ABSTRACT: Management of groundwater quality is becoming a key feature of a sustainable future while implementing sustainable development goals which are given by United Nations. During past decades, rapid land-use changes, urbanization, and population expansion are highly influenced the groundwater quality. To provide policymakers and water managers with reliable information on groundwater quality is a challenge to achieving sustainable development goals in developing countries. Therefore, this study intended to assess the spatial variability of groundwater quality using selected physicochemical parameters at the 39 available groundwater wells during the southwest monsoon period. Spatial variability is explained in 13 Divisional Secretariat Division (DSD) levels in Colombo district due to easier interpretation and management purposes. Afterward, groundwater quality was related to urbanization using population density and built-up density in 13 DSD levels in Colombo district, Sri Lanka. PCA (Principal Component Analysis) shows that 08 DSD levels are urban and 05 DSD levels are rural. pH (3.22–6.73), COD (8.91–52.9 mg/L), BOD₅ (1.2–9.9 mg/L), and DO (2.17–5.05 mg/L) showed deviations from the given standards by local authorities in Sri Lanka. A significant relationship ($p < .05$) was found between urbanization and physicochemical parameters in regression analysis. The water quality index shows poor water quality indices in urban areas and vice versa in rural areas which is similar to the results obtained by statistical analysis. A sustainable urban development plan with continuous groundwater quality monitoring is necessary to protect groundwater resources in Sri Lanka.

KEYWORDS: Colombo district, urbanization, groundwater quality, PCA, sustainable development

Introduction

Spatial distribution of groundwater is higher than the surface water while temporal variability of groundwater is less than the surface water. Groundwater is less exposed to pollution than surface water. However, restoration or clean-up procedures are extremely difficult and expensive in case of pollution. Even though many natural and anthropogenic pollution triggering factors are available, they can be varied in different countries due to their geographical location and development status. There are many direct and indirect associations between urbanization and groundwater degradation because groundwater contamination in the urban environment is influenced by various numbers of potential contamination sources (Misra, 2011).

Domestic, commercial, and industrial wastes from urbanized areas are among the prime sources of pollution (Azzellino et al., 2019; Bougheria et al., 2014; Villholth & Rajasooriyar, 2010). On the other hand, increased agricultural use of fertilizers and pesticides are major threats to groundwater quality in rural areas (Elhatip et al., 2003; Hildebrandt et al., 2008; Jeyaruba & Thushyanthy, 2009). These pollutants can percolate into aquifers through seepage and contribute to polluting the groundwater (Kuruppuarachchi, 2012; WHO, 2011). Groundwater resources are widely used for domestic, agricultural, commercial, and industrial purposes, and hence, the demand for groundwater is steadily increasing in Sri Lanka (Herath, 2007; Rajasooriyar et al., 2013). Such large demands on groundwater have caused exploitation and at the same time, groundwater quality in the Colombo district is triggered by both natural and anthropogenic sources (Gunawardhana et al., 2002; Herath & Ratnayake, 2007; Mahagamage et al., 2015; Rathnasri & Manage, 2016). But the monitoring and management of groundwater resources have not been prioritized by the authorities.

Statistical tools are successfully utilized by researchers for analyzing spatial distribution of the physicochemical characteristics of groundwater over large areas. In addition, many studies have integrated statistical techniques and approaches to establishing strategies to manage groundwater resources (Arulbalaji & Gurugnanam, 2017; Gulgundi & Shetty, 2018).

Therefore, this study aims to assess the groundwater quality by analyzing the selected physicochemical parameters and correlating them with urbanization in the Colombo district.

Methodology

Study area

Rapidly urbanizing Colombo district in western province, Sri Lanka was selected as the study area (Figure 1a). It consists of 13 Divisional secretariats divisions (DSDs) and a total area extent of about 699 km². The total population is about 2,375,000 according to the 2015 statistics. Western part of the study area is exposed to the ocean and other directions of the study area are exposed to landmasses of Gampaha, Kegalle, Ratnapura, and Kalutara districts. Drainage network is drained off to the ocean (Figure 1a).
Major land-use classes (built-up, industrial areas, agriculture, waterbody, vegetation) in Colombo district are shown in Figure 1b (Antalyn & Weerasinghe, 2020). The major aquifer types in the study area are alluvium aquifer, laterite (cakook), and a few crystalline limestone (marble) bands. These aquifers are recharged and expand mainly during the wet season and contract during the dry season (Gunawardena & Pabasara, 2016).

