Major ions and Nutrients loading by atmospheric wet deposition in Mbeya Urban, Tanzania

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Abstract

This study aimed to investigate the contributions of the atmospheric wet depositions to the major ions and nutrient loading in the surface water of Mbeya urban. A total of 22 rainwater samples were collected from six different sampling stations (MUST, Mbalizi, Kabwe, Rufaa, Uyole, and Kalobe) using the rain collector buckets installed 2 meters above the ground from December (18.12.2021) to February (06.02.2022). All the rainwater samples were analyzed for the major ions (Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-, CO_3^{2-}, and SO_4^{2-}) and nutrients (NH_4^+, PO_4^{3-}, and NO_3^-), pH, and temperature. The pH of the rainwater was found to range from 6.8 to 9.3, indicating that in the region there are emissions of alkaline dust into the atmosphere. The temperature was found to range from 17°C to 22°C, with a mean temperature of 19.77°C. The dominance of the major cations and anions was found in the order of $Mg^{2+} > Ca^{2+} > Na^+ > K^+$ and $HCO_3^- > Cl^- > SO_4^{2-} > CO_3^{2-}$ ions respectively, and the nutrient dominance sequence followed the order of $NH_4^+ > SO_4^{2-} > NO_3^- > PO_4^{3-}$. Some parameters showed decreasing trends from one rain event to another, and some showed non−uniformity of the trend among the rain events. The non−uniformity of the trend of the parameters was associated with the point source pollution in the specific sampling stations and the non−uniformity of the rain in the region. Despite the non−uniformity of the trend of the parameters, the results have shown the contributions of the atmospheric wet depositions to the major ions and nutrient loading on the surface. In this regard, to get a clear and representative picture of the pollution status of the Mbeya urban area, major ions and nutrients loaded onto the surface of both wet and dry atmospheric depositions need to be analyzed.

1. Introduction

Atmospheric deposition is the main mechanism for removing organic carbon (OC) pollutants/particulate matter and dissolved inorganic and organic gases from the atmosphere, influencing both atmospheric and landscape processes(Iavorivska et al., 2016; Migliavacca et al., 2005). The major sources of pollution inputs into the atmosphere are urbanization and anthropogenic activities. Particulate matter (PM) is one of the most significant pollutant carriers in the atmosphere, emitted by anthropogenic sources such as coal combustion, biomass combustion, mining activities, agricultural operations, industrial activities, traffic, bush fires, traditional charcoal production (particularly in Africa), and resuspension processes from urban surfaces (Francova et al., 2017; Fakinle et al., 2020; Lacaux et al., 1994; Merico et al., 2020; Zhou et al., 2019). The PM in the atmosphere combines with water droplets to form clouds, which then fall to the earth's surface as rain. The chemical compositions of atmospheric wet depositions are influenced by the nature and composition of the PM (Al−Khashman, 2005; Li et al., 2007; Tripathee et al., 2014).

Atmospheric deposition is an important factor in determining pollutant levels and understanding anthropogenic contributions to atmospheric pollution. Changes in the chemical composition of atmospheric deposition are an important indicator of pollution emissions and reflect the atmospheric quality of a specific region indirectly (Calvo et al., 2010). It can also provide data on the regional and long-term transport of anthropogenic pollutants, as well as their impact on ecosystems through deposition processes (Li et al., 2007; Mphepya et al., 2004).

Numerous studies on precipitation chemistry from around the world have found that atmospheric wet depositions have a significant impact on solute loading in surface water. The chemistry of closed alkaline lakes and rivers is influenced by atmospheric precipitation. (Yechieli & Wood, 2002). Atmospheric inputs are significant sources of trace metals, dissolved Fe, and Co in surface seawater (Desboeufs et al., 2022). The Carbon and nutrient inputs into soil and surface water are aided by atmospheric deposition (Mladenov et al., 2012; Qiao et al., 2015). Likewise, atmospheric wet deposition has been identified as a source of global acid deposition on the earth's surface (Charola & Ware, 2002; Whelpdale et al., 1997). Furthermore, atmospheric precipitation contributes significantly to the major ion flux into surface water (Al−Khashman, 2005; Kyoung Lee et al., 2000; Williams & Melack, 1991; Zhou et al., 2019).

