Spatial and physicochemical assessment of groundwater quality index in the urban coastal region of Sri Lanka

TANT Perera (nilusha@et.cmb.ac.lk)
University of Colombo https://orcid.org/0000-0001-9867-2056
HMMSD Herath
University of Colombo
Ranjana U.K Piyadasa
University of Colombo
Liu Jianhui
Ministry of Natural Resources of the People's Republic of China
Li Bing
Ministry of Natural Resources of the People's Republic of China

---

Research Article

Keywords: GIS modelling, potable water, WQI, water quality standards

Posted Date: June 18th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-634457/v1

Version of Record: A version of this preprint was published at Environmental Science and Pollution Research on October 14th, 2021. See the published version at https://doi.org/10.1007/s11356-021-16911-x.

Abstract

This study used the groundwater quality index (GWQI) and Geographic Information System (GIS) techniques to examine groundwater quality in the western coastal region of Sri Lanka. The spatial and temporal variation of 18 groundwater samples' physiochemical parameters [pH, electrical conductivity (EC), turbidity, total dissolved solids (TDS), sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), and bicarbonate (HCO_3^-)] were studied. According to the WHO and SLS, 11% of samples had EC levels that were above the acceptable range, and 22% had turbidity levels that were beyond the acceptable range. When considering, pH, TDS, other cations, and anions analyzed in the study were still below the standard permissible levels. The western coastline region, as well as several areas of the central study region, had significant concentrations of physicochemical parameters. According to the GWQI, water was consumable in 77.78% of locations in the study region and unsatisfactory in 22.22%. Furthermore, due to severe coastal erosion, the quality of groundwater in the study region is deteriorating, therefore maintaining a comprehensive groundwater management strategy to promote sustainable water consumption is imperative.

1. Introduction

Groundwater pollution has a significant impact on the environment and human existence today, as it is the primary source of water (Farzaneh et al. 2021; Khanoranga & Khalid 2019; Yang et al. 2016). Agriculture, domestic consumption, industrial activity, and other activities all depend on groundwater (Mukherjee & Singh 2018; Tiwari et al. 2017). Excessive irrigation, excessive use of agricultural inputs, sanitary landfills, climate change, and population growth are all putting strain on groundwater resources (UN 2019). Groundwater, on the other hand, meets the needs of two-thirds of the world's population through their water-dependent activities (Adimalla & Li 2019).

To address the issue of water scarcity and management, the United Nations (UN) has made priorities to achieve clean drinking water for everyone in their Millennium Development Goals and in the Agenda 30 by 2030 (WHO 2017). As a result, to combat ground water pollution, more consideration should be given, as many countries are currently experiencing a scarcity of fresh water resources (Pant 2011; UNEP 2018). In several regions of Sri Lanka, specifically in the Maha Oya river basin, there is a high amount of contamination. 74% of inhabitants in the western coastal region utilize their land for residential and industrial purposes (tourism, hotels, and restaurants), whereas 24% use their lands for agricultural production. Water contamination in the Western coastal region is induced by nutrient and toxic inputs from agricultural, as well as urban and industrial development. In the Maha Oya basin, untreated domestic water is usually released into rivers (Hayzoun et al. 2015). In light of these many issues, policymakers and decision-makers depend heavily on WQI to estimate the efficiency of a water source while also determining the usefulness of initiatives and activities aimed at improving groundwater quality. The Water Quality Index can be used to determine the quality of water (Jain et al. 2010; Nihalani & Meeruty 2020).

By aggregating and evaluating various criteria using a single mathematical classification scheme, this method can be used to evaluate water quality and facilitate in decision-making (De La Mora-Orozco et al. 2017). The WQI is calculated by combining physicochemical and biological properties of water (Gitau et al. 2016; Vaiphei et al. 2020). The Water Quality Index (WQI) is an important indicator for determining the extent of contamination in water (Singh et al. 2019; Tian et al. 2019; Wang & Zhang 2018). Water monitoring can be used to determine the amount of pollutants present in a pool of water. As a result, the results of water quality monitoring can be employed to evaluate the status of bodies of water (Chathuranga et al. 2018).

In some regions, water quality characteristics in groundwater can be used to calculate the ground water quality index. Excess concentrations of these parameters (NO_3^-, PO_4^{3-}, etc.) in water can cause serious health problems, whereas some other parameters in excess quantities do not affect but do impair the appetite (Sadat-Noori et al. 2013). In recent years, a great percentage of groundwater contamination and intrusion studies have primarily been carried out in various parts of Sri Lanka (Herath & Ratnayake 2007; IGES 2007; International Water Management Project 2005) and have used a variety of approaches to realize groundwater contamination and identify the cause (Villholth & Rajasooriyar 2010).

Seawater intrusion and nitrate contamination of groundwater are quite common along the Jaffna peninsula of Sri Lanka, according to Herath et al. (2017) and Thushyanthy et al. (2010). Furthermore, the area's ground water quality measurements were above the SLS permissible range. Mikunthan and De Silva (2008) used geostatistical approaches to assess groundwater quality in the Thirunelvely and Kondavil areas. They concluded that positive management strategies including soil conservation and fertilizer reduction (N-top dressing) had a substantial impact on high ground water chemistry. According to a study conducted by Cooray et al. (2019), all water sources in the dry zone of Sri Lanka required further treatment before consumption, with the exception of 6.4 % samples.

The Geographic Information System (GIS) has risen to prominence as the most popular tool for gathering, classifying, and displaying spatial data, as well as for using the data to make decisions, in many domains, including geographical and geo-environmental disciplines (Eltarabily & Moghazy 2021; Gunaalan et al. 2018; Rajasooriyar et al. 2013). However, a precise physicochemical description of groundwater content has yet to be determined in Sri Lanka's western coastline region. As a result, the study's main goals are to (a) use a Geographic Information System (GIS) to create a spatial distribution map of various physicochemical parameters, (b) locate suitable and unsuitable groundwater quality zones for drinking, and (c) evaluate groundwater quality by developing a groundwater quality index (GWQI). The findings of this study may be useful to decision-makers and the scientific community in determining the best course of action for groundwater quality conservation.

2. Methodology

2.1 Study area

The targeted case study region (Waikkala – 7.2838° N, 79.8578° E - Fig. 1) is situated in the Puttlam District of Sri Lanka's North Western Province. It covers 3,072 square kilometers. To the north, the Kala Oya and Modaragam Aru, to the east, the Anuradhapura District and Kurunegala District, to the south, the Ma Oya, and to the west, the Indian Ocean.

From the Maha Oya River Mouth left bank, which is the southern boundary of Puttlam District, to the northwards, the study region encompasses a 24 km^2 area. The mouth of the Gin Ganga River is also included in the case study area. This region, which is part of the Wennappuwa Divisional Secretariat Division, comprises 28 Grama Niladhari Divisions. According to the 2012 census statistics from the Department of Census and Statistics, the population density distribution of this area is 1746km^2. The alluvial deposits and ferruginous gravels, as well as the unconsolidated sands and spits of the coastal region, retain groundwater. The most prevalent groundwater abstraction technologies are dug wells, dug-cum bore wells, and bore wells, and their yields are mostly governed by the recharge conditions in the region. The annual average rainfall in the district is 1174 mm, with November being the wettest month of the year. Puttalam, which is located on the seashore, is mostly flat, though the land rises to approximately 60 meters inland. There are regions of reddish brown earth and low humic gley soils inland, and the soils are mostly red-yellow latosols.

