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

Thanippuli Arachchige Nilusha Tharangani Perera1 · Herath Mudiyanselage Malhamige Sonali Dinesha Herath1 · Ranjana Udaya Kumara Piyadasa1 · Liu Jianhui2 · Li Bing3

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Abstract
Rising sea levels, groundwater exploitation, and urbanization were the primary causes of seawater intrusion, exerting pressure on coastal aquifers. In Sri Lanka’s urban coastal region, a comprehensive physicochemical description of groundwater has yet to be identified. Therefore, the objectives of this research were to (a) use a Geographic Information System (GIS) to designate spatial distribution of various water physicochemical characteristics, (b) detect “suitable” groundwater zones for drinking, and (c) estimate groundwater quality by developing a groundwater quality index (GWQI) in Sri Lanka’s urban coastal region. The physiochemical parameters of 18 groundwater samples [pH, electrical conductivity (EC), turbidity, total dissolved solids (TDS), Na+, K+, Ca2+, Mg2+, Cl−, and HCO3−] were studied in terms of their spatial and temporal variation. According to the World Health Organization (WHO) and Sri Lankan Standard Institution (SLS), EC levels in 11% of samples were above the acceptable range, while turbidity levels in 22% of samples were above the acceptable range. Water was consumable in 77.78% of the locations and unsatisfactory in 22.22%. The main hydrochemical facies detected in groundwater samples were Na+–Cl− and the mixed Ca2+–Mg2+–Cl− face, which indicated carbonate dissolution and weathering of silicate minerals and the main mechanism controlling the water chemistry in the study area is water–rock interaction. Based on daily water consumption, it was discovered that the HQ is greater than one, in 61% of males, 78% of females, and 89% of children, indicating a health hazard. Furthermore, groundwater quality in the study region is deteriorating due to significant coastal erosion, making it critical to maintain a comprehensive groundwater management strategy to promote sustainable water consumption.

Keywords GIS modelling · Hydrochemical facies · Hazard quotient · Potable water · WQI · Spatial distribution map · Water quality standards

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 2019; Yang et al. 2016). Agriculture, domestic consumption, industrial activities, and other activities all depend on groundwater (Mukherjee and Singh 2018; Tiwari et al. 2017). Groundwater, on the other hand, meets the needs of majority (2/3) of the world’s inhabitants through their water-dependent activities (Adimalla and Li 2019). The major groundwater contaminants include inorganic salts, cations (Na+, Ca2+, Mg2+, etc.), anions (CO32−, HCO3−, Cl−, etc.), and heavy metals (Wijesinghe et al. 2016). Excessive concentrations of certain pollutants in water can lead to health problems, but excessive amounts of other parameters have no effect but do impair appetite (Gunarathna et al. 2016; Wanasinghe et al. 2018). To address the issue of water scarcity, pollution, and management, the United Nations (UN) has prioritized the achievement of clean drinking water for everyone in their Millennium Development Goals and in

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Thanippuli Arachchige Nilusha Tharangani Perera
nilusha@et.cmb.ac.lk

1 Department of Environmental Technology, Faculty of Technology, University of Colombo, Colombo, Sri Lanka
2 Third Institute of Oceanography, Ministry of Natural Resources, Shandong Xiamen, China
3 Island Research Centre, Ministry of Natural Resources, Shandong Xiamen, Fujian, China

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the Sustainable Development Goals by 2030 (WHO 2017; Weerasooriya et al. 2021). As a result, more consideration should be given to combating groundwater pollution, as many countries are currently experiencing a scarcity of fresh water resources (Pant 2011; UNEP 2018). Furthermore, the United States Environmental Protection Agency (USEPA) has proposed a method for determining the health risk (hazard quotient—HQ) for humans when exposed to harmful levels of chemicals in water (Narsimha and Rajitha 2018; USEPA 1993). This was commonly used by different researchers around the world to assess potential health risks caused by ingestion, oral intake, or dermal intake of harmful elements (Chen et al. 2017).