In recent years, atmospheric chemists, particularly in Tanzania, have focused on studying the contributions of anthropogenic activities and atmospheric deposition to nutrient and ionic loading in surface water, and as a result, some atmospheric chemistry studies have been published. (Gao et al., 2018; Mkoma et al., 2009; Mmari et al., 2013; Tamatamah et al., 2005; Vuai et al., 2013). The findings from these studies revealed that atmospheric wet deposition has a significant influence on nutrient and organic and inorganic solute inputs in surface water. All of these studies were carried out in coastal areas, particularly Dar es Salaam, Mwanza, and Kigoma, which are not representative of the country as a whole. The studies on the contributions of atmospheric wet deposition to major ion and nutrient loading in Tanzanian southern highland urban areas have been rarely reported in the literature. Mbeya

region is one of Tanzania's fastest-growing cities, with residents relying on agriculture, industry, trade, transportation, mining, and construction. All of these socioeconomic operations emit pollutants into the atmosphere, contaminating surface water when it falls as rain. This study aims to determine the major ions and nutrient composition of precipitation in Mbeya urban, investigate variations in the chemical composition of rainwater samples, and provide an update on the region's atmospheric pollution levels. The hypothesis is that there is a decrease in nutrients and major ions concentration from one rain event to another.

2. Materials And Methods

2.1 Description of the study area

Mbeya Urban is located within latitude 8°54'33.84"S and longitude 33°27'38.79"E in the southern highlands of Tanzania in the Mbeya Region. It's bordered by Mbeya Rural District to the north; Rungwe District to the east; Ileje District to the south; and Mbozi District to the west. The Mbeya urban area experiences temperatures averaging between 16°C in the highlands and 25°C in the lowlands, and the mean annual precipitation of 924mm (Majule, 2017). In the study area, the rainy season begins in November and ends in May, followed by a dry and windy season from June to October. The area of the study also encompasses a diversified range of anthropogenic sources, amongst which are vehicles (diesel-powered or gasoline-powered), agricultural activities, industrial activities, commercial activities, and a population of approximately 700,000 inhabitants. The emissions from various industrial typologies in the city, on the other hand, contribute to the total amount of pollutants emitted in the area. The sampling stations were selected based on a variety of criteria, including proximity to vehicular, population, and other anthropogenic sources. The locations of the sampling sites were shown in Fig. 1. All of the sampling points were in an urban area where various anthropogenic activities were taking place.

2.2 Precipitation sample collection

Precipitation samples were collected from six different sampling stations in Mbeya urban as shown in Fig. 1. The samples were collected during the beginning of the rain season from December (18.12.2021) to February (06.02.2022) by varying the intervals depending on the rain event to monitor the precipitation compositions as tabulated in Table 1. The rain collectors were positioned and installed 2 meters above the ground to avoid contamination with surface water during rain, and when rain was forecasted the rain collectors were installed as shown in Fig. 2. Immediately after sampling on the sampling sites, temperature and pH were measured. The collected samples were placed in a thoroughly cleaned plastic bottle and stored in the refrigerator before being taken to the laboratory for the chemical analysis of nutrients and major ions. The stored samples were sent to the Iringa water chemistry laboratory for chemical analysis in an ice−cold box.

2.3 *Sample analysis*

In the field conditions after rainwater collection, pH and temperature were immediately measured. The pH measurement was made using a pH meter and the temperature was measured using a thermometer. Major cations (Na^+ and K^+) were determined by the flame photometric method, while (Ca^{2+} and Mg^{2+}) were determined by the titrimetric method. The major anion (Cl^-) was determined by argentometric titration with silver nitrate using a potassium dichromate indicator. SO_4^{2-} was determined by the SulFaVer4 method using DR890, while the concentration of HCO_3^- and CO_3^{2-} was determined by calculation using pH and alkalinity of the rainwater sample. The concentration of the NO_3^- was determined by the cadmium reduction method using DR 890. The concentration of the NH_4^+ was determined by the Nessler method (DR1900) and the concentration of the PO_4^{2-} was determined by the Ascorbic acid method (DR 890).

3. Results And Discussion

3.1 *Precipitation pH and Temperature*

The precipitation pH, temperature, major ions, and nutrient chemical compositions of the atmospheric wet depositions in Mbeya urban were summarized in Table 1. The pH of the precipitation collected was found to range from 6.8 to 9.3 with the slightly acidic precipitation at the Kabwe location, as seen in Table 1. This slightly acidic condition is thought to be caused by the point−source

pollution from the rice mills' industrial emissions of various gases. In other sampling sites, the pH is high, indicating low emissions of acidic gases and high concentrations of alkaline dust (Galloway et al., 1989; Morales et al., 1995) from these areas. The general trends indicate that there is an increase in pH from Rf1 to Rf4. This increase in pH is thought to be caused by an abnormally high concentration of alkaline dust, which is quickly washed away by the first and subsequent rain events, and this increasing trend in pH agrees with our hypotheses. The temperature of the collected rain was found to range from 17°C to 22°C, with a mean temperature of 19.77°C. The temperature of the sampled rain indicated an almost similar constant trend in all rain events and the mean is within the Mbeya region's annual temperature range of 16°C in the highlands and 25°C in the lowlands (Majule, 2017).

