Evaluation of Groundwater Quality and Potability Based on Land Use Variations: A Case Study from Mahiyanganaya, Sri Lanka

Gamage P.G.M.S.[1], Ven Pinnawala Sangasumana[2], Patabandi. K.P.L.N[3]

[1]Department of Earth Science, Peradeniya University of Sri Lanka

[2]Department of Geography, University of Jayewardenepura, Sri Lanka.

[3]Department of Geography and Environmental Management, Sabaragamuwa University of Sri Lanka

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ABSTRACT

This study evaluates groundwater quality and its suitability for drinking, highlighting the impact of land use patterns on water composition. Groundwater samples from 18 wells were analyzed for essential physicochemical parameters, including pH, dissolved oxygen (DO), electrical conductivity (EC), Total dissolved solids (TDS), Alkalinity, Total hardness (TH), Calcium, Magnesium, Sodium, Potassium, Sulfate, and Chloride. The results were compared to World Health Organization (WHO) guidelines for potable water. Spatial distribution analysis, utilizing ArcGIS Pro and the inverse distance weighting (IDW) method, revealed notable deterioration in groundwater quality in urban and paddy field areas due to anthropogenic influences, while forested regions exhibited superior water quality. The findings revealed that 33% of samples from paddy fields, 58% from urban and residential areas, and 83% from forested regions complied with WHO-recommended limits. Hydro-chemical facies were predominantly Ca–Mg–HCO_3, indicating significant geological and anthropogenic influences on water quality. The study concludes that while groundwater remains largely suitable for drinking, continuous monitoring and targeted management strategies are crucial in urban and paddy regions where elevated hardness levels pose contamination risks, thus ensuring the sustainable protection of this vital resource for drinking purposes.

Keywords Kriging, Geo – statistical modelling, dynamics, Groundwater Quality, land use

INTRODUCTION

The global impacts of disorderly human activities and unsustainable population growth have become critical issues, exacerbating the strain on water resources due to inappropriate land use. Since the 1960s, the world's population has more than doubled, increasing by 2.3 times, while food production has nearly tripled to meet the demands of this growing population (Villholth & Rajasooriya, 2010; Kumara et al., 2016). This intensification of land use has led to the significant degradation of natural resources, particularly water. Groundwater, a vital resource for life, is increasingly vulnerable to contamination from agrochemicals, industrial waste, and urban runoff (Smith et al., 2019). Without effective management, this issue is expected to create a severe threat to global groundwater resources in the future.

Natural resources are interconnected, and the accumulation of anthropogenic factors impacts ecosystems both positively and negatively, as the built environment is subjected to human consumption. Urbanization, in particular, introduces numerous sources of pollution, which pose substantial risks to groundwater quality (Misara, 2011). Globally, these activities have placed water resources at risk, making the assessment of groundwater quality a critical necessity. The sustainable use and preservation of groundwater are untenable without thorough evaluation (Sadat-Noori et al., 2014; Yadav et al., 2018).

In Sri Lanka, the situation is equally concerning. Inappropriate land use practices, which are increasing daily, are a direct cause of the degradation of groundwater quality. Groundwater quality in a given region is influenced by various physical and chemical parameters, which in turn are affected by both geological formations and

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human activities (Subramani et al., 2005; Schiavo et al., 2006; Magesh & Chandrasekar, 2011; Krishna Kumara et al., 2011). Groundwater is a crucial resource for Sri Lanka's domestic, agricultural, and industrial needs, with approximately 80% of the population relying on it (Panabokke & Perera, 2005). However, nearly one-third of the country's groundwater resources are at risk due to unsustainable land use practices (WRB, 2011). Agricultural activities, particularly the use of fertilizers and pesticides, as well as urban and industrial expansion, have been identified as major contributors to groundwater contamination (Sadat-Noori et al., 2014).

This study focuses on the groundwater quality in the Pujanagaraya Grama Niladhari Division, located within the Mahiyanganaya Divisional Secretariat Division in the Badulla District, Uva Province, Sri Lanka. This region is emblematic of the dry zone areas of Sri Lanka, where overutilization of groundwater and poor well management practices are prevalent. Despite these challenges, no comprehensive evaluation of groundwater potability has been conducted in these areas.

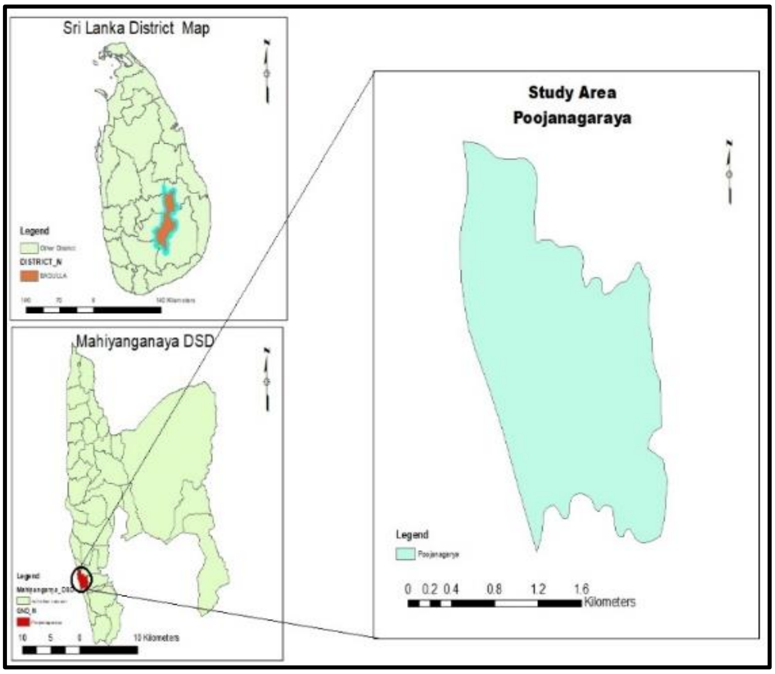
The main objective of this research is to assess the drinking suitability of groundwater by analyzing fluctuations in key water quality parameters such as pH, Total Dissolved Solids (TDS), Total Hardness (TH), Alkalinity, Sodium (Na^+), Sulfate (SO_4^{2-}), Chloride (Cl^-), Dissolved Oxygen (DO), Electrical Conductivity (EC), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Bicarbonate (HCO_3^-), and Potassium (K^+). Additionally, the study aims to evaluate the spatial distribution of these parameters in water samples collected from different land use types, including forest, residential, urban, and paddy fields.

