Monitoring of Rainwater Quality in Kandy and Peradeniya, Sri Lanka

H.L.S.S. Wijewantha
University of Peradeniya
B.D.P. Dharaka
University of Peradeniya
N. Priyantha (namal.priyantha@yahoo.com)
University of Peradeniya
M.P. Deeyamulla
University of Kelaniya

Research Article

Keywords: Deposition, rainwater, water quality parameters, volume weighted average (VWA), correlation coefficient

Posted Date: May 24th, 2023

DOI: https://doi.org/10.21203/rs.3.rs-2953546/v1

Additional Declarations: No competing interests reported.

Version of Record: A version of this preprint was published at Environmental Monitoring and Assessment on January 30th, 2024. See the published version at https://doi.org/10.1007/s10661-024-12352-4.

Abstract

The composition of atmospheric deposition is a measure of air quality, an important aspect of the health of the ecosystem. Consequently, continuous monitoring of atmospheric deposition is crucial to obtain remedial measures to avoid undesirable aspects that would affect living things. In this context, the objective of this study was to determine the rainwater quality at selected locations in Kandy and Peradeniya area of Sri Lanka, namely, Kandy city, Polgolla and University of Peradeniya (UOP), and to identify possible correlations between quality parameters through statistical means. Forty (40) rainwater samples from the UOP site and seven (07) samples each from the Kandy city and Polgolla sites were collected from the 18th May 2020 to 28th April 2021. The volume weighted average (VWA) pH values of UOP, Kandy and Polgolla sites were determined to be 7.44, 7.19 and 7.19, respectively, and moreover, acid rain ($pH < 5.6$) occurrences were not detected during the sampling period. The VWA values of rainfall, conductivity, salinity, TDS and hardness at the UOP site were 40.12 mm, 51.93 $\mu S\ cm^{-1}$, 0.0300 ppt, 26.59 $mg\ L^{-1}$ and 13.55 $mg\ L^{-1}$, respectively. The corresponding values of the Kandy city site were 16.52 mm, 64.04 $\mu S\ cm^{-1}$, 0.0361 ppt, 30.80 $mg\ L^{-1}$ and 19.49 $mg\ L^{-1}$, respectively; and those of the Polgolla site were 33.10 mm, 53.90 $\mu S\ cm^{-1}$, 0.0310 ppt, 25.76 $mg\ L^{-1}$ and 19.31 $mg\ L^{-1}$, respectively. The VWA values of conductivity, salinity, TDS were the highest at the Kandy city site. Further, the VWA values of hardness at Kandy and Polgolla were approximately equal, probably due to spring of Ca^{2+} and Mg^{2+} particulates from the dolomite quarry located in Digana area. The most prominent anion was identified as Cl^- in bulk deposition at all three sites, while NO_3^- showed the lowest concentration of all sites. Moreover, very strong significant positive correlations were identified between conductivity-TDS, conductivity-salinity, conductivity-hardness, TDS-hardness, TDS-salinity, salinity-hardness, SO_4^{2-} - Cl^-, and NO_3^- - Cl^- according to relevant Pearson correlation coefficients. It is thus concluded that the pollutants come from the same sources, either natural or anthropogenic.

Introduction

Atmospheric deposition, which occurs as wet or dry deposition, is an important process of scavenging pollutants from the atmosphere (Gunawardena et al., 2013; Weerasundara et al., 2017). In wet deposition, atmospheric compounds are dissolved in clouds, and precipitation droplets then deliver to the earth's surface by rain, hail or snow (Staelens et al., 2005; Nandasena et al., 2010). On the other hand, in dry deposition, gases and aerosol particles come into contact with vegetation, soil and water surface in the earth system (Staelens et al., 2005; Dharmapriya et al., 2023). Atmospheric precipitation thus contains naturally originated substances such as sea salt and soil dust, and those due to anthropogenic activities such as traffic, incineration of sewage and industrial activities (Staelens et al., 2005; Adachi, 2006; Weerasundara et al., 2017). Therefore, determination of chemical composition of rainwater is considered to be an indirect measurement about the quality of the atmosphere (Migliavacca et al., 2005; Liyandeniya et al., 2020a).

The process of condensation of water vapour in clouds in the atmosphere, and subsequent falloff to the earth surface under gravity as droplets of liquid water is known as rain (Migliavacca et al., 2005; Liyandeniya et al., 2020b). Although pure water has a pH 7.0 due to having equal concentrations of H_3O^+ (aq) and OH^-(aq), natural unpolluted rainwater has pH at about 5.6 due to the presence of acidic substances such as CO_2, nitrogen oxides and sulphur oxides originated from natural process (Xu et al., 2015; Ileperuma, 2020) . Consequently, acid rain is considered to be having pH < 5.6, which is caused by emission of sulfur dioxide and nitrogen oxide through anthropogenic activities producing nitric acid and sulfuric acid by reacting with atmospheric water ((Charlson & Rodhe, 1982; Chantara & Chunsuk, 2008; Xu et al., 2015). Nevertheless, the pH of rainwater is not solely determined by acidic gases because basic ions, such as Ca^{2+}, released from various anthropogenic activities leading to increased levels of pH (Gunawardana et al., 2012; Liyandeniya et al., 2020c). In addition, transformation of primary pollutants into secondary pollutants via atmospheric chemical reactions also contribute to changes in pH of rain ((Bayraktar & Turalioglu, 2005; Al-Momani et al., 2007). As such, rainwater composition is strongly affected by chemical composition of the atmosphere. If toxic chemicals are present in the atmosphere, they would reach the surface of the earth through precipitation which would harm or discomfort living organisms including humans, and cause damage to natural vegetation and the structure of the atmosphere (Nandasena et al., 2010; Gunawardena et al., 2012; Nandasena et al., 2012).

Atmospheric pollution has no boundary, and hence, trans-boundary effects could cause environmental damages to neighbouring countries (Abeyratne & Ileperuma, 2006; Sakihama et al., 2008). Sri Lanka, being an island surround by the Indian ocean, whose climate is based on tropical features of temperature, seasonal rainfall, spatial patterns of wind, relative humidity, and other climate elements, particularly during monsoon seasons, significantly experiences atmospheric pollution originating from countries in the Asian region, such as India, China, and Thailand (Ileperuma, 2000; Jayawardhane et al., 2005; Migliavacca et al., 2005; Dharmapriya et al., 2023). Sri Lanka has undergone rapid industrialization since 1980's, and therefore, the energy consumption and the number of motor vehicles usage have increased (Ileperuma, 2000; Perera et al., 2010). Traffic congestion in urban areas, overloaded buses and trucks, poorly managed road systems have contributed to air pollution in major cities, namely, Colombo and Kandy, posing serious environmental and health problems (Abeyratne & Ileperuma, 2006; Gunawardena et al., 2013).

Atmospheric pollution gives an invisible effect to the health of organisms, economy and the environment as negative consequences. Also, it has increased the number of causes related to respiratory diseases, such as chronic obstructive pulmonary diseases (Goldsmith 1968; Anderson, 1999; Gunawardena et al., 2013). However, there are a few number of studies available in Sri Lanka on atmospheric pollution, and thus, this is an area which requires attention of researchers (Chathuranga et al., 2020). In this context, the purpose of this study was to determine the rainwater quality in three selected locations in Kandy District of Central Province, Sri Lanka, to investigate comparison with respect to atmospheric quality among the three sites, and to identify possible correlations between rainwater quality parameters. Moreover, rainwater quality parameters were compared with those reported in previous studies of the same geographical areas to find out the impact of Covid 19 pandemic on the quality of the atmosphere in Kandy, Sri Lanka.

Material and Methods

Study area

Kandy, widely known to have historical heritage, is the capital city in the Central Province of Sri Lanka (Figure 1). It is the second largest city in the country next to Colombo. Also, Kandy is located in the mountainous and thickly forested interior of the island which is home to tea plantation and rainforest. Mountain ranges of Knuckles and Hanthana surround Kandy city. The geographical location of this area is like a colander and the area surrounding is about 26 km^2. This shape gives a thermal inversion to the city atmosphere, and the bottle–neck road structure creates traffic congestion within the city. Consequently, Kandy city is heavily polluted. The bulk depositions were collected from three sampling sites in Kandy district, namely Kandy City site, Polgolla and the University of Peradeniya.

Kandy sampling site

Kandy City (Site A in Figure 2) is a high-density built-up area with frequent heavy traffic activities. This site is located in the Department of Education of Central Province, 518 m above the sea level. The sample site is located by the S.W.R.D. Bandaranayake Road and is in the vicinity of the Kandy Railway Station, Kandy Municipal Central Market, Kandy Municipal Council car park and a part of Kandy Bus Station. The sampling site is surrounded by Hanthana, Bahirawakanda and Knuckles Mountain ranges, and Udawatta Kelle forest is located about 2.7 km away from the site. Incomplete fossil fuel combustion, highly intensive traffic activities, building construction and low vegetation cover are the significant sources of changing atmospheric condition in this area.

Polgolla sampling site

The Polgolla site (site B in Figure 3) at 449 m above sea level is located in the premises of the Mahaweli Development Authority of Central Province, Ceylon Tobacco Company and Polgolla Reservoir Airport. This site is in proximity of 20 m from the Polgolla Dam which was constructed to divert water of Mahaweli River for irrigation. Limited number of vehicles cross the Dam, and the area of the Pologolla reservoir is about 204,000 m^2. The prevailing wind is dominant due to the reservoir area. The site was selected to represent a sub-urban area with less traffic activities, low residential activities, and high vegetation cover.

University of Peradeniya sampling Site

The University of Peradeniya (UOP) site (site C in Figure 4) is in an open area 500 m above sea level. It is located in front of the Department of Chemistry of the Faculty of Science, University of Peradeniya. This site is in a densely vegetated area partly surrounded by the Hanthana mountain range. The area although has fewer socio-economic activities, building construction activities are continued in the vicinity during the sample collection period. Incomplete fossil fuel combustion and high traffic were present during the daytime on Colombo – Kandy (A1) road, which is about 1 km away from the sampling site.

Sample collection

Sampling period

Rainwater samples were collected from the 2nd week of May 2020 to the 4th week of April 2021 on a weekly basis at the University of Peradeniya site. This sampling period included four monsoon seasons in force in Sri Lanka. Further, this period included the 1st wave of the COVID−19 Pandemic period from March-May 2020 during which human activities and road traffic were significantly reduced. The situation became normal from August - 1st week of October 2020, and less traffic was again experienced from October 2020 – January 2021 due to the 2nd wave of the Pandemic. Then, the situation became normal again from February to April 2021.

Sampling of rainwater was also performed on a weekly basis from the 3rd week of August – the 4th week of September 2020 from Kandy and Polgolla sampling sites. The sampling period of these two sites included the Southwest monsoon (May - September).

Sample collector

The sample collector (Figure 5) was used for collecting bulk deposition. It was constructed with a 5.00 L high-density polyethylene (HDPE) bottle and a polyethylene funnel with 20.6 cm with a slope of 45°. The system is connected to a star picket bar. It was fixed at a height of 1.5 m above ground to minimize contamination from re-suspended particles. A cotton plug was placed on the mouth of the funnel to prevent material contamination, such as dust particles, bird droppings, debris, and insects.

Storage of samples collected

The samples were collected every Wednesday between 7:00 to 9:00 a.m. In the case of dry deposition, both the funnel and the container were washed with 200 mL of ultra-pure water. The resulting water sample was used for analysis.