Table 1
The major ion and nutrient composition of the atmospheric precipitation (Concentrations are in mg/l).

Site	Rain	pH	T(°C)	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	HCO_3^-	CO_3^{2-}	NH_4^+	NO_3^-	PO_4^{3-}
MUST	Rf1	9	19	2.08	0.97	0.80	1.58	1.12	2	7.67	0.00067	1.84	1.9	1.05
	Rf2	9.2	18	0.9	0.4	0.34	1.03	0.93	1	3.84	0.00011	0.60	0.4	0.73
	Rf3	9.3	19	1.01	0.43	0.55	0.75	0.56	1	3.64	0.00030	0.54	0.9	0.23
	Rf4	9.4	20	0.51	0.18	0.34	0.48	0.7	0	2.63	0.00013	0.26	0.3	0.18
Kabwe	Rf1	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
	Rf2	6.8	21	2.64	0.98	1.89	1.81	1.12	3	9.29	0.00045	0.49	1.98	0.16
	Rf3	7.3	20	1.46	0.85	0.42	0.81	2.23	1	5.05	0.00024	0.91	0.7	0.27
	Rf4	8	20	0.96	0.47	0.29	0.86	0.74	1	3.43	0.00019	0.55	0.6	2.38
Uyole	Rf1	8	24	0.79	0.21	0.29	0.40	1.3	0	2.42	0.00011	0.33	0.6	0.08
	Rf2	8.4	20	1.31	0.24	0.00	0.07	1.49	1	2.83	0.00008	0.29	0.9	0.13
	Rf3	8.7	22	1.11	0.19	0.00	0.09	1.12	0	3.23	0.00009	0.50	0.3	0.8
	Rf4	8.9	21	1	0.14	0.00	0.14	1.12	1	1.41	0.00004	0.37	0.8	0.01
Rufaa	Rf1	8.7	19	1.68	0.46	1.68	1.59	0.37	1	8.08	0.00044	0.58	0.7	0.05
	Rf2	8.9	19	0.16	0.14	0.29	0.40	0.56	0	2.02	0.00005	0.19	0.5	0.09
	Rf3	9.2	20	0.84	0.24	2.77	1.96	0.74	0	8.89	0.00042	0.37	1.6	0.07
	Rf4	9.3	19	0.98	0.24	1.30	0.87	0.93	1	5.45	0.00039	0.56	1.2	0.13
Mbalizi	Rf1	8.2	19	1.58	0.54	0.42	0.71	0.93	1	4.44	0.00017	0.64	0.6	0.01
	Rf2	8.4	20	0.98	0.47	0.88	0.82	0.93	1	4.44	0.00038	0.46	0.6	0.16
	Rf3	8.7	20	1.86	0.65	1.18	1.00	0.93	0	7.07	0.00054	1.01	0.7	0.38
	Rf4	9.1	21	0.37	0.26	0.59	0.62	0.93	1	4.44	0.00030	0.49	0.5	0.06
Kalobe	Rf1	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
	Rf2	8.7	19	4.21	1.48	0.97	1.00	0.37	1	12.72	0.00151	1.51	1	0.1
	Rf3	8.9	17	1.54	0.31	0.42	0.37	1.12	1	2.83	0.00013	0.67	0.7	0.02
	Rf4	9.2	18	1.03	0.49	1.13	1.01	1.3	1	16.76	0.00559	3.01	1.9	0.23

Note. Rf1–Rf4 is the rain samples collected at different date intervals

Rf1(18.12.2021), Rf2(01.01.2022), Rf3(17.01.2022), Rf4(06.02.2022)

3.2 *Nutrients concentrations*

The nutrients and chemical compositions measured in each rain sample were used to construct the box plots as shown in Fig. 4. As is typical for rainwater, all the nutrients showed a wide variation from one rain sample to another. The distributions and

contributions of the atmospheric wet depositions to the nutrient loading on the surface are examined by the median and mean value of each nutrient. The distributions of atmospheric precipitation to NH_4^+ loading in surface water were shown in Fig. 4(a). The results indicated that the NH_4^+ concentrations are different for each of the collected rain events, with a slightly decreasing trend between Rf1 and Rf2, which agrees with our expectation that for each rain event, there is washing out of the atmosphere that causes the decrease in concentrations. From Rf3 to Rf4, there is a slightly increasing trend of NH_4^+, which is contrary different to the expected decreasing trends. This increasing trend of NH_4^+ is thought to be contributed by point source pollution, especially in the Kalobe sampling site as seen in Table 1 Rf4. The higher NH_4^+ emissions for Rf4 might be due to the emissions of NH_3 gas caused by bacterial decomposition of urea in animal excreta (Schlesinger & Hartley, 1992) from the Kalobe wastewater treatment plant. We thought there might be a higher rate of decomposition of the waste discharged from the brewery industry and other sources in wastewater treatment plants, which could be the reason for this increasing trend of NH_4^+ in Rf4.