The overarching aim is to guide the implementation of sustainable land use practices that will protect this vital resource and secure its availability for future generations. The complexity of this issue necessitates comprehensive research and the development of effective strategies to safeguard both the environment and human health (UNEP, 2019; Rockstrom et al., 2009).

MATERIALS AND METHODS

Study Area

The study was conducted in the Pujanagaraya Grama Niladhari Division (Fig. 1,A) located within the Uva Province in Sri Lanka's Badulla District. This area, part of Sri Lanka's dry zone, experiences a tropical climate with distinct wet and dry seasons. The area is characterized by diverse land uses, including urban, residential, agricultural (paddy), and forested zones (Fig. 1,B). The geographic coordinates of the study area range from approximately 7.3227 °N latitude to 80.9906 °E longitude.



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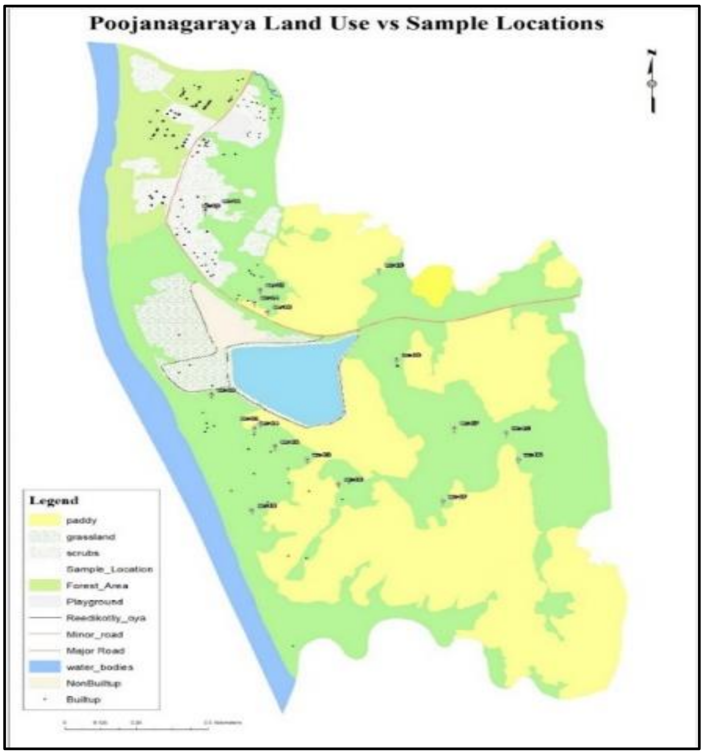

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Fig .1 (A, B): Map showing the study area & sample Location.

Groundwater Sampling

A total of 18 groundwater samples were collected from various land use categories within the study region: Urban (5 samples), Paddy (7 samples), Residential (2 samples), and Forest (4 samples). Samples were collected using 2-liter screw-capped polypropylene bottles, which were pre-treated by washing with dilute nitric acid and rinsing three times with demineralized water to ensure sample integrity. On-site measurements for pH, electrical conductivity (EC), and total dissolved solids (TDS) were performed using a multi-parameter water meter.

Laboratory Analysis

In the laboratory, water samples were analyzed for total hardness (TH), alkalinity, sodium (Na^+), sulfate (SO_4^{2-}), chloride (Cl^-), calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^+) using standard volumetric, titrimetric, and spectrophotometric methods as recommended by APHA guidelines. The concentrations of calcium (Ca^{2+}) and magnesium (Mg^{2+}) were determined through volumetric titration with ethylenediamine tetra acetic acid (EDTA), while bicarbonates (HCO_3^-) were quantified by the same method. Chloride (Cl^-) concentrations were determined using a silver nitrate titration in a neutral medium with potassium chromate as an indicator. Nitrate (NO_3^-) and sulfate (SO_4^{2-}) concentrations were measured using a spectrophotometric method. Sodium (Na^+) and potassium (K^+) concentrations were analyzed using a flame photometer.

The results of the laboratory analyses were compared to World Health Organization (WHO 2004) guidelines to assess the potability of the water for human consumption.

GIS-analysis

Various physio-chemical parameters were analyzed using Google Earth Pro, ArcGIS, and ArcGIS Pro software. The spatial interpolation of groundwater quality was performed using the Inverse Distance Weighting (IDW) algorithm, which estimates values between measurement points by considering nearby data points within a defined search radius. This method calculates each grid node's value as a weighted average, where closer points have a greater influence on the estimated value (Heuvelink,1998). This analysis effectively illustrates the spatial distribution of groundwater quality across different land-use areas.

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RESULTS AND DISCUSSION

Hydro-geochemical Characteristics of Groundwater

The variation of each physicochemical parameter in the study area was analyzed in detail, as summarized in (Table 1.) The assessment revealed insights into the distribution of data across different land use types.

Table 01 : Summary statistics of parameters

Parameter	N	WHO	Minimum	Maximum	Mean	Std.deviation
Temperature	18	-	27.8	32.6	30.27778	1.471116
pH	18	**6.5-8.5**	6.52	7.7	6.887778	0.35942
DO	18	**6.5-8**	3.7	19.75	9.101111	5.881139
EC	18	**1400**	131.1	1565.9	1187.194	570.3455
TDS	18	**500-1500**	68	1658.1	1259.089	650.9614
Alkalinity	18	**200**	50.6	598	453.0056	215.0076
TH	18	**100-500**	41	687	482.0556	240.7416
Ca	18	**75-200**	66.3	401.4	239.4444	127.21
Mg	18	**50-150**	98.2	281.2	171.4	61.40328
Na	18	**200**	56.1	187.1	145.5172	43.24255
K	18	**12**	8.61	44.2	22.36944	13.48484
HCO_3	18		132	371	257.5556	72.60062
SO_4	18	**200-400**	0.012	1.231	0.142222	0.282596
Cl	18	**200-600**	0.96	31	15.81111	8.365668

Source : (Field Survey, 2023)

The hydro-chemical analysis of groundwater samples revealed significant variations across different land use types. pH values ranged from 6.52 to 7.7, with all samples falling within the acceptable WHO range (6.5–8.5). However, urban areas exhibited elevated concentrations of total dissolved solids (TDS), total hardness (TH), sodium (Na), and chloride (Cl), exceeding WHO guidelines for drinking water. Paddy field areas also displayed high levels of sodium, potassium (K), and magnesium (Mg), likely attributed to prolonged fertilizer application and irrigation return flows.