Upon collection of wet deposition at all three sites, samples were brought to the laboratory, and volumes were measured separately for the estimation of average weekly rainfall at each site. Each sample was separated into three parts for analysis. The first part (unfiltered) was used to determine water quality parameters: pH, conductivity, total dissolved solids (TDS) and salinity. The second part (unfiltered) was used to determine hardness. The third part was filtered through 0.45 μm alpha-cellulose filter papers and divided into two parts; one part was stored in a pre-cleaned polyethylene bottle and refrigerated at 4 °C for anion and cation analysis. The other part was transferred to a pre-cleaned polyethylene bottle, preserved at pH < 2 with the addition of con. HNO_3 with pH < 2 and refrigerated at 4 °C for metal analysis.

Analysis of Samples

Water quality parameters

The pH of unfiltered rainwater samples was measured soon after sampling using pH meter (ORION model 420A). Conductivity, TDS, and salinity were also measured soon after sampling using multi-parameter meter (Thermo Scientific – EuTech Con 450). Calibration of the conductivity meter was performed with a standard solution of KCl (conductivity = 1413 $\mu S\ cm^{-1}$) solution.

The hardness of rainwater samples was determined by titrating with ethylenediamine tetraacetic acid (EDTA) using Eriochrome Black T (EBT) indicator. The EDTA solution was standardized using a standard $CaCO_3$ solution. To determine the hardness of rainwater, 25.00 mL of rainwater sample was transferred to a titration flask, and 2.0 mL of buffer solution (pH = 10.00) was added into it. Then, 2-3 drops of EBT indicator were added, and the titration was performed against a standard EDTA solution until the color change occurred from pink to pale blue.

Quantitative determination of anions (F^-, Cl^-, NO_3^-, SO_4^{2-}) in rainwater samples was carried out by Thermo Scientific Dionex ICS-900 ion chromatography. For anions analysis, Dionex ionpack AS23 (4 × 250 mm) column was used. The mobile phase consisted of 2.0 M H_2SO_4 (Dionex anion regenerant concentrate), 4.5 mM Na_2CO_3 and 8.08 mM $NaHCO_3$ (Dionex AS23 eluent concentrate).

Minitab 17 software was used for statistical treatment of data, and to find out descriptive statistics and correlation between parameters.

Results and Discussion

Rainfall variation

Rainfall is the quantity of rain falling to a particular area within a given time. Rainfall varies with the time and area. It is an important factor for the determination of particulates and dissolved pollutants in the atmosphere in a particular area (Migliavacca et al., 2005; Liyandeniya et al., 2020a). Rainfall was calculated using Equation (1) in three sites in mm.

$$\text{Rainfall} = \frac{V}{A} \qquad (1)$$

$$A = \pi(D/2)^2 \qquad (2)$$

where V is the rainwater collected (mm^3), A is the surface area of funnel (mm^2), and D is the diameter of the funnel (mm).

Out of a total of 40 samples collected from the University of Peradeniya (UOP) site within the sampling period including both North-east monsoon (NEM) and South-west monsoon (SWM) seasons, five samples were dry only deposition, while the remaining samples were wet deposition (Figure 6). Further, among seven samples collected from the Kandy sampling site, three samples were due to dry deposition while the remaining samples were wet only deposition. In the Polgolla site, two samples were dry only deposition, while five samples were wet deposition. The mean weekly rainfall of UOP, Kandy and Polgolla sampling sites were 40.12 mm, 16.52 mm and 33.15 mm, respectively. The volume weighted average values of water quality parameters and anions concentrations are summarized in Table 1.

Table 1: VWA values of water quality parameters, major anion concentration of three sampling sites.

	Parameters	**UOP**	**Kandy**	**Polgolla**
Water quality parameters/ VWA	Mean rainfall/ mm	40.12	16.52	33.15
	pH	7.34	7.36	7.13
	Conductivity / µS cm^{-1}	40.45	53.59	37.22
	Salinity / ppt	0.22	0.33	0.22
	TDS/ ppm	20.05	19.64	18.22
	Total hardness / ppm	9.31	17.74	10.73
Anion concentration VWA / µeq L^{-1}	Cl-	70.62	82.51	141.24
	NO_3^-	3.47	<MDL	22.22
	SO_4^{2-}	34.63	48.65	38.14

3.2 pH Variation

The pH parameter represents the acidity or basicity of aqueous solution (Liljestrand, 1985) . The UOP site recorded an average pH value of 7.34, and further, out of 40 samples, 13 samples showed pH < 7.00, which is usual, due to the dissolution of atmospheric CO_2 (Figure 7). The sample collecting period was divided into three categories namely, after fully lockdown (AFLD), normal situation (NS), and partial lockdown (PLD). After the country became normal and within the initial part of PLD, the pH of precipitation was about 6.25 which could be attributed to traffic activities and re-starting regular chemical analysis in laboratories in the proximity to the sampling site (Figure 7). The pH being greater than 7.00 in many samples is indicative of atmospheric contamination due to basic pollutants. Also, Ca is the most abundant element which is generated as soil-borne element in the Kandy city area (Gunawardana et al., 2012). Another indication of atmospheric pollution is the growth of algae in samples having pH close to 9.00.

The average pH values of Kandy and Polgolla sites were 7.36 and 7.13, respectively. Due to the activation of SWM season, the trans-boundary air pollution affects the air quality (Abeyratne & Ileperuma, 2006). Hence, the pH values of depositions at all sites varied between 6.50 and 7.50 during this period (Figure 8). Observation of high pH at the Kandy site can be attributed to high traffic activities with incomplete fossil fuel combustion; such activities are less in the other two sites (Gunawardana et al., 2012; Yatigammana et al., 2022)

Conductivity variation

Dissolved salts and other inorganic substances contribute to increased conductivity in water although organic substances do not much contribute to (Kramer et al., 1996). The average values of conductivity of the UOP, Kandy and Polgolla sampling sites were 40.45 µS cm^{-1}, 53.59 µS cm^{-1} and 37.22 µS cm^{-1}, respectively. The maximum average conductivity reported at the Kandy site can be attributed to high traffic and construction activities, producing high content of pollutants, some of which would form ions in rainwater thereby increasing the conductivity in the area (Gunawardana et al., 2012; Ileperuma, 2020; Yatigammana et al., 2022) . As UOP and Polgolla sites are in sub-urban areas with low human activities, conductivity of deposition is expected to be low (Liyandeniya et al., 2020a; Madhushani et al., 2023). Nevertheless, prevailing wind due to the large reservoir in the vicinity of the Polgolla site promoting particulate matter to travel through atmosphere complicates the situation having varying conductivities (Figure 9) (Dharmapriya et al., 2023). Moreover, as sample collection periods of all the sites included SWM and NWM seasons, the conductivity of deposition samples were decreased due to the dilution effect because of rainfall (Chathuranga et al., 2020).

Total dissolved solids (TDS) variation

Total dissolved solid is a measure of the dissolved content of all inorganic and organic substances in a liquid (Kramer et al., 1996). The total dissolved solid, usually expressed in ppm, is directly linked with conductivity and salinity ((Rusydi, 2018)). The average values of TDS in UOP, Kandy and Polgolla sites were recorded as 20.05 ppm, 19.64 ppm and 18.22 ppm, respectively. At both Kandy and Polgolla sites, the maximum and minimum TDS values were reported in dry or significantly low wet deposition, and wet deposition periods, respectively. As observed in conductivity measurements, dilution of pollutants in the atmosphere due to SWM activated period leads to decreased TDS values. Regarding the UOP site, the highest TDS of rainwater sample (Figure 10) was recorded as 74.00 ppm during the NEM activation period. During this period, the country had become normal without any lockdown, after the first wave of COVID-19 pandemic, and the number of vehicles traveling in the Colombo-Kandy (A1) Road, which is closer to the UOP site, was normal. Then, the minimum TDS value was reported to be 3.62 ppm in the SWM activation period. During this period, the second wave of COVID–19 pandemic affected the country, and the Western Province was locked down to mitigate the spread of the disease. Consequently, the number of vehicles traveled in the A1 Road became significantly less. This fact supports decreased TDS values of deposition samples.

Salinity variation

Salinity is the total concentration of all dissolved salts, and it mainly contributes to the conductivity of a solution (Lucas Rego Barros Rebello et al., 2020). The average values of salinity in Kandy, Polgolla and UOP sites were recorded as 0.0361 ppt, 0.0310 ppt and 0.0299 ppt, respectively. The highest salinity of 0.0740 ppt was recorded in Polgolla sampling site (Figure 11). The prevailing wind due to the reservoir would be the main cause for varying the salinity at the Polgolla site as compared to the other two sites, and hence, no significant variation in the salinity with rainfall was observed at the UOP and Kandy sites (Dharmapriya et al., 2023).

Hardness variation

Hardness in water is due to the presence of dissolved salts of calcium and magnesium and is expressed as ppm $CaCO_3$. The total hardness occurs due to the presence of bicarbonate, chloride and sulphates of calcium and magnesium ions. The degree of hardness standard as established by the World Health Organization (WHO) is shown in Table 2.

Table 2: Degree of hardness standard established by WHO.

Degree of hardness	Range (ppm)
Soft	< 60
Moderately hard	60 - 120
Hard	120 - 180
Very hard	>180

The average values of hardness at UOP, Kandy and Pollgolla sites were determined to be 9.31 ppm, 17.74 ppm and 10.73 ppm, respectively. Hardness values of depositions of all samples at the UOP and Kandy sites were less than 60 ppm, indicating that depositions were soft as per WHO standards (Figure 12). Regarding the Polgolla site, one sample, out of seven, was recorded to have hardness of greater than 60 ppm, while the other samples had hardness < 60 ppm. The maximum hardness value of 83.2 ppm was recorded on the 30th of September 2020 at the Polgolla site. During this period, the SWM was activated, and the anthropogenic activities were normal after the lockdown period of COVID-19 pandemic. Also, limestone quarries located in Digana area of about 13.4 km away from the sampling site, construction activities, and Gneiss quarries located in Kandy area emit Ca^{2+} and Mg^{2+} into the atmosphere, contributing to hardness of depositions (Gunawardena et al., 2012; Samaradiwakara et al., 2021; Dharmapriya et al., 2023) . When compared to the volume weighted average hardness values at UOP, Kandy and Polgolla sites reported as 17.32 ppm, 19.69 ppm, and 14.96 ppm, respectively, in a previous publication (Madhushani et al., 2023) it is clear that the hardness values are significantly less in the duration of the present study due to less traffic activities as a result of lockdown periods. However, in Kandy and Polgolla sites hardness values variation is significantly lower, due to the continuous function of limestone quarries located in Digana area after the first wave of COVID 19 pandemic. The area close to Kandy Railway Station has a high level of particulate matter with a high concentration of Ca^{2+} (Samaradiwakara et al., 2021). The situation in the country after Week 17 became completely normal and the transport activities became regular. Therefore, the sample from the Kandy site in week 17 showed high values for many parameters.