Groundwater contamination is widespread in several areas of Sri Lanka, particularly in the Maha Oya river basin. In the western urban coastal region, 74% of residents use their land for residential and industrial purposes (tourism, hotels, and restaurants), while 24% use their land for agricultural production. Groundwater contamination in the Western urban coastal region is induced by nutrient and toxic inputs from agriculture, sea water intrusion, as well as urban and industrial development. Furthermore, 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, WQI” was an essential indicator for determining the degree of water pollution (Singh et al. 2019; Tian et al. 2019; Wang and Zhang 2018); it may be used to assess the quality of groundwater (Jain et al. 2010; Nihalani and Meeruty 2020). Horton (1965) developed the concept of WQI, and there are now numerous methodologies to determine WQI that have been refined by different authors in different regions of the world (Aouiti et al. 2020; Lopes et al. 2020; Şener et al., 2021). By aggregating and evaluating various water quality sub-indices using a single mathematical classification scheme, this method can be used to evaluate water quality and facilitate decision-making (Gitau et al. 2016). According to Vaiphei et al. (2020), the WQI is calculated by combining physicochemical and biological properties of water.

In recent years, a great percentage of groundwater contamination and intrusion studies have primarily been carried out in various parts of Sri Lanka (Herath and Ratnayake 2007; IGES 2007; International Water Management Project 2005; Perera et al. 2018) and have used a variety of approaches to realize groundwater contamination and identify the cause (Villholth and Rajasooryar 2010). According to Herath et al. (2017) seawater intrusion and contamination of groundwater are quite common along the Jaffna peninsula of Sri Lanka. Furthermore, the area’s groundwater quality measurements were above the SLS permissible range. Mikunthan and De Silva (2008) assessed groundwater quality in the Thirunelvely and Kondavil areas using geostatistical techniques. They concluded that positive management strategies, such as soil conservation and fertilizer reduction (N—top dressing), had a significant impact on high groundwater chemistry. Cooray et al. (2019) discovered that, with the exception of 6.4% of samples, all water sources in Sri Lanka’s dry zone required additional treatment before consumption.

However, in the western coastline region of Sri Lanka, a precise physicochemical description of groundwater content has yet to be determined. As a result, the study’s main objectives were to (a) use a Geographic Information System (GIS) to create maps to indicate spatial distribution different physicochemical parameters; (b) identify “suitable” and “unsuitable” groundwater zones for drinking; and (c) evaluate groundwater quality by developing a 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.

Materials and methodology

The research was consistent with physicochemical analysis of groundwater chemistry, calculation, spatialization of GWQI with sub-indices, and human health risk assessment. The methodology employed is summarized in the flowchart shown in Fig. 1.

Study area

The targeted case study region (Waikkala, 7.2838° N, 79.8578° E, Fig. 2) is located in the Puttlam District of Sri Lanka’s North Western Province where groundwater is a major source of water consumption. It covers an area of 3072 km², to the north, the Kala Oya and Madaragam Aru; to the east, the Anuradhapura District and Kurunegala District; to the south, the Ma Oya; and to the west, the Indian Ocean (Phok et al. 2021).

The study region encompasses 24 km² and extends from the left bank of the Maha Oya River, which serves as the southern boundary of Putttlam District, to the north. The case study area includes the mouth of the Gin Ganga River as well (Mahagamage and Jayakody 2020). This region includes 28 Grama Niladhari divisions and is part of the Wennappuwa Divisional Secretariat Division. This region has a population density distribution of 1746km² (Statista 2021). Groundwater is retained by alluvial deposits and ferruginous gravels, as well as unconsolidated sands and spits in the coastal region. Diverse, confined aquifers have been identified within the sedimentary limestone and sandstone.
formations of the northwestern and northern coastal plains (Herath 2006). The most common abstraction technologies for groundwater are “dug wells, dug-cum bore wells, and bore wells,” and their yields are largely determined by the recharge levels in the region. The district’s yearly average precipitation is 1174 mm, with November being the wettest month of the year. Puttalam, which is located on the seashore, is mostly flat, with the land rising to about 60 m inland. In land, there are reddish brown earth and low humic gley soils, and the soils are mostly red-yellow latosols (Abeykoon et al. 2021; Wickramasinghe 2013).

**Physicochemical analysis of groundwater**

**Sample collection**

Between January 2019 and January 2020, groundwater samples were collected in triplicate at 18 different locations once a month, from a previously drilled well or a deep bore hole. Groundwater samples were collected in accordance with APHA guidelines and the most recent research (APHA 2012; Mao et al. 2021; Senthilkumar et al. 2021). Pre-cleaned, 1-L high-density polythene sample vials were used to collect water samples. The samples were labeled and delivered to a chemical laboratory for physicochemical analysis at 4 °C (Jehan et al. 2020).