The concentrations of the phosphate ion loaded by the atmospheric precipitation into the water surface are presented in Fig. 4(b). The results indicated the different distributions of the PO_4^{3-} nutrient among the rainwater sample collected. The decreasing trend is seen between Rf1 and Rf2 while the increasing trend of the concentrations is observed from Rf3 to Rf4. This slight increasing trend is thought to be influenced by the non−uniformity of the rain since from Rf2 to Rf3 the rain stopped for a while which could result in the resuspension of the particulate matter to the atmosphere. The significantly higher concentrations of the PO_4^{3-} in Rf4 can be also caused by the point source pollution of anthropogenic origin(Singh et al., 2007) especially in the Kabwe sampling site (Rf4) as seen in Table 1. We thought the rice mills industry and high traffic in the Kabwe sampling site contributed to these higher concentrations of PO_4^{3-} in Rf4.

The nitrate and sulfate concentrations and distributions of the collected atmospheric precipitation in Mbeya urban were presented in Figs. 4 (c) and (d) respectively and tabulated in Table 1. The results indicated in most of the samples the nitrate concentrations were lower than 2 mg/l with a slight decrease in the trend of NO_3^- among Rf1, Rf2, and Rf3. The Rf4 showed a little rise in the trend of the NO_3^-, which can be explained by the point source of anthropogenic origin. The results indicated that the distributions were different among the different rain events. Rf1 and Rf2 showed almost similar mean values, while in Rf3 the mean value of SO_4^{2-} was lower compared to the rest of the rain sample. The main sources of NO_3^- and SO_4^{2-} in the region can be associated with the anthropogenic applications of artificial fertilizer in the agricultural fields of the region.

3.3 *Major ion concentrations*

The major ion compositions of the atmospheric precipitation samples of the Mbeya Urban were tabulated in Table 1, and the average chemical compositions of cations and anions of the collected rain (Rf1, Rf2, Rf3, and Rf4) were plotted on the Schoeller diagram (Fig. 7). The Schoeller plot showed the same pattern of the major ions for all collected rainwater samples, where HCO_3^- ions loaded on the surface were higher than any other ions. The average bicarbonate ion concentrations in all rain samples (Rf1, Rf2, and Rf3) were almost similar except for the Rf3, which was slightly lower. Figure 5 shows that HCO_3^- ion account for about 67% of the total anions in rainwater. This higher dominance of HCO_3^- could be associated with the presence of alkaline dust particles in the atmosphere (Al−Khashman, 2005). The Cl^- was the second dominant anion from HCO_3^- and the mean concentrations were almost similar in all rain events, except Rf3, which has shown a slightly higher concentration. This slightly higher concentration of Cl^- observed in Rf3 is thought to be influenced by point−source pollution of anthropogenic origin in the region during the non−uniformity of the rain experienced from Rf2 to Rf3, which added the Cl^- content in the atmosphere. The SO_4^{2-} was the least dominant in the anion's dominance sequence. Figure 3 indicates that the concentrations during the rain event follow the following order: RF2 > Rf1 > Rf4 > Rf3. This irregularity in the concentration trend of SO_4^{2-} in the rain events is thought to be caused by the point source pollution in the region. The average mean of the anions in the rainwater of the region followed the dominance sequence order $HCO_3^- > Cl^- > SO_4^{2-}$ as shown in Fig. 5.

The Mg^{2+} was the most dominant cation (Fig. 6) among the analyzed cations where the concentrations of the Rf1 were higher than Rf4 while similar concentrations were seen for Rf2 and Rf3 as seen in Fig. 7. The Ca^{2+} was second in the cation's dominance sequence (Fig. 6) where the concentrations of all the rainwater were closely similar as seen in Fig. 7. The Na^+ was the third

dominant cation (Fig. 6) dissolved in rainwater over the other cations analyzed and followed the order of Rf2 > Rf1 > Rf3 > Rf4. The decreasing trend was seen between Rf3 and Rf3(Fig. 7), which seems to be similar to our hypothesis. The concentrations of the K^+ ions (Fig. 6 and Fig. 7) were lower among all other cations, whereby the concentrations of each rain event were almost similar to all rain events. In general, the region where rainwater samples were collected followed the cation dominance sequence order of Mg^{2+} > Ca^{2+} > Na^+ > K^+.