Anion variation

Chemical analysis (Cl^-, SO_4^{2-}, and NO_3^-) performed for obtaining volume weighted mean anion concentrations on samples of the three sampling sites (UOP site: from 1st week of July 2020 to 4th week of March 2021; Kandy and Polgolla sampling sites: from 3rd week of August 2020 to 5th week of September 2020) indicates that Cl^- was the most prominent anion, while NO_3^- showed the lowest concentration at all three sampling sites (Figures 13 - 16). More specifically, the volume weighted mean (VWM) anion concentration of all the sites follows the order, $Cl^- > SO_4^{2-} > NO_3^-$. As samples of UOP included the SWM and NEM, and those of the other two sites included SWM, it is argued that Cl^- ions would have come from sea salt through monsoon rains (Ileperuma, 2020; Liyandeniya et al. 2020a). Another fact is that the UOP site, being in the vicinity of chemical laboratories of the Faculty of Science, which emit SO_2, NO_2, and H_2S to the atmosphere, contributes to changing the natural composition of the atmosphere although this site experienced less traffic activities (Dharmapriya et al., 2023; Madhushani et al, 2023). Also, construction activities in the vicinity would also have contributed to enhance the pollution levels in depositions.

Although Kandy site experiences more traffic congestion, more urbanization and less vegetation cover as compared to the Polgolla site, Cl^- and SO_4^{2-} levels, in general, are higher at the Kandy site (Abeyratne et al. 2006; Gunawardena et al.2012). The presence of NO_3^- at the Polgolla site can be attributed to the Ceylon Tobacco Company located near site. This industry would act as a point source of NO_3^- (Dharmapriya et al., 2023). Moreover, the digestion of organic waste accumulated in the reservoir in the vicinity of the site would result in emission of SO_2, NO_2 and H_2S (Dharmapriya et al., 2023; Madhushani et al, 2023). Overall, the levels of nitrate anions were much less as compared to the observations reported by Liyandeniya et.al 2020a and Madushani et.al 2023 due to the pandemic.

Statistical analysis

Pearson correlation analysis

The Pearson correlation (*r*) can be categorized by considering a linear relationship, as identified in Equation 3, between two variables (Alastuey et al., 1999).

$$r = \frac{N\sum \mathrm{xy} - (\sum \mathrm{x})(\sum \mathrm{y})}{(N\sum x^2 \ -(\sum \mathrm{x})^2)(\ N\sum y^2 - (\sum \mathrm{y})^2\ )} \qquad (3)$$

where N is the number of pairs of scores, $\sum xy$ is sum of the products of paired scores, $\sum x$ is the sum of x scores, $\sum y$ is the sum of y scores, $\sum x^2$ is the sum of squad x scores and $\sum y^2$ is the sum of squared y scores. The correlation coefficient of greater than zero represents a positive correlation between two variables, while correlation coefficient less than zero represents the negative correlation between the two variables. Then, correlation coefficient near zero is very weak linear relationship and the value of exactly -1 and +1 represent perfect linear relationship. Further, the strength of the relationship is interpreted based on the magnitude of the correlation as follows: 0.00 – 0.19 very weak; 0.20 – 0.39 weak; 0.40 – 0.59 moderate; 0.60 – 0.79 strong; and
0.80 – 1.00 very strong (Chathuranga et al. 2020). Correlation coefficient is associated with a probability (p) value, and the $p < 0.05$ concludes that there is a significant association between the respective pairs of variables.

Pearson correlation of water quality parameters

Regarding the UOP site, the highest value of 0.906 was reported between salinity and TDS, a very strong positive correlation. The other strong positive corrections observed are conductivity - TDS (0.788), conductivity - salinity (0.756), conductivity - hardness (0.625), and hardness – TDS (0.631), while salinity - hardness showed a moderate positive correlation (0.557). Other pairs of water quality parameters showed weak or very weak correlations at the UoP site. The Pearson correlation coefficients of water quality parameters in bulk deposition at the UOP site are represented in Table 3.

Table 3: Pearson correlation of water quality parameters at UOP site.

	Rainfall	**pH**	**Conductivity**	**TDS**	**Salinity**
pH	0.173				
***p* value**	0.287				
Conductivity	-0.286	0.135			
***p* value**	0.073	0.406			
TDS	-0.274	0.256	0.788		
***p* value**	0.052	0.110	0.000		
Salinity	-0.274	0.177	0.756	0.906	
***p* value**	0.087	0.276	0.000	0.000	
Hardness	-0.448	-0.013	0.625	0.631	0.557
***p* value**	0.005	0.938	0.000	0.000	0.000

A very strong positive correlation of 0.968 at the Kandy sampling site was observed between salinity and TDS. Rainfall - TDS (-0.743) and rainfall - salinity (-0.700) showed a strong negative correlation. Conductivity - salinity (0.412) and pH - rainfall (0.570) showed moderate positive correlation without a significant relationship. Also, rainfall-conductivity (-0.572) and pH - conductivity (-0.486) showed moderate negative correlation. Other, pairs of water quality parameters showed week or very week correlations at the Kandy site (Table 4).

Table 4: Pearson correlation of water quality parameters at Kandy site.

	Rainfall	**pH**	**Conductivity**	**TDS**	**Salinity**
pH	0.570				
_p_ value	0.182				
Conductivity	-0.572	-0.486			
_p_ value	0.180	0.268			
TDS	-0.743	-0.194	0.321		
_p_ value	0.056	0.679	0.483		
Salinity	- 0.700	-0.084	0.412	0.968	
_p_ value	0.080	0.858	0.358	0.000	
Hardness	-0.104	0.321	-0.015	0.199	0.189
_p_ value	0.825	0.483	0.974	0.669	0.684

A very strong positive correlation at the Polgolla site was observed between conductivity -TDS (0.999), conductivity – salinity (0.999), TDS - salinity (0.998), conductivity - hardness (0.956), salinity - hardness (0.956), TDS - hardness (0.946) with significant relationship. The other pairs of water quality parameters showed week or very week correlations (Table 5).

Table 5: Pearson correlation of water quality parameters at Polgolla site.

	Rainfall	**pH**	**Conductivity**	**TDS**	**Salinity**
pH	0.149				
p value	0.750				
Coductivity	-0.337	0.102			
_p_ value	0.460	0.828			
TDS	-0.331	0.076	0.999		
_p_ value	0.469	0.872	0.000		
Salinity	-0.368	0.098	0.999	0.998	
_p_ value	0.417	0.835	0.000	0.000	
Hardness	-0.302	0.346	0.956	0.946	0.956
_p_ value	0.511	0.447	0.001	0.001	0.001

Pearson correlation coefficient of anions

At the UOP site, a moderate positive correlation was observed between NO_3^- and SO_4^{2-} with significant relationship. Hence, it is possible that these two anions were generated by the same sources which could be natural or anthropogenic sources such as traffic activities, construction activities, and fossil fuel combustion. Other pairs showed weak or very week correlations. In contrast, the Kandy site showed a very strong positive correlation between Cl^- and SO_4^{2-} with significant relationship. Hence, these two anions would have been released from the same sources. Furthermore, at the Polgolla site, a very strong positive correlation was observed between Cl^- - NO_3^- and SO_4^{2-}- Cl^- with significant relationship, while a moderate positive significant correlation was observed between SO_4^{2-}- NO_3^-. Hence, these two anions would have been released by the same source. The Pearson correlation coefficients of anions at the three sampling sites are represented in Table 6.

Table 6: Pearson correlation coefficient of anions at three sampling sites.

	Cl^-	**NO_3^-**
UOP site		
NO_3^-	-0.119	
***p* value**	0.587	
SO_4^{2-}	0.251	0.433
***p* value**	0.249	0.039
Kandy site		
NO_3^-		
***p* value**		
SO_4^{2-}	0.800	
***p* value**	0.056	
Polgolla site		
NO_3-	0.918	
***p* value**	0.010	
SO_4^{2-}	0.830	0.589
***p* value**	0.041	0.218

Conclusion

The pH values of the University of Peradeniya (UOP), Kandy city and Polgolla sites were 7.40, 7.18 and 7.18, respectively, with no occurrences of acid rain in any site during the sampling period. The Kandy city site is in an urban area with high traffic activities, while the UOP and Polgolla sites are in sub-urban areas. In general, many parameters showed less values due the impact of Covid-19 pandemic. Average values of other water quality parameters, namely, conductivity, salinity, TDS, and hardness, were higher at the Kandy city site than those at the other two sites. The chemical analysis of anions, Cl^- , NO_3^- and $SO_4{}^{2-}$, in bulk deposition carried out by ion chromatography indicated that the most predominant anion was Cl^-, while the NO_3^- level was the lowest in all three sites. According to the Pearson correlation coefficient values of anions and water quality parameters, bulk precipitation in three sites shows a very strong significant correlations among many variables. These results indicate that these have strong correlation between ions pairs and water quality parameters came from the same sources of anthropogenic or natural. Results of this research would provide baseline data which is valuable for prediction of future trends with respect to air quality monitoring based on the most air polluted city, Kandy, in Sri Lanka. Further, the study of the quality of the atmospheric deposition is important to produce information on air quality and source of pollutants and is useful to formulate remedial measures to reduce to extent of air pollution due to anthropogenic activities.

Declarations

Funding

The authors declare that this work received no financial support from external grants or other organizations during the study.

Competing Interests

The authors have no relevant financial or non-financial interests to disclose regarding this work.

Author Contribution

All authors contributed to the conception and design of the study in different aspects. Initial planning of the study, supervision, and final corrections were performed by N. Priyantha[3*], and M.P. Deeyamulla[2]. Sample collection, determination of rainwater quality parameters and analysis were performed by H.L.S.S.Wijewantha[1]. Data interpretation, compiling of the initial draft of the manuscript and finalizing was done by B.D.P.Dharaka[1].

All authors have read, commented, and approved the final manuscript of the study.

Data Availability

The data generated during and/or analyzed during the current study are available with the corresponding author, N. Priyantha[3*], upon request.

Ethical approval

Not applicable – This research did not involve any human or animal subjects or biological material or their data.

Consent to participate

Not applicable – This research did not involve any human subjects.

Consent for publication

Not applicable – This research did not involve any human subjects.

Acknowledgements

Authors are grateful to the Provincial Department of Education, and Mahaweli Authority of Sri Lanka, for collaborations provided for sampling. Authors also thank the Postgraduate Institute of Science, University of Peradeniya, Sri Lanka, for providing some facilities for chemical analysis.

References

1. Abeyratne, V.D.K. and Ileperuma, O.A. (2006) ‘Air Pollution Monitoring in the City of Kandy: Possible transboundary effects’, *Journal of the National Science Foundation of Sri Lanka*, 34(3), p. 137. https://doi:10.4038/jnsfsr.v34i3.3644.
2. Adachi, K. (2006) “Characterization of Atmospheric Dry Deposition Particulates in Kobe, Japan,” *Chemosphere*, 64(8), pp. 1311–1317. https://doi.org/10.1016/j.chemosphere.2005.12.055.
3. Alastuey, A., Querol X, Chares A., Ruiz C.R., Carratula, Lopez-Soler A., (1999) “Bulk deposition in a rural area located around a large coal-fired power station, Northeast Spain,” *Environmental Pollution*, 106(3), pp. 359–367. Available at: https://doi.org/10.1016/s0269-7491(99)00103-7.
4. Al-Momani, I.F., Monani, K.A., Jaradat, Q.M., Massadeh, A.M., Yousef, Y.A, Alomary, A.A. (2007) “Atmospheric Deposition of Major and Trace Elements in Amman, Jordan,” *Environmental Monitoring and Assessment*, 136(1-3), pp. 209–218. https://doi.org/10.1007/s10661-007-9676-4.
5. Anderson, H.R. (1999) ‘Health effects of air pollution episodes’, *Air Pollution and Health*, pp. 461–482. https://doi:10.1016/b978-012352335-8/50096-x.
6. Bayraktar, H., Turalioglu, F.S. (2005) “Composition of Wet and Bulk Deposition in Erzurum, Turkey,” *Chemosphere*, 59(11), pp. 1537–1546. https://doi.org/10.1016/j.chemosphere.2005.02.013.
7. Chantara, S., Chunsuk, N. (2008) “Comparison of Wet-Only and Bulk Deposition at Chiang Mai (Thailand) Based on Rainwater Chemical Composition,” *Atmospheric Environment*, 42(22), pp. 5511–5518. https://doi.org/10.1016/j.atmosenv.2008.03.022.

