced by climate change patterns, and the subsequent risks related to these diseases are increasing (Wu et al., 2015). Over the past two decades, floods have become increasingly prevalent in developing nations, characterized by heightened severity, resulting in fatalities, injuries, displacement, infrastructure damage, and environmental degradation. India has been identified as one of the most flood-vulnerable regions in South Asia, with a rising frequency of extreme flood events (Singh and Goyal, 2017; Sudheer et al., 2018; Mujumdar et al., 2020; Malik, 2023). While historical extreme flood events have been within the bounds of climate variability, the potential for increased magnitude, frequency, and extent of flooding due to climate change is a concerning prospect. The impacts of climate change on flood patterns may shift priorities for food risk reduction, potentially amplifying hazards in numerous flood-prone areas (Mohammed et al., 2018; Saharia et al., 2021). Notably, India has experienced severe flood disasters in recent years attributed to extreme rainfall conditions, including the Leh Flood (2010), Kedarnath Flood (2013), Jammu and Kashmir Flood (2014), Chennai Flood (2015), Kerala Flood (2018 and 2019), and Bengaluru Flood (2018) (Sudheer et al., 2018; Mujumdar et al., 2020; Malik, 2023). Regions such as the Western Ghats have witnessed a notable increase in extreme rainfall events since 2018, posing a significant threat to water resources in these areas.

The climate dynamics of the Indian Peninsula are significantly influenced by the presence of the Western Ghats, which serve as a substantial climatic barrier separating the western coastal region from the interior parts of the peninsula (Gunnell, 1997). The orographic features of the Western Ghats, characterized by their topographic complexity, relief patterns, and steep windward slopes, exert a profound influence on rainfall distribution. During the Indian Summer Monsoon (ISM) season, the intricate topography, elevated summits, and steep slopes of the Western Ghats contribute to the intensification of rainfall, particularly along the windward slope (Tawde & Singh, 2015). The drainage networks of numerous small river basins situated in the windward slope of the Western Ghats heavily depend on the precipitation received during the ISM, thus significantly shaping the hydrology and water availability in these regions. Therefore, in this study, an attempt has been made to assess the groundwater quality and the associated health risk in one of the worst affected river basins of 2018 Kerala floods- Periyar River Basin (PRB), Kerala, India. This study may be helpful in similar future studies since the Western Ghats are prone to climate extreme impacts.

2. Study Area

Kerala, located along the southwestern coast of India, is distinguished by its unique geographical features, with the Western Ghats forming its eastern boundary and the Arabian Sea to the west. As the first region to receive the Indian Summer Monsoon Rainfall (ISMR), Kerala experiences some of the highest monsoon rainfall levels in the country, making it a critical area for studying monsoon dynamics and their associated impacts on regional hydrology and ecosystems. The Periyar River, the longest river in Kerala (l = 244 km; A = 4,793 km²), spans from latitude 9°16' N to 10°20' N and longitude 76° E to 77°30' E. Its basin configuration resembles an inverted 'L' shape, characterized by a dendritic drainage pattern (Krishnakumar et al., 2022). Originating from an elevation of 2438 meters above mean sea level (AMSL) within the Western Ghats Mountain range, the river flows westward, ultimately discharging into the Arabian Sea. Elevations within the basin range from 2695 meters AMSL to sea level, reflecting its topographical diversity. Given its perennial nature, the Periyar River plays a crucial role as a water source in central Kerala, catering to a population exceeding 4,391,362 individuals as per the 2011 Census. The climate of the Periyar River Basin is tropical-humid, with a bimodal rainfall pattern concentrated from June to November, contributing 60% and 25% of the total rainfall, respectively contributing to a mean annual precipitation of 3200 mm. During the last week of July and the first and second weeks of August, a significant portion, approximately 80%, of the daily discharge exceeds 2000 m^3/s in the Basin. Temperature variations oscillate between 25°C to 32°C for maximums and 14°C to 19°C for minimums, exhibiting a gradient from upstream to downstream where the average annual temperature ranges from 28°C to 30°C. Annual evapotranspiration in the basin averages approximately 850 mm. Geologically, the Periyar River Basin (PRB) is characterized by three distinct formations: Precambrian crystalline rocks, Tertiary formations, and Quaternary deposits. The basin's major soil types include forest loam, lateritic soil, brown hydromorphic soil, and alluvial soils, with forest loam and lateritic soil covering approximately 60% of the area (GSI, 1995). The land use within the basin is predominantly plantation (52.02%) and forested (33.31%) areas, featuring clay and loam soil textures. The forest cover mainly consists of tropical evergreen species and cultivated plantations such as rubber, eucalyptus, teakwood, coconut, and areca nut (Krishnakumar et al., 2023). The region's agro-climatic conditions are well-suited for cultivating cash crops, including rice, millet, coffee, pepper, and cardamom, which constitute the primary sources of income for the local population.