Conclusions

The atmospheric wet depositions samples collected in Mbeya Urban located in the southern highland of Tanzania were analyzed for the major ions and nutrients for the period of December 2021 to February 2022. This was the first study in the regions aimed to investigate the contributions of the atmospheric wet depositions to the surface and to evaluate the trend of the atmospheric washout of the major ions and nutrient compositions in the atmosphere. The results showed that the precipitations collected were slightly acidic during the first rain event of some sampling stations caused by some point source emission of the acidic gases while in the consecutive rain event the water samples were basic with a pH above 8 this revealed the influence of the precipitation the cleaning of different atmospheric acidic gases. The results also showed that the HCO_3^- was most of the dominant ions in all of the rain events which indicated the presence of the alkaline dust in the region originated from natural sources. Other ions have shown a decreasing trend from one rain event to another although in some cases the trend is not uniform which revealed the presence of continuous point source emissions of the major ions. The cations and anions dominance sequence in the rainwater followed the order Mg^{2+} > Ca^{2+} > Na^+ > K^+ and HCO_3^- > Cl^- > SO_4^{2-} > CO_3^{2-} ions respectively. The nutrients in the precipitation followed the order NH_4^+ > NO_3^- > PO_4^{3-}, the dominance of NO_3^- and NH_4^+ in the rainwater originated from the anthropogenic sources from specific point source pollution. The non−uniformity of the trend of the nutrients from one rain event to another was due to the point source emission and non−uniformity of the rain which resulted in the resuspensions of the dust particles to the atmosphere. To better understand the pollution status of the region, the intensive study of the chemical compositions for both wet and dry depositions is of great need.

Declarations

Ethical approval and consent to participate

Not applicable

Consent for publication

All authors have agreed to submit this manuscript for publication and we confirm that the order of the authors listed in the manuscript has been agreed upon by all of us.

Availability of data and materials

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of interest

The authors declare no conflicts of interest.

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Author Contributions

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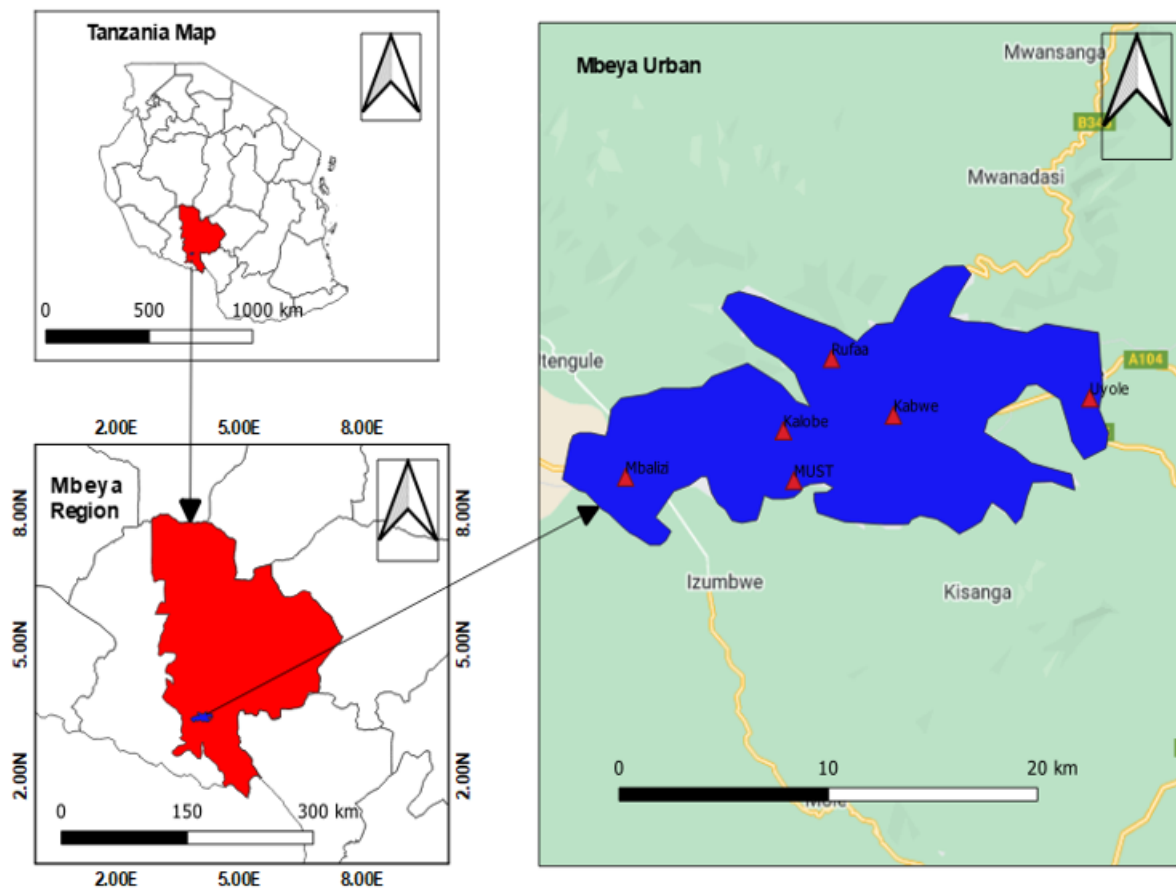
Figures