8. Charlson, R.J., Rodhe, H. (1982) “Factors Controlling the Acidity of Natural Rainwater,” *Nature*, 295(5851), pp. 683–685. https://doi.org/10.1038/295683a0.
9. Chathuranga, R.A.J., Liyandeniya, A.B., Dharmapriya, T.N., Priyantha, N. (2020) “Risk Assessment and Source Apportionment of Wet Bulk Deposition in Three Typical Sites of Gampaha District, Sri Lanka,” *SN Applied Sciences*, 2(8). https://doi.org/10.1007/s42452-020-3007-6.
10. Chughtai, M., Mustafa, S. and Mumtaz, M. (2014) “Study of physicochemical parameters of rainwater: A case study of karachi, Pakistan,” *American Journal of Analytical Chemistry*, 05(04), pp. 235–242. Available at: https://doi.org/10.4236/ajac.2014.54029.
11. Dharmapriya, T.N., Rathnayake, I.M.S.K., Madushani, L.S., Deeyamulla, M.P., Priyantha, H.M.D.N. (2023) “Comparison of Ionic Concentrations (Na^+, Ca^{2+}, Mg^{2+}, NH^{4+}, Cl^-, SO_4^{2-}, NO_3^-) and Water Quality Parameters of Bulk Depositions Among Three Sites in Kandy Area, Sri Lanka.” https://doi.org/10.21203/rs.3.rs-2731158/v1.
12. Goldsmith, J.R. (1968) ‘Effects of air pollution on human health’, *Air Pollution and its Effects*, pp. 547–615. https://doi:10.1016/b978-0-12-666551-2.50021-2.
13. Gunawardana, C., Goonetilleke A., Egodawatta P., Dawes L., Kokot S. (2012) ‘Source characterisation of road dust based on chemical and mineralogical composition’, *Chemosphere*, 87(2), pp. 163–170. https://doi:10.1016/j.chemosphere.2011.12.012.
14. Gunawardana, C., Goonetilleke, A., Egodawatta, P., Dawes, L., Kokot, S.(2012) “Source Characterisation of Road Dust Based on Chemical and Mineralogical Composition,” *Chemosphere*, 87(2), pp. 163–170. https://doi.org/10.1016/j.chemosphere.2011.12.012.
15. Gunawardena, J., Egodawatta, P., Ayoko, G.A, Goonetilleke, A. (2012) “Role of Traffic in Atmospheric Accumulation of Heavy Metals and Polycyclic Aromatic Hydrocarbons,” *Atmospheric Environment*, 54, pp. 502–510. https://doi.org/10.1016/j.atmosenv.2012.02.058 .
16. Gunawardena, J., Egodawatta, P., Ayoko, G.A., Goonetilleke A. (2013) “Atmospheric Deposition as a Source of Heavy Metals in Urban Stormwater,” *Atmospheric Environment*, 68, pp. 235–242. https://doi.org/10.1016/j.atmosenv.2012.11.062.
17. Ileperuma, O.A. (2000) “Environmental Pollution in Sri Lanka: A Review,” *Journal of the National Science Foundation of Sri Lanka*, 28(4), p. 301. https://doi.org/10.4038/jnsfsr.v28i4.2644.
18. Ileperuma, O.A. (2020) “Review of Air Pollution Studies in Sri Lanka,” *Ceylon Journal of Science*, 49(3), p. 225. Available at: https://doi.org/10.4038/cjs.v49i3.7773.
19. Jayawardene, H.K.W.I., Sonnadara, D.U.J. and Jayewardene, D.R. (2005) “Trends of Rainfall in Sri Lanka Over the Last Century,” *Sri Lankan Journal of Physics*, 6, p. 7. https://doi.org/10.4038/sljp.v6i0.197.
20. Krämer, M., Schüle, M. and Schütz, L. (1996) ‘A method to determine rainwater solutes from ph and conductivity measurements’, *Atmospheric Environment*, 30(19), pp. 3291–3300. https://doi:10.1016/1352-2310(96)00070-2.
21. Liljestrand, H.M. (1985) ‘Average rainwater pH, concepts of atmospheric acidity, and buffering in open systems’, *Atmospheric Environment (1967)*, 19(3), pp. 487–499. https://doi:10.1016/0004-

6981(85)90169-6.

22. Liyandeniya, A.B., Deeyamulla, M.P. and Priyantha, N. (2020b) “Source Apportionment of Rainwater Chemical Composition in Wet Precipitation at Kelaniya in Sri Lanka,” *Air Quality, Atmosphere & Health*, 13(12), pp. 1497–1504. https://doi.org/10.1007/s11869-020-00903-w.
23. Liyandeniya, A.B., Deeyamulla, M.P. and Priyantha, N. (2020c) “Atmospheric chemical composition of bulk deposition at two geographically distinct locations in Sri Lanka,” *Environmental Monitoring and Assessment*, 192(7). Available at: https://doi.org/10.1007/s10661-020-08412-0.
24. Liyandeniya, A.B., Deeyamulla, M.P., Abeysundara, S.P., Priyantha, N. (2020a) “Chemical Characteristics of Wet Precipitation at Peradeniya in Sri Lanka,” *Environmental Monitoring and Assessment*, 193(1). https://doi.org/10.1007/s10661-020-08772-7.
25. Lucas Rego Barros Rebello, Thauara Siepman and Santiago Drexler (2020) “Correlations between TDS and electrical conductivity for high-salinity formation brines characteristic of South Atlantic pre-salt basins,” *Water SA*, 46(4 October). Available at: https://doi.org/10.17159/wsa/2020.v46.i4.9073.
26. Madhushani, L.S., Dharmapriya, T.N., Dharaka, B.D.P., Deeyamulla, M.P., Priyantha N. (2023) “Chemical composition of rainwater at three sites in Kandy/Peradeniya, Sri Lanka, and its effect on air pollution.” , https://doi.org/10.2139/ssrn.4415804.
27. Migliavacca, D., Teixerira, E.C., Wiegand, F., Machado, A.C.M., Sanchrz, J. (2005) “Atmospheric Precipitation and Chemical Composition of an Urban Site, GuaíBa Hydrographic Basin, Brazil,” *Atmospheric Environment*, 39(10), pp. 1829–1844. https://doi.org/10.1016/j.atmosenv.2004.12.005.
28. Nandasena, S., Wickremasinghe, A.R. and Sathiakumar, N. (2012) “Air pollution and public health in developing countries: Is sri lanka different?,” *Journal of the College of Community Physicians of Sri Lanka*, 17(1), p. 15. Available at: https://doi.org/10.4038/jccpsl.v17i1.4932.
29. Nandasena, Y.L., Wickremasinghe, A.R. and Sathiakumar, N. (2010) “Air Pollution and Health in Sri Lanka: A Review of Epidemiologic Studies,” *BMC Public Health*, 10(1). https://doi.org/10.1186/1471-2458-10-300.
30. Perera, G.B.S., Emmanuel, R., Nandasena, Y.L.S., Premasiri, H.D.S., (2010) “Exposure to Aerosol Pollution and Reported Respiratory Symptoms among Segments of Urban and Rural Populations in Sri Lanka,” *Built-Environment Sri Lanka*, 7(2), p. 31. https://doi.org/10.4038/besl.v7i2.1941.
31. Rusydi, A.F. (2018) “Correlation between conductivity and total dissolved solid in various type of water: A Review,” *IOP Conference Series: Earth and Environmental Science*, 118, p. 012019. Available at: https://doi.org/10.1088/1755-1315/118/1/012019.
32. Sakihama, H., Ishiki, M., Tokuyama, A. (2008) “Chemical Characteristics of Precipitation in Okinawa Island, Japan,” *Atmospheric Environment*, 42(10), pp. 2320–2335. https://doi.org/10.1016/j.atmosenv.2007.12.02.
33. Samaradiwakara, D.S., Pitawala, H.M. (2021) “Extent of Air Pollution in Kandy Area, Sri Lanka: Morphological, Mineralogical and Chemical Characterization of Dust,” *Ceylon Journal of Science*, 50(4), p. 475. https://doi.org/10.4038/cjs.v50i4.7946.

34. Staelens, J., Schrijver, A.D., Avermaet, P.V, Genouw, G., Verhoest, N. (2005) “A Comparison of Bulk and Wet-Only Deposition at Two Adjacent Sites in Melle (Belgium),” *Atmospheric Environment*, 39(1), pp. 7-15. https://doi.org/10.1016/j.atmosenv.2004.09.055.
35. Weerasundara, L. *et al.* (2017) “Microorganisms and heavy metals associated with atmospheric deposition in a congested urban environment of a developing country: Sri Lanka,” *Science of The Total Environment*, 584-585, pp. 803–812. Available at: https://doi.org/10.1016/j.scitotenv.2017.01.121.
36. Xu, Z., Wu, Y., Liu, W.J., Liang, C.S., Ji, J., Zhao, T., Zhang, X., (2015) “Chemical Composition of Rainwater and the Acid Neutralizing Effect at Beijing and Chizhou City, China,” *Atmospheric Research*, 164-165, pp. 278–285. https://doi.org/10.1016/j.atmosres.2015.05.009.
37. Yatigammana, S., Fernando, G. and Liyanage, M. (2022) ‘A study on local air pollution due to transport emissions in Kandy City’, *Proceedings of the SLIIT International Conference on Engineering and Technology* [Preprint]. https://doi:10.54389/buot2540.