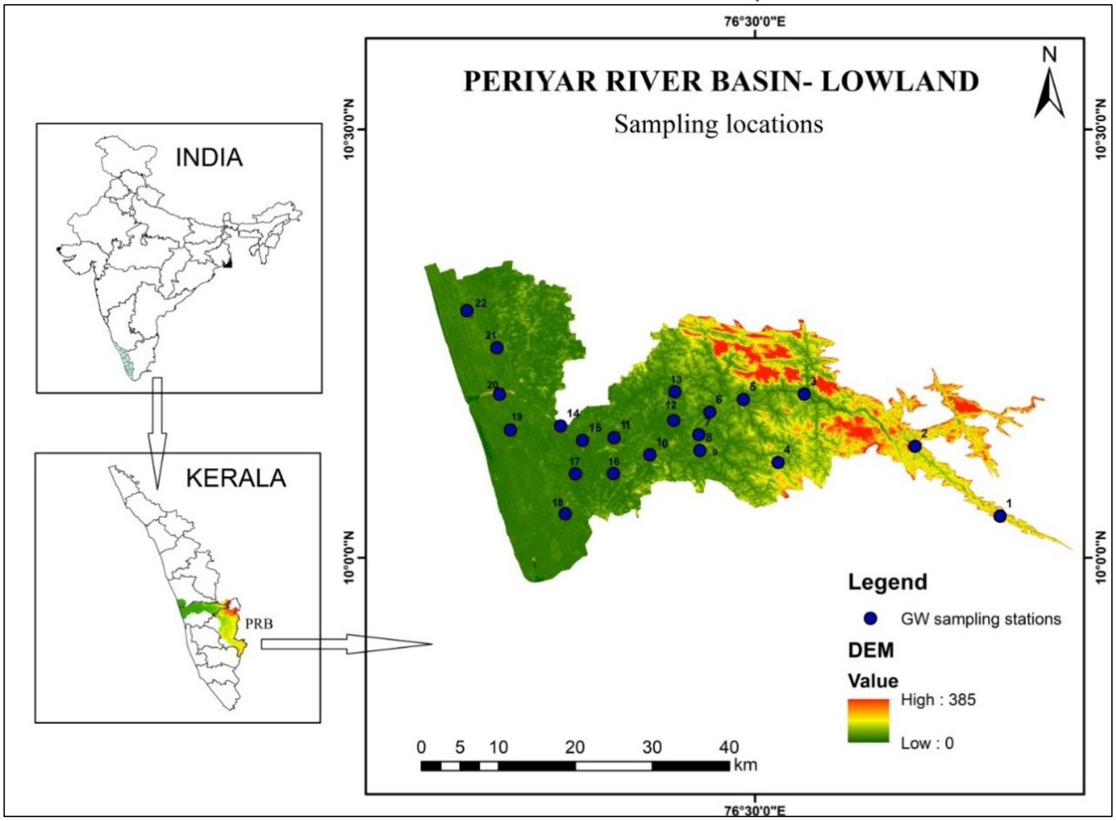

Fig.1 Location map of the study area with sampling locations

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3. Materials and Methods

Water samples were obtained from 47 strategically selected sites within the lower reaches of the PRB for hydrochemical investigation. Sampling was conducted during the pre-flood, flood, and post-flood periods of 2018 (26 samples), as well as during the non-flood period of 2021 (22 samples) (Fig. 1). All samples for cation and anion analysis were collected in pre-cleaned high-density polyethylene (HDPE) bottles, rinsed thoroughly with the respective sample water at least three times prior to collection, in -accordance with APHA (1995) guidelines.

