Water Air Soil Pollut (2020) 231: 492
https://doi.org/10.1007/s11270-020-04840-3

Trace Metal Composition of Bulk Precipitation in Selected Locations of Kandy District, Sri Lanka

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Received: 28 April 2020 / Accepted: 20 August 2020 / Published online: 19 September 2020

Abstract Atmospheric precipitation in Sri Lanka occurs mainly through rain whose terrestrial composition significantly varies based on the location as the regional geography and anthropogenic factors can largely affect environmental pollutants that are added to the atmosphere. It is therefore very important to have baseline data on the chemical composition of the atmosphere to take regulatory measures to control atmospheric pollution although very limited data available in Sri Lanka. The main objective of this study was thus to quantitatively determine selected trace metals (Al, Cr, Cu, Fe, Mn, Pb, and Zn) in bulk precipitation samples collected weekly in three sampling locations, namely the University of Peradeniya (UoP), Polgolla, and Kandy City Central (KCC), for a period of 1 year from March 2018 to March 2019. Trace metals determined using atomic emission spectrophotometry indicated that the KCC site showed the highest contamination following the sequence (with respective volume-weighted mean (VWM) concentration values) of Al (79.7 $\mu g\ L^{-1}$) > Fe (42.8 $\mu g\ L^{-1}$) > Zn (39.3 $\mu g\ L^{-1}$) > Mn (13.9 $\mu g\ L^{-1}$) > Cu (9.8 $\mu g\ L^{-1}$) > Cr (2.4 $\mu g\ L^{-1}$). The corresponding values of the Polgolla site showed the sequence Zn (64.3 $\mu g\ L^{-1}$) > Al (52.1 $\mu g\ L^{-1}$) > Fe (17.9 $\mu g\ L^{-1}$) > Mn (11.1 $\mu g\ L^{-1}$) > Cu (5.4 $\mu g\ L^{-1}$) > Cr (1.8 $\mu g\ L^{-1}$). Due to less industrialization and less traffic congestion, the UoP site showed low trace metal levels in the order Zn (29.8 $\mu g\ L^{-1}$) > Al (21.3 $\mu g\ L^{-1}$) > Fe (14.2 $\mu g\ L^{-1}$) > Cu (7.4 $\mu g\ L^{-1}$) > Mn (4.3 $\mu g\ L^{-1}$) > Cr (0.9 $\mu g\ L^{-1}$). Principal component analysis indicated that Cu, Mn, and Zn originated mainly from anthropogenic activities, such as combustion of fossil fuel and burning of municipal waste, while Al and Fe mainly originated from natural sources.

Keywords Bulk deposition · Trace metals · Atmospheric pollution · Principal component analysis

1 Introduction

Atmospheric deposition, which occurs as wet and dry precipitation, or bulk precipitation in combined form, is the primary mechanism of transporting water from the atmosphere to the surface of the earth. It is the major scavenging process of removing pollutants from the atmosphere (Zhang et al. 2007; Huang et al. 2008; Tositti et al. 2018). Wet deposition delivers atmospheric compounds present in cloud and precipitation droplets to the earth's surface by rain, hail, or snow. Although wet-only samplers are available, owing to their many

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drawbacks, open funnels or bulk collectors are often used to collect precipitation in environmental studies (Staelens et al. 2005). On the other hand, dry deposition is the transfer of atmospheric pollutants accumulated as aerosol particles and gases to the earth's surface in dry form, which would subsequently affect soil, vegetation, and water when it comes into contact. Many acidic compounds originated from the earth fall back to earth through dry deposition as a result of turbulence diffusion under Brownian motion or sedimentation under earth's gravity (Mosello et al. 1988). Factors affecting wet deposition include cloud parameters and precipitation, while dry deposition depends on meteorological conditions, and characteristics of pollutants and the surface on which deposition occurs (Martins et al. 2019; Nadzir et al. 2017; Rao et al. 2016; Vlastos et al. 2019; Wang et al. 2019; Wu et al. 2016).

Rainfall is the most common form of wet deposition in Sri Lanka, and it occurs when water droplets grow into a size of diameter 0.5 mm or more, and drizzling occurs when the diameter of the droplet is less than 0.5 mm (Harikumar et al. 2010). Rainwater obtains its composition greatly by dissolving particulate matter in the troposphere when droplets of water nucleate on particulates, followed by dissolving gasses present in the atmosphere. Composition of rainwater varies according to geography and anthropogenic activities. Toxic heavy metals in the atmosphere, such as Cd, Cr, Cu, Ni, Pb, V, and Zn, which are on the rise, have been mobilized in the environment by expansion of industrial activities to meet the demand of ever-increasing population, especially in urbanized regions (Gerdol et al. 2000; Fernández et al. 2002; Couto et al. 2004; Migliavacca et al. 2004; Balestrini et al. 2007; Weerasundara et al. 2017, 2018). Heavy metals emitted by combustion processes usually have relatively high solubility and reactivity, because of the small particle size (Couto et al. 2004). Therefore, the local climate created due to such undesirable activities on earth would indirectly control the quality of terrestrial rainwaters, some of which have unexpectedly high pollutant concentrations (Huang et al. 2019; Tositti et al. 2018).