Figures

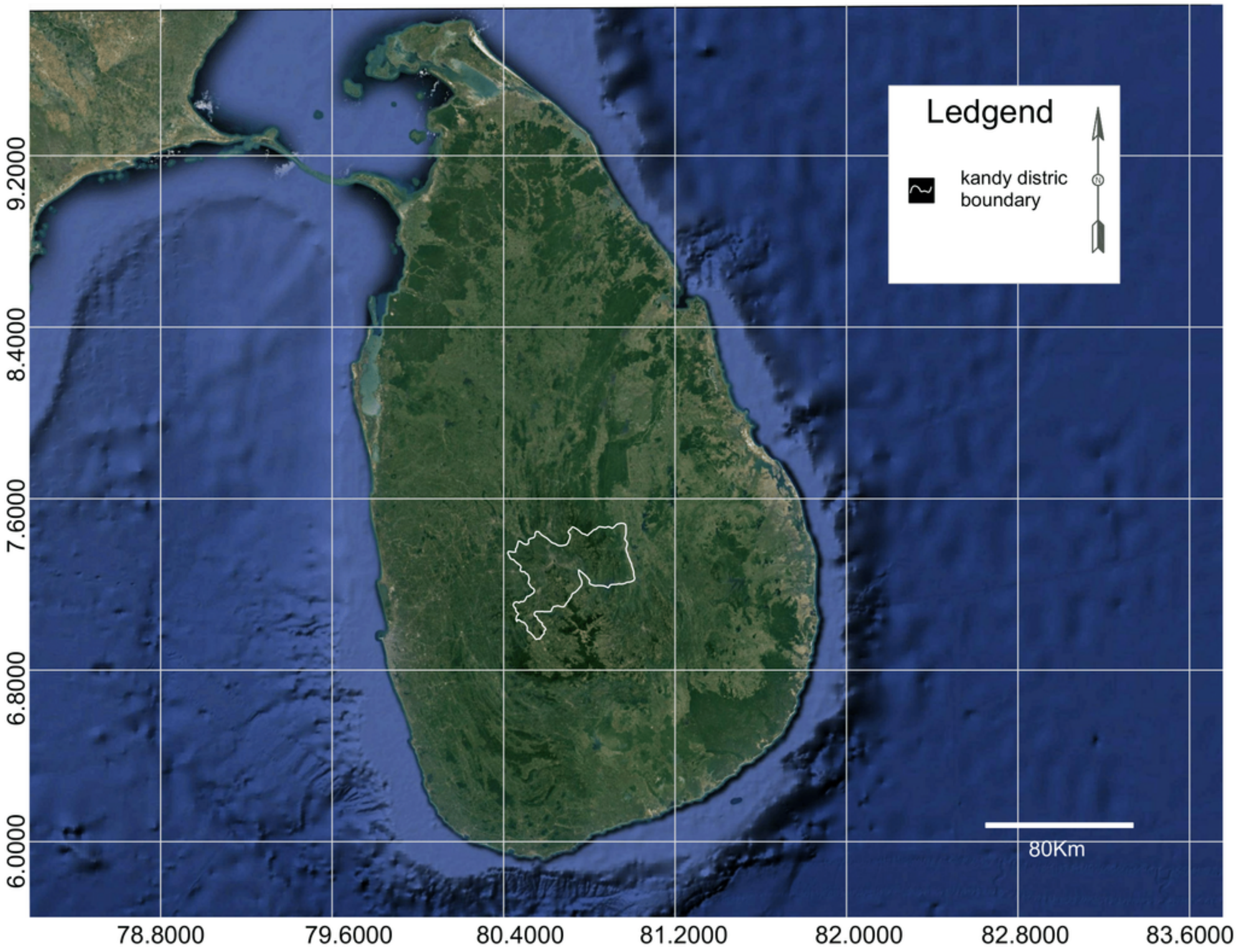


Figure 1

Area of Kandy district in Sri Lanka

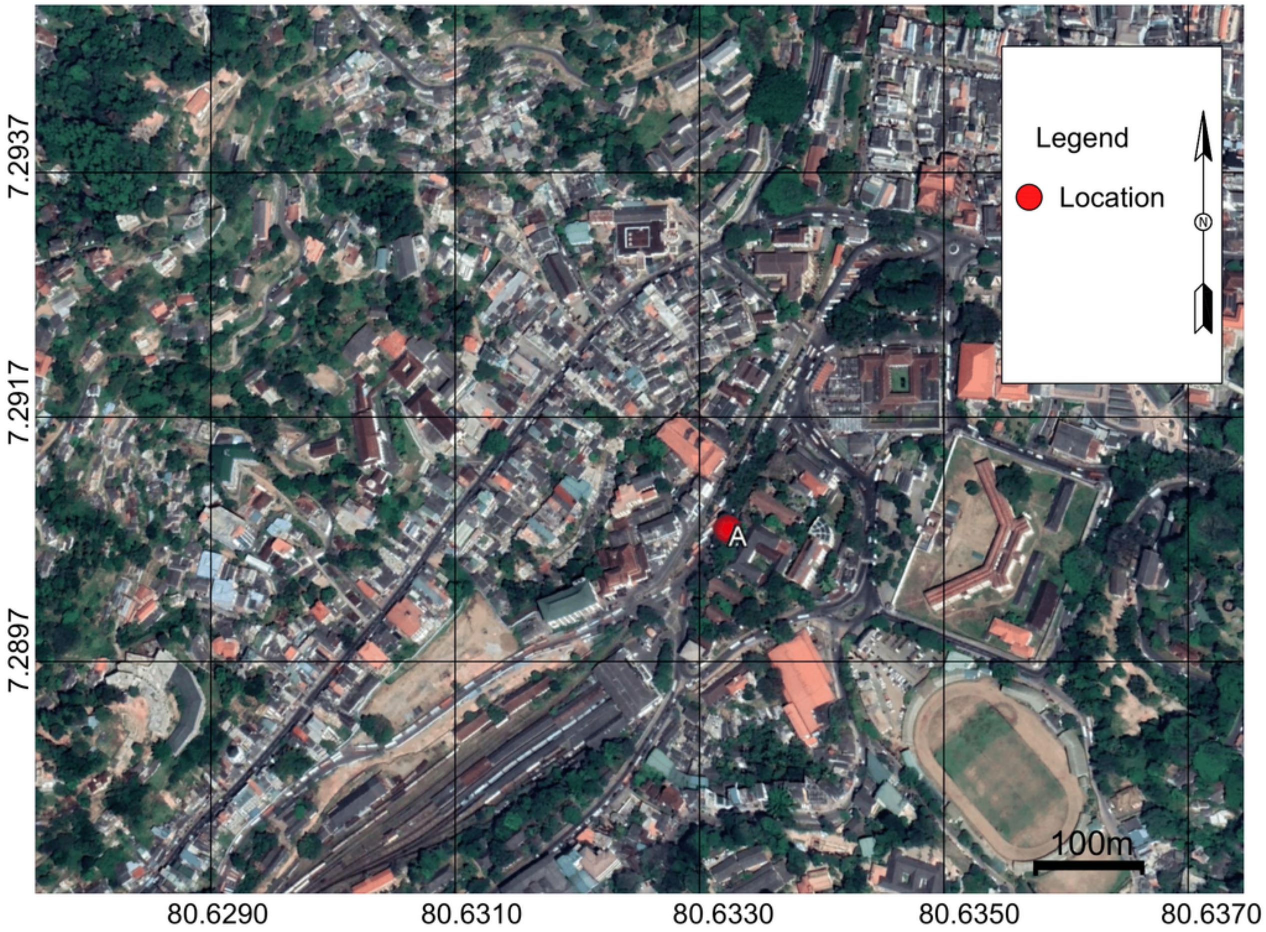


Figure 2

Location of Kandy city sampling site.

Figure 3

Location of Polgolla sampling site.

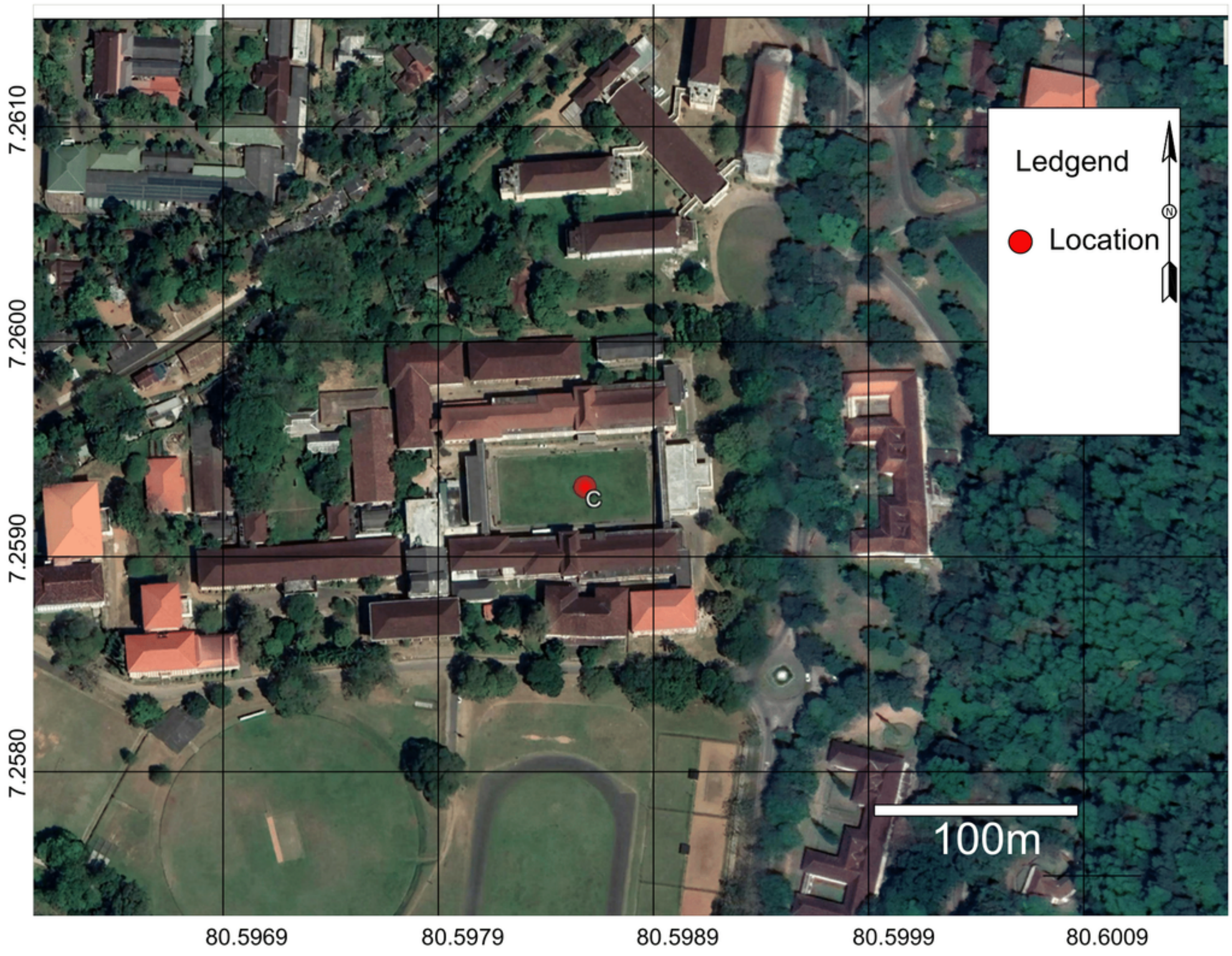


Figure 4

Location of University of Peradeniya sampling site.