2.2 Groundwater sample collection and chemical analysis

Groundwater samples were gathered at 18 locations between January 2019 and January 2020, from a drilled well that had previously been dug or a deep bore hole that had previously been drilled. The groundwater samples were taken according to APHA guidelines (APHA 2012) (Table 1). The water samples were collected in pre-cleaned 1L high-density polythene sample vials. The samples were tagged and delivered to a chemical laboratory, where they were physicochemically evaluated under 4°C conditions (Jehan et al. 2020).

Using Arc GIS 10.2 software, the case study region will be partitioned into a 9«5 grid. A GPS position at the mid-point of selected spots for water quality monitoring method has been navigated in each cell of the grid in the study region. A handheld optical pH/EC/TDS meter (Hanna HI 9811-5) was used to determine physico-chemical parameters such as electrical conductivity (EC), hydrogen ion concentration (pH), and total dissolved solids (TDS) in the field. The basic protocols of the American Public Health Association were used to examine other chemical parameters (APHA 2012). The $AgNO_3$ titration was used to determine the chloride (Cl^-) concentration. The magnesium (Mg^{2+}) was calculated using equations 1 and 2 (Adimalla & Taloor 2020).

Magnesium Hardness = Total Hardness - Calcium Hardness ………………………… Eq. 1

Mg^{2+} (mg/L) = MgH « equivalent weight of Mg^{2+} « Normality of EDTA ………………… Eq. 2

Table 1 Methods used for chemical analysis of groundwater samples along with their relative weights, used in the computation of groundwater quality

Parameters	Units	Analytical method	Reagent	Weight wi	Relative weight (Wi): $Wi = \frac{wi}{\sum_i^n wi}$
pH		PH/EC/TDS meter (Eutech''s Cyber Scan CD650 waterproof handheld multipara meter) (APHA 2012).	pH 4, 7 and 10	3	0.11
EC	µS/ cm	PH/EC/TDS meter (APHA 2012).	KCl	3	0.11
TDS	Mg/L	PH/EC/TDS meter (APHA 2012).	KCl	5	0.18
Cl^-	Mg/L	Titrimetric method (APHA 2012).	Silver nitrate ($AgNO_3$), and potassium chromate (K_2CrO_4)	4	0.14
Mg^{2+}	Mg/L	Titrimetric method (APHA 2012).	EDTA, sodium hydroxide and murexide	3	0.11
Ca^{2+}	Mg/L	Titrimetric method (APHA 2012).	EDTA, Sodium hydroxide and murexide	3	0.11
K^+	Mg/L	Flame photometric (APHA 2012).	NaCl and KCl	1	0.04
Na^+	Mg/L	Flame photometric (APHA 2012).	NaCl and KCl	2	0.07
HCO_3^{2-}	Mg/L	Titrimetric method (APHA 2012).	Hydrosulfuric acid (H_2SO_4), Methyl Orange indicator	2	0.07
Turbidity	NTU	EUTECH waterproof Cyber scan pH650 handheld meter kit (APHA 2012).	Formazin suspensions	2	0.07

2.3 Spatial distribution maps

The exact sampling locations were marked using a portable Global Positioning System (GPS, Garman eTrex 30), and the geographical coordinates were imported into a Geographic Information System (GIS) program. The spatiotemporal behavior analysis and geographic distribution map of groundwater quality were accomplished using the spatial observer model of ArcGIS version 10.1 (Şener et al. 2021).

2.4 Groundwater quality index (GWQI)

The ground water quality index (GWQI) was developed using the collected data to assess the water's acceptability for drinking (Adimalla et al. 2018; Chathuranga et al. 2018; Ramakrishnaiah et al. 2009; Rabeiy 2018). The first stage in the GWQI classification process was to assign weights (wi) to each parameter and then calculate relative weight (Wi) (Eq. 3). Based on expert opinions gathered from various previous studies, a minimum weight of one (1) has been assigned to parameters such as Na^+ and K^+ because they are less important in groundwater quality evaluation (Rajmohan 2021), and a maximum weight of five (5) has been assigned to parameters which are more pertinent in groundwater quality evaluation such as TDS (Table 1).

$$Wi = \frac{wi}{\sum_i^n wi} \text{ .... } \quad \text{Equation 3 (Adimalla \& Taloor 2020)}$$

According to WHO guidelines, each parameter's consistency rating scale (Qi) is calculated by multiplying its concentration in each water sample by its corresponding standard and then multiplying by 100 (Eq. 4).

$$Qi = \frac{Ci}{Si} \times 100 \text{ ....} \text{Equation 4 (Adimalla \& Taloor 2020).}$$

Where ci is the concentration of each criterion of groundwater quality, Qi is the quality rating, and Si is the chemical parameter's recommended guideline value. Using equations 5 and 6, the Sub-index (SIi) and GWQI were determined.

SIi = *Wi* « *Qi* ………………………………….. Eq. 5 (Adimalla & Taloor 2020)

$$GWQI = \sum_{i=0}^{n} SIi \text{ .... } \quad \text{Equation 6 (Adimalla \& Taloor 2020).}$$

3. Results And Discussion

3.1 Physicochemical parameters of the ground water

The significance of groundwater resource quality is critical since it is a fundamental factor in determining its suitability for potable use in the studied area. The descriptive information for the various physicochemical properties of groundwater samples is shown in Table 2. The data were also compared to WHO (2017) and SLS Guidelines to see if they were suitable for drinking in the study location.

Table 2
Descriptive statistics of sub-indices of water quality parameters.

Parameters	Unit	Min	Max	Mean	SD	SLS	WHO
pH	mg/L	6.21	7.68	6.93	0.37	6.5-9.0	6.5–8.5
EC	µS/cm	430.10	99144.72	10709.76	28948.70	750	1500
TDS	mg/L	168.25	748.77	299.20	139.80	2000	1000
Cl-	mg/L	110.00	443.00	191.17	92.52	250	600
Mg^{2+}	mg/L	1.67	23.00	10.56	6.87	150	150
Ca^{2+}	mg/L	5.00	43.00	19.94	12.89	100	300
Na^{+}	mg/L	22	173	60.76	35.08	200	200
K^{+}	mg/L	2.00	24.67	12.52	6.53	-	-
HCO_3^{-}	mg/L	26	54	37.11	8.25	-	350
Turbidity	NTU	0.62	41.67	5.38	9.44	2–8	5

3.1.1 Hydrogen ion concentration (pH)

pH measures the acidity and alkalinity of groundwater. Despite the fact that pH has no direct impact on human health, it is one of the most important water quality parameters. According to WHO guidelines, a suitable pH range of 6.5 to 8.5 is recommended (WHO 2017). The groundwater samples were acidic to alkaline in nature, with a pH ranging from 6.21 to 7.68, with an average of 6.93, according to the study's findings (Table 2). The pH range for groundwater in Sri Lanka was 6.50-9.00, with a maximum permissible level of 9.00. However, no location was found to be above the maximum permitted limit in any of the groundwater tests (Table 2). According to Sampath et al. (2011), the pH range of ground water in Sri Lanka's Puttlam district was 6.30–8.20. In addition, Young et al. (2011) detected a pH range of 5.76 to 8.70 in Sri Lanka's north-western province. The pH variation in ground water in Sri Lanka's western province was below the SLS permitted level (4.0 to 8.2) and was not hazardous for drinking (Premalal & Jayewardene 2015). Figure 2a depicts the geographic distribution of pH in the research area.