Using Arc GIS 10.2 software, the case study region was partitioned into a 9x5 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 (Naik et al. 2021).

**Sample analysis**

A handheld optical pH/EC/TDS meter (Hanna HI 9811–5) was used to determine water physical parameters such as EC, pH, and TDS in the field immediately after collection (Maspalma et al. 2018; Narsimha and Sudarshan 2017; Şener et al. 2017). EUTECH waterproof Cyber scan pH650 handheld meter kit was used to determine turbidity (APHA 2012). Calibration was done by using standard solutions. The basic protocols of the American Public
Health Association were used to examine other chemical parameters. The AgNO₃ back titration (Argentometric method) (Shukla et al. 2018) was used to determine the Cl⁻ concentration in the laboratory. The Mg²⁺ and Ca²⁺ were determined using EDTA titration method which used for hardness calculation (Chakraborty 2021; Yadav et al. 2021). The following equations (Eqs. 1 and 2) were used to calculate final Mg²⁺ and Ca²⁺ concentrations (Adimalla and Taloor 2020). Furthermore, K⁺ and Na⁺ concentrations of the water samples were analyzed by using flame photometer (Model 130 Systronics) (Nath et al. 2021; Singh et al. 2021) and HCO₃⁻ were measured by titration with 0.02 N H₂SO₄ using methyl orange indicator (Şener et al. 2017) (Adimalla and Taloor 2020).

Magnesium Hardness (MgH) = Total Hardness − Calcium Hardness (1)

Mg²⁺(mg/L) = MgH × equivalent weight of Mg²⁺ × Normality of EDTA (2)

All the reagents and chemicals used for water sample analysis were of analytical standard and they were prepared in Type I (18.2 MΩcm) Milli-Q water. [KCl (99%), Silver nitrate (AgNO₃, 98%), potassium chromate (K₂CrO₄, 99%), sodium hydroxide (NaOH, 97%), sodium chloride (NaCl, 98%), sulfuric acid (H₂SO₄, 98%), ethylenediamine tetraacetic acid (EDTA) (99%), Eriochrome Black T (EBT), and murexide].

**Development of groundwater quality index (GWQI)**

The groundwater quality index (GWQI) was developed using the collected data to assess the water’s acceptability for drinking (Adimalla et al. 2018; Chaturangla et al. 2018; Ramakrishnaiah et al. 2009; Rabeiy 2018). The first step in the GWQI classification process was to assign weights (wi) to each parameter such as chloride, TDS, Na⁺, pH, Ca²⁺, K⁺, Mg²⁺, and HCO₃⁻ and then calculate relative weight (Wi) (Eq. 3). Based on expert opinions gathered from various previous studies (Barbosa Filho and de Oliveira 2021; Harun et al. 2021; Kayemah et al. 2021), 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 the maximum weight of five (5) was allocated to the parameters which are more pertinent in groundwater quality evaluation such as TDS (Table 1) (Adimalla and Taloor 2020).

\[
Wi = \frac{wi}{\sum_i wi}
\] (3)
According to WHO guidelines, each parameter’s consistency rating scale \((Q_i)\) is calculated by multiplying its concentration in each water sample by its corresponding standard and then multiplying by 100 (Eq. 4) (Adimalla and Taloor 2020).

\[
Q_i = \frac{c_i}{S_i} \times 100
\]  

(4)

where \(c_i\) is the concentration of each parameter, \(Q_i\) is the quality rating, and \(S_i\) is the chemical parameter’s recommended guideline value. Using Eqs. 5 and 6, the sub-index (\(S_i\)) and GWQI were determined (Adimalla and Taloor 2020).

\[
S_i = W_i \times Q_i
\]  

(5)

\[
GWQI = \sum_{i=0}^{n} S_i
\]  

(6)

Development of spatial distribution maps

The Geographic Information System (GIS) has risen to prominence as the most popular tool for gathering, classifying, and displaying groundwater spatial data, as well as for using the data to make decisions, in many domains, including geographical and geo-environmental disciplines (Eltarabily and Moghazy 2021; Gunaalan et al. 2018; Rajasooriyar et al. 2013). Hence, the exact sampling locations were marked using a portable Global Positioning System (Garman eTrex 30), and the marked coordinates were imported into 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).