Many health problems and hygienic issues are associated with contaminated water, and consequently, consumption of good-quality water is a major factor to maintain human health (Hunter et al. 2010; Musoke et al. 2018). Rain is in fact an effective global network to supply sufficient water for many parts of the society, especially in developing countries which have inadequate access for pipe-borne purified water. Additionally, rainwater is the main contributor to agriculture, and vegetation would suffer badly if the rainwater quality is poor. Further, acidity of rainwater would affect buildings and the esthetic nature of the environment (Ileperuma 2000).

It is therefore very important to have baseline data on the chemical composition of the atmosphere to take regulatory measures to control atmospheric pollution, which has already become a global need as the atmospheric quality is not limited to a particular region or a country unlike water or soil pollution. Despite the need, not much information on air quality is available on global scale as compared with water quality data, and Sri Lanka also follows the same trend of not having adequate and continuous data on atmospheric quality. Furthermore, trace metals, most of which are toxic to the ecosystem, could pose severe health issues if they are present beyond respective threshold levels. This aspect has not been given due attention, and the present situation with regard to trace metal levels in the atmosphere would get even worse if remedial measures were not taken. In this context, the objective of this research was to quantitatively determine selected trace metals, namely, Al, Cr, Cu, Fe, Mn, Pb, and Zn, in bulk precipitation samples collected weekly in three sampling locations, namely the University of Peradeniya (UoP), Polgolla, and Kandy City Central (KCC) for a period of 1 year from March 2018 to March 2019. Identification of possible point and nonpoint sources contributing to the above trace metals, through statistical means, has also been paid attention.

2 Weather/Climate in Sri Lanka

The climate in Sri Lanka is tropical, and there are very distinctive wet and dry seasons. The average temperature normally ranges from 28 to 32 °C which may change due to global weather conditions as a whole. The coldest months are December and January, while the warmest months are April and August. Sri Lanka, being an island, has a diverse topography. The highlands are in the center of the southern part of the island. The major highlands consist of a range of topographical features, including peaks, plateaus, valleys, basins, escarpments, and ridges. The rest of the island is fairly flat except for small scattered hills. These features greatly affect the temperature, wind patterns, seasonal rainfall, and humidity of the country which is fairly prominent during the monsoon season. Rainfall in Sri Lanka consists of monsoonal, convectional, and expressional, and the monsoons play a major role in the annual rainfall, averaging less than 900 mm in the north-western and south-eastern parts of the country to over 5000 mm in the western slopes and the central highlands.

Due to the location of the island in the equatorial and tropical zones, four distinctive seasons have been influenced by the monsoons. They are as follows: first inter-monsoon season (March–April), that is, thunderstorm-type rainfall with warm and uncomfortable conditions; southwest-monsoon season (May–September), that is, the warm season is eased away by the windy weather during this particular monsoon season. Rains can be expected during any time of the day; second inter-monsoon season (October–November), that is, the rains occur with thunder storms while the influence of the weather system like depression and cyclones in the Bay of Bengal is considered to be common. The whole island experiences wide spread rain with strong winds, and the last one is the northeast-monsoon season (December–February), that is, cold and dry windy weather which can be expected during this season, while cloud-free days and days filled with sunshine can be expected. During this season, rain can be expected in several parts of the island as well (Dissanayake and Weerasooriya 1985; Ileperuma 2015; Tennakoon et al. 2006).

3 Materials and Methods

3.1 Study Area

Three study areas were selected in Kandy District located in the Central Province of Sri Lanka to carry out this research (Fig. 1). The capital of the District is Kandy. This District covers an area of 1906.3 km^2 and has an average population of 1.37 million. The average values of daytime ambient temperature, monthly rainfall, and daytime relative humidity have the following ranges: 28–32 °C; 52–398 mm; and 63–83%, respectively. Three sampling sites, separated by 7 km apart, were selected for the study in Kandy District as given below:

Site A. KCC site which represents an urban environment (GPS coordinates—latitude 7.290862, longitude 80.6334)

Site B. UoP which represents a sub-urban environment (GPS coordinates—latitude 7.25912, longitude 80.59840)

Site C. Polgolla area near Mahaweli River which represents a sub-urban environment (GPS coordinates—latitude 7.323325, longitude 80.64666)

The above three locations have unique characteristics. For example, the KCC site experiences high traffic congestion while the other two experience moderate traffic congestion. Moreover, the KCC site is located in a valley with restricted air flow. The Polgolla site is located at the bank of the longest river in Sri Lanka. Comparatively, the Peradeniya site is located in a sub-urban area of Peradeniya. Apart from these differences, the three locations selected have similar environmental features as well; for example, they are located in the wet zone of Sri Lanka where similar climatic conditions prevail.