3.1.2 Electrical conductivity (EC)

According to (Kanga et al. 2020), the ionic concentration of groundwater is commonly measured by calculating the EC, which varies depending on the concentration, type of ions present in the water, and temperature. The EC in the research area's groundwater ranged from 430.10 to 99144.72 S/cm, with an average of 10709.76 S/cm (Table 2). According to WHO drinking water recommendations, the maximum permitted EC concentration in water is 1500 S/cm (WHO 2017). The maximum allowed level of groundwater in Sri Lanka is 750 S/cm. Only 11% of groundwater samples were found to be above the permitted level (Table 2). Figure 2b depicts the geographic distribution of EC in the research area.

According to a study conducted by Sampath et al. (2011), EC levels were greater than the acceptable values of WHO drinking water quality guidelines in 76% of areas in the Puttlam area of Sri Lanka. Another study in Sri Lanka's Puttlam area found that the maximum permitted amount of EC has been exceeded by the WHO and SLS (Arasaretnam et al. 2018; Edirisinghe et al. 2016; Matharaarachchi et al. 2014; Subba Rao et al. 2012).

Furthermore, Young et al. (2011) found that EC in the north-western province ranged from 143 to 3549 S/cm. Gopalakrishnan et al. (2020) discovered that ground water in the Jaffna peninsula of Sri Lanka had a high salinity (EC = 20000 S/cm). As a result, salinization may have an impact on groundwater quality in the research area in the coming next few years.

3.1.3 Total dissolved solids (TDS)

TDS stands for Total Dissolved Solids, which refers to the numerous minerals that are present in dissolved form in water (Narsimha & Sudarshan 2017). The principal dissolved solids in water are large carbonates, bicarbonates, sulfates, chlorides, silica, phosphates, sodium, potassium, calcium, and magnesium (Adimalla & Venkatayogi 2018; Gnanachandrasamy et al. 2015). As a result, it's an important consideration for evaluating the consistency of drinking water and other forms of water. TDS content fluctuates between 168 and 749 mg/L, with a mean value of 299 mg/L, according to our research. All of the groundwater samples had TDS levels below the WHO (2017) limit (1000 mg/L) and SLS levels below the WHO (2017) threshold (2000 mg/L). According to previous studies, TDS concentrations in the Puttlam district of Sri Lanka are below the ideal threshold in 80% of the locations and 20% of the sites surpass the ideal level. Furthermore, TDS concentrations in all areas were of sufficient quality for drinking (Sampath et al. 2011; Wickramasinghe et al. 2021).According to Adimalla & Taloor (2020), almost 95% of the total samples were below the ideal threshold for drinking (TDS: 1000 mg/L), while the remaining samples were suitable for irrigation (TDS: 1000–3000 mg/L). The geographic distribution map of TDS is depicted in Figure 2c.

3.1.4 Magnesium (Mg^{2+}) and calcium (Ca^{2+})

According to WHO (2017) standards, the maximum permissible Mg^{2+} concentration is 150 mg/L. Groundwater Mg^{2+} values in the study region varied from 1.6 to 23 mg/L, with an average of 10.5 mg/L. (See Table 2) The concentration of Mg^{2+} in the sample region's groundwater was determined to be below the WHO (2017) or SLS-recommended maximum permissible level. The north and south-western regions of the sample area had higher concentrations (Fig. 3b). According to the study's findings, the Ca^{2+} concentration in groundwater in the research area ranged from 5 to 43 mg/L, with an average of 20 mg/L. (Fig. 3c). Furthermore, all of the samples fall well within the established parameters (WHO 2017). According to Young et al. (2011), Mg^{2+} and Ca^{2+} concentrations in Sri Lanka's north-western province ranged from 4.98 to 112 mg/L and 1.29 to 98 mg/L, respectively. Carbonate minerals dissolving caused comparatively high quantities of Mg^{2+} and Ca^{2+} in various sections of the northwestern province. According to Sampath et al. (2011), total hardness (Ca^{2+} and Mg^{2+}) in Puttlam district water surpasses the ideal level, with only 16 % of places having sufficient potable water.

3.1.5 Sodium (Na^+) and potassium (K^+)

The geographic distributions of Na^+ and K^+ are depicted in Figures 4a and 4b, respectively. The research area's central and northern regions have higher Na^+ concentrations, while the northwestern and south-eastern regions have higher K^+ concentrations. The content of Na+ in groundwater, on the other hand, varied from 22 to 173 mg/L, with a mean of 60 mg/L. (Table 2). The findings revealed that none of the groundwater samples tested fulfilled the WHO and SLS criteria (WHO, 2006). The average Na^+ and K^+ concentrations in the north-western province, according to Young et al. (2011), were 79.77 mg/L and 6.12 mg/L, respectively. K^+ is the most important nutrient for humans (Adimalla & Venkatayogi 2018), and too much of it might cause constipation (Alam et al. 2012). K^+ concentrations in the sample area's groundwater range from 2 to 25 mg/L, with an average of 12.52 mg/L. (Table 2).However, WHO recommendations for K^+ have yet to be established because it occurs naturally in drinking water at quantities far below those considered harmful to human health (Sakram & Adimalla 2018; WHO 2017).

3.1.6 Bicarbonate (HCO_3^-)

The HCO_3^- concentration in the sample area's groundwater ranges from 26 to 54 mg/L, with a mean value of 37.11 mg/L. (Table 2). Figure 5a shows a geographic distribution map of HCO_3^- concentrations, which reveal that larger concentrations were found in the southern northern region of the sample region, while low concentrations were found in the northern part. According to Young et al. (2011), HCO_3^- concentrations in the northwestern province ranged from 10 to 240 mg/L, while Jayasena et al. (2008) found it to be between 3.5 and 966 mg/L.

3.1.7 Chloride (Cl^-)

Excessive Cl^- concentrations in groundwater are considered to be a sign of contamination from a variety of sources, and they give water a salty taste (Marghade et al. 2012). The concentration of Cl^- in the sample area varies between 110 and 443 mg/L. However, the mean Cl^- concentration in the groundwater samples studied (191 mg/L) is lower than the overall permitted value of 600 mg/L (Table 2) (WHO 2017). Figure 5b depicted the geographic distribution map of Cl^-. Previous investigations in Sri Lanka's coastal region have revealed desirable Cl^- values (32–1100 mg/L) in accordance with the SLS (Mikunthan & Silva 2010). Despite the fact that no health risks have been identified, people in coastal areas are unwilling to drink water due to texture and taste concerns.

3.1.8 Turbidity

Turbidity refers to the water's relative clarity, which inhibits light transmission. The turbidity of ground water in the research area ranged from 0.62 to 41.67 NTU (Figure 5c). The maximum turbidity level was surpassed in 22% of locations, according to the SLS and WHO drinking water quality guidelines. As a result, it's unlikely to be suitable for drinking. Several earlier investigations have found that the turbidity in the groundwater of Puttlam district was much higher than the WHO and SLS permitted values.According to Galhenage et al. (2021), turbidity ranged from 1.6 to 164 NTU, while Gunarathna et al. (2021) found that turbidity ranged from 44 to 723 NTU. Furthermore, the study found that the mean turbidity in ground water was much higher than in surface water (Gunarathna et al. 2021).