Notably, the minimum concentrations of electrical conductivity (EC), TDS, and alkalinity were recorded at 131.1 mg/L, 68 mg/L, and 50.6 mg/L, respectively, while maximum values in urban areas reached 1565.9 mg/L, 1658.1 mg/L, and 598 mg/L. All five urban water samples surpassed the WHO recommended limits for EC, TDS, and alkalinity, indicating that land use practices are contributing to the deterioration of groundwater quality.

Additionally, the maximum concentrations of calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K) were reported as 401.4 mg/L, 281.2 mg/L, 187.1 mg/L, and 44.2 mg/L, respectively, in groundwater obtained from paddy fields. Importantly, sulfate (SO_4) and chloride (Cl) concentrations in all 18 water samples remained within the WHO recommended limits for potability.

These findings emphasize the impact of land use on groundwater quality and indicate the necessity for targeted management strategies to mitigate contamination risks.

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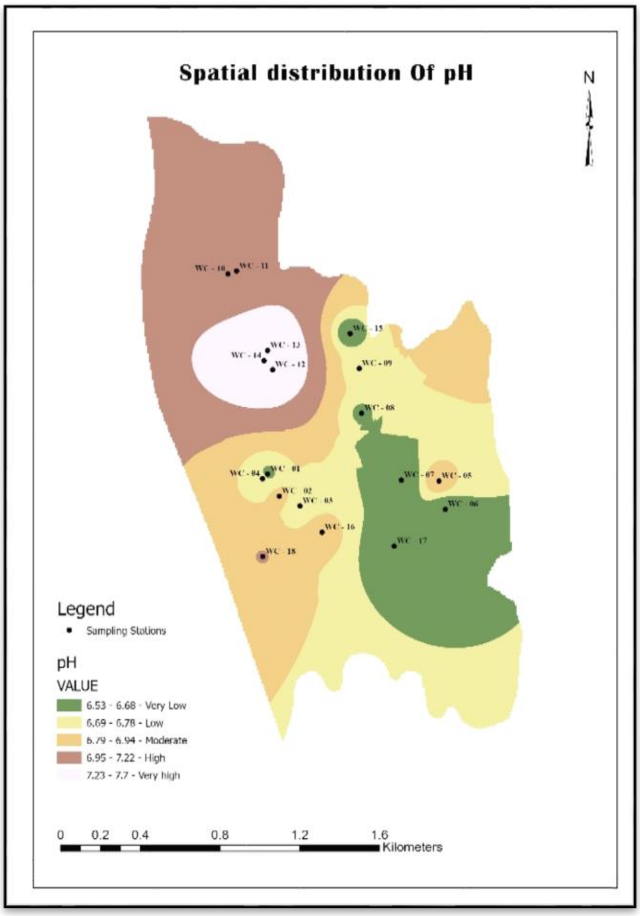

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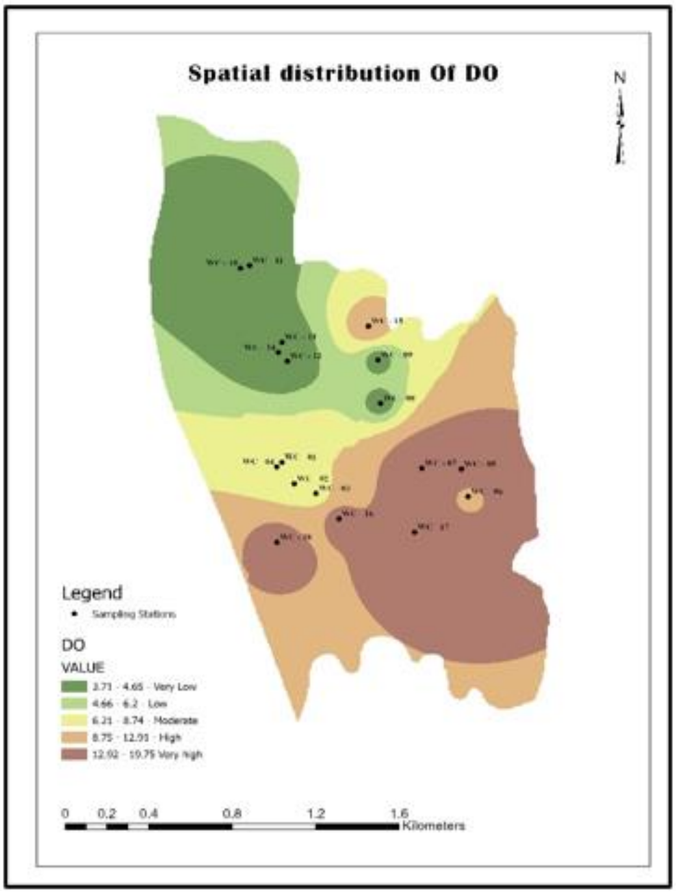