Geochemical characterization of groundwater

Hydrochemical type and facies of groundwater samples were determined by piper plots. Piper plots are an effective method in graphical illustration of water types and facilitate to decide the sources of the dissolved constituents in groundwater (Aouiti et al. 2020; Elsayed et al. 2021; Moreno et al. 2021). Piper diagram categorized four dominants for cations [(A) \(Ca^{2+}\) type, (B) \(Mg^{2+}\) type, (C) \(Na^+\), and \(K^+\) type], four dominants for anions [(E) \(SO_4^{2-}\) type, (G) \(HCO_3^-\) type, (F) \(Cl^-\) type], a (D) dominant type which is common for both anions and cations, and six facies [(1) \(Ca^{2+}–Mg^{2+}–HCO_3^-\), (2) \(Na^+–Cl^-\), (3) mixed \(Ca^{2+}–Na^+–HCO_3^-\), (4) mixed \(Ca^{2+}–Mg^{2+}–Cl^-\), (5) \(Ca^{2+}–Cl^-\), and (6) \(Na^+–HCO_3^-\)] for groundwater. Groundwater chemistry controlling factors were determined by Gibbs plots and it was created by TDS versus anions \((Cl^-/Cl^- + HCO_3^-)\) and cations \((Na^+/Na^+ + Ca^{2+})\). The following calculations (Eq. 7 and 8) have been used to determine Gibbs ratios and controlling factors and then categorized into three groups such as evaporation dominance, precipitation dominance, and rock dominance. All the ionic concentrations were expressed in mill equivalents per liter (meq/L) (Khan et al. 2021).

\[
Gibbsratio_I = \frac{Cl^-}{Cl^- + HCO_3^-}
\]  

(7)

\[
Gibbsratio_{II} = \frac{Na^+ + K^+}{Na^+ + K^+ + Ca^{2+}}
\]  

(8)

Human health risk assessment

Examination of health risks due to non-carcinogenic elements in different gender and age groups was done by considering the oral or ingestion pathway of drinking water. According to Chen et al. (2017), element inhalation and
dermal contact were always very low, so the impact on human health is negligible. Thus, the non-carcinogenic risk through ingestion of the groundwater was calculated using hazard quotient (HQ). The following Eqs. 9 and 10 were used to calculate HQ and the chronic daily intake dose (CDI) (Adimalla et al., 2019; Bodrud-Doza et al., 2020; Zhang et al., 2020) (Adimalla et al., 2019).

\[ CDI = \frac{C \times IR \times ED \times EF}{ABW \times AET} \]  

\[ HQ = \frac{CDI}{RfD} \]

where CDI is the chronic daily intake, \( C \) is the element concentration in the groundwater (mg/L), IR is the ingestion rate (L/day), ED is the exposure duration (years), HQ is hazard quotient, RfD is the reference dose for chronic oral exposure of particular element in mg/kg/day, EF is the exposure frequency (days/years), ABW is the average body weight (kg), and AET is the averaging time for non-carcinogens (days) (Adimalla et al., 2019; Zhang et al., 2020).

Furthermore, Table 3 shows the recommended values of selected non-carcinogenic health risk parameters for assessing chronic daily intake via oral ingestion for males, females, and children. According to the USEPA’s recommendation, the limit of HQ is 1, and groundwater samples with HQ values greater than 1 (HQ > 1) posed a substantial

| Parameters                      | Unit       | Adult | Children | Reference            |
|---------------------------------|------------|-------|----------|----------------------|
| Ingestion rate (IR)             | L/day      | 2.5   | 0.7      | Zhang et al. (2020)   |
| Exposure frequency (EF)         | Days/years | 365   | 365      | Adimalla et al. (2019); Zhang et al. (2020) |
| Exposure duration (ED)          | Years      | 30    | 12       |                      |
| Average body weight (ABW)       | kg         | 70    | 15       |                      |
| Average exposure time (AET)     | Days       | 10,950| 4,380    |                      |
| RfD value for Cl\(^-\)          | mg/kg/day  | 3.29E+01 | 3.29E+01 | USEPA 1993 (2016)   |
| RfD value for Na\(^+\)          | mg/kg/day  | 2.14E+01 | 2.14E+01 |                      |
| RfD value for Mg\(^{2+}\)       | mg/kg/day  | 1.86E+01 | 1.86E+01 |                      |
| RfD value for Ca\(^{2+}\)       | mg/kg/day  | 6.55E+00 | 6.55E+00 |                      |

Table 3 Key parameters for calculating the health risks through ingestion and oral pathways

Fig. 3 Spatial distribution of (a) pH, (b) EC, and (c) TDS in the groundwater samples of the study area
health risk due to a specific element (Achary et al., 2016; Adimalla et al., 2019; Amarasinghe, 2020; Bodrud-Doza et al., 2020; Zhang et al., 2020).