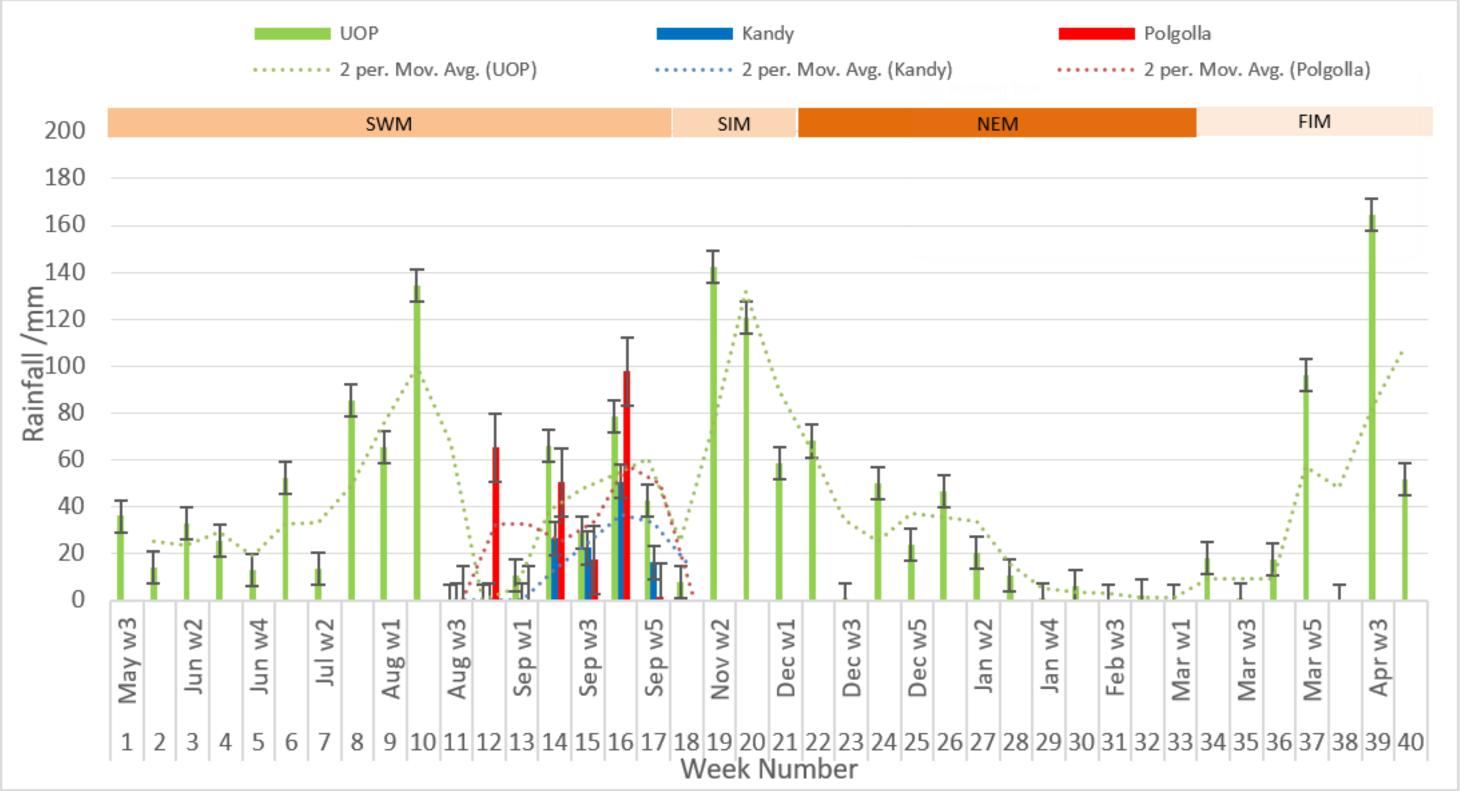
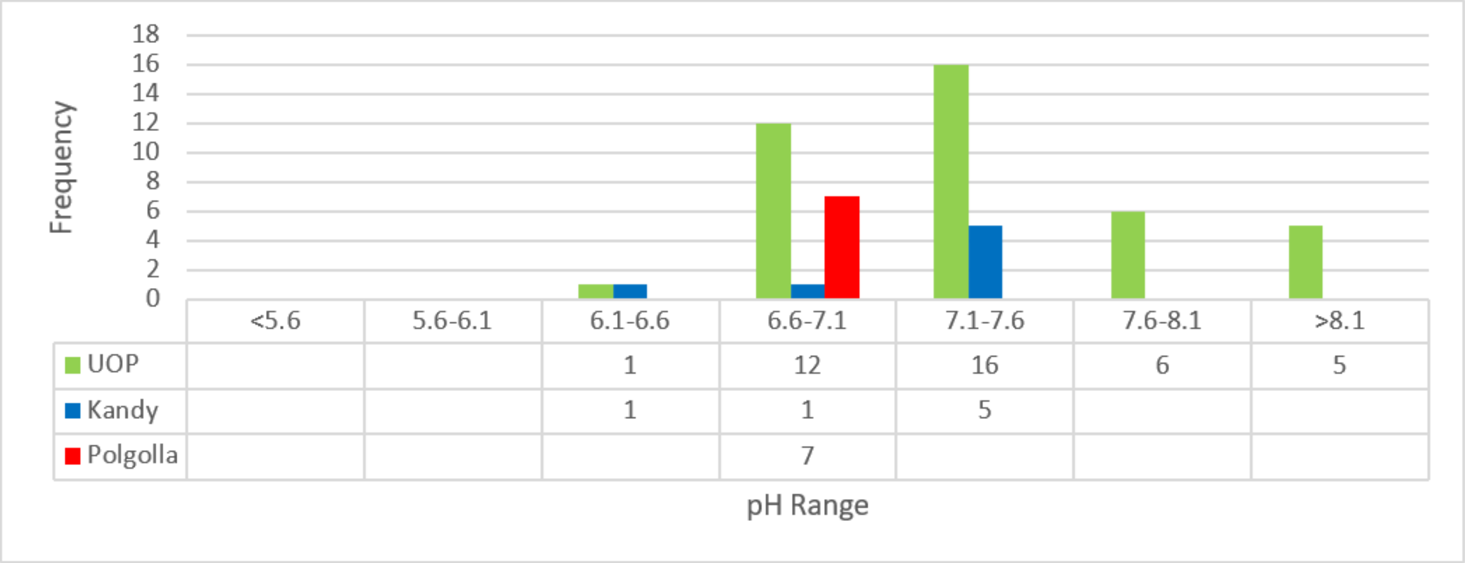


Figure 6

Rainfall estimated for each week (w1, w2, etc.) of sampling at three sampling sites covering different monsoon areas: First inter-monsoon (FIM); second inter-monsoon (SIM); Sound-west monsoon (SWM); and North-east monsoon (NEM). Dotted lines represent the two-point moving average at each sampling point.



	<5.6	5.6-6.1	6.1-6.6	6.6-7.1	7.1-7.6	7.6-8.1	>8.1
🟩 UOP			1	12	16	6	5
🟦 Kandy			1	1	5		
🟥 Polgolla				7			

Figure 7

Classification of pH values at three sampling sites.

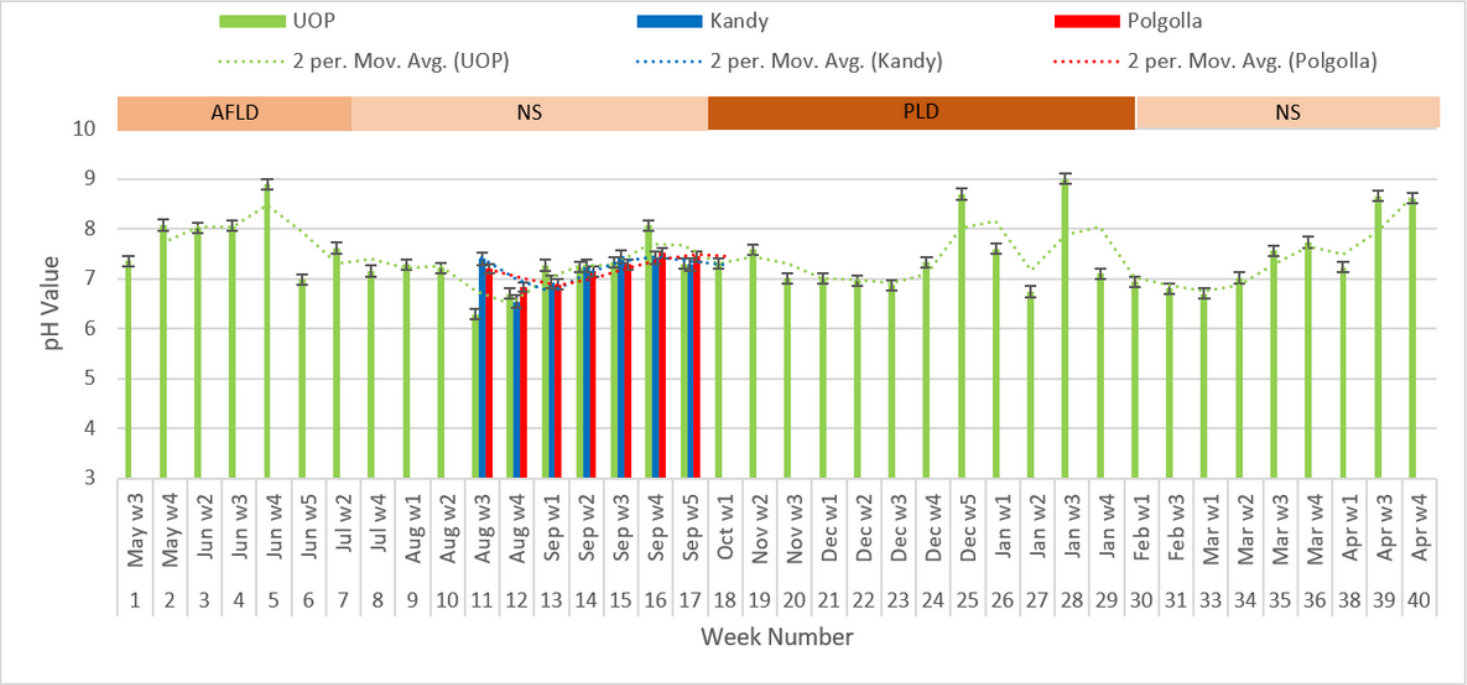


Figure 8

Variation of pH at three sampling sites for each week (w1, w2, etc.) of sampling at three sampling sites after fully lockdown (AFLD), under normal situation (NS) and under partial lockdown (PLD). Dotted lines represent the two-point moving average at each sampling point.

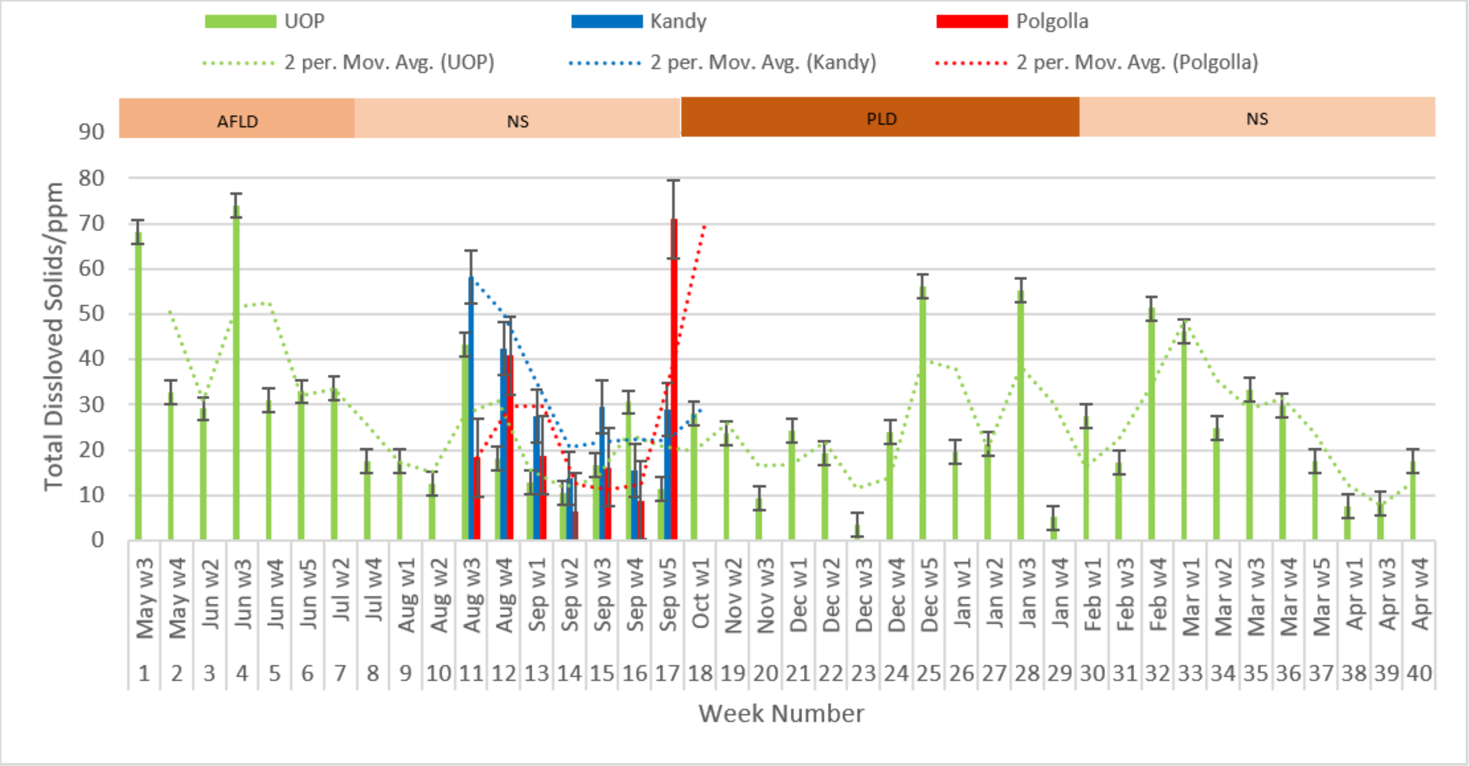


Figure 10

Variation of total dissolved solids (TDS) at three sampling sites. Abbreviations are as per Figure 8.