3.2 Groundwater quality index (GWQI)

Table 3 shows the GWQI values calculated for each groundwater sample. Table 3 shows that GWQI values in groundwater in the research region ranged from 45.12 to 2700.55, with an average of 337.78. Excellent water (WQI = 50), good water (WQI = 50 to 100), and poor water (WQI = 100 to 200), very poor water (WQI = 200 to 300) and water unsuitable for drinking (WQI = > 300) are some of the categories for GWQI (Ramakrishnaiah et al. 2009) (Fig. 6). Based on this classification, 16.67 % of groundwater samples fall excellent, 61.11% and 11.11% fall under good and poor for drinking purpose categories in the study region (Fig. 7). NW6 and NW 14 were not suitable for drinking (11.11%).

Table 3
Results of groundwater quality index (GWQI) values in the study region.

Sample numbers	GWQI values	Type of water
NW 1	51.79	Good
NW 2	52.69	Good
NW 3	82.49	Good
NW 4	49.30	Excellent
NW 5	2200.12	Unsuitable
NW 6	159.59	Poor
NW 7	70.81	Good
NW 8	132.69	Poor
NW 9	55.09	Good
NW 10	98.05	Good
NW 11	45.12	Excellent
NW 12	65.74	Good
NW 13	49.91	Excellent
NW 14	2700.55	Unsuitable
NW 15	54.54	Good
NW 16	70.39	Good
NW 17	62.87	Good
NW 18	78.25	Good

4. Conclusions

The groundwater condition in the western coastal region of Sri Lanka begins to depreciate largely due to seawater intrusion and therefore, the water consumption has become uncertain. Hence, investigating water quality in the groundwater was crucial in the western coastal region in Sri Lanka. This study was used GIS to create a spatial distribution map of various physicochemical parameters and locate suitable and unsuitable groundwater quality zones for drinking and evaluated groundwater quality by developing a groundwater quality index (GWQI).

The groundwater in the research area is neutral to slightly alkaline in the composition according to the study. The most abundant cations and anions were Na^+ and Cl^-, respectively. This could be owing to the region's coastal erosion and seawater intrusion. Ca^{2+} (5–43 mg/L), Na^{+} (22–173mg/L), and K^{+} (2-24.67mg/L) ions concentrations in the groundwater of the research region are within the maximum allowable limits when compared to WHO (Mg^{2+} 300mg/L, Na^{+} 200mg/L, K^{+} Not recommended) drinking water quality guidelines and Sri Lankan water quality standards (Ca^{2+} 100mg/L, Na^{+} 200mg/L, K^{+} Not recommended). Excessive quantities of Turbidity (22%) and EC (11%) have also been discovered at a few groundwater sample sites in the research area. According to the GWQI, the groundwater quality in the study region ranges from excellent to poor for drinking. Turbidity and electrical conductivity had the greatest impact on groundwater quality index. The groundwater samples that are acceptable for drinking comprise 77.78% of the total, while the samples that are not appropriate for drinking constitute 22.22%. The research area's poor and unfit water for human consumption is mostly concentrated in the center and western coastal areas according to the spatial distribution maps. Therefore, to safeguard community well-being and safety, it is essential to make consistent monitoring valuation of seawater intrusion in the western coastal province of Sri Lanka.

Declarations

Ethics approval and consent to participate - Not applicable

Consent for publication - Not applicable

Availability of data and materials - Not applicable

Competing interests - The authors declare that they have no competing interests

Funding - Not applicable

Authors' contributions

T.A.N.T. Perera: Conceptualization, Data curation, Formal analysis, Methodology, Validation, Visualization, Writing - original draft, Writing - review & editing.

HMMSD Herath: Conceptualization, Resources, Software, Validation, Visualization.

Ranjana UK Piyadasa: Conceptualization, Funding acquisition, Investigation, Project administration, Resources, Software, Supervision.

Liu Jianhui: Conceptualization, Investigation, Methodology, Resources, Supervision.

Li Bing: Conceptualization, Investigation, Methodology, Resources.

References

1. APHA (2012) Standard Methods for the Examination of Water and Wastewater, twenty-second ed. American Public Health Association, Washington, DC
2. Adimalla N, Taloor AK (2020) Hydrogeochemical investigation of groundwater quality in the hard rock terrain of South India using Geographic Information System (GIS) and groundwater quality index (GWQI) techniques. Groundwater for Sustainable Development 10(126):100288. https://doi.org/10.1016/j.gsd.2019.100288
3. Adimalla N, Li P (2019) Occurrence, health risks, and geochemical mechanisms of fluoride and nitrate in groundwater of the rock-dominant semi-arid region, Telangana State, India. Hum Ecol Risk Assess Int J 25 (1–2), 81–103. https://doi. org/10.1080/10807039.2018.148035
4. Adimalla N, Li P, Venkatayogi S (2018) Hydrogeochemical evaluation of groundwater quality for drinking and irrigation purposes and integrated interpretation with water quality index studies. Environ Process 5 (2), 363–383. https://doi.org/10.1007/ s40710-018-0297
5. Arasaretnam S, Prasadini HRP, Venujah K (2018) Assessment of Open well Water Quality around Puttalam District, Sri Lanka. International Journal of Advances in Scientific Research Engineering 4(12):225–232. https://doi.org/10.31695/ijasre.2018.33024
6. Bouderbala A (2017) Assessment of water quality index for the groundwater in the upper Cheliff plain, Algeria. J Geol Soc India 90, 347–356 (2017). https://doi.org/10.1007/s12594-017-0723-7
7. Chathuranga AGL, Perera TANT, De Silva PMCS, Jayasinghe GY (2018) Assessment of Physico-Chemical Parameters of Drinking Water Quality in Selected DS Divisions - Hambanthota District. 11th International Research Conference of KDU at: General Sir John Kotelawala Defence University, 47
8. Cooray T, Wei Y, Zhong H, Zheng L, Weragoda SK, Weerasooriya R (2019) Assessment of groundwater quality in CKDu Affected areas of Sri Lanka: Implications for drinking water treatment. International Journal of Environmental Research Public Health, 16(10). https://doi.org/10.3390/ijerph16101698
9. De La Mora-Orozco C, Flores-Lopez H, Rubio-Arias H, Chavez-Duran A, Ochoa-Rivero J (2017) Developing a Water Quality Index (WQI) for an Irrigation Dam. International Journal of Environmental Research and Public Health, 14(5), 439. MDPI AG. Retrieved from http://dx.doi.org/10.3390/ijerph14050439
10. Edirisinghe EANV, Karunarathne GRR, Samarakoon ASMNB, Pitawala HMTGA, Dharmagunawardhane HA, Tilakarathna IANDP (2016) Assessing causes of quality deterioration of groundwater in Puttalam, Sri Lanka, using isotope and hydrochemical tools. Isot Environ Health Stud 52(4–5):513–528. https://doi.org/10.1080/10256016.2015.1127918
11. Eltarabily MG, Moghazy HEM (2021) GIS-based evaluation and statistical determination of groundwater geochemistry for potential irrigation use in El Moghra, Egypt. Environ Monit Assess 193(5):306. https://doi.org/10.1007/s10661-021-09058-2
12. Farzaneh G, Khorasani N, Ghodousi J, Panahi M (2021) Assessment of Surface and Groundwater Resources Quality Close to Municipal Solid Waste Landfill Using Multiple Indicators and Multivariate