3.2 Method of Sampling

In the sample collector, a funnel (diameter = 20.6 cm) was attached to a high-density polyethylene bottle through a hole in the lid. Cotton wool was plugged to the funnel to prevent contamination, such as debris and bird excrement. The device used to collect samples is shown in Fig. 2. The sampler and the funnel were thoroughly cleaned with ASTM type I ultra-pure water (Elga Purelab Option Q) and allowed to dry before placing. The collector was mounted at a height of 150 cm from the ground level. After collecting the sample, it was brought into laboratory. Then, volume was measured using graduated measuring cylinder (500 mL), and thereafter, it was filtered through a 0.45-μm cellulose acetate filter paper. Sample was preserved by acidification to about $\mathrm{pH} < 2$ by adding ACS grade conc. HNO_3 (Sigma-Aldrich 70%, ≥ 99.999% trace metal basis) and refrigerated at 4 °C prior to metal analysis. Bulk precipitation was collected once a week for a period of approximately 1 year from 2 March 2018 to 6 March 2019.

3.3 Methods of Chemical Analysis

Quantitative determination of trace metal elements (Al, Cr, Cu, Fe, Mn, Pb, and Zn) in acidified samples was carried out using Agilent 4100 MP-AES (Microwave

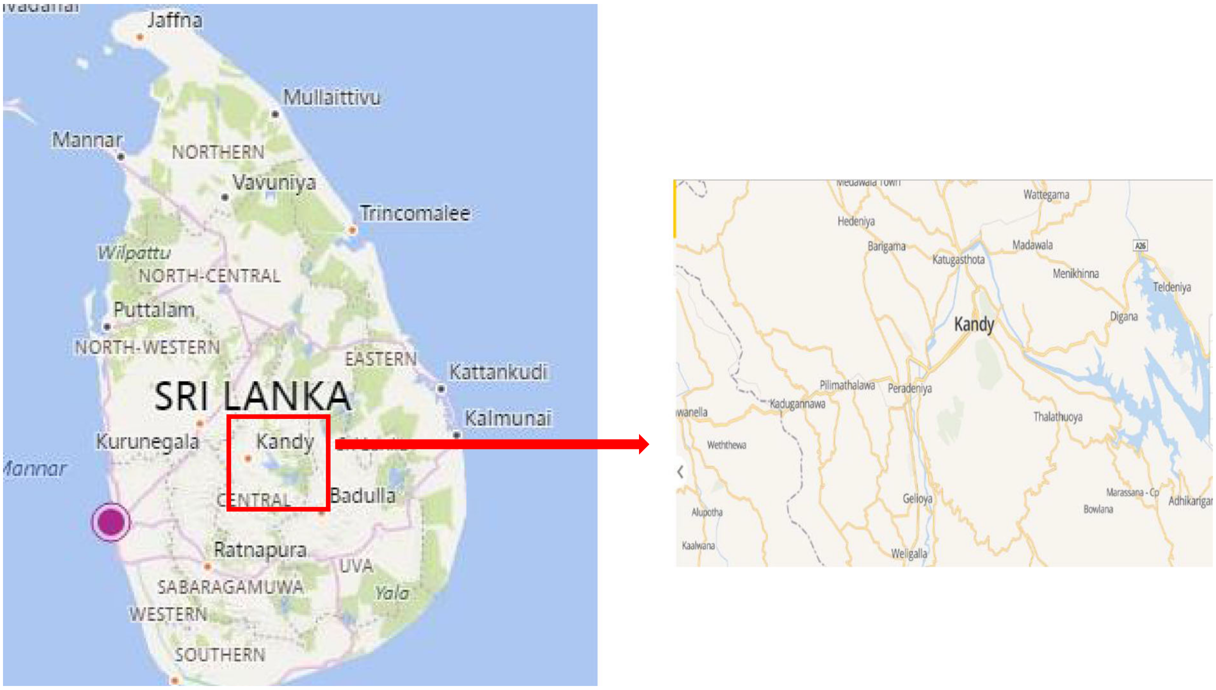


Fig. 1 Map of Sri Lanka showing sampling site

Plasma Atomic Emission Spectrometer). Trace metal standard solutions (Al, Cr, Cu, Fe, Mn, Pb, and Zn) were prepared using Sigma-Aldrich standards. The MP-AES technique provides fairly accurate results with sufficiently low detection limits. Detection limits for elements were within the range of 0.1–2.0 μg L^{-1} (Al—0.4, Cr—0.1, Cu—0.7, Fe—4.6, Mn—0.2, Pb—3.3, and Zn—4.5). Quality of the analysis was achieved by running known standard with the same matrix as analyte between 20 sample-intervals to check percentage recovery of the analyte.