**Results and discussion**

**Physicochemical parameters of the groundwater**

The significance of groundwater resource quality is critical since it is a fundamental factor in determining its suitability for consumption in the studied area. The data were also compared to the WHO (2017) and SLS guidelines to see if they were suitable for drinking.

**pH and EC**

The groundwater acidity and alkalinity can be measures using the hydrogen ion concentration or the pH. Despite the fact that pH has no direct impact on human health, it is one of the most important water quality parameters. The groundwater samples in the study area were acidic to alkaline in nature, with a pH ranging from 6.21 to 7.68, with an average of 6.93. Figure 3a depicts the pH geographic distribution in the research area. According to the WHO guidelines, a suitable pH range of 6.5 to 8.5 is recommended by the WHO (2017) and the pH range for groundwater in SLS was 6.50–9.00, with a maximum permissible level of 9.00. However, no location was found to be exceeding the permissible level in any of the groundwater standards. According to Sampath et al. (2011), the pH range of groundwater in Sri Lanka’s Puttlam district was 6.30–8.20, and Young et al. (2011) discovered a pH range of 5.76 to 8.70 in northwestern province. The pH variation in groundwater in Sri Lanka’s western province was below the SLS permitted level (4.0 to 8.2) and was not hazardous for drinking (Premalal and Jayewardene 2015).

According to Kanga et al. (2020), the ionic concentration of groundwater was commonly measured by calculating the EC, which fluctuates depending on the concentration, ion types available in the water, and temperature. The EC in the research area ranged from 430.10 to 99,144.72 μS/cm, with an average of 10,709.76 μS/cm. When referring to the WHO drinking water recommendations, the maximum permitted EC in water is 1500 μS/cm (WHO 2017) and the maximum allowed level in Sri Lanka is 750 μS/cm. According to the results obtained from the present study, only 11% of groundwater samples were founded to be above the maximum allowable level. The geographic distribution of EC is depicted in Fig. 3b. Furthermore, in 76% of areas in the Puttlam district of Sri Lanka, EC levels exceeded the acceptable values of the WHO drinking water quality guidelines, according to a study conducted by Sampath et al. (2011). Several other studies in Sri Lanka revealed that the Puttlam district had exceeded the maximum permissible level of EC in groundwater (Arasaretnam et al. 2018; Edirisinghe et al. 2016). Furthermore, Young et al. (2011) discovered that EC ranged from 143 to 3549 μS/cm in the northwestern province. Gopalakrishnan et al. (2020) discovered high salinity groundwater in Sri Lanka’s Jaffna peninsula (EC = 20,000 μS/cm). As a result, salinization could have an effect on groundwater quality in the research area in the coming years.

**Total dissolved solids (TDS)**

TDS is a term that refers to the various minerals that are present in dissolved form in water (Narsimha and Sudarshan 2017). Large carbonates, bicarbonates, sulfates, chlorides, silica, phosphates, sodium, potassium, calcium, and magnesium are the most common dissolved solids in water (Adimalla et al. 2018; Gnanachandrasamy et al. 2015). As...
a result, it is an important factor to consider when assessing the consistency of drinking water and other types of water. The TDS content in the current study ranges from 168 to 749 mg/L, with a mean value of 299 mg/L. However, all the samples had TDS levels below the WHO limit (1000 mg/L) and SLS levels (2000 mg/L). According to previous studies, TDS concentrations in the Puttlam district were below the ideal threshold level in 80% of the locations and 20% of the sites exceeded the ideal level. Furthermore, TDS in several other areas in western urban coastal region were of sufficient quality for drinking (Sampath et al. 2011; Wickramasinghe et al. 2021). In the study conducted by Adimalla and Taloor (2020), almost 95% of the samples were below the ideal threshold levels 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 Fig. 3c.