Figure 1

The site locations for this study

Figure 2

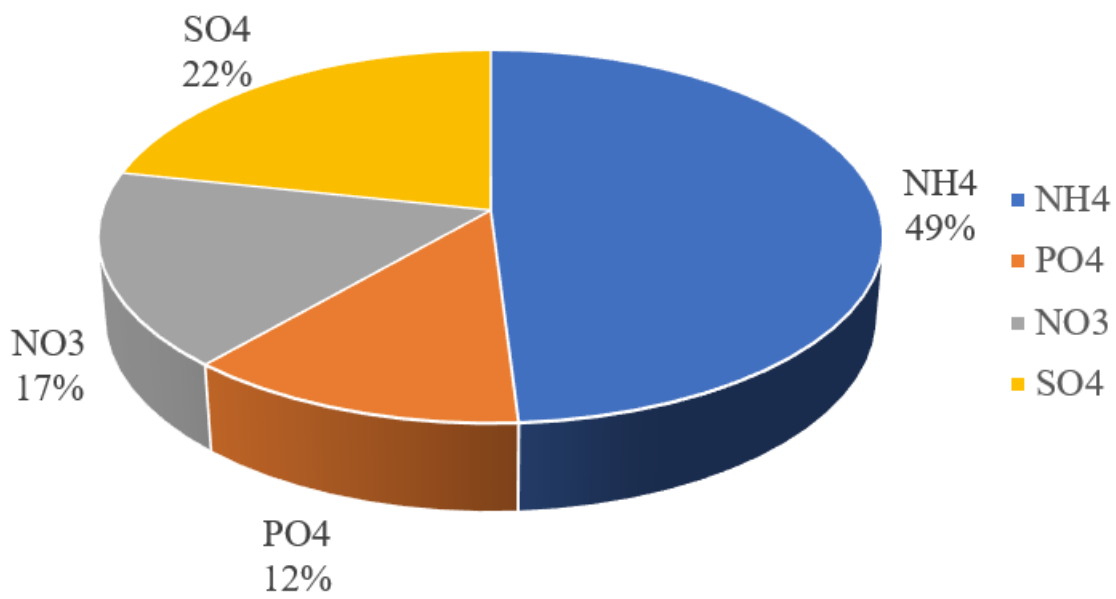The installed rain collector

Figure 3

The average nutrients loading by atmospheric wet depositions to Mbeya urban surface
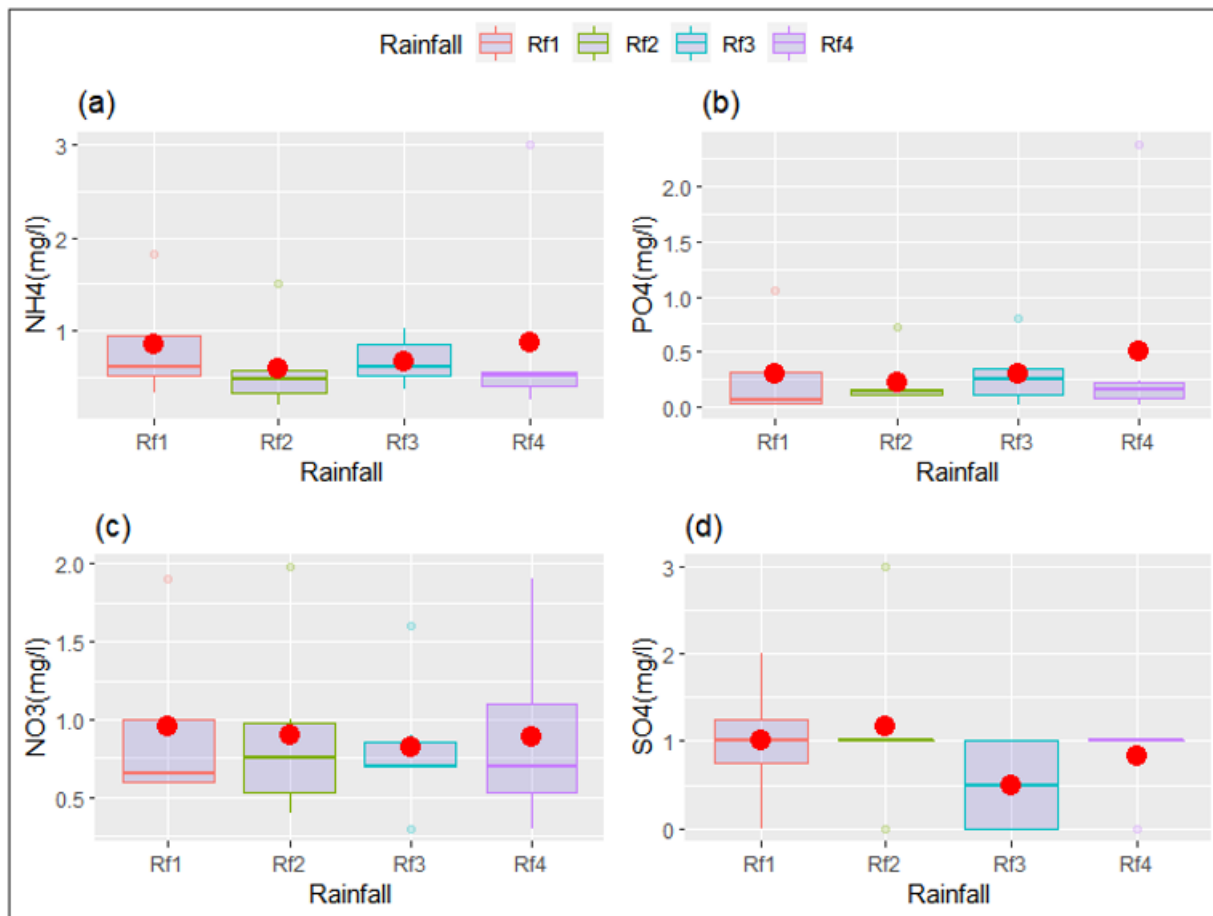
Figure 4

Box plots for the average nutrients and chemical compositions of the