Selecting groundwater sampling sites

From each DSD, 3 locations were selected randomly according to the availability of open drinking water wells to cover the entire Colombo district by making altogether 39 well locations (Figure 1a).

Since groundwater does not have a boundary, DSDs were selected as the hypothetical boundary for the analysis of the study and to facilitate interpretation of the results. Therefore, sampling points were selected randomly as three sampling wells from each DSD. In this study the spatial variation is considered but not the temporal variation is considered, hence sampling intervals were not included.

Physicochemical parameters for groundwater quality assessment

Sampling was carried out during the southwestern monsoon from June 2018 to September 2018. From each well, three water samples were collected randomly to make 3 replicates from each well at once during 9 am to 11 am to estimate the errors in the procedures. Standard Errors (SE) show the accuracy level of each method followed. The depth of the wells ranged from 10 to 15 m and water levels ranged from 5 to 10 m from the ground surface. Samples were collected between 0 and 3 m from the water level in open wells by bailing with a clean container. Filtration was done before determining nitrate-N concentration. Preservation was done to the collected samples of Nitrate—N, Total phosphate, Total Suspended Solids (TSS), and Chemical Oxygen Demand (COD) then transported to the laboratory of the Department of Zoology and Environmental Management. Samples were stored at 40°C temperature until to conduct the standard laboratory testing. Selected in-situ and ex-situ physicochemical parameters were measured using methods as mentioned in Table 1. Standard procedures were followed, and calibrated instruments were used to achieve accurate and reliable results. Instruments were calibrated at room temperature which was ranged from 30°C to 32°C. The results were compared with locally proposed ambient water quality standards.

Data analysis

Collected data showed normal distribution. Principal Component Analysis (PCA) was used to categorize urbanization in Colombo district as urban and rural DSDs in the study area. Regression analysis was done to find the correlation between groundwater quality and the urbanization of the study area.

Categorize urbanization in Colombo district as urban and rural areas using PCA. In order to characterize urbanization in Colombo district, the indicators of population density and built-up density of each DSD level (Table 2) were used. Population data were obtained from Department of census in Colombo, Sri Lanka. The latest land uses of each DSD were obtained from the literature (Antalyn & Weerasinghe, 2020). Population density was derived by dividing usable area of each DSD. Here DSDs were used to visualize and interpret the urbanization in Colombo district effectively.
Population density and built-up density were subjected to PCA considering all the DSDs using MINITAB version 14.0 software package. A score plot was used to group rural and urban DSDs in Colombo district. Positive PC1 (Principal Component 1) areas were considered as urban areas and negative PC1 areas were considered as rural areas (Table 5). The scores of the principal components were stored in specified columns as PC1_UI (Principal component 1 for Urban indicators) for regression analysis. Scores are the linear combinations of the data using the coefficients.

Groundwater quality analysis using physicochemical parameters. In order to relate with the urbanization, physicochemical parameters of groundwater wells were also determined for the DSD levels. Hence mean value (±SE) of groundwater samples in each DSD was taken to represent the groundwater quality of

Table 1. Selected Physicochemical Water Quality Parameters.

| WATER QUALITY PARAMETERS | STANDARD METHOD/INSTRUMENT |
|--------------------------|----------------------------|
| **In-situ parameters**   |                            |
| pH                       | Calibrated Multimeter HACH/Model: Hq40d multi parameter |
| Electrical conductivity  | Calibrated Multimeter HACH/Model: Hq40d multi parameter |
| Total solids             | Calibrated Multimeter HACH/Model: Hq40d multi parameter |
| Salinity                 | Calibrated Multimeter HACH/Model: Hq40d multi parameter |
| Dissolved oxygen         | Calibrated Multimeter HACH/Model: Hq40d multi parameter |
| Temperature              | Calibrated Multimeter HACH/Model: Hq40d multi parameter |
| **Ex-situ parameters**   |                            |
| Chemical Oxygen demand   | 5220C Closed Reflux, Titrimetric Method |
| Biochemical oxygen demand| 5210B 5-day BOD Test |
| Nitrate nitrogen concentration | 45004,500-NO3-B Ultraviolet, Spectrophotometric Screening Method |
| Total phosphate          | 4500-P E. Ascorbic Acid Method |
| Total suspended solids   | 2540D Total Suspended Solids dried at 103°C–105°C |

Source: APHA (2012).