The exact geographic coordinates of each sampling location were recorded in the field using a Global Positioning System (GPS) device. In-situ measurements, including temperature, pH, electrical conductivity, and total dissolved solids (TDS), were obtained using a Hydrolab Multiparameter Sonde. Major cations-calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), and potassium (K^{+}) were quantified using Microwave Plasma-Atomic Emission Spectroscopy (MP-AES). Key anions, including nitrate (NO_3^{-}), sulfate (SO_4^{2-}), and chloride (Cl^{-}), were analysed using a Continuous Flow Analyser and a UV-VIS-NIR spectrophotometer.

3.1 Water quality index

The Bureau of Indian Standard Water Quality Index (BIS WQI) is the Indian national WQI standard parameter which is defined by the Government of India under IS: 10500. To evaluate the overall suitability of water for irrigation and to integrate multiple water quality parameters into a single representative value, the Water Quality Index (WQI) approach was utilized-recognized as a widely accepted method in hydrochemical assessments. The calculation of WQI in this study followed a structured four-step procedure, as outlined below:

Step 1: Collection of data regarding the relevant physicochemical water quality parameters.
Step 2: Calculation of Proportionality constant "K" value using the formula;

$$K = \left[\frac{1}{1/\sum nisi}\right] \text{.................. Eq 2}$$

where "si" is standard permissible for the nth parameter.
Step 3: Calculation of quality rating for the nth parameter (Qn) where there are n parameters.

$$Qn = 100 * \left\{\frac{Vn-Vi}{Sn-Vi}\right\} \text{............... Eq 3}$$

where Vn = Estimated value of the nth parameter of the given sampling station.
Vi = Ideal value of the nth parameter in pure water. And Sn = Standard permissible value of the nth parameter.

Step 4: Calculation of unit weight for the nth parameter.

$$Wn = \left(\frac{K}{Sn}\right) \text{.....................Eq 4}$$

Step 5: Calculate the water quality index (WQI) using the formula,

$$WQI = \frac{\sum Wn*Qn}{\sum Wn} \text{.................. Eq 5}$$

The classification of water quality status was determined based on the computed WQI values, followed by Brown et al., 1972 (Table 1).

Table 1. Categorization of Water Quality based on WQI values and Recommended Use (Brown et al.,1972)

WQI range	Water Quality Status (WQS)	Suggested Applications
0-25	Excellent	Safe for drinking, irrigation and industrial activities
26-50	Good	Suitable for drinking, irrigation and industrial use
51-75	Poor	Acceptable for irrigation and industrial usage only
76-100	Very Poor	Restricted to irrigation purposes
Above 100	Not Suitable (Untreated)	Requires treatment; unsuitable for drinking or aquaculture

4. Results and Discussion

4.1 Impact on major ion chemistry

The results of this study reveal that flooding exerts a substantial influence on groundwater systems within the low-lying zones of the Periyar River Basin (PRB). Excessive rainfall during flood events has sustained high groundwater levels in coastal aquifers, thereby reducing the risk of seawater intrusion into adjacent coastal aquifers. Conversely, periods of low hydrostatic pressure preceding floods have increased the vulnerability to seawater intrusion. These dynamics are reflected in the observed Electrical Conductivity (EC) values, which were lower in post-flood and higher in pre-flood (Sylus & Ramesh., 2014; Seenipandi et al., 2019). The study revealed distinct variations in water quality parameters during flood events compared to pre-flood and post-flood periods. During floods, there was a decrease in pH, total dissolved solids (TDS), EC, total hardness (TH), NH_3^-, NO_2^-, HCO_3^-, SO_4^{2-}, SiO_4^{4-}, Mg^{2+}, and K^+, while Ca^{2+}, Na^+, Cl^-, and turbidity levels increased. In the post-flood period, a slight increase was noted in pH, TDS, EC, turbidity, NH_3^-, HCO_3^-, SO_4^{2-}, SiO_4^{4-}, Mg^{2+}, Na^+, and K^+ compared to flood conditions, with turbidity, NH_3^-, SO_4^{2-}, Na^+, and K^+ values slightly exceeding those observed in the pre-flood period. Pre-flood conditions exhibited higher values for pH, TDS, EC, TH, NO_2^-, Cl^-, HCO_3^-, SiO_4^{4-}, PO_4^{3-}, Ca^{2+}, Mg^{2+}, and E. coli compared to post-flood periods (Fig. 2). The spatio-temporal variability of physico-chemical properties revealed the dominance of cations in the order $Ca^{2+} > Mg^{2+} > Na^+ > K^+$ and anions in the order $Cl^- > HCO_3^- > SiO_4^{4-} > SO_4^{2-}$, with other constituents found in lower concentrations (Fig. 3).