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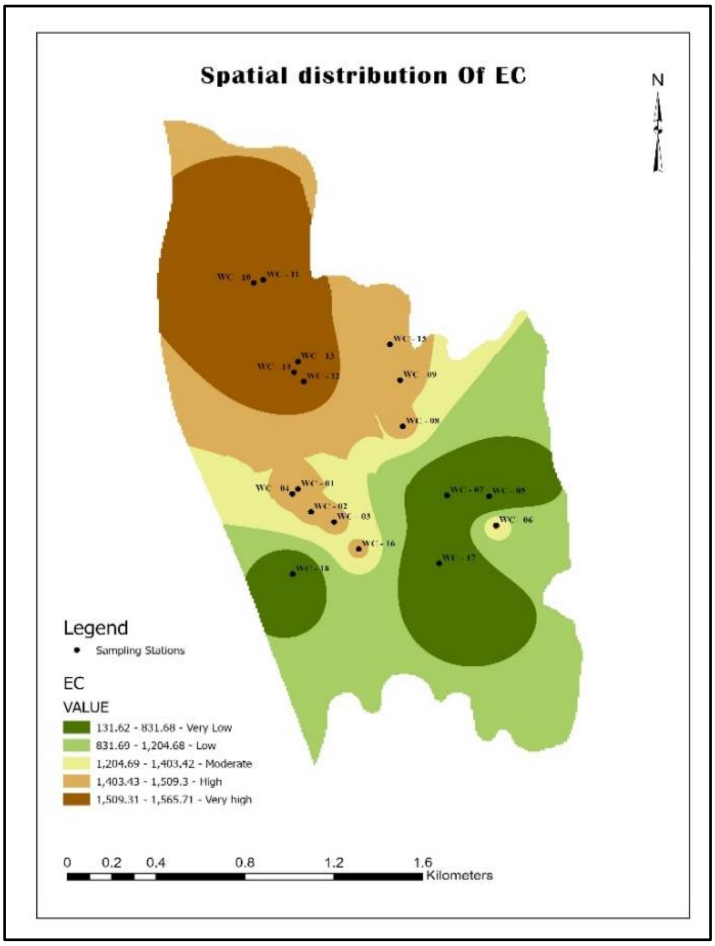

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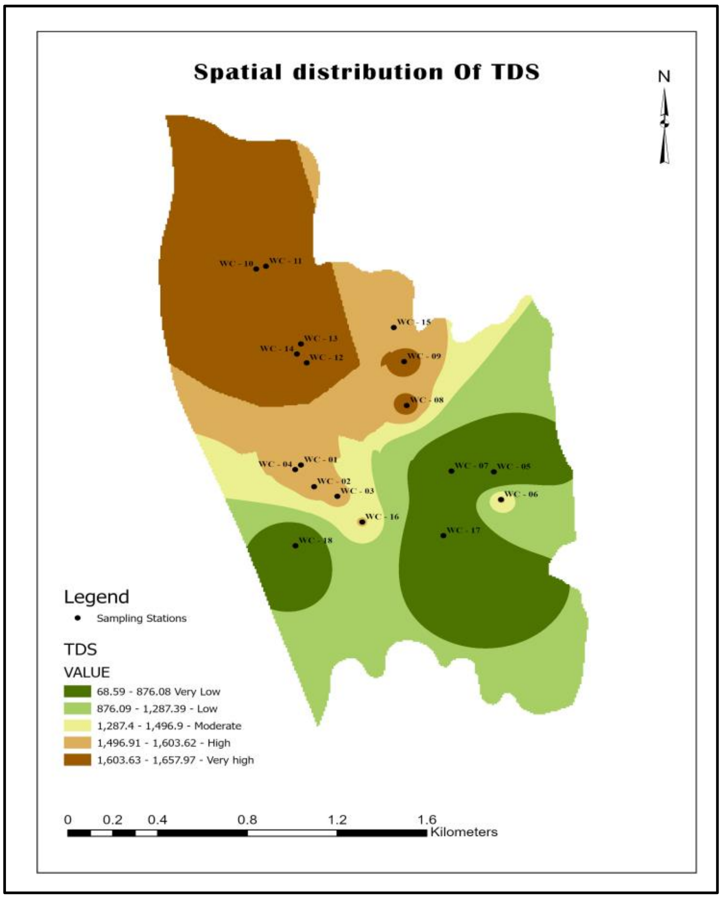

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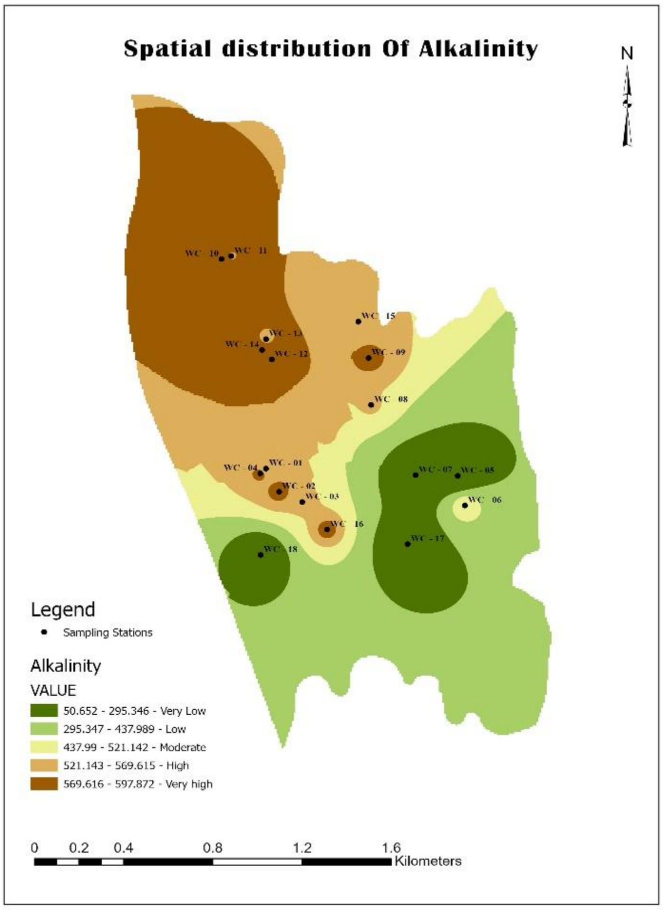