Cations (Mg$^{2+}$, Ca$^{2+}$, Na$^{+}$, and K$^{+}$)

According to the WHO (2017) standards, the 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. 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. However, closer sampling points to the coastal area have showed higher Mg$^{2+}$ content than inside sampling points (Fig. 4a).

According to the findings, the Ca$^{2+}$ concentration in groundwater in the research area varied from 5 to 43 mg/L, with an average value of 20 mg/L (Fig. 4b). Although closer sampling points to the coastal area showed a higher Ca$^{2+}$ content than inside sampling points, all of the samples were well within the WHO standard level (WHO 2017). Mg$^{2+}$ and Ca$^{2+}$ concentrations in Sri Lanka’s northwestern province ranged from 4.98 to 112 mg/L and 1.29 to 98 mg/L, respectively, according to Young et al. (2011). The dissolution of carbonate minerals resulted in relatively high amounts of Mg$^{2+}$ and Ca$^{2+}$ in various sections of the northwestern province. Total hardness (Ca$^{2+}$ + Mg$^{2+}$) levels in Puttlam district water have been found to be higher than the allowable levels, with only 16% of places having sufficient quality for potable water (Sampath et al. 2011).

Figure 4c and d show the geographical distributions of Na$^{+}$ and K$^{+}$. Higher Na$^{+}$ concentrations have been found in the study region’s central and northern regions, while higher K$^{+}$ concentrations were also found in the northwestern and southeastern regions closer to the shoreline. The Na$^{+}$ content of groundwater, on the other hand, ranged from 22 to 173 mg/L, with a mean value of 60 mg/L. The results showed that none of the groundwater samples tested fulfilled...
the WHO and SLS guidelines (WHO, 2017). According to Young et al. (2011), the average Na\(^+\) and K\(^+\) concentrations in the northwestern province were 79.77 mg/L and 6.12 mg/L, respectively. K\(^+\) is the most important nutrient for humans, and too much of it can cause constipation (Adimalla and Venkatayogi 2018). K\(^+\) concentrations ranged from 2 to 25 mg/L in the sampling location, with mean value of 12.52 mg/L. Nevertheless, the WHO recommendations for K\(^+\) have yet to be established because it occurs naturally in drinking water at levels far below those deemed harmful to human health (Adimalla and Venkatayogi 2018; WHO 2017).

**Anions (HCO\(_3^-\) and Cl\(^-\)) and turbidity**

The concentration of HCO\(_3^-\) in the sample ranged from 26 to 54 mg/L, with a mean value of 37.11 mg/L. The geographic distribution of HCO\(_3^-\) is shown in Fig. 5a, with higher concentrations found in the south shoreline and lower concentrations found in the north shoreline. HCO\(_3^-\) concentrations in the northwestern province ranged from 10 to 240 mg/L, according to Young et al. (2011), while Jayasena et al. (2008) found it to be between 3.5 and 966 mg/L.

Excessive Cl\(^-\) concentrations in groundwater are regarded as a sign of contamination from a variety of sources, and they impart a salty flavor to the water (Marghade et al. 2012). The Cl\(^-\) concentration in the sample area varied from 110 to 443 mg/L. However, the average Cl\(^-\) concentration in the groundwater samples studied (191 mg/L) is lower than the overall permissible limit of 600 mg/L (WHO 2017). The geographic distribution map of Cl\(^-\) is depicted in Fig. 5b and higher concentrations found in the north shoreline. Previous studies in the coastal region of Sri Lanka have revealed desirable Cl\(^-\) values (32–1100 mg/L) in accordance with the SLS (Mikunthan and Silva 2010). Despite the fact that no health risks have been identified, residents of coastal areas are reluctant to drink water due to texture and taste concerns.

Turbidity refers to the relative clarity of the water, which prevents light transmission. Groundwater turbidity in the study area ranged from 0.62 to 41.67 NTU (Fig. 5c). According to the SLS and WHO drinking water quality guidelines, the maximum turbidity level was exceeded in 22% of locations. As a result, it is unlikely to be suitable for consumption. Several previous investigations discovered that the turbidity in the Puttalam district’s groundwater was much higher than the WHO and SLS permitted values. Turbidity ranged from 1.6 to 164 NTU, according to Galhenage et al. (2021), while Gunarathna et al. (2021) discovered turbidity ranged from 44 to 723 NTU. Furthermore, Gunarathna et al. (2021) discovered that the mean turbidity of groundwater was significantly higher than that of surface water.