3.4 Statistical Analysis

Pearson correlation and principal component analysis were used for further analysis of bulk precipitation data. Minitab statistical software (Minitab 18) was used for in order to fulfill this task.

3.5 Pearson Correlation

Pearson correlation is known as the best method of measuring the association between variables of interest because it is based on the method of covariance. It gives information about the magnitude of the association, or correlation, and the direction of the relationship assuming that the correlation coefficient can take a value between − 1 and + 1. In a positive correlation, as one variable increases, the other variable has a tendency to also increase. In contrast, as one variable increases, the other variable has a tendency to decrease in a negative correlation. If there is no correlation between a pair of variables, then one variable does not tend to either increase or decrease with respect to the other. Values of the correlation coefficient are as follows: 0.00–0.19 very weak correlation; 0.20–0.39 weak correlation; 0.40–0.59 moderate correlation; 0.60–0.79 strong correlation; and 0.80–1.00 very strong correlation.

4 Results and Discussion

4.1 Variation of the Concentration of Trace Metal Elements—KCC Site

The main trace elements analyzed during the study period are Al, Cr, Cu, Fe, Mn, Pb, and Zn, in forty-seven (47) samples starting from the 1st week of March 2018 for a period of approximately 1 year. Variation of the levels of the above trace metals in bulk deposition samples collected at the KCC site within the entire period of investigation is shown in Fig. 3. It is

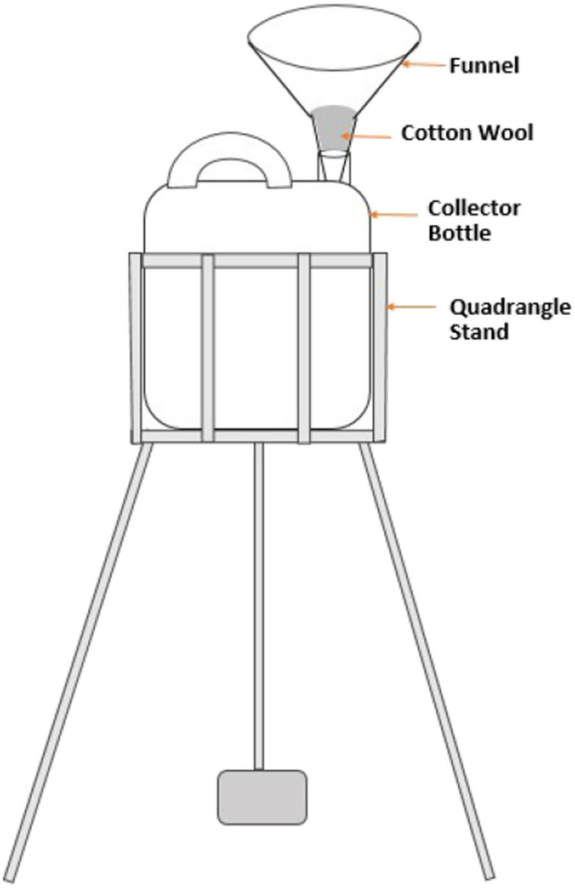


Fig. 2 Device used for collecting bulk precipitation

clear that the dominant element in the KCC site is Al with the exception of higher levels of Fe as determined on two occasions at the 44th and 46th weeks, at relatively low rainfall. This indicates the possibility that Fe shows stronger affinity to be trapped into dust particles than Al does so that rain would carry Fe onto earth. This is further supported by the fact that high Al levels being recorded between the 20th and 30th weeks within which the KCC site experienced higher rainfall. It is also determined that Al shows the highest volume-weighted mean (VWM) value of 86.1 ppb (Table 1), followed by Fe and Zn over the entire period of investigation. The mean concentrations of Cu and Mn are not much different from each other, and Cr shows the lowest average concentration in rainwater samples. It is also noticed in Fig. 3 that both Cr and Mn show a similar distribution pattern. In general, amounts of most metals present in bulk depositions were higher from July to September 2018. This period is included in the south-monsoon period which experiences a windy weather. This is a major reason to disperse and circulate air pollutants. Overall, the amounts of metals present at the KCC site vary according to the order, Al > Fe > Zn > Mn > Cu > Cr.

4.2 Variation of the Concentration of Trace Metal Elements—Polgolla Site

According to Fig. 4, Zn is the major metal present in this site, followed by Al and Fe. It is interesting to observe that the Zn levels in deposition samples are fairly consistent throughout the sampling period unlike other metals that have higher and lower values, i.e., broad variation ranges, depending on the day of sampling. Similar to the observations made at the KCC site, levels of all metals were high during July–September 2018.