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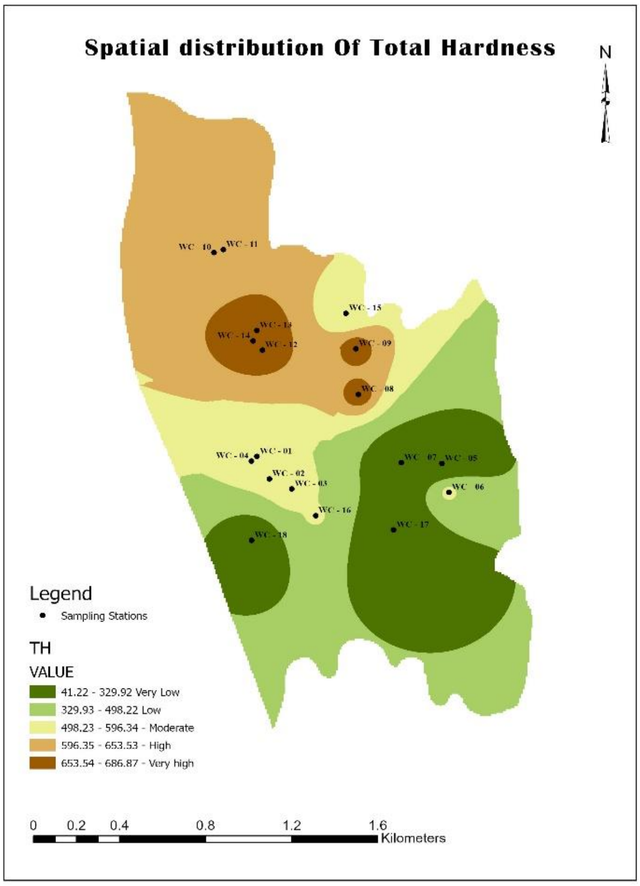

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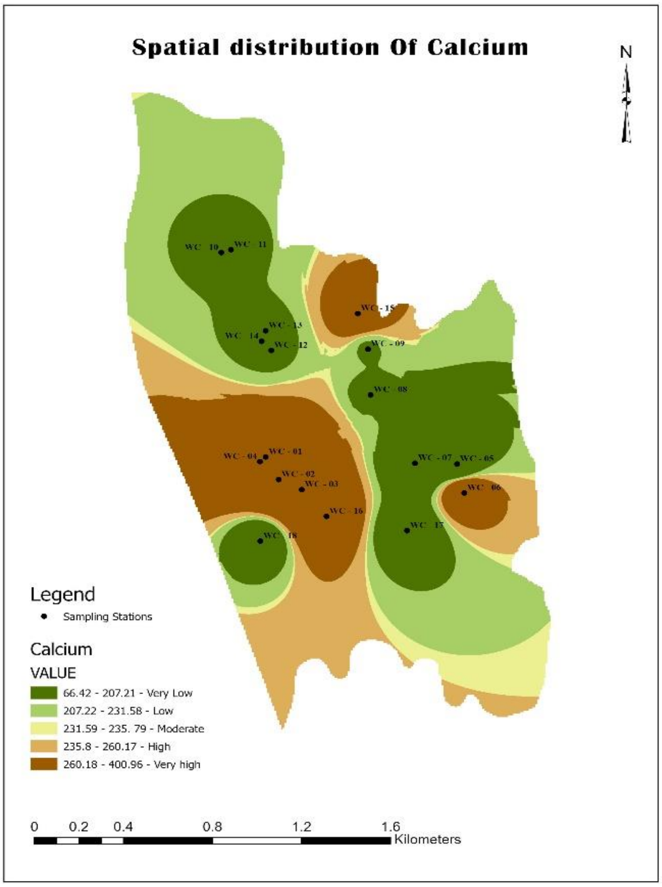

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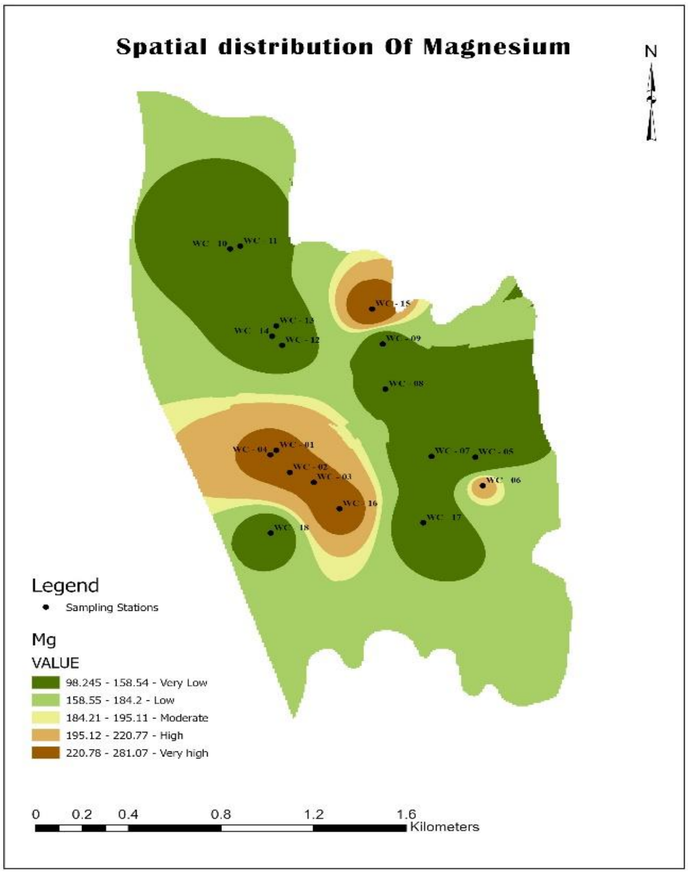

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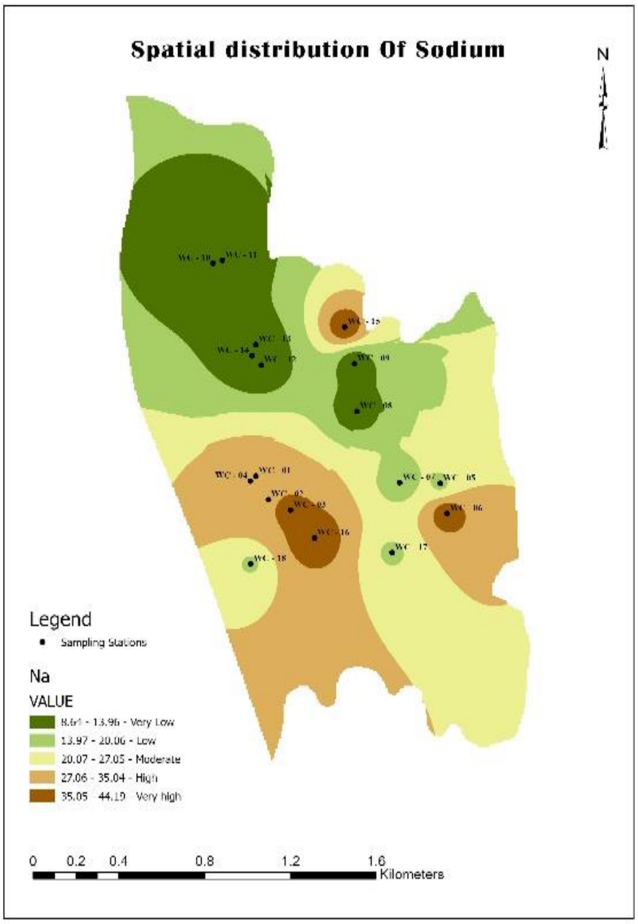