**Groundwater quality index (GWQI)**

Ramakrishnaiah et al. (2009) presented several categories for GWQI such as excellent water (WQI = 50), good water (WQI = 50 to 100), poor water (WQI = 100 to 200), very poor water (WQI = 200 to 300) and unsuitable water for drinking (WQI = > 300) are some of the categories for GWQI. According to this classification, 16.67% of samples

![Spatial distribution map for the WQI of the study region](image1.png)

![Classification of groundwater quality index (GWQI) in the groundwater of the study area](image2.png)

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in the study area were excellent (NW4, NW11, NW13), 61.11% are good (NW1, NW2, NW3, NW7, NW9, NW10, NW12, NW15, NW16, NW17, NW18), and 11.11% are poor (NW6, NW8) for drinking purposes (Fig. 7). NW5 and NW14 were unsafe to drink (11.11%). Furthermore, values were ranged from 45.12 to 2700.55, with an average of 337.78 (Figs. 6 and 7).

**Geochemical depiction of groundwater**

Piper diagrams were drawn using dissolved ion (anions and cations) concentrations. It represented the hydrochemical progression of groundwater parameters as well as the overall effects of major ion reactions. According to Fig. 8, the cations in the water samples belonged to the Na$^+$ and K$^+$ types, with no dominant type, whereas the anions belonged to the Cl$^-$ type. Overall, the majority of the water samples were assigned to zones 2 and 4, which represent the Na$^+$–Cl$^-$ face and the mixed Ca$^{2+}$–Mg$^{2+}$–Cl$^-$ face, respectively.

The interaction between aquifer materials and groundwater was the most important factor in determining groundwater genesis and quality. As a result, the Gibbs diagrams were used to examine the evolution mechanisms. Most previous studies used Gibbs plots to interpret the three dominant factors involved in groundwater or surface water chemistry (evaporation, precipitation, and rock-water interaction) (Liu et al. 2021; Meng et al. 2021; Wanda et al. 2021). Gibbs ratios were ranged from 0.71 to 0.94 (ratio I) and 0.47 to 0.91 (ratio II), with a mean of 0.78 and 0.82, respectively. All of the sampling sites, as shown in Fig. 9, were in the middle of both cation- and anion-based plots, representing rock dominance or water–rock interaction category. According to the findings, rock weathering was a major factor in controlling the ionic composition and chemistry of groundwater.

However, the Na$^+$–Cl$^-$ and the mixed Ca$^{2+}$–Mg$^{2+}$–Cl$^-$ water types specify the silicate mineral weathering in the study area as well as carbonate dissolution. Moreover, agricultural activities and saline water intrusion can be a major reason for Na$^+$–Cl$^-$ water type in the study area. Limestone and sandstone weathering also can be affected for Ca$^{2+}$ and Mg$^{2+}$ elements in the water samples (Adimalla and Taloor 2020; Khan et al. 2021).

**Health risk assessment of groundwater**

The groundwater was the major source of drinking water in the urban western coastal region in Sri Lanka (Amarasinghe, 2020). According to the physiochemical
analysis and hydrochemistry of the study region, 

\[ \text{Na}^+–\text{Cl}^- \text{ and } \text{Ca}^{2+}–\text{Mg}^{2+}–\text{Cl}^- \] were the distinct facies of the groundwater samples. Therefore, the potential health risk for human through these elements (\(\text{Na}^+, \text{Ca}^{2+}, \text{Mg}^{2+}, \text{Cl}^-\)) might be high, and its assessment is critical (Nta et al., 2020). The total HQ limit for non-carcinogenic health risk, which always safe for human, has been set for less than 1 (HQ < 1) (Achary et al., 2016; Adimalla et al., 2019; Bodrud-Doza et al., 2020; Zhang et al., 2020).