4.2 Impact on drinking water quality

Evaluating the Water Quality Index (WQI) for groundwater samples from the lower reaches of the Periyar River Basin (PRB) is crucial due to the prevalence of diverse anthropogenic activities in the study area. According to the WQI model, analysis of 26 samples revealed that 69% of wells exhibited improved water quality, 19% experienced deterioration, and 12% remained unchanged in post-flood. In contrast, during the 2021 pre-monsoon (PRM) and post-monsoon (POM) seasons, water quality was poor in 15% and 11% of samples, respectively (Krishnakumar et al., 2022). The WQI results further indicate that coastal aquifers are substantially affected by seawater intrusion, climatic variations, topographical changes, and industrial waste disposal. The proximity of these locations to tidal influences likely exacerbates these impacts. Despite observed declines in water quality following the major floods in late August 2018, the WQI suggests an overall improvement in water quality in flood-affected areas. This enhancement is likely due to post-flood cleaning and chlorination efforts by government and public interventions. In this study, the maximum concentration of E. coli colonies detected in groundwater samples was 760 CFU/ml during the pre-flood period, 50 CFU/ml during the flood period, and 280 CFU/ml during the post-flood period. Among the 26 samples collected during each period, E. coli was detected in 6 samples each during the pre-flood and post-flood periods, and in 2 samples during the flood period, with all values exceeding the World Health Organization (WHO) standards for potable water (WHO, 2017). The presence of E. coli indicates recent fecal contamination and suggests the potential presence of harmful bacteria, viruses, and other pathogens. The higher concentrations of E. coli observed during the pre-flood and post-flood periods, as compared to the flood period, may be attributed to septic tank or sewer line leakage, which is consistent with findings of increased fecal contamination during periods of reduced hydrostatic pressure and subsequent infiltration.

4.3 Comparison of groundwater quality- 2018 vs- 2021

To assess variations in groundwater quality, the average values of key physico-chemical parameters in the lowland region of the Periyar River Basin (PRB) during 2021 were compared with data from the flood period of 2018 (Table 2). The comparative analysis revealed that the trends for most parameters in 2021 were consistent with those observed during the post-flood period of 2018. Specifically, the mean pH in 2021 was comparable to that recorded during both the pre-flood and flood periods of 2018. Similarly, the mean electrical conductivity (EC) and total dissolved solids (TDS) in 2021 mirrored the values observed during the flood period of 2018. However, while the major cations and anions in 2021 showed similar patterns to those in the post-flood period of 2018, calcium (Ca^{2+}) exhibited different trends (Krishnakumar et al., 2023).

4.4 Impact on the occurrence of diseases

Continuous observations from 2013 to 2022 in the Periyar River Basin (PRB) indicate that the 2018 deluge significantly impacted groundwater quality, increasing the incidence of diarrheal disorders. Floodwaters contaminated groundwater sources, primarily affecting shallow water tables in the lower reaches of the basin, thereby heightening the risk of communicable diseases associated with inadequately treated or unprotected water sources (Krishnakumar et al., 2022). During the 2018 Kerala floods, all open wells in the lowland regions of PRB were inundated with stormwater. Subsequently, these wells were cleaned and chlorinated by government agencies and village authorities, which contributed to a decrease in reported cases of Acute Diarrheal Disease (ADD) in 2018 compared to 2017 (Krishnakumar et al., 2022). The floods of 2018, followed by the 2019 floods and the COVID-19 pandemic, heightened public awareness of hygiene practices, leading to a reduction in viral fever and malaria cases from 2018 to 2022 compared to 2017. However, an increase in diseases such as Dengue and Leptospirosis was observed during 2021-2022 (Fig. 4) as per data collected from District Medical Office, Ernakulam. This trend may be attributed to factors including changes in temperature, rainfall, relative humidity, and unplanned urbanization in Kerala over the past decade (Yadav & Upadhayay, 2023). Additionally, the movement of animal populations, particularly rodents, due to changing food resources has facilitated virus transmission across larger regions, exacerbated by climate change and deforestation (Saeed & Piracha, 2016). Deforestation has raised local and indoor temperatures, enhancing conditions for malaria transmission. Heavy rainfall and droughts have driven livestock to seek favorable conditions, increasing human exposure and contributing to emerging infectious diseases such as anthrax and H1N1.