Statistical Methods. International Journal of Environmental Research 15(2):383–394. https://doi.org/10.1007/s41742-020-00307-9

13. Galhenage AC, Kumari EGSS, Kumara AMLU, Thalgaspitiya TWLR, Edirisinghe V, Vithanage M, Athapattu BCL (2021) Assessment of Groundwater Quality for Drinking Water from Deep Confined Aquifer in Wanathawilluwa. Lecture Notes in Civil Engineering, 94, 503–516. https://doi.org/10.1007/978-981-15-7222-7_41
14. Gitau MW, Chen J, Ma Z (2016) Water Quality Indices as Tools for Decision Making and Management. Water Resour Manage 30(8):2591–2610
15. Gnanachandrasamy G, Ramkumar T, Venkatramanan S (2015) Accessing groundwater quality in lower part of Nagapattinam district, Southern India: using hydrogeochemistry and GIS interpolation techniques. Appl Water Sci 5(1):39–55. https://doi.org/10.1007/s13201-014-0172-z
16. Gopalakrishnan T, Kumar L, Mikunthan T (2020) Assessment of spatial and temporal trend of groundwater salinity in Jaffna Peninsula and its link to paddy land abandonment. Sustainability (Switzerland), 12(9). https://doi.org/10.3390/su12093681
17. Gunaalan K, Ranagalage M, Gunarathna M, Kumari M, Vithanage M, Srivaratharasan T, Saravanan S, Warnasuriya TWS (2018) Application of Geospatial Techniques for Groundwater Quality and Availability Assessment: A Case Study in Jaffna Peninsula, Sri Lanka. ISPRS International Journal of Geo-Information 7(1):20. https://doi.org/10.3390/ijgi7010020
18. Gunarathna N, Amarasinghe A, Wijesundara S, Iddawela D, Wickramasinghe S (2021) Isolation, molecular characterization and phylogeny of Naegleria species in water bodies of North-Western Province, Sri Lanka. PLoS ONE 16(3 March):e0248510. https://doi.org/10.1371/journal.pone.0248510
19. Hayzoun H, Garnier C, Durrieu G, Lenoble V, Le Poupon C, Angeletti B (2015) Organic carbon, and major and trace element dynamic and fate in a large river subjected to poorlyregulated urban and industrial pressures (Sebou River, Morocco). Science of the Total Environment, 502(2015), 296–308. https:// doi.org/10.1016/j.scitotenv.2014.09.014
20. Herath G, Ratnayake U (2007) Urban Groundwater Management Issues in Sri Lanka. Engineer: Journal of the Institution of Engineers, Sri Lanka, 40(4), 123. https://doi.org/10.4038/engineer.v40i4.7163
21. Herath HAS, Kubota K, Kawakami T, Nagasawa S, Motoyama A, Weragoda SK, Chaminda GGT, Yatigammana SK (2017) Potential risk of drinking water to human health in Sri Lanka. Environ Forensics 18(3):241–250. https://doi.org/10.1080/15275922.2017.1340364
22. IGES Freshwater Management Project (2007) the Study of the Management of Groundwater Resources in Sri Lanka. Sustainable Groundwater Management in Asian Cities2, 110–136. http://enviroscope.iges.or.jp/modules/envirolib/upload/981/attach/08_chapter3-5srilanka.pdf
23. International Water Management Project (2005) Planning Groundwater Use for Sustainable Rural Development Why must groundwater be managed better ? Water Policy, 14

24. Jain CK, Bandyopadhyay A, Bhadra A (2010) Assessment of ground water quality for drinking purpose, District Nainital, Uttarakhand, India. Environ Monit Assess 166(1–4):663–676. https://doi.org/10.1007/s10661-009-1031-5
25. Jayasena HAH, Chandrajith R, Dissanayake CB (2008) Hydrogeochemistry of the groundwater flow system in a crystalline terrain: A study from the Kurunegala district, Sri Lanka. Environ Geol 55(4):723–730. https://doi.org/10.1007/s00254-007-1024-z
26. Jehan S, Ullah I, Khan S, Muhammad S, Khattak SA, Khan T (2020) Evaluation of the Swat River, Northern Pakistan, water quality using multivariate statistical techniques and water quality index (WQI) model. Environ Sci Pollut Res 27(31):38545–38558. https://doi.org/10.1007/s11356-020-09688-y
27. Kanga IS, Naimi M, Chikhaoui M (2020) Groundwater quality assessment using water quality index and geographic information system based in Sebou River Basin in the North-West region of Morocco. International Journal of Energy Water Resources 4(4):347–355. https://doi.org/10.1007/s42108-020-00089-y
28. Khanoranga Khalid S (2019) An assessment of groundwater quality for irrigation and drinking purposes around brick kilns in three districts of Balochistan province, Pakistan, through water quality index and multivariate statistical approaches. J Geochem Explor 197:14–26
29. Marghade D, Malpe DB, Zade AB (2011) Geochemical characterization of groundwater from northeastern part of Nagpur urban, Central India. Environ Earth Sci 62(7):1419–1430. https://doi.org/10.1007/s12665-010-0627-y
30. Mikunthan T, De Silva CS (2008) Vulnerability Assessment for Shallow Aquifers Using Chemical Quality of Groundwater: A Case Study from Thirunelvely and Kondavil in Jaffna District. Tropical Agricultural Research 20:303–312
31. Mikunthan T, De Silva CS (2010) Sources of extent of groundwater pollution in shallow aquifer: A case study from Jaffna District in Sri Lanka. Third International Conference on Hydrology and Watershed Management in India, 41–48
32. Mukherjee I, Singh UK (2018) Groundwater Fluoride Contamination, Probable Release, and Containment Mechanisms: a Review on Indian Context. Environmental Geochemistry and Health
33. Narsimha A, Sudarshan V (2017) Contamination of fluoride in groundwater and its effect on human health: a case study in hard rock aquifers of Siddipet, Telangana State, India. Appl Water Sci 7(5):2501–2512. https://doi.org/10.1007/s13201-016-0441-0
34. Nihalani S, Meeruty A (2020) Water quality index evaluation for major rivers in Gujarat. Environ Sci Pollut Res, 1–9. https://doi.org/10.1007/s11356-020-10509-5
35. Pant BR (2011) Ground water quality in the Kathmandu valley of Nepal. Environ Monit Assess 178(1–4):477–485. https://doi.org/10.1007/s10661-010-1706-y
36. Premalal WAV, Jayewardene DT (2015) Effect of Low pH of Groundwater in Rathupaswala Area, Sri Lanka: A Case Study. publication/272175683_ Effect_of_Low_pH_ of_

Groundwater_in_Rathupaswala_Area_Sri_Lanka_A_Case_Study, pp 8–10. https://www.researchgate.net/