The results of the non-carcinogenic risk assessment revealed that the total HQ values of drinking water containing \(\text{Na}^+\), \(\text{Ca}^{2+}\), \(\text{Mg}^{2+}\), and \(\text{Cl}^-\) to adults and children in Sri Lanka’s western coastal region ranged from 0.15 to 2.85 for males, 0.19 to 3.58 for females, and 0.86 to 6.86 for children, with a mean of 1.19, 1.50, and 2.01, respectively. Furthermore, the locations that were above the recommended total HQ limit (HQ = 1) were 61% for males, 78% for females, and 89% for children, respectively. However, NW2, NW3, NW5, NW6, NW7, and NW15 were not used for human consumption, whereas other wells were used for a variety of domestic purposes, including drinking.

As a result, the non-carcinogenic health risk associated with ingesting excessive \(\text{Na}^+, \text{Ca}^{2+}, \text{Mg}^{2+}, \text{and } \text{Cl}^-\) via groundwater/drinking water had a significant health impact on adults and children in the study region (Fig. 10). Children were more vulnerable than adults when exposed to these elements.

The majority of previous studies have revealed a number of non-carcinogenic health risks associated with groundwater contamination in various parts of the world, including Sri Lanka (Achary et al., 2016; Amarasinghe, 2020; Bodrud-Doza et al., 2020; Zhang et al., 2020).

Fig. 9 Groundwater chemistry and geochemical process in the study region—Gibbs plots

Fig. 10 Boxplots showing the results of non-carcinogenic health risks for adults and children
Conclusions

The groundwater condition in Sri Lanka’s western urban coastal region has begun to deteriorate as a result of seawater intrusion. Hence, investigating water quality in groundwater was critical, as it is the primary source for drinking and domestic use. This study used the GIS to indicate spatial distribution of different water physicochemical parameters and locate “suitable” and “unsuitable” groundwater zones for drinking among 18 locations, and evaluated water quality by developing a groundwater quality index (GWQI) using water quality sub-indices.

According to the study, the groundwater in the research area is neutral to slightly alkaline in composition. Na+ and Cl− were the major abundant cations and anions, respectively. This could be due to coastal erosion and seawater intrusion in the region. Ca2+ (5 – 43 mg/L), Na+ (22 – 173 mg/L), and K+ (2 – 24.67 mg/L) ion concentrations in the research region’s groundwater are within the maximum allowable limits when compared to the WHO drinking water quality guidelines (Mg2+ 300 mg/L, Na+ 200 mg/L, K+, not recommended) and Sri Lankan water quality standards (Ca2+ 100 mg/L, Na+ 200 mg/L, K+, not recommended). Excessive turbidity (22%) and EC (11%) have also been discovered at a few groundwater sample sites in the research area. The groundwater quality in the study region ranges from excellent to poor for drinking, according to the GWQI. The most significant influences on the groundwater quality index were turbidity and EC. Groundwater samples that are suitable for drinking account for 77.78%, while samples that are not suitable for drinking account for 22.22%. The study of groundwater chemistry, Gibbs and Piper diagram in urban coastal region, Sri Lanka, revealed that the rock-water interaction were the major cause for groundwater quality. In the urban coastal region, water types such as Na+ and K+, Cl−, Na+–Cl−, and Ca2+–Mg2+–Cl− were discovered. According to the non-carcinogenic risk assessment, total HQ values of drinking water containing Na+, Ca2+, Mg2+, and Cl− to adults and children in Sri Lanka’s western coastal region ranged from 0.15 to 2.85 for males, 0.19 to 3.58 for females, and 0.86 to 6.86 for children, with a mean of 1.19, 1.50, and 2.01, respectively. Furthermore, the locations that were above the recommended total HQ limit (HQ = 1) were 61% for males, 78% for females, and 89% for children, respectively.

According to the spatial distribution maps, the research area’s poor and unfit water for human consumption is mostly concentrated in the central and western coastal areas. The spatialization of the WQI using GIS can be a useful tool for decision-makers to evaluate the effectiveness of water management projects and to take actions to reduce the impacts on groundwater pollution. As a result, consistent monitoring of seawater intrusion in Sri Lanka’s western urban coastal areas is critical to ensuring community well-being and safety.

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HMMSD Herath—conceptualization, resources, software, validation, visualization.
Ranjana UK Piyadasa—conceptualization, funding acquisition, investigation, project administration, resources, supervision.
Liu Jianhui—conceptualization, funding acquisition, investigation, methodology, resources.
Li Bing—conceptualization, funding acquisition, investigation, methodology, resources.
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Declarations

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