Table 2. Population Density and Built-Up Density of DSDs.

| ID | DSD           | POPULATION | POPULATION DENSITY | BUILT-UP DENSITY |
|----|---------------|------------|--------------------|-----------------|
| 1  | Colombo       | 330,301    | 18,974.3           | 0.891           |
| 2  | Thimbirigasyaya | 243,245   | 10,573.6           | 0.877           |
| 3  | Dehiwala      | 90,901     | 11,325.5           | 0.932           |
| 4  | Rathmalana    | 97,587     | 7,459.4            | 0.863           |
| 5  | Moratuwa      | 171,947    | 8,881.2            | 0.808           |
| 6  | Kollonnawa    | 195,864    | 7,237.8            | 0.714           |
| 7  | Kotte         | 110,277    | 6,682.5            | 0.800           |
| 8  | Maharagama    | 200,703    | 5,409.9            | 0.705           |
| 9  | Kesbewa       | 250,576    | 4,030.0            | 0.584           |
| 10 | Kaduwela      | 257,533    | 3,023.4            | 0.494           |
| 11 | Homagama      | 243,089    | 2,071.6            | 0.369           |
| 12 | Hanwella      | 116,287    | 795.8              | 0.108           |
| 13 | Padukka       | 66,689     | 634.2              | 0.099           |

Source: Department of Census, Sri Lanka (2015) and Antalyn & Weerasinghe, 2020.
the particular DSD. Mean values were compared with the proposed ambient water quality standards for inland waters. Administrative area of DSD was used as a hypothetical area boundary for the study, to do the regression analysis between urbanization and groundwater quality in Colombo. Groundwater quality visualization at the DSD level will be an advantage for policymakers in their decision-making toward sustainability as well as water managers to implement their strategies at the administrative level.

Mean values of physicochemical parameters were subjected to PCA using MINITAB version 14.0 software package. The scores of the principal components were stored in specified columns as PC1_WQ (Principal Component 1 for water quality parameters) for regression analysis.

Regression analysis of groundwater quality and urbanization in Colombo district. The stored scores of principal components (PC1_WQ) which is derived from the analysis of physicochemical parameters (dependent variables) were plotted against the stored scores of principal components (PC1_UI) which is derived from the analysis of urbanization indicators (independent variables). The regression analysis results were used to describe the association between physicochemical parameters and urbanization. The first principal components (PC1) with large values were used for explaining the regression plot.

Calculation of WQI in DSDs. WQI (Water quality index) was calculated using pH, TDS, DO, COD, TSS, BOD₅, nitrate, and phosphate. The methodology for calculating WQI was similar to the study done by Rathnasri and Manage (2016).

A weight value from a scale of 1 to 5 was assigned for each parameter. Parameters with major importance were assigned the maximum weight value of 5. The relative weight of ith parameter was calculated using the following equation.

\[ Wi = wi / \sum_{i=1}^{n} wi \]  
Eq1

Where \( Wi \) is the relative weight of ith parameter, \( wi \) is the assigned weight of the ith parameter. A quality rating scale for each parameter was assigned using the following Equation.

\[ qi = 100Ci / Si \]  
Eq2

Where \( qi \) is the quality rating, \( Ci \) is the concentration of each physicochemical parameter in each water sample and \( Si \) is the Sri Lankan drinking water standard or each physicochemical parameter. To calculate the WQI the SI value for each parameter was calculated using the following equation.

\[ SIi = Wi / qi \]  
Eq3

Where \( SIi \) is the sub-index of ith parameter and \( Wi \) is the relative weight of ith parameter and \( qi \) is the quality rating. Then the WQI was determined by the following equation.

\[ WQI = \sum_{i=1}^{n} SIi \]  
Eq4

Where \( n \) is the number of physicochemical parameters measured in each well water sample. The computed WQI values were classified into five types from excellent water to water unsuitable for drinking (Table 3).

### Results and Discussion

**Urbanization in Colombo according to the indicators of urbanization**

The PCA analysis of urbanization indicators showed eigenvalues of 1.8129, 0.1871, and proportions of 0.906, 0.094 respectively. Since the PC1 component explains 90.6% (proportion of 0.906) of the variations of population density and built-up density, PC1 was used to classify DSDs in Colombo district into urban and rural categories based on population density and built-up density. The results of urbanization in Colombo district shows as urban and rural DSDs are shown in Figure 2.

**Spatial variation of selected groundwater physicochemical parameters of Colombo district**

Mean values of groundwater physicochemical parameters are shown below in DSD levels of Colombo district. Local standards are also shown in the graphs for visual interpretation.