37. Rabeiy RES (2018) Assessment and modeling of groundwater quality using WQI and GIS in Upper Egypt area. Environ Sci Pollut Res 25(31):30808–30817. https://doi.org/10.1007/s11356-017-8617-1
38. Rajasooriyar LD, Boelee E, Prado MCCM, Hiscock KM (2013) Mapping the potential human health implications of groundwater pollution in southern Sri Lanka. Water Resources Rural Development 1–2:27–42. https://doi.org/10.1016/j.wrr.2013.10.002
39. Rajmohan N (2021) Application of water quality index and chemometric methods on contamination assessment in the shallow aquifer, Ganges River basin, India. Environ Sci Pollut Res 28(18):23243–23257. https://doi.org/10.1007/s11356-020-12270-1
40. Ramakrishnaiah CR, Sadashivaiah C, Ranganna G (2009) Assessment of water quality index for the groundwater in Tumkur taluk, Karnataka state, India. E J Chem 6(2):523–530
41. Sadat-Noori SM, Ebrahimi K, Liaghat AM (2013) Groundwater quality assessment using the Water Quality Index and GIS in Saveh-Nobaran aquifer, Iran. Environmental Earth Sciences, 71(2014), 3827–3843. https://doi.org/10.1007/s12665-013-2770-8.DOI10.1007/s12665-013-2770-8
42. Samanmali Matharaarachchi, Ranjana UK, Piyadasa D Wickramasinghe (2014) Groundwater quality variation in kalpitiya peninsula -Sri Lanka. SAITM Research Symposium on Engineering Advancements 2014 (SAITM – RSEA 2014)
43. Sampath GRA, Hewawasam ALT, Dias P (2011) Assessment of Groundwater Quality Status in Puttalam and Chillaw Area to Demonstrate its Suitability. as a Source of Potable Water
44. Şener Ş, Varol S, Şener E (2021) Evaluation of sustainable groundwater utilization using index methods (WQI and IWQI), multivariate analysis, and GIS: the case of Akşehir District (Konya/Turkey). Environ Sci Pollut Res, 1–20. https://doi.org/10.1007/s11356-021-14106-y
45. Singh S, Ghosh NC, Krishan G, Kumar S, Gurjar S, Sharma MK (2019) Development of indices for surface and ground water quality assessment and characterization for Indian conditions. Environ Monit Assess 191(3):1–20. https://doi.org/10.1007/s10661-019-7276-8
46. Tian Y, Jiang Y, Liu Q, Dong M, Xu D, Liu Y (2019) Using a water quality index to assess the water quality of the upper and middle streams of the Luanhe River, northern China. Sci Total Environ, 667(219), 142–151. https://doi. org/10.1016/j.scitotenv.2019.02.356
47. Tiwari AK, De Maio M, Amanzio G (2017) Evaluation of Metal Contamination in the Groundwater of the Aosta Valley Region, Italy. International Journal of Environmental Research 11(3):291–300. https://doi.org/10.1007/s41742-017-0027-1
48. United Nations Environment Programme (2018) Progress on Ambient Water Quality: Piloting the monitoring methodology and initial fndings for SDG 6 indicator 6.3.2. https://www.unwater.org/publications/progress-on-ambient-water-quality-632/
49. United Nations (2019) Leaving no one behind. https://unesdoc.unesco.org/ark:/48223/pf0000367306

50. Vaiphei SP, Kurakalva RM, Sahadevan DK (2020) Water quality index and GIS-based technique for assessment of groundwater quality in Wanaparthy watershed, Telangana, India. Environ Sci Pollut Res 27(36):45041–45062. https://doi.org/10.1007/s11356-020-10345-7
51. Villholth KG, Rajasooriyar LD (2010) Groundwater Resources and Management Challenges in Sri Lanka-an Overview. Water Resour Manage 24(8):1489–1513. https://doi.org/10.1007/s11269-009-9510-6
52. Wang X, Zhang F (2018) Multi-scale analysis of the relationship between landscape patterns and a water quality index (WQI) based on a stepwise linear regression (SLR) and geographically weighted regression (GWR) in the Ebinur Lake oasis. Environ Sci Pollut Res 25(7):7033–7048. https://doi.org/10.1007/s11356-017-1041-8
53. WHO (2017) Guidelines for drinking-water quality. In: Incorporating 1st Addendum. fourth ed. World Health Organization, Geneva
54. Wickramasinghe BNB, Jayasena HAH, Perera KVGS, Rajapakse RRGR (2021) Assessment of hydrogeological scenario in a cross-section from Anamaduwa to Kalpitiya in Northwest Sri Lanka. Ceylon Journal of Science 50(1):83. https://doi.org/10.4038/cjs.v50i1.7850
55. Yang Y, Yin X, Yang Z (2016) Environmental flow management strategies based on the integration of water quantity and quality, a case study of the Baiyangdian Wetland China. Ecological Engineering. 96(2016), 150–161. https://doi.org/10.1016/j.ecole ng.2015.12.018
56. Yenugu SR, Vangala S, Badri S (2020) Monitoring of groundwater quality for drinking purposes using the WQI method and its health implications around inactive mines in Vemula-Vempalli region, Kadapa District, South India. Applied Water Science 10(8):202. https://doi.org/10.1007/s13201-020-01284-2
57. Young SM, Pitawala A, Ishiga H (2011) Factors controlling fluoride contents of groundwater in north-central and northwestern Sri Lanka. Environ Earth Sci 63(6):1333–1342. https://doi.org/10.1007/s12665-010-0804-z

Figures

Figure 1

The selected case study region

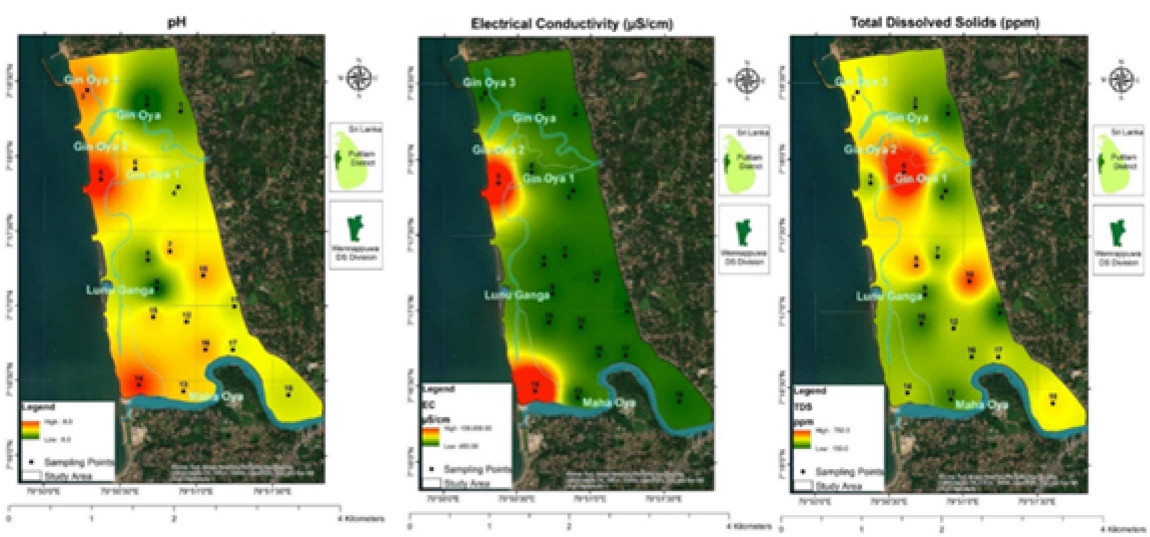

Figure 2

Spatial distribution of Left: (a) pH Middle: (b) EC Right(c) TDS in the groundwater samples of the study area.