Fig. 3 Weekly variation of content of trace metal elements in bulk precipitation at KCC site

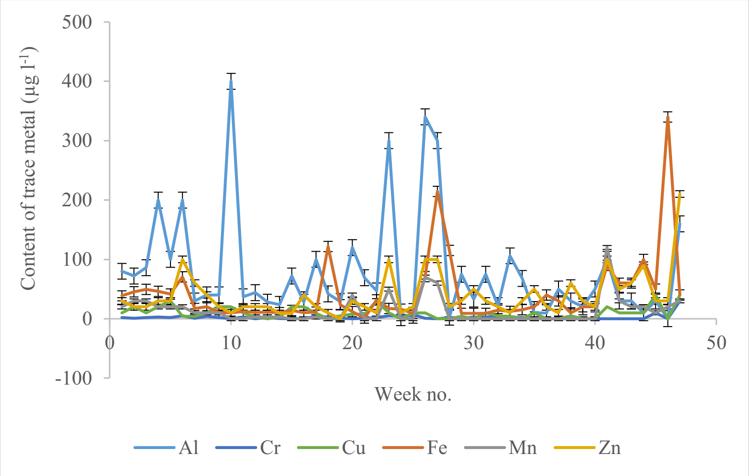


Table 1 Volume weighted mean concentration of metals in each site

Variable	Mean concentration (μg L^{-1})				% recovery of check standards
	Detection limits	UoP	Polgolla	KCC	
Al	0.4	21.3	52.1	79.7	98–103
Zn	4.5	29.8	64.2	39.3	96–104
Fe	4.6	14.2	17.9	42.8	97–105
Mn	0.2	4.3	11.1	13.8	98–102
Cu	0.7	7.4	5.4	9.8	96–103
Cr	0.1	0.9	1.8	2.4	97–104

The contents of metals present in the Polgolla site vary in the order, Zn > Al > Fe > Mn > Cu > Cr, where Al, Fe, and Mn show similar distribution patterns.

4.3 Variation of the Concentration of Trace Metal Elements—UoP Site

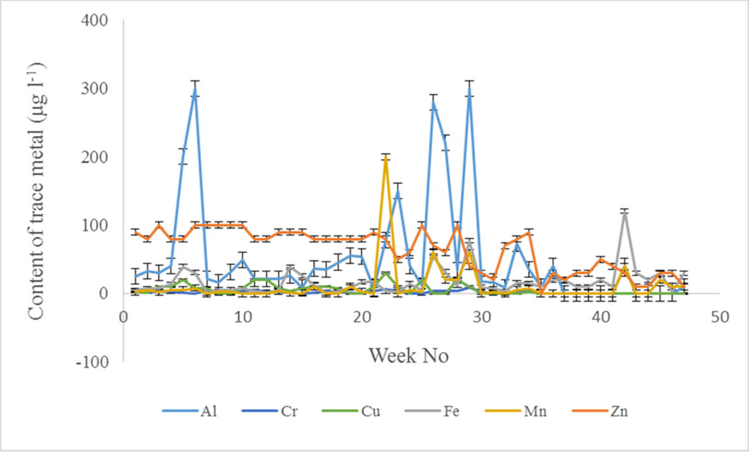
The dominant metal was Zn with the highest VWM value of 29.8 μg L^{-1} (Table 1), followed by Al. Furthermore, Cu and Fe showed similar variation pattern during the study period (Fig. 5). Chromium was present at a very low VWM value of 0.9 μg L^{-1}, and Mn, the next more abundant metal, is present at much higher levels compared with Cr, both of which showed a similar distribution pattern. The amounts of metals present vary in the order Zn > Al > Fe > Cu > Mn > Cr.

4.4 Comparison of Trace Metal Elements in Three Sites

Although the three sites are about 7 km apart, the levels of trace metals at each site are different from each other, which indicates that mixing of air through diffusion and wind operations would not be effective. This situation has been observed in early studies as well which is mainly due to the fact that Kandy City is located in a small valley (plateau) surrounded by a line of high mountains, namely Hantana, Bahirawakanda, and Knuckles. This situation possibly creates thermal inversions, and hence, air gets re-circulated within the city's atmosphere (Ileperuma 2015). The KCC site experiences high vehicular congestion, bus stands, railway stations, and low vegetation cover. The UoP site is beyond the valley on the other side of the Hantana mountain range, and the Polgolla site is located at a river bank. These two sites are suburban areas with low vehicular volume, high vegetation cover, high winds, and low traffic congestion (Ileperuma 2000). The above features lead to more air pollution in the Kandy City environment, and hence, the air quality of the bulk deposition of the KCC site could be distinctly different from that of the other two sites, although they are close to the KCC site.