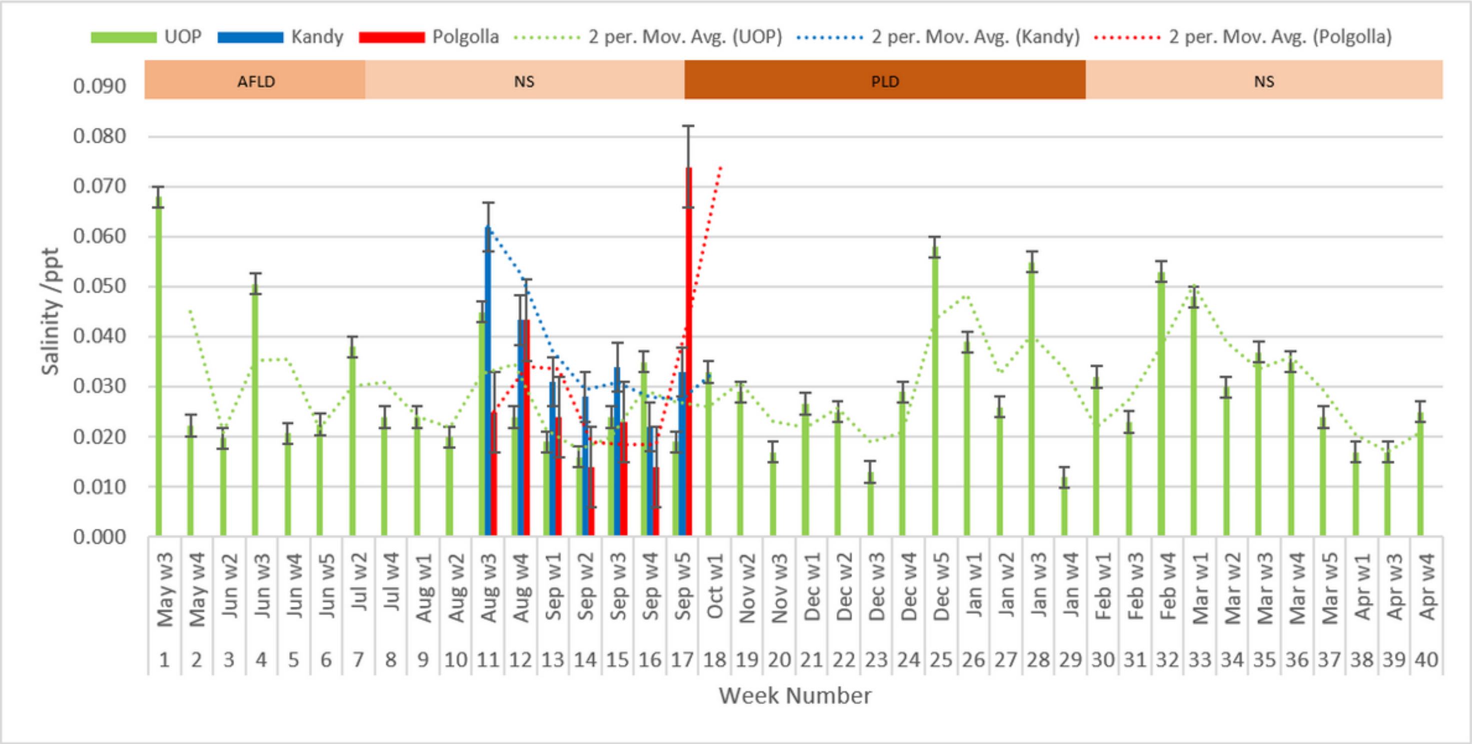


Figure 11

The variation of salinity at three sampling sites. Abbreviations are as per Figure 8.

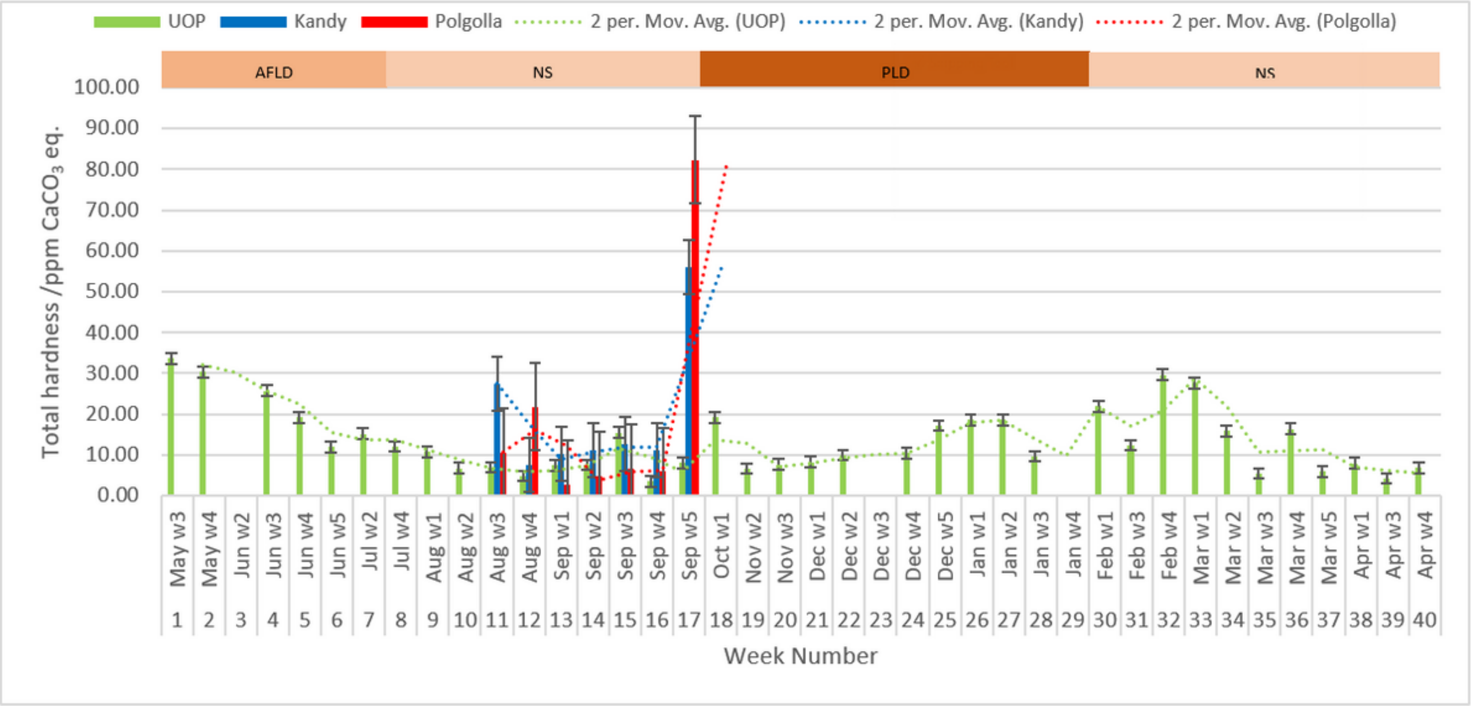


Figure 12

Variation of hardness at three sampling sites. Abbreviations are as per Figure 8.

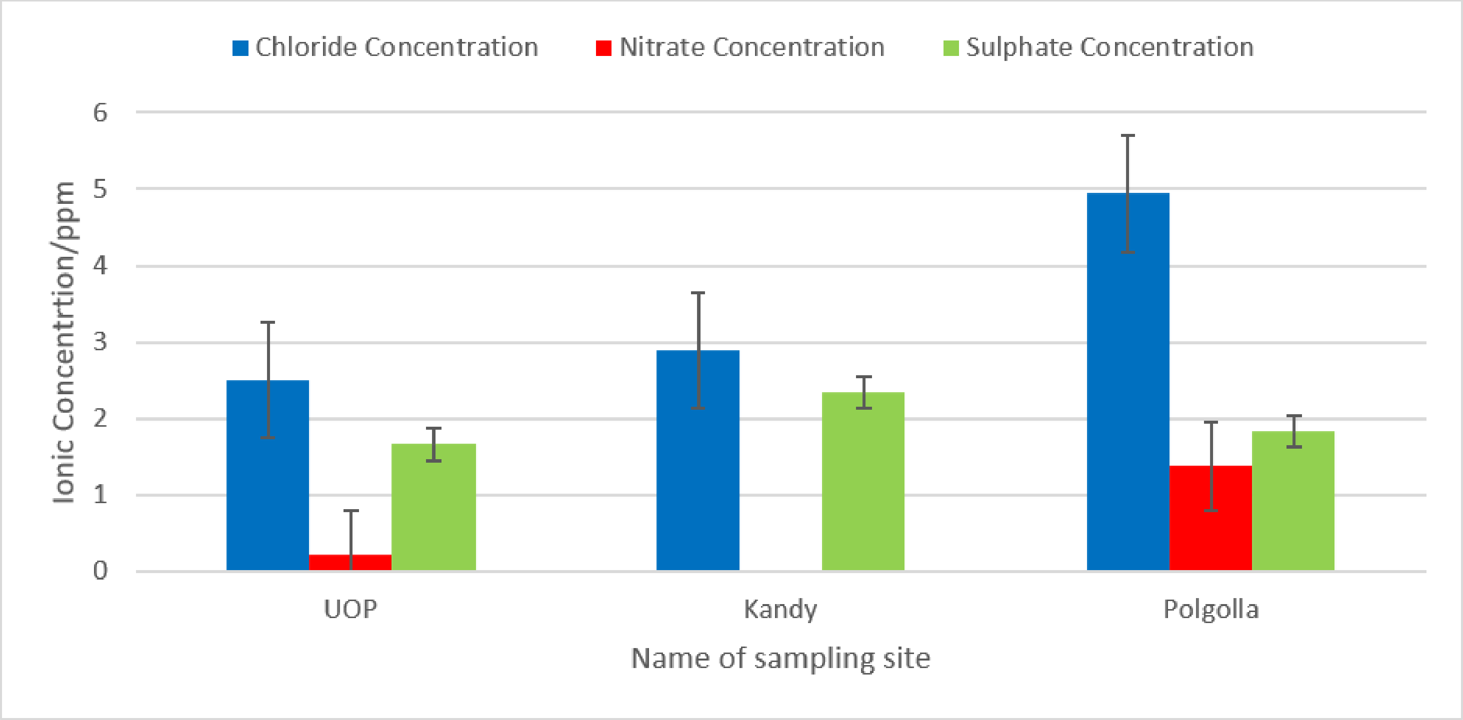


Figure 13

Summary of anionic concentration at three sampling sites.