rainwater samples, for the period between December (18.12.2021) to February (06.02.2022) in Mbeya urban. The red dot (in the box) is the arithmetic mean.
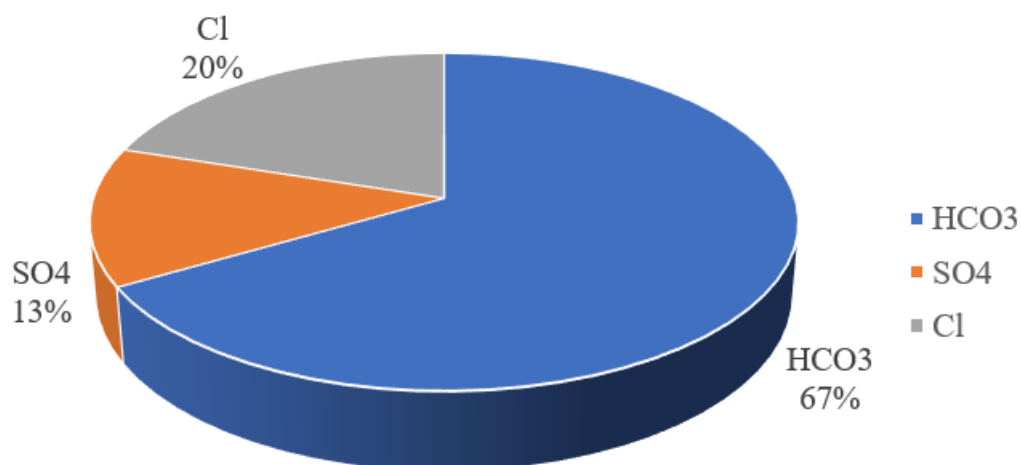

Figure 5

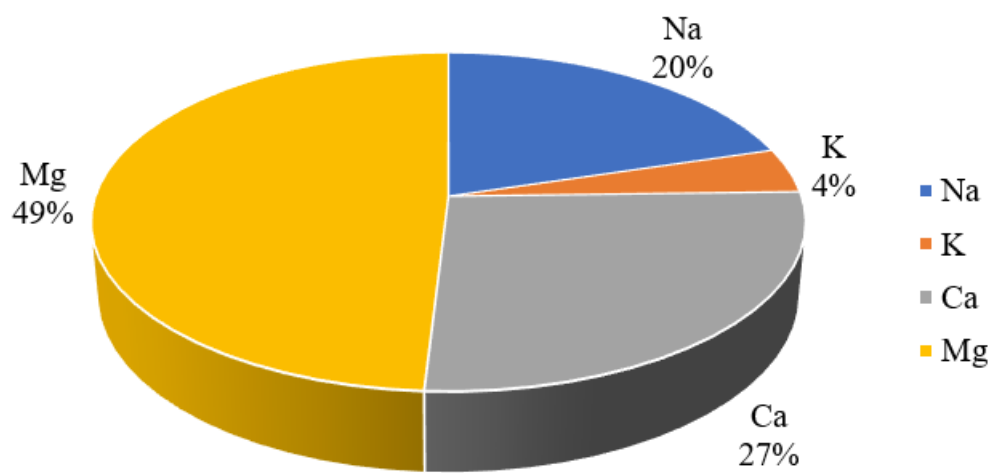The average major anions loading to the Mbeya urban surface by atmospheric wet depositions