The mean pH values of the wells ranged from 3.22 to 6.73. The wells in urban (Colombo-1) DSD showed highest mean pH value while the wells in rural (Kesbewa-9) DSD showed the lowest mean pH value. The mean temperature values of the wells ranged from 27.77°C to 31.26°C. The wells in urban DSD (Dehiwala-3) showed highest mean temperature value while the wells in rural DSD (Padukka-13) showed the lowest mean temperature value. The mean DO values of the wells ranged from 2.17 to 5.05 mg/L. The wells in urban DSD (Kotte-7) showed highest mean DO value while the wells in rural DSD (Hanwella-12) showed the lowest mean DO value. The mean COD values of the wells ranged from 8.91 to 52.9 mg/L. The wells in urban DSD (Moratuwa-5) showed highest mean COD value while the wells in rural DSD (Kaduwela-10) showed the lowest mean COD value. The mean TSS values of the wells ranged from 1.50 to 6.17 mg/L. The wells in urban DSD (Moratuwa-5) showed highest mean TSS value while the wells in rural DSD (Hanwella-12) showed the lowest mean TSS value. The mean BOD values of the wells

### Table 3. Classification of Water Quality Index.

| WQI  | SUITABILITY FOR DRINKING PURPOSES |
|------|----------------------------------|
| <50  | Excellent                        |
| 50–100 | Good water                      |
| 100–200 | Poor water                      |
| 200–300 | Very poor water                 |
| >300 | Unsuitable for drinking         |
ranged from 1.2 to 9.9 mg/L. The wells in urban DSD (Thimbirigasyaya-2) showed highest mean BOD value while the wells in rural DSD (Padukka-13) showed the lowest mean BOD value. The mean nitrate-N values of the wells ranged from 1.31 to 5.6 mg/L. The wells in urban DSD (Thimbirigasyaya-2) showed highest mean nitrate-N value while the wells in urban DSD (Rathmalana-4) showed the lowest mean nitrate-N value. The mean total phosphate values of the wells ranged from 0.0027 to 0.081 mg/L. The wells in rural DSD (Hanwella-12) showed highest mean total phosphate value while the wells in urban DSD (Kotte-7) showed the lowest mean total phosphate value. The mean conductivity values of the wells ranged from 89.8 to 457.7 µS/cm. The mean TDS values of the wells ranged from 39.0 to 221.0 mg/L. The mean salinity values of the wells ranged from 0.04% to 0.22%. Mean values of conductivity, TDS, and salinity were high in the wells in urban DSD (Thimbirigasyaya-2) while the wells in rural DSD (Hanwella-12) showed the lowest. pH (3.22–6.73), COD (8.91–52.9 mg/L), BOD (1.2–9.9 mg/L), and DO (2.17–5.05 mg/L) showed deviations from the given standards by local authorities in Sri Lanka. The results of the regression analysis between urbanization and groundwater quality parameters will effectively discuss the above results in section 3.4.

Results of PCA analysis for groundwater physicochemical parameters and urbanization indicators

The summary of Eigenvectors, and stored principal component scores of PCA analysis based on physicochemical parameters and urbanization indicators are given in Tables 4 and 5. These values were used in regression analysis.

Table 4. Eigenvectors (Loadings).

| VARIABLES | PC1 |
|-----------|-----|
| pH        | −0.347 |
| Temperature | −0.391 |
| TDS       | −0.434 |
| Salinity  | −0.433 |
| DO        | −0.018 |
| COD       | −0.366 |
| TSS       | −0.096 |
| BOD       | −0.396 |
| Nitrate—N | −0.119 |
| TP        | 0.189 |

Coefficients in the linear combinations of variables making up PC’s.

Results of regression analysis of PC1_WQ vs PC1_UI

The principal component scores PC1_UI were plotted against principal component scores PC1_WQ to analyze the association (Figure 5). It shows R² value of 62.3% at a p-value of .001. In these results, the p-value is .001 which is less than the significance level of .05. These results indicate that the association between PC1_WQ and PC1_UI is statistically significant. The graph explains 62.3% (R²) of the variation of the data and the R² value indicates that the model fits the data well. Figure 4 shows that groundwater wells in urbanized DSDs (DSD No 1,2,3,4,5,6,7, and 8) have relatively higher temperature, TDS,
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salinity, COD, BOD$_5$, and pH levels. In contrast groundwater wells in rural DSDs (DSD No 9, 10, 11, 12, and 13) show lower temperature, TDS, salinity, COD, BOD, and pH levels. Higher groundwater temperature in urban areas than rural areas may be due to more radiation absorption by roads and buildings, lack of vegetation resulting in loss of shades, and inhibited cooling by convection (Tran et al., 2006).