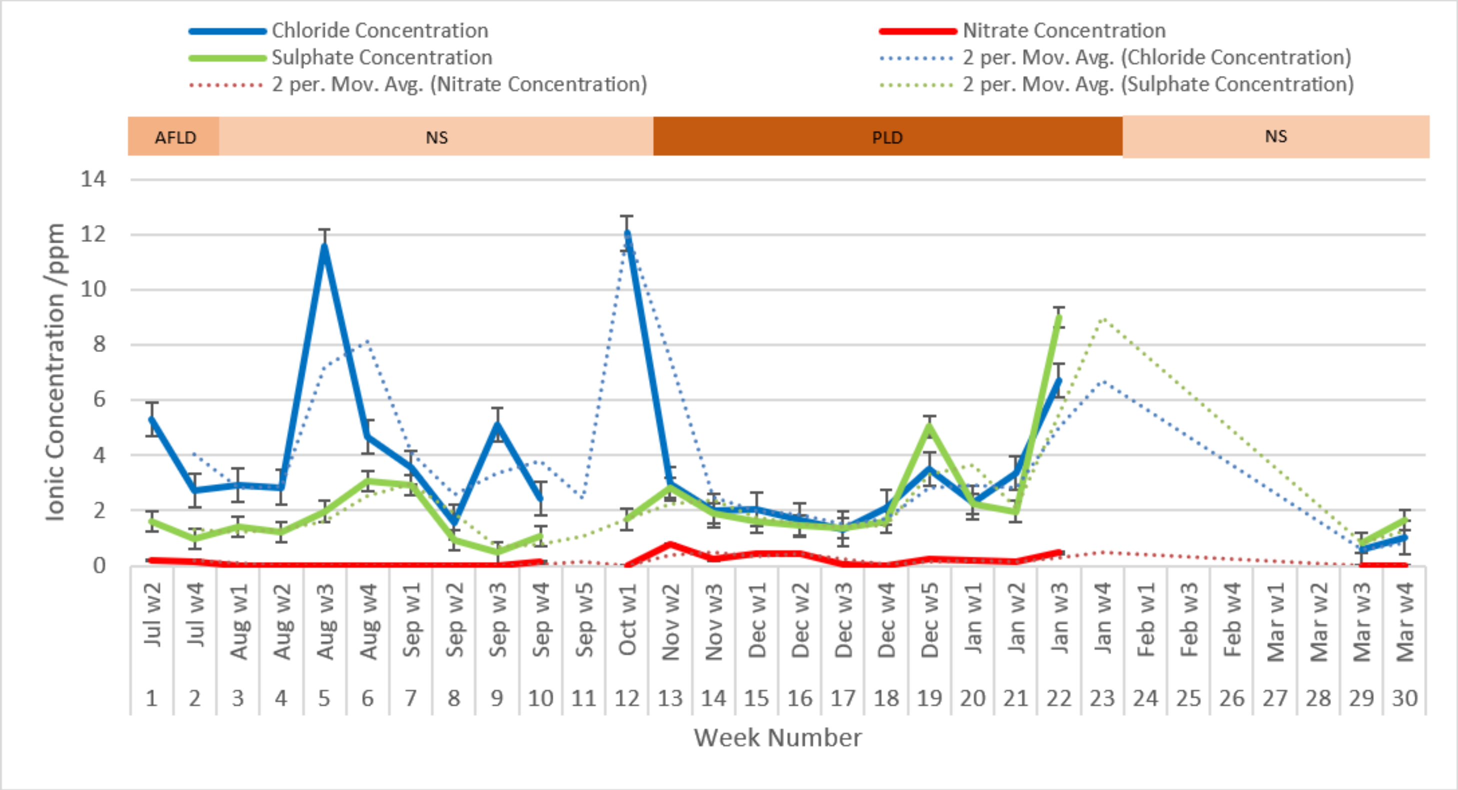


Figure 14

Anion variation at UOP site. Abbreviations are as per Figure 8.

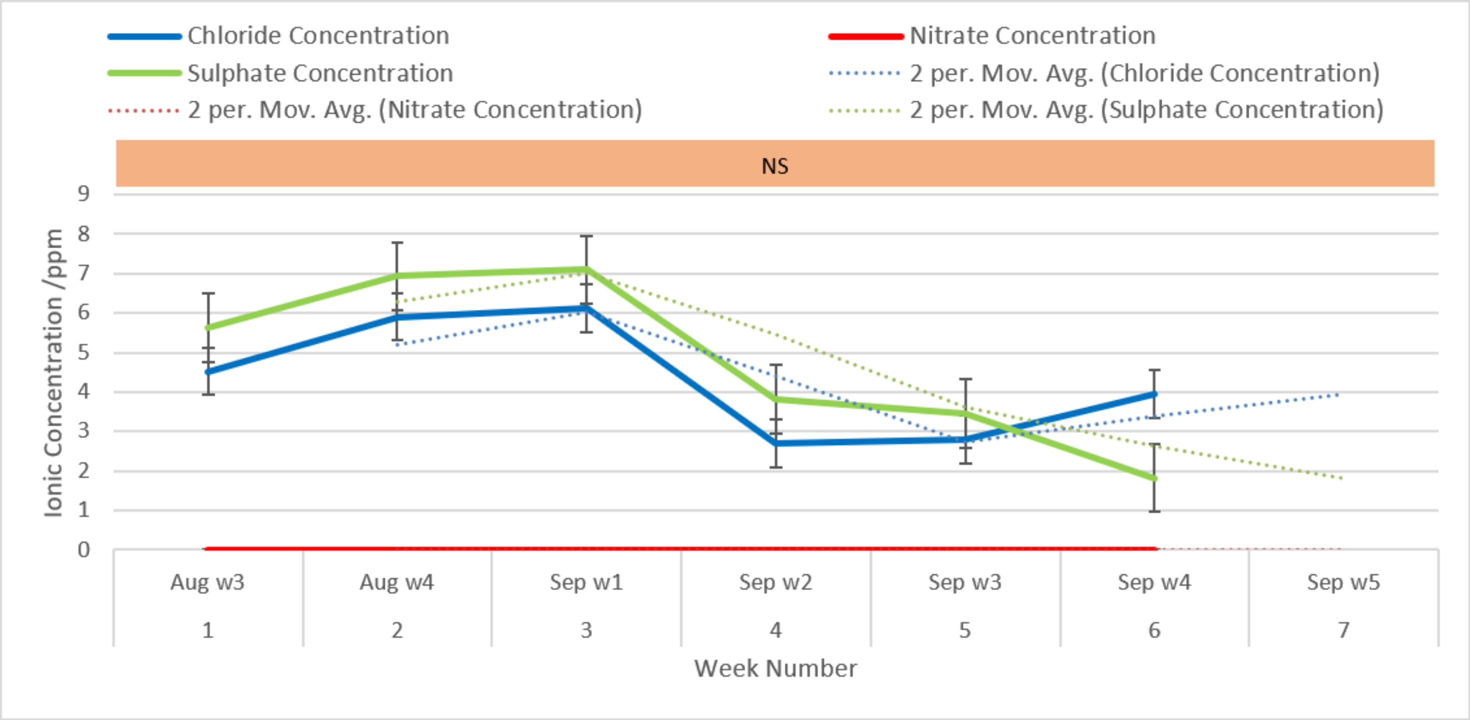


Figure 15

Anion variation at Kandy site. Abbreviations are as per Figure 8.

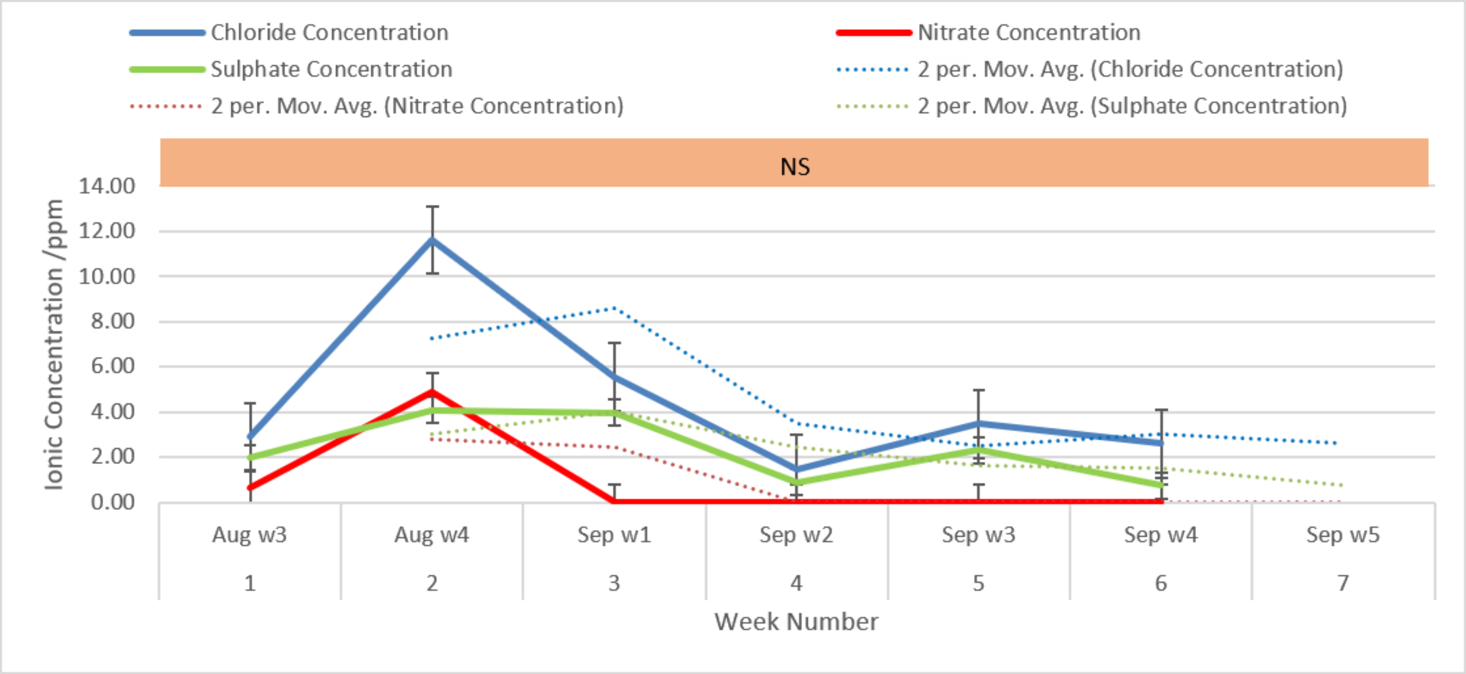


Figure 16

Anion variation at Polgolla site. Abbreviations are as per Figure 8.