When comparing the three sites, Zn was the dominant metal in the Polgolla and the UoP sites, followed by

Fig. 4 Weekly variation of content of trace metal elements in bulk precipitation at Polgolla site



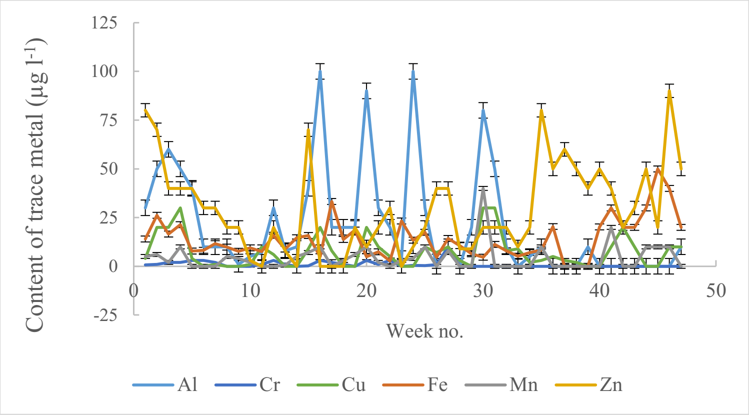


Fig. 5 Weekly variation of content of trace metal elements in bulk precipitation at Peradeniya site

Al and Fe. On the other hand, Al was the dominant metal in the KCC site, followed by Fe and Zn. It can therefore be argued that Al, Fe, and Zn were the major trace metals present in all three sites. The minor metals, Mn, Cr, and Cu, were determined to have much lower levels at all three sites as compared with the major metals. These metals vary as, Mn > Cu > Cr, in the KCC and Polgolla sites, whereas Mn and Cu were in reverse order at the UoP site. Overall, except for Zn, all other metals are at the highest level at the KCC site, and it could therefore be argued that this is the most polluted site. Polgolla is next to the KCC site as far as the pollution levels of trace metals are considered, and the UoP site has a relatively better atmospheric quality. Many other parameters, such as conductivity, salinity, and Ca^{2+}, have been reported to be at the highest level at the KCC site as compared with the other two sites supporting the above claim. Nevertheless, Pb was at undetectable levels at the KCC and Polgolla sites although four deposition samples of the UoP site contained Pb at 4.10 μg L^{-1}, 7.44 μg L^{-1}, 8.25 μg L^{-1}, and 23.24 μg L^{-1} levels. The highest Pb concentration was recorded in the 2nd week of September 2018.

A major metal, Al, found at all three sites is contributed by many sources. Mining activities located in Kandy District contain gneiss, which is a source for Al, K, Na, Mg, and Fe. Some quarries are located in close proximity to all three sites, namely, Peradeniya, Elugoda, Sarasavigama, Manikhinna, Nugawela, and Pallekele. Therefore, contribution of Al to depositions of all three sites would not be much different from each other. In addition, Al is emitted to the air via the production of aluminum alloys and compounds, resuspended by vehicular traffic and burning of waste. Among these, contribution of high vehicular traffic is much more significant to depositions of the KCC site having the highest level among all seven metals investigated and among the three sites. It should be stated that nearly 100,000 vehicles enter Kandy City daily (Ileperuma 2000).

Another major metal, Zn, was contributed by coated roofing material, lubricants, brass manufacture, hot-dip galvanizing, metal plating, and vehicular emission. Iron is the fourth most abundant element in the earth's crust; soil particles are major source of Fe. Moreover, Mn can be found in metal ores. Some metals and metallic compounds kept in open areas could be transported through wind and flood. Other sources of Fe would be combustion of fossil fuel, biomass burning, corrosion of steel products, vehicle service centers, brake pads, construction activities, and mining activities. Among these, the highest content of Fe determined at the KCC site can be attributed to vehicle-related operations specified above as Kandy City experiences the worst traffic conditions, and major construction activities as compared with the other two sites. Based on the above facts, it is clear that rainwater in the selected areas have Zn, Al, and Fe as major contaminants. Dry deposition and bulk deposition samples of four sites located in heavy-traffic areas in Kandy have also indicated relatively high concentrations of Fe, Al, and Zn, supporting findings of this research (Weerasundara et al. 2016).

There are many laboratories in the vicinity of the UoP site contributing many metallic elements to bulk precipitation. Furthermore, Cr is naturally available in soil, rocks, and plants, and it is also used in toners in photocopying machines. Therefore, Cr is introduced by both natural and anthropogenic activities. However, Cu is introduced more by anthropogenic activities (e.g., brass industry) than natural sources. Ash and particulate matters added to the atmosphere through crematory operations carried out in several areas, such as Amunugama, Ampitiya, Arambegama, Mawilmada, Wagolla, and Kossinna, in Kandy District could be another source of metallic composition in bulk precipitation.

It is a well-known fact that the degree of air pollution is considerably higher during the north-east monsoon period due the pollutants in the air which could have originated in neighboring countries. There is a number of coal power plants along the south-east coast of India, and pollutants and acidic fumes emitted from them could be carried over to Sri Lanka and deposited as bulk precipitation. Preliminary studies have also indicated that central hill areas, such as Kandy, receive pollutants produced in the Western Province which has large number of automobiles on roads. Once the pollutants enter Kandy, they could not be diffused back easily.