If COD value is high, the water is rich in organic matter and other oxidizable components (APHA, 2012) which indicate pollution. According to locally proposed ambient water quality standards, the standard level of COD should be below 15 mg/L for drinking purposes. But most of the groundwater wells were above the limit and the highest mean values were observed in groundwater wells in Thimbirigasyaya (2), Moratuwa (5), and Kesbewa (9) DSDs. The reasons might be due to high urban runoff and sewage seepage from built-up areas (Fineza et al., 2014). Sewage and industrial contamination were detected through BOD and COD values. Similar results were obtained in other studies (Herath, 2007; Hettige et al., 2014). According to the PCA score plot, groundwater wells in urbanized areas show higher COD values than groundwater wells in rural areas. It may be happened due to wastewater contamination with groundwater through surface water since more industries are located in urbanized areas. It is important to monitor groundwater quality on a regular basis and encourage to installation and maintain wastewater treatment plants in the area. The overall conductivity, TDS, and salinity of groundwater in the study area show an increasing tendency toward the urbanized areas which are located along the coast and lower part of the drainage network. In high tide season, groundwater can be contaminated with seawater. Other than that, due to the accumulation of ionic compounds, contaminants via surface water runoff, and industrial effluent. Also, by natural regosols, soil type in the urbanized area contains a fair amount of weatherable mineral fragments which may contribute to higher EC and TDS (Moorman & Panabokke, 1961).

Saltwater intrusion is another factor that may contribute to the poor water quality in the coastal areas where most of the urbanized DSDs are located (Khan et al., 2011). The interference from seawater can be delineated by using TDS, conductivity, and salinity levels. If TDS values are between 0.998 and 998 mg/L or EC values are between 0 and 1,389 µS/cm, it is considered freshwater (Shin & Hwang, 2020). Another study states that electrical conductivity of groundwater up to 250 µS/cm as excellent, 250 to 750 µS/cm as good, and above 750 µS/cm is considered as poor groundwater quality (Thorne, 1954). Since the measured levels showed the highest TDS value of 221 mg/L and highest conductivity of 457.67 µS/cm, the possibility of seawater intrusion to the coastal aquifers is less likely.

According to the PCA score plot, most of the urbanized groundwater wells’ pH falls within the standard range but groundwater wells in rural areas show below standard values. This can be due to natural acidification, including the pH values of red-yellow podzolic soils (generally pH below 6 and often below 5.5) (Moorman & Panabokke, 1961) and acidification from the precipitation, which in its natural state has a pH value of around 5.6. But pH values in rural areas show a significantly lower value ranging between 2.62 and 6.71 and most of them were below pH 5. According to locally proposed ambient water quality standards, the standard level of pH should range between 6 and 8.5 for drinking purposes. This may be due to the removal of crops and timber with nutrient

| ID | DSD     | PC1_WQ  | PC1_UI  |
|----|---------|---------|---------|
| 1  | Colombo | −0.95576| 2.34502 |
| 2  | Thimbirigasyaya | −4.16877| 1.13819 |
| 3  | Dehiwala | −1.68441| 1.37846 |
| 4  | Rathmalana | 0.34150| 0.66913 |
| 5  | Moratuwa | −1.24195| 0.73221 |
| 6  | Kolannawa | −1.12262| 0.27155 |
| 7  | Kotte   | −1.23805| 0.40568 |
| 8  | Maharagama | 1.11969| −0.00570|
| 9  | Kesbewa | 0.00279| −0.49603|
| 10 | Kaduwela | 2.31411| −0.85798|
| 11 | Homagama | 1.75767| −1.29840|
| 12 | Hunwella | 3.05025| −2.11872|
| 13 | Padukka | 1.82555| −2.16341|
Figure 3. (Continued)
Figure 3. Physicochemical parameters (a) pH, (b) Temperature, (c) Total phosphorus, (d) COD, (e) TDS, Conductivity, Salinity (f) TSS (g) DO, (h) BOD₅, (i) TSS in 13 DSDs.

Figure 4. WQI of DSDs.

Figure 5. The fitted line plot of PC1 scores of urbanization indicators (build up density and population density) versus PC1 scores of water quality parameters.
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