4.5 Analysis of land use change

Land use and land cover (LULC) dynamics exert a notable influence on water quality indicators at the sub-basin scale, especially within river basins subject to intensive anthropogenic pressures. In this study, LULC changes for the years 2017 and 2023 were analysed using Sentinel-2 satellite imagery via the Landcover Explorer tool (Fig. 6). The analysis revealed increases in water bodies, cropland/agricultural areas, and settlement zones by approximately 1%, 0.5%, and 1.5%, respectively, over the six-year period. Conversely, forested areas and grasslands declined by about 2% and 0.9%, respectively (Table 3). Key land cover transitions included conversions from plantations to settlements and from forests to plantations, alongside notable bidirectional changes between forest and plantation classes.

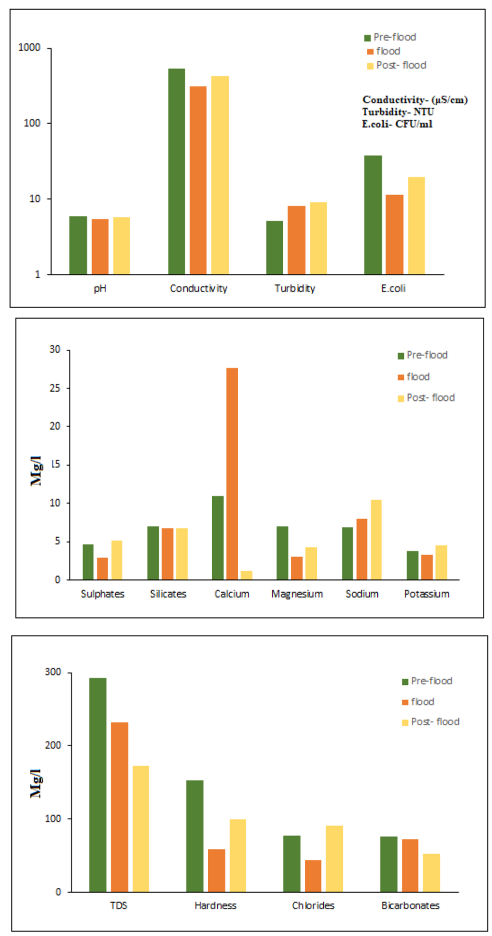

Fig 2. Comparative variation of different hydrochemical parameters during pre-flood, flood and post-flood periods