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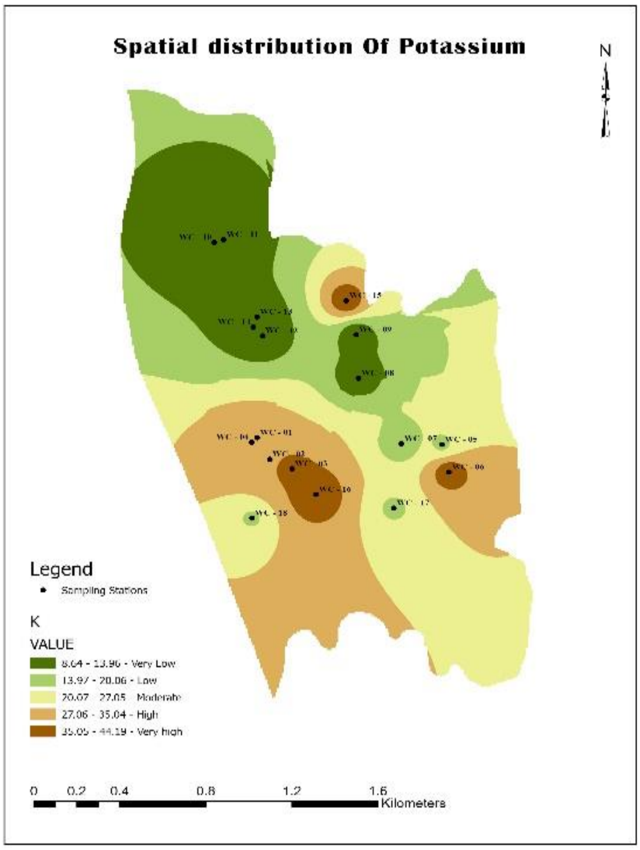

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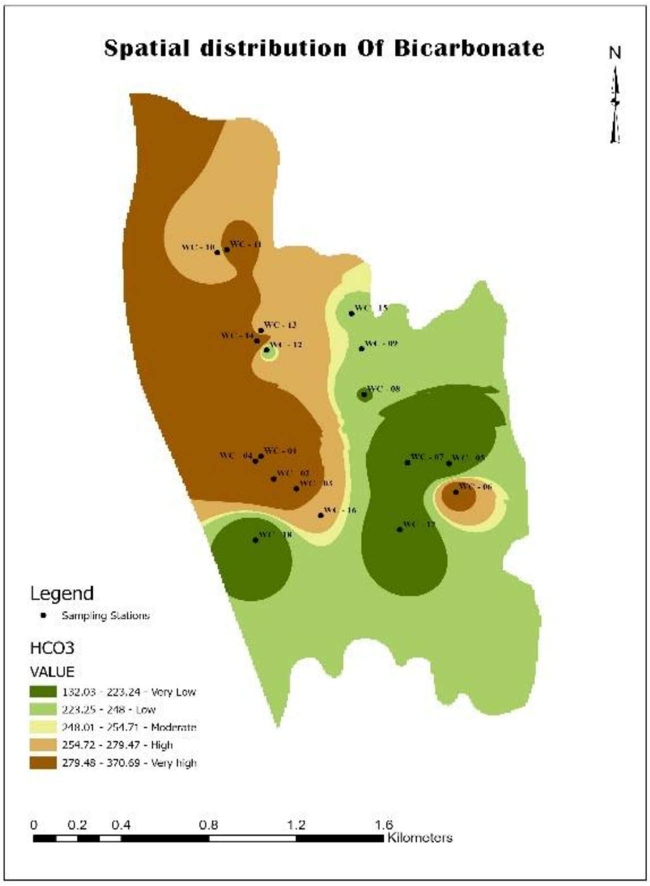

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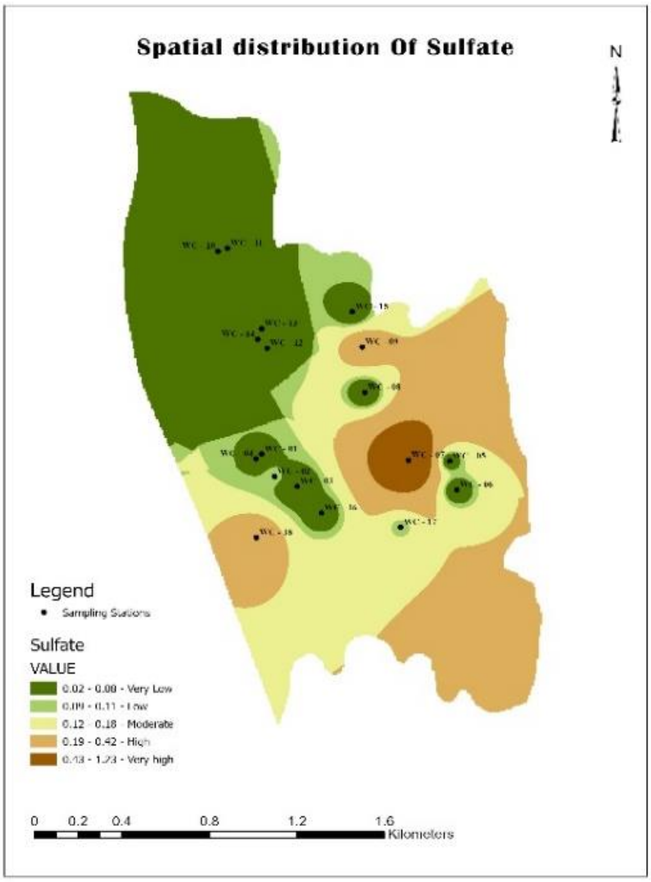