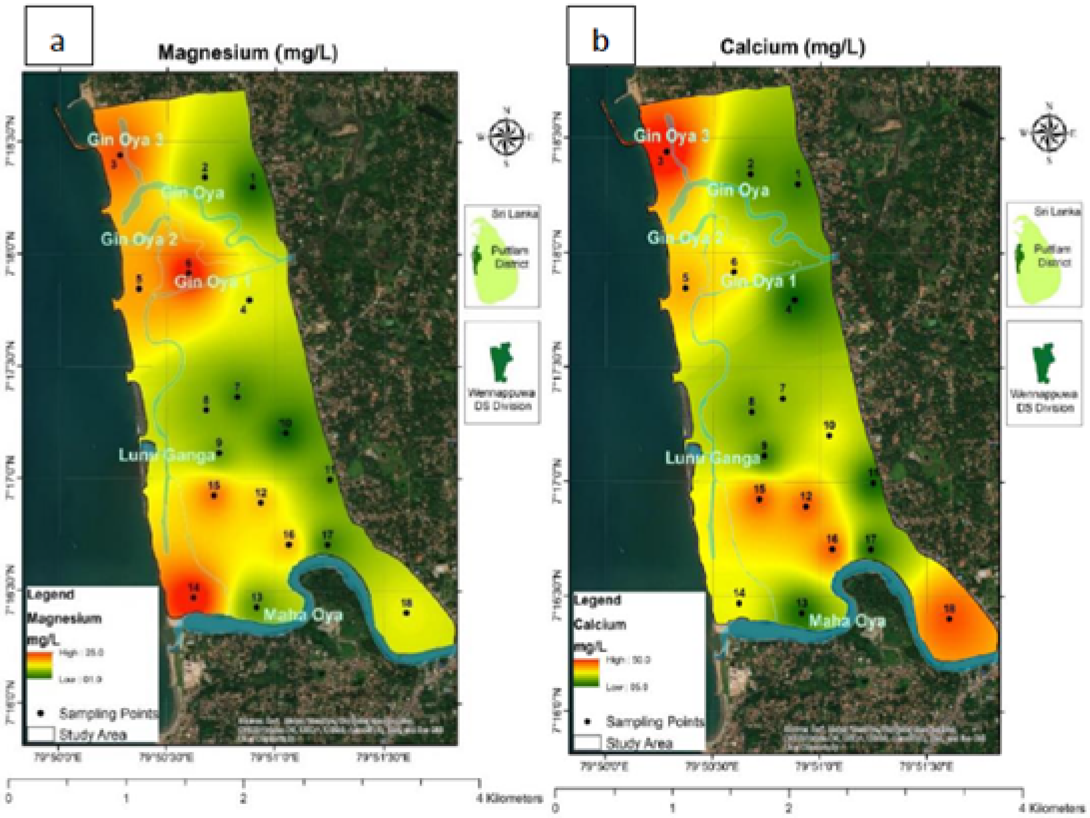

Figure 3

Spatial distribution of (a) Mg2+(b) Ca2+ in the groundwater samples of the study area.

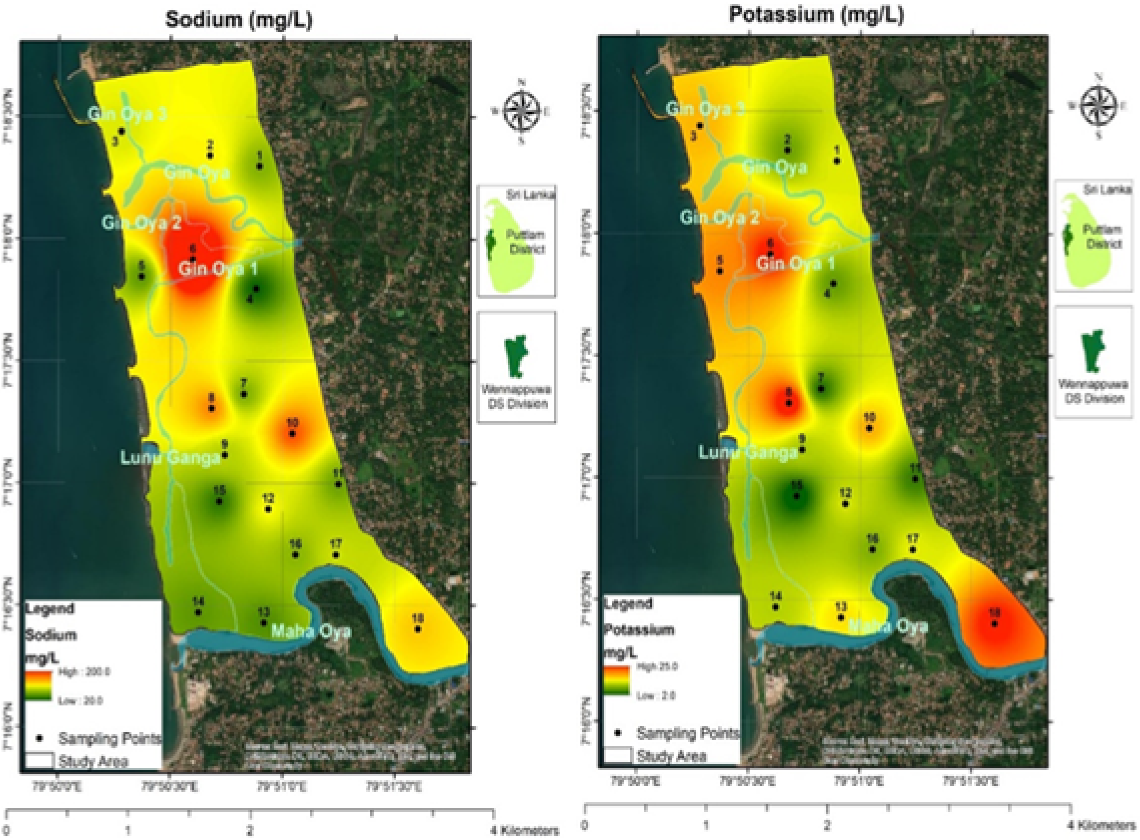

Figure 4

Spatial distribution of Left: (a) Na+ Right: (b) K+ in the groundwater samples of the study area.

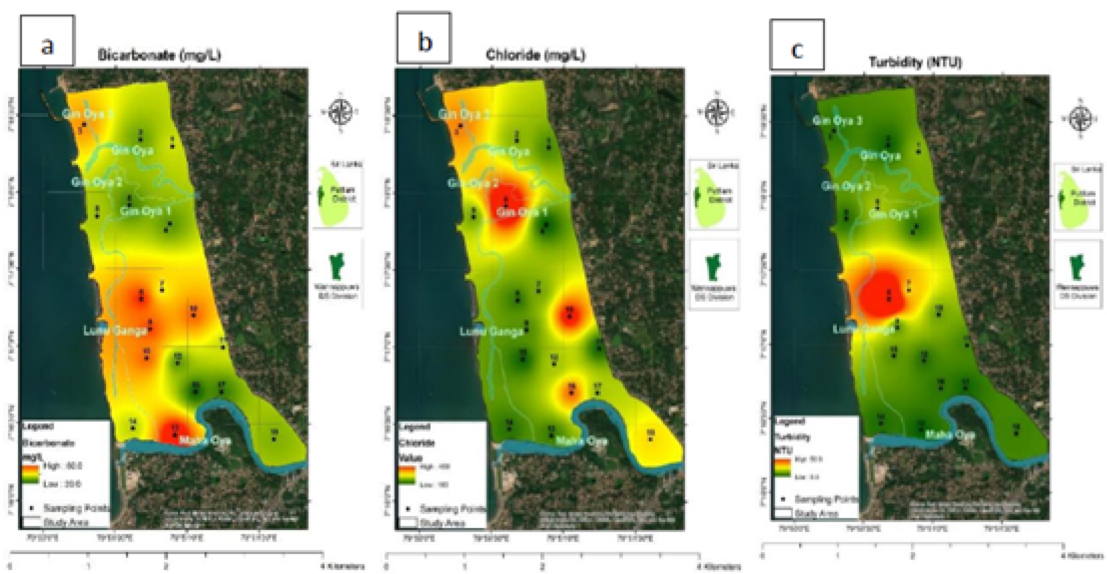

Figure 5

Spatial distribution of (a) HCO3-(b) Cl- (c) Turbidity in the groundwater samples of the study area.