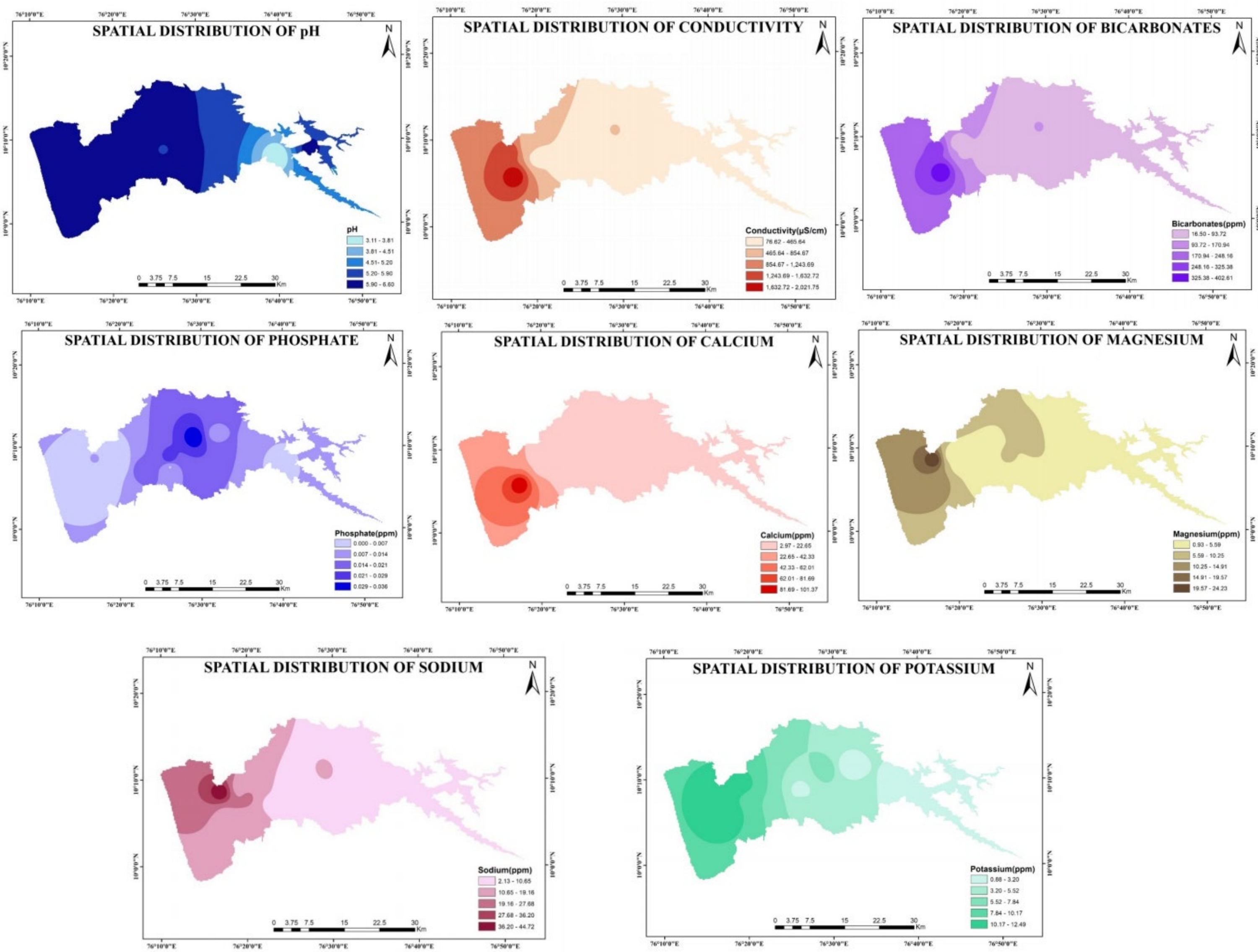

Fig 3. Spatial variation maps representing different physio-chemical parameters of GWs for 2018

Table 2. Comparison of the present study with the results of 2018

Sampling Phase	pH	EC (µS/cm)	TDS (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Na^{+} (mg/l)	K^{+} (mg/l)	Cl^{-} (mg/l)	HCO_3^- (mg/l)	SO_4^{2-} (mg/l)	$NO2^{-}$ (mg/l)	PO_4^{-} (mg/l)	Reference
Periyar Rb	5.82	314	205	10.45	4	9.44	3.6	45.5	81.5	12.8	9.93	5.01	Present study
RPLB (pre-flood)	6.02	532	293	10.97	7	6.83	3.76	77	76.17	4.70	-	0.04	2018 (Krishnakumar et al., 2018)
RPLB (flood)	5.49	314	173	27.62	3.04	8.05	3.35	91.03	52.83	2.87	-	0.04	
RPLB (post flood)	5.84	422.7	232.49	1.24	4.27	10.52	4.51	43.46	72.24	5.15	-	0.01	