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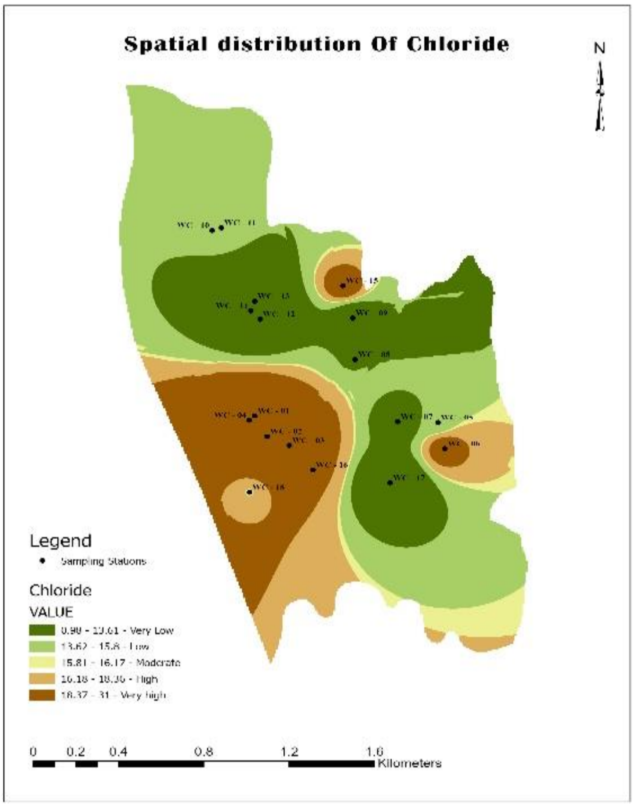

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Drinking Suitability and Spatial Distribution of Groundwater Quality

The World Health Organization (WHO) has established drinking water quality standards to ensure safety and suitability for human consumption (WHO, 2004). This study focuses on evaluating major ions (Ca, Mg, Na, K, HCO_3, SO_4, Cl) and key physico-chemical parameters, including pH, electrical conductivity (EC), total dissolved solids (TDS), and total hardness (TH). By comparing the results with WHO guidelines, the analysis assesses the groundwater's suitability for drinking in the study area. Furthermore, Fig. 2. (a, b, c,d,e,f,g,h,j,k,l,m) illustrates the spatial distribution of these groundwater quality parameters across the region, demonstrating the influence of land use and environmental factors on water quality. The results for all groundwater samples are analyzed and discussed in the following sections.

pH

The groundwater pH in the study area ranges from 6.52 to 7.7, with 88.9% of the samples falling within the WHO-recommended range of 6.5 to 8.5 for drinking water. The variation in pH is attributed to anthropogenic activities such as fertilizer use in paddy fields and sewage disposal in urban and residential areas, which slightly alter the pH levels. In contrast, forested areas demonstrate lower pH values, influenced by organic matter decomposition, while brackish water intrusion into sandy aquifers also plays a role in adjusting the geochemical balance. Only 11.1% of the samples, mostly from forested regions, exhibit mild acidity, falling slightly below the recommended range.

Dissolved Oxygen (DO)

DO concentrations in the groundwater range from 3.7 to 19.75 mg/L, with 66.7% of the samples adhering to the WHO-recommended minimum of 5 mg/L for potable water. Spatially, DO levels vary with land use patterns, showing moderate levels in paddy fields due to waterlogged conditions, while urban and residential areas display reduced DO, likely caused by organic matter decomposition and limited infiltration. Forested areas report the highest DO values, reflecting natural recharge and minimal human activity. However, 33.3% of the samples, predominantly from urban and residential areas, fall below the recommended threshold, indicating potential oxygen depletion and associated water quality concerns.

Electrical Conductivity (EC)

EC, which indicates the concentration of dissolved salts in groundwater, ranges from 131.1 to 1,565.9 µmhos/cm in the study area, with 94.4% of the samples conforming to the WHO limit of 1,500 µmhos/cm. Moderate EC values are recorded in paddy fields (1,412.2–1,484.4 µmhos/cm), reflecting fertilizer application and irrigation practices. Urban and residential areas exhibit higher EC values (1,455.8–1,565.9 µmhos/cm), suggesting anthropogenic influence and possible saline intrusion. In contrast, forested regions show the lowest EC values (131.1–184.9 µmhos/cm), indicating minimal salt enrichment through natural processes. Only 5.6% of the samples, primarily from urban areas, indicate medium salt enrichment.

Total Dissolved Solids (TDS)

TDS concentrations, ranging from 68 to 1,898.21 mg/L, are a key measure of groundwater quality. According to WHO guidelines, 82% of the samples are classified as desirable for drinking (TDS < 500 mg/L), 14% as permissible (500–1,000 mg/L), and 4% as suitable mainly for irrigation. Elevated TDS levels, particularly in paddy fields (1,512.4–1,597.9 mg/L) and urban areas (1,621.6–1,658.1 mg/L), are likely due to salt leaching and domestic sewage percolation. Forested areas show much lower TDS values (68–84.1 mg/L), underscoring the influence of land use on water quality.

Alkalinity

Alkalinity values range from 50.6 mg/L to 598 mg/L, with all samples from paddy, residential, and urban areas exceeding the WHO's desirable limit of 200 mg/L for drinking water. Elevated alkalinity in paddy fields can be linked to fertilizer use, while forested areas display significantly lower values (50.6–74.2 mg/L), likely due to organic acid production from decomposition. These results demonstrate the variation in alkalinity based on land use and highlight the need for effective water management practices to safeguard groundwater quality.

Total Hardness (TH)

Total hardness in the groundwater ranges from 41 mg/L to 687 mg/L, with most samples from paddy, residential, and urban areas exceeding the acceptable WHO range (100–500 mg/L). High levels of hardness in these areas may necessitate treatment for safe consumption, while forested regions show much lower hardness values (41–88 mg/L), reflecting reduced mineral content. These findings illustrate the significant effect of land use on groundwater hardness.