Figure 6

The average major cation loading to the Mbeya urban surface by atmospheric wet depositions
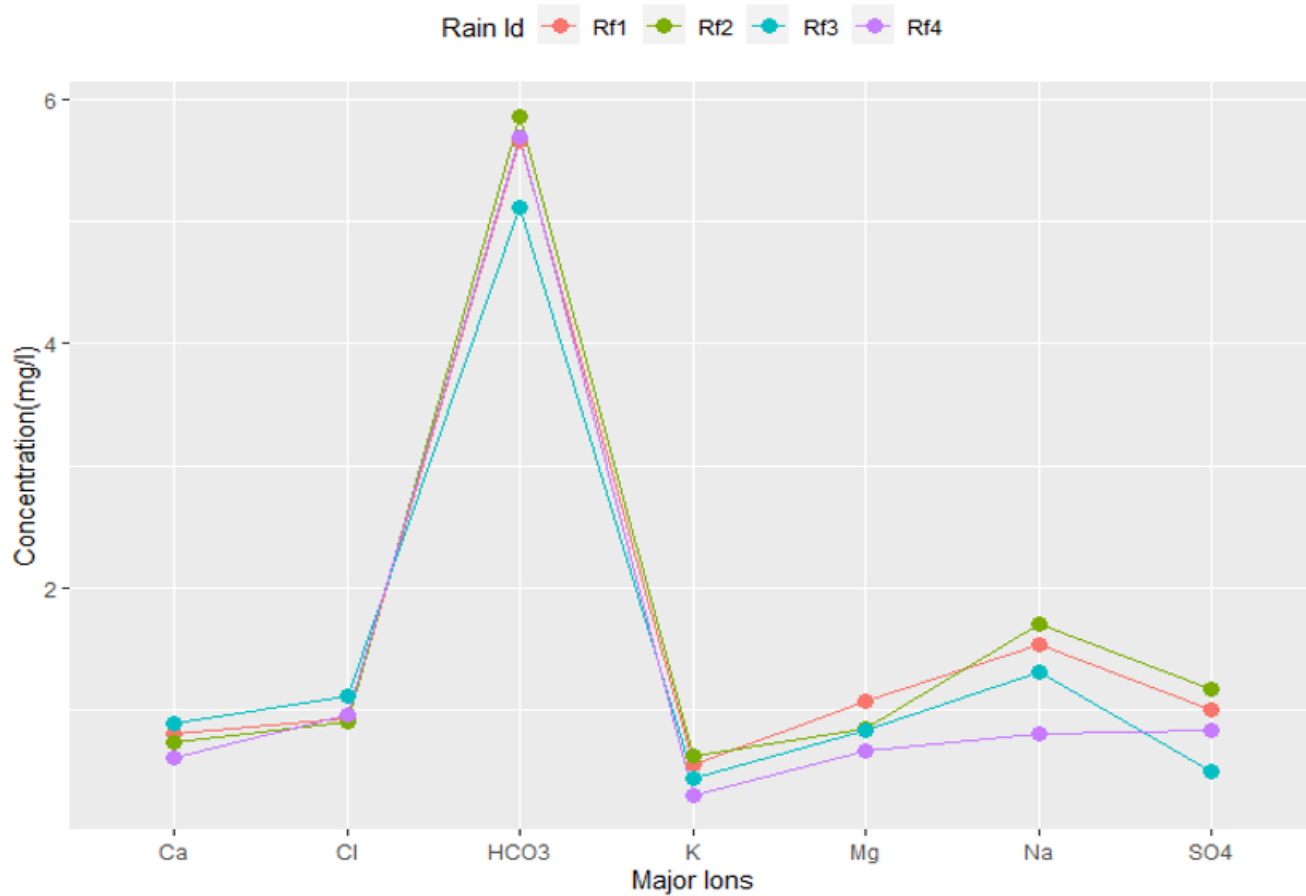

Figure 7

Scholler diagram for the major ion's chemistry of the atmospheric precipitation samples (concentrations are in mg/l) in the Mbeya Urban.