* RPLB- River Periyar lower basin

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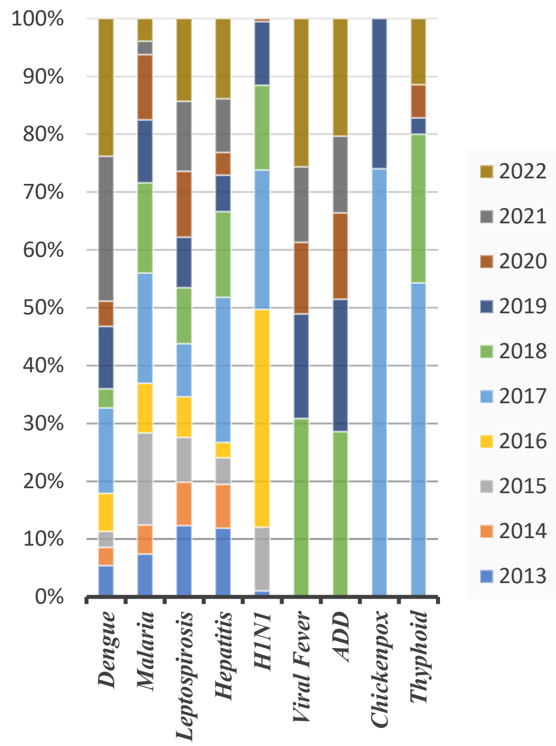

Fig 4. Reported cases of various communicable diseases in the study area (Data source: District Medical Office, Ernakulam)

In the Periyar River Basin (PRB), the observed decline in barren land is predominantly attributed to its transformation into plantation zones. Notably, the highland regions of the basin, which encompass reserved forest areas, are experiencing gradual encroachment along their buffer zones through the expansion of plantation activities. Consequently, existing plantations are being converted to croplands, and croplands to settlements. Similarly, according to Sadhwani et al. (2023), future LULC changes projected for the Periyar River Basin (PRB) indicate increases in cropland and urban areas by 5.1% and 17.63%, respectively, by 2100, alongside a decrease in forest cover by 24.58%. Cropland, barren land, and forest areas are expected to decline, while settlements and plantations are projected to expand. Water bodies will exhibit minimal change, with a marginal decrease of 0.4%. Settlements and plantations are predicted to grow from 3% to 14% and 0.48% to 2.7%, respectively, while cropland, barren land, and forest areas will decrease from 40% to 34%, 5% to 3.7%, and 46% to 40%, respectively.

Table 3. Changes in LULC pattern for 2017 and 2023 in PRB

Land use types	Period	
	2017 (%)	2023(%)
Waterbody	0.168	0.178
Forests and other vegetation	0.25	0.23
Flooded vegetation	0.011	0.008
Cropland/ agriculture	0.076	0.081
Settlements	0.06	0.075
Grassland/ Barren land	0.434	0.425

The findings suggest that continued deforestation and urban expansion are likely to accelerate land degradation, with significant implications for the watershed's hydrological regime. Elevated surface runoff is expected to reduce infiltration rates and baseflow contributions, thereby lowering soil moisture availability. These changes can degrade soil structure and fertility, disrupt natural streamflow dynamics, and increase the risk of flooding and associated environmental disturbances.

5. Conclusions

This study investigated the effects of the 2018 Kerala floods on groundwater quality and disease prevalence trends in the Periyar River Basin (PRB), within the broader context of climate variability. The analysis revealed a declining trend in several hydrochemical parameters such as pH, total hardness, nitrite, chloride, bicarbonate, silicate, phosphate, calcium, and magnesium from the pre-flood to post-flood periods. During the flood, concentrations of many solutes were notably lower at several sites, likely due to dilution, although indicators such as pH, turbidity, and Escherichia coli exceeded WHO permissible limits. The elevated E. coli concentrations were attributed to faecal contamination arising from compromised septic systems and sewage overflows.