4.5 Statistical Analysis

4.5.1 Correlation among Metallic Elements at KCC Site

Correlation coefficients between pairs of trace metals for the three sites under investigation are shown in Tables 2, 3, and 4. These values also give evidence that the three sites have different characteristics although they are not much far from each other. When considering the KCC site, a strongest positive correlation coefficient of 0.60 among many pairs of metals was observed between Zn and Mn (Table 2). However, the other two sites do not show any strong correlation between the above metals (0.03 for Polgolla site and 0.10 for UoP site). Further, the correlation coefficients for Mn and Fe for the three sites, KCC, Polgolla, and UoP, are 0.36, 0.23, and 0.19, respectively. The corresponding values of Al and Mn are 0.47, 0.32, and 0.39, respectively, while those of Zn and Cr are 0.58, 0.38, and 0.04, respectively. These coefficients for Cu and Cr are 0.51, 0.53, and 0.16, respectively, while those for Al and Zn are 0.43, 0.16, and − 0.15, respectively.

The correlation coefficients given above indicate that there is a strong possibility to have the same source for the metals, Al, Cr, Cu, Fe, Mn, and Zn, in the Kandy City. It is therefore argued that industrial pollution would not be the main contributor toward air pollution as no industry would usually release all types of metals simultaneously. Therefore, biomass burning, corrosion of metallic objects, vehicle-related operations, and crematory operations, all of which are common in the Kandy metropolitan area which release many metals, would be the main air pollution contributors of Kandy City. Not having the above operations being in common in Polgolla and Paradenya explains low or negative correlation coefficients between some pairs of metals. The correlation coefficient for Zn and Fe at the KCC site could be attributed to hot-dip galvanizing activities. Further, a value of 0.45 for Cu and Fe at the UoP site could be attributed to brass industry which is prevalent in close proximity to Peradeniya.

4.6 Correlation Among Metal Elements in KCC Site

Table 2 Correlation coefficient values of metallic elements at KCC site

	Al	Zn	Fe	Mn	Cr
Al					
Zn	**0.43**				
Fe	0.08	0.22			
Mn	**0.47**	**0.60**	**0.36**		
Cr	0.11	**0.58**	− 0.08	0.03	
Cu	0.20	**0.29**	− 0.14	0.22	**0.51**

$p < 0.050$ are in bold; those are statistically significant

4.7 Correlation Among Metal Elements in Polgolla Site

Table 3 Correlation coefficient values of metallic elements at Polgolla site

	Al	Zn	Fe	Mn	Cr
Al					
Zn	**0.16**				
Fe	**0.44**	− 0.26			
Mn	**0.32**	0.03	0.23		
Cr	**0.43**	**0.38**	0.03	**0.43**	
Cu	0.17	**0.48**	− 0.15	**0.43**	**0.53**

$p < 0.050$ are in bold; those are statistically significant

4.8 Correlation Among Metal Elements in Peradeniya Site

Table 4 Correlation coefficient values of metallic elements at UoP site

	Al	Zn	Fe	Mn	Cr
Al					
Zn	**−0.15**				
Fe	−0.17	0.19			
Mn	**0.39**	0.10	**0.19**		
Cr	0.24	**−0.04**	**−0.10**	−0.00	
Cu	**0.56**	0.05	0.45	0.42	**0.16**

$p < 0.050$ are in bold; those are statistically significant

4.9 Principal Component Analysis

Principal component analysis (PCA) is a multivariate statistical analysis method which derives linear combinations of multiple quantitative variables. It describes the largest percentage of variations among such variables. It develops artificial variables, called “principal components” and can be categorized as PC1, PC2, PC3 and so on. It is a dimension reduction tool that causes reduction of large set of variables to a small set which still contains most of the information in the large set. In this study, the principal component analysis was applied to the set of data of each metal in bulk deposition samples collected. It can also be used to identify reliable influence of the anthropogenic and natural sources of ions and metals in the area of study (Migliavacca et al. 2009).

4.10 PCA for Metal Elements at KCC Site

After applying the PCA for metallic elements, three principal components were related to eigenvalues greater than one. Table 5 shows the results of PCA for data obtained from bulk precipitation of the KCC site. This explains 79.5% of total variance with 3 PCs whose eigenvalues are > 1. The PC1 explains 40.6% of the total variance with higher loading of Al, Mn, and Zn. Further, higher loading of Al indicates that the contribution of natural sources, such as soil, of the study area. PC2 explains 24.4% of the total variance. It shows higher loading of Fe and Mn. On the other hand, PC3 explains 14.5% of total variance which shows the highest loading of Fe. Al and Fe mainly originated from natural sources as those metals are the major components of aluminosilicate based from earth’s crust.