Calcium and Magnesium (Ca^{2+} and Mg^{2+})

Calcium levels range from 66.3 mg/L in forested regions to 401.4 mg/L in paddy fields, while magnesium concentrations span from 98.2 mg/L to 281.2 mg/L across different land uses. Both parameters exceed WHO limits in paddy fields, attributed to fertilizer use and mineral leaching, highlighting the need for continuous monitoring to ensure safe water quality.

Sodium and Potassium (Na^{+} and K^{+})

Sodium concentrations range from 56.1 mg/L in forested regions to 187.1 mg/L in paddy fields, with 22.2% of the samples exceeding the WHO limit of 200 mg/L. Potassium levels range from 8.61 mg/L to 44.2 mg/L, with most samples within acceptable limits. These findings underscore the influence of agricultural activities, particularly fertilizer use, on sodium and potassium levels in groundwater.

Sulfate and Chloride (SO_4^{2-} and Cl^{-})

Sulfate concentrations in the study area are notably low, ranging from 0.012 mg/L to 1.231 mg/L, with all samples well within the WHO recommended limit. Chloride levels range from 6.07 mg/L to 31 mg/L, with only

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a small percentage of samples approaching the upper limit. Elevated chloride levels in agricultural areas point to the impact of fertilizers, while forested regions reflect the natural filtration processes. Regular monitoring of sulfate and chloride levels is necessary to ensure water remains safe for consumption.

Land Use Impact on Groundwater Quality

The findings demonstrate that groundwater in urban and agricultural areas is more susceptible to contamination than in forested regions. Urban areas, in particular, showed elevated levels of pollutants, likely due to the discharge of untreated wastewater and industrial activities. In contrast, the forested areas exhibited the best water quality, with most parameters falling well within WHO guidelines. This suggests that land use practices such as urban development and agricultural intensification are major drivers of groundwater quality deterioration in the study area.

Hydro-chemical Facies

The Piper trilinear diagram (Figure 2) functions as an essential tool for analyzing the hydro chemical facies of groundwater in the study area.

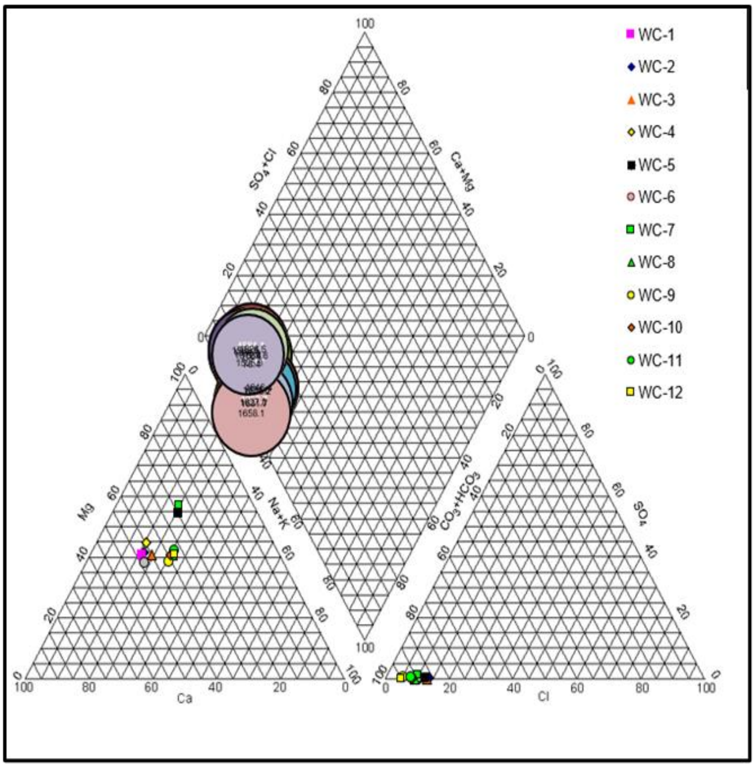

Fig.3: Piper plot describing hydro chemical facies of the study area

This diagram effectively visualizes the major ions present in the water, allowing for a detailed categorization of groundwater composition by representing cations (Ca, Mg, Na, K) and anions (HCO_3, Cl, SO_4).The analysis reveals a predominant sequence of anions, with bicarbonate (HCO_3) ranking highest, followed by chloride (Cl) and sulfate (SO_4). For cations, calcium (Ca) is the most abundant, followed by sodium (Na), magnesium (Mg), and potassium (K). This sequence indicates a significant prevalence of the Ca-Mg-HCO_3 hydro chemical facies within the region.

Moreover, the analysis identifies distinct hydro chemical profiles among specific samples. For instance, samples WC-5 and WC-7 exhibit characteristics similar to evaporated minerals, reflecting certain groundwater characteristics. Conversely, sample WC-14 presents a unique sulfate-chloride profile, suggesting influences from specific industrial activities, particularly wastewater discharge.

This comprehensive exploration of hydro chemical facies is invaluable in understanding the hydrogeological factors that impact groundwater quality in the area.

CONCLUSION

This study provides a comprehensive evaluation of groundwater quality and its suitability for drinking purposes in the Mahiyanganaya DSD of Badulla District, Sri Lanka, based on an analysis of 18 groundwater samples. The results indicate that 88.9% of the samples fall within the WHO-recommended pH range of 6.5–8.5, and 66.7% meet the guideline for dissolved oxygen (≥5 mg/L). Furthermore, 94.4% of the samples adhere to the WHO limit for electrical conductivity (1,500 µmhos/cm), while 82% are classified as desirable for total dissolved solids (TDS), which range from 68 to 1,898.21 mg/L. However, total hardness poses a significant concern, particularly in urban areas where many samples exceed acceptable drinking water limits. The hydro-chemical facies, predominantly Ca–Mg–HCO_3, suggests potential anthropogenic influences impacting water quality.

While the majority of groundwater samples are suitable for drinking, emerging concerns, such as elevated total hardness and contamination risks in urban areas, highlight the need for continuous monitoring and targeted management. It is recommended to establish regular groundwater quality monitoring programs and adopt sustainable land use practices to reduce anthropogenic impacts. Public awareness efforts should also be implemented to ensure the long-term protection and safe use of groundwater resources for drinking purposes.

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