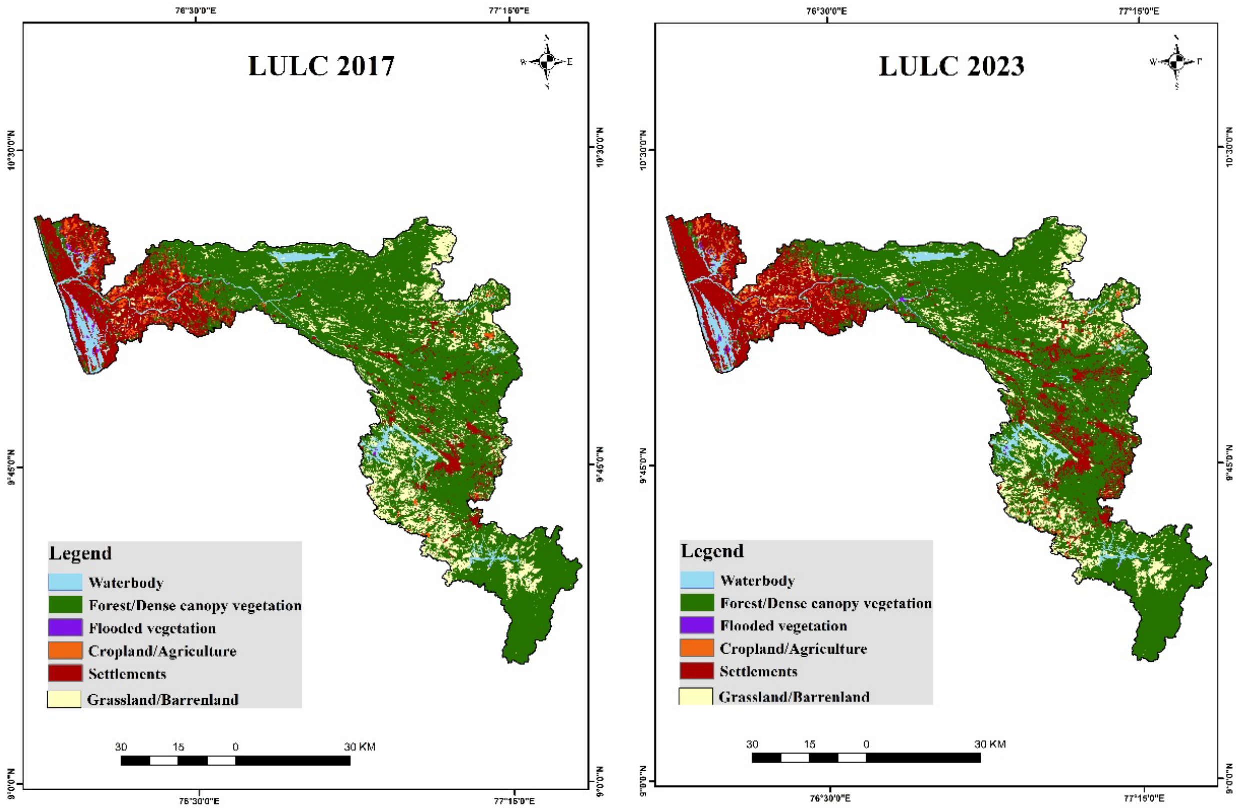

Fig 5. Change in LULC during 2017 and 2023

Water Quality Index (WQI) evaluations indicated that, prior to the flood, many groundwater samples were unsuitable for drinking due to elevated ionic loads and salinity. However, these parameters were diluted to acceptable levels during and after the flood, with the exception of certain lowland zones. Overall, most groundwater samples across the seasons were classified as having good quality. Nonetheless, deteriorated water quality was observed during the pre-monsoon (PRM) and post-monsoon (POM) periods near river mouths, likely due to saline intrusion driven by tidal influences. In terms of public health, disease trend analysis revealed a decline in reported diarrheal illnesses, whereas cases of dengue and leptospirosis showed an upward trajectory. Land cover changes—specifically, the reduction in natural vegetation and expansion of urban areas were found to significantly influence the watershed's hydrological balance. These changes have altered patterns of runoff, baseflow, rainfall distribution, and flood/drought intensity, thereby affecting both water quality and availability. Despite these stressors, groundwater quality in the lower PRB remained within acceptable thresholds during the flood and post-flood phases, underscoring both the resilience and vulnerability of the region's aquifer systems to climatic and anthropogenic pressures.

CRediT authorship contribution statement.

A.K. contributed to conceptualization, sample collection, formal analysis, data curation, investigation, concept, writing original draft, validation, methodology, visualization. **S.K.A.** contributed to conceptualization, formal analysis, data curation, supervision, concept, writing original draft, validation, project administration, resources. K.A.K. contributed to conceptualization, data curation, formal analysis, visualization. **G.R.** contributed to data curation, formal analysis. **M.K.J.** contributed to formal analysis, validation, data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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