Table 5 PCA analysis of metal elements for bulk precipitation at KCC site

Variable	PC1	PC2	PC3
Al	*0.401*	0.193	−0.665
Zn	*0.559*	0.008	0.208
Fe	0.169	*0.571*	*0.594*
Mn	*0.466*	*0.401*	−0.149
Cr	0.388	−0.515	0.381
Cu	0.361	−0.459	−0.090

PCs® > 0.400 are in italic as they are considered significant

4.11 PCA for Metal Elements in Polgolla Site

When applying PCA for samples of the Polgolla site (Table 6), the first factor (PC1) has shown higher loading of Al, Cu, and Mn with 33.0% of the total variation in relation to the raw data. Higher loading of Al indicates the contribution of natural sources of the study area. The second factor (PC2), with 23.0% of the total variance, is shown by Fe. Then, 15.6% of the total variance is shown by a third factor (PC3) for the higher loading of Cr and Zn. Overall, the results of the principal component analysis for samples of bulk precipitation at Polgolla explains 71.6% of the total variance of the data (Table 6).

4.12 PCA for Metal Elements at UoP Site

The results of the principal component analysis for samples of bulk precipitation in Peradeniya site explain 78% of the total variance of the data (Table 7).

Table 6 PCA analysis of metal elements for bulk precipitation at Polgolla site

Variable	PC1	PC2	PC3
Al	*0.597*	−0.202	−0.102
Zn	−0.024	0.546	*0.555*
Fe	−0.025	*0.644*	0.030
Mn	*0.481*	0.368	−0.241
Cr	0.251	−0.321	*0.789*
Cu	*0.589*	0.091	−0.013

PCs® > 0.400 are in italic as they are considered significant

Table 7 PCA analysis of metal elements for bulk precipitation at UoP site

Variable	PC1	PC2	PC3
Al	0.395	− 0.468	− 0.109
Zn	*0.564*	− 0.015	0.037
Fe	− 0.030	− 0.309	*0.928*
Mn	*0.453*	− 0.455	− 0.164
Cr	*0.412*	*0.536*	0.313
Cu	0.389	*0.436*	− 0.013

PCs® > 0.400 are in italic as they are considered significant

The PC1 has shown higher loading of Cr, Mn, and Zn with 39.7% of the total variation. Major sources of Zn include roofing materials, lubricants, and metal plating. Furthermore, Mn is released due to mining operations, welding works, fuel additions, and corrosion of ferromanganese productions. PC2 has 21.9% of the total variance for Cr and Cu which could be anthropogenic sources of laboratory activities in the university. On the other hand, Cr is naturally available in soil, rocks, and plants. Furthermore, Cr is used in toners of photocopying machines. Therefore, presence of Cr is due to both natural and anthropogenic activities. Then, 16.4% of the total variance was shown by a third factor (PC3) for the higher loading of Fe, which mainly originated from natural sources as it is a major component of the earth's crust. Furthermore, Fe is released from soil dust, mining operations, and corrosions of metallic commodities.

5 Conclusion

Analysis of bulk depositions collected at the three sites, namely the Kandy City Central (KCC) site, Polgolla site, and the University of Peradeniya (UoP) site, over a period of approximately 1 year from March 2018 to March 2019 indicates that the contents of trace metals, namely Al, Cr, Cu, Fe, Mn, and Zn, of the first site, in general, are higher than those of the other two sites. Biomass burning, corrosion of metallic objects, vehicle-related operations, and crematory operations would be responsible for the deterioration of the air quality of the Kandy metropolitan area in addition to natural sources. The Polgolla and the UoP sites being in suburban areas having a vegetation cover to some extent have less sources of trace metal pollution. Nevertheless, Al, Fe, and Zn are determined to be the dominant metal elements at all the three sites. Mining and processing of ores, the production of alloys and metallic compounds, re-suspended by vehicular traffic, fossil fuel combustion, brake pads, lubricant oil, roofing materials, corrosion of commodities, roofing materials, and vehicle service centers, are the major sources for metal elements at all the three sites. As unleaded gasoline is used in the country, small amounts of Pb were determined only in a few samples. Pearson correlation coefficient values of metals in bulk precipitation at all the sites show a significant correlation among many variables. According to the principal component analysis (PCA) of trace metallic elements, Al, Cu, and Mn were the high-loading metals at the Polgolla site, and Cr, Zn, and Mn were the high-loading metals at the UoP site, while Al, Mn, and Zn were the high-loading metals at the KCC site. Considering the distribution of trace metals in the air at the sampling sites, it is recommended that remedial measures be taken to improve the air quality of the Kandy metropolitan area. Furthermore, it is proposed that mitigation strategies, such as easing of vehicular traffic, providing by-pass roads, and improving the quality of fuel and condition of vehicles be necessary to reduce air pollution levels, mainly with respect to Al, Cr, Cu, Fe, Mn, and Zn. Use of an efficient public transport system is a viable solution to reduce traffic congestion. Furthermore, continuous monitoring of air quality in Kandy is very important as it has been identified as a world heritage city.

Funding The authors thank the National Research Council of Sri Lanka for providing instrumentation facilities through Grant No. NRC/11/127.

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