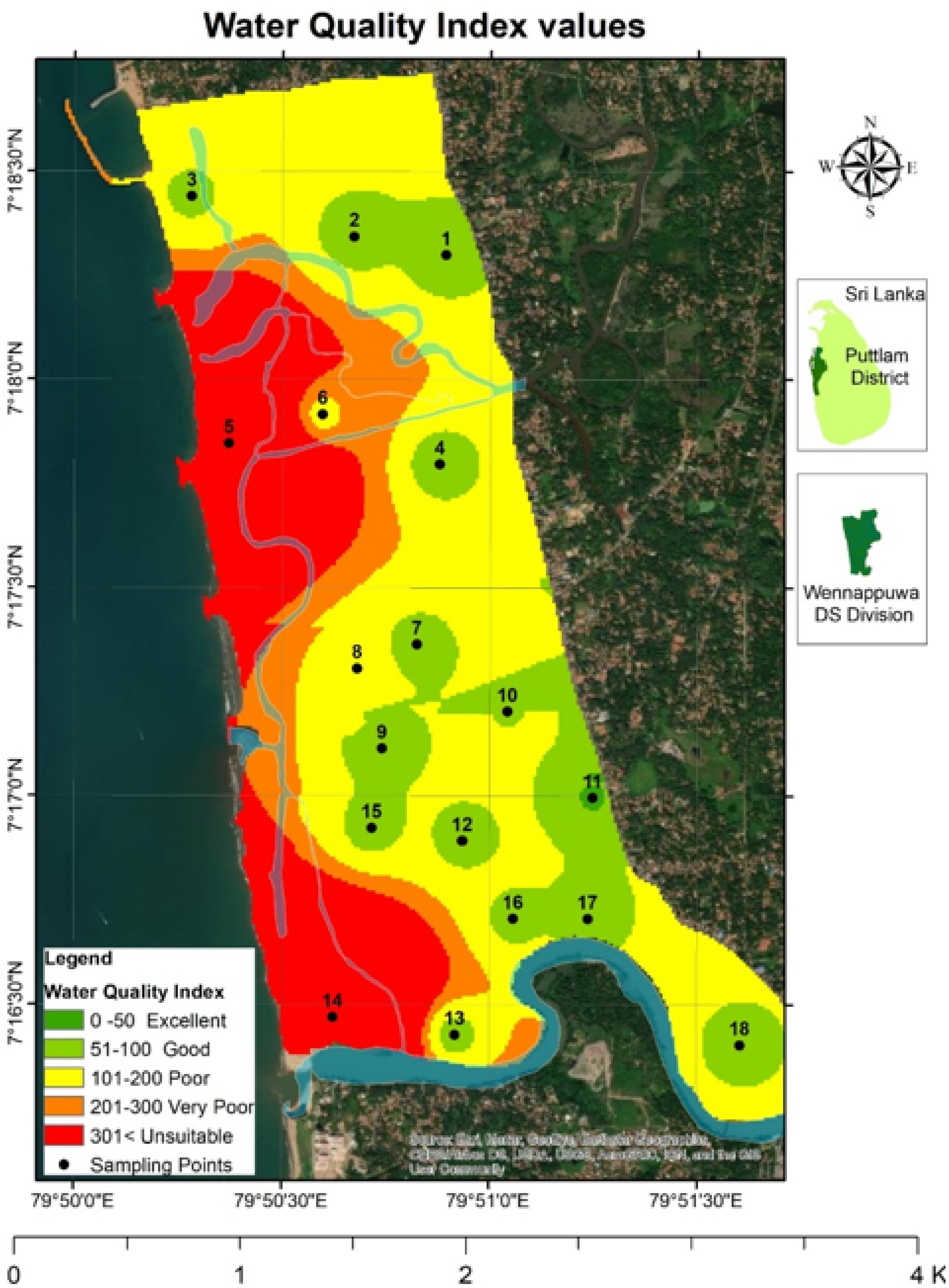

Figure 6

Spatial distribution map for the WQI of the study region

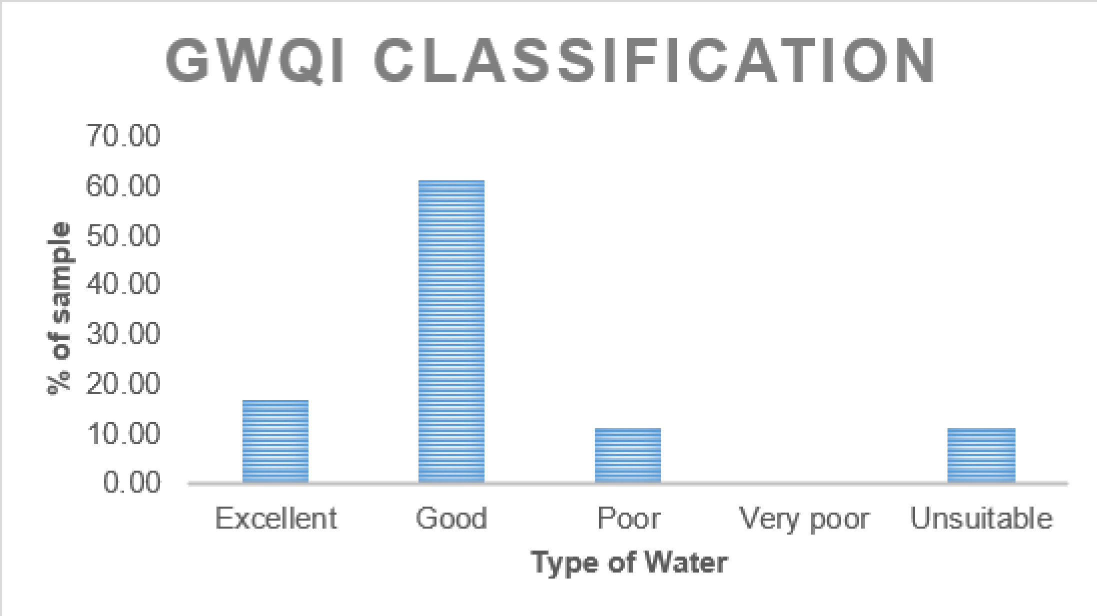

Figure 7

Classification of groundwater quality index (GWQI) in the groundwater of the study area.