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Full Length Research Paper

Aluminum, Silicon and Nutrients Characteristics in Precipitation of Semi-Arid Area in Dodoma Municipality, Tanzania

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Abstract

Dodoma region is a semi arid area experiencing long dry season accompanied with very strong wind. This condition results into suspension of particles in the atmosphere originating from the blown soil dust which may transport nutrients and other metals and causing negative consequences to the ecosystem. Contribution of this phenomenon to the atmospheric aluminum, silicon and nutrients is not well understood. The study was conducted to assess atmospheric deposition of aluminum, silicon and nutrients in Dodoma Municipality. The samples of rain water were collected in event basis from three different areas reflecting a combination of natural and anthropogenic activities and analyzed for aluminum, silicon, ammonium, nitrate and phosphate. The results show that there is strong variation in rainfall intensity within Dodoma Municipality caused by niches of micro meteorological factors. The concentration of nutrients showed that NO_3^->NH_4^+>PO_4^{3-} with volume weighted mean concentrations 500, 210 and 160μgL^{-1}, respectively. Nutrients deposition in Dodoma Municipality show clear spatial variation due to nature and intensity of anthropogenic activities. It was also found that annual deposition flux of the nitrogen based nutrient is low compared to the other reported area with similar rainfall intensity reflecting less industrial activities and relatively low population density. However phosphorous deposition is relatively high due to burning of biomass during land preparation and dissolution from soil particles. Silicon and aluminum in the precipitation around Dodoma Municipality was significantly high showing clear spatial variation as results of variation of rainwater pH. It was concluded that strong wind during dry condition disperse nutrients and bring soil dust which results into high concentrations of aluminum and silicon and low concentrations of nitrogen in the wet precipitation.

Keywords: Silicon; Aluminum; Nutrient; Semi Arid; Precipitation.

INTRODUCTION

Rainfall is an important supplementary source of water for domestic and agricultural uses especial in semi-arid and arid areas (Moges et al., 2011; Sazakli et al., 2007). However its quality is affected by natural and anthropogenic activities which may have negative consequences to the human health and environment. Atmospheric deposition is a very important transport process for gases and particles from the atmosphere to the terrestrial and aquatic surfaces. This process is a part of biogeochemical cycling of various chemicals in the earth system. While emitted to the atmosphere from various natural and anthropogenic sources, gases and particles are transported with air masses and undergo dry and wet deposition from the air to water and land. The deposition of dust and water-soluble chemical species is directly connected to changes in the dust concentrations in the atmosphere, where they affect the earth's radiation budget (Tegen et al., 1996) as well as contributing to acidification and eutrophication of ecosystems in terrestrial and ocean regions (Sehmel, 1980; Wesley and Hicks, 2000). Many monitoring programs have been applied to study wet deposition of sulfur, nitrogen, metals and organic compounds in relation to micro or macro meteorology, regional emission sources and other parameters (Lovett et al., 1984). The study of the regional sources impact (natural

or anthropogenic) in relation with the micrometeorology may give information about the scavenging mechanisms taking place for the ambient particles and gases. Sazakli et al., (2007) reported that rain water quality depending on the atmospheric pollution of the individual area and the proximity to pollution sources. This signifies importance for further study depending on the local environmental conditions.

Dodoma region is located in the semi-arid climate that experience unimodal rainfall pattern. The rainfall is highly affected by niches of micro-climate which lead to unpredicted rain event with a strong spatial and temporal variation. The dry climate of April to November results into drying of vegetation and the land become beard. The season is also accompanied with very strong wind with maximum up 8.7m/s (TMA, 2013). This condition results into suspension of dust particle in the atmosphere. In addition to that land preparation which involves burning of vegetation is being done in November and October prior to rainfall seasons which may affect precipitation chemical characteristics.

Dodoma municipality is the capital city of Tanzania. However it was dormant for quite long. Recently it has been growing very fast due to influx of many high learning institutions. For example university of Dodoma only hosts about 20,000 students. This increase in population goes hand in hand with increase in anthropogenic activities including fuel combustion and waste production. These complex natural and anthropogenic factors may affect precipitation characteristics and quality in this area. This study aims to investigate silicon, aluminum and nutrients characteristics in precipitation in Dodoma Municipality.

MATERIALS AND METHODS

Study Site

Dodoma Region lies at a latitude of 4^{o} to 7^{o} south of equator and longitude of $35^{o} – 37^{o}$ east. It is a region centrally positioned in Tanzania (Figure 1). Much of the area of the region is a plateau rising gradually from some 830m in Bahi Swamps to 2000m above sea level in the highlands north of Kondoa (Dodoma Regional commission office Report, 2009). The region has a total area of 41,311 square kilometres with municipality covering a 2,576km^{2} of which 625 square kilometers is urbanized. The population of Dodoma according to the census of 2002 was 1,735,000 and Dodoma Urban District population was 324,347, while in the census of 2012 indicates 2,083,588 of the region population and 410,956 Dodoma Urban District which shows the increase of 26% in the urban area compared to 20% of the whole region.

The characteristic vegetation of the region is of “bush” or thicket type, which is widespread throughout the area. Depressions and seasonally wet areas with impeded drainage support grasses and sometimes a mixture of grasses mixed with woody plants. Wherever the natural vegetation has been altered by agricultural activities, regenerating bushes mixed with annual herbs and grasses forming a type of induced vegetation. Most of the hill ranges, steep slopes and protected forest reserves are covered with large woody plants, which form good watershed protective covers.

The soil in Dodoma region is acidic and generally low in plant nutrients especially nitrogen and phosphorus (Hassan, 1984). The most common soils in the district can be described as thin stony soils on hill tops, with predominantly sand or sandy loams on the slopes varying from grey to red, with lighter color sands or dark clays on the bottom land depending upon whether the drainage is free or impeded. The dark clay soils (Mbuga soils) are found in the flood plains, and they are more fertile than those found on the slopes.

Lithostratigraphy of Archaean rock age of Dodoma region is covered by Dodoman super group aging 2.93-2.88 Ga years. It is mainly sedimentary origin and forms a band across the southern part of the craton. Its system comprises sericite and quartz schists, hornblende gneisses and granite gneisses, ferruginous banded quartzites, migmatites, granites, amphibolites and talc-chlorite and corundum-bearing rocks. There are also metamorphosed mafic and ultramafic rocks (Harpum, 1970).

Study design

The study was designed to collect samples from three different areas reflecting a combination of natural and anthropogenic activities. Two sites are located at the University of Dodoma campus; College of Education (COED) and College of Humanities and Social Sciences (CHSS). One site is located at city centre (Majengo Street). The sampling location was selected based on population density. For example College of Humanities and Social Sciences hosts about 7000 students while college of Education hosts about 5000 students. It is assumed that this big number of student is accompanied with activities which may increase concentration of chemical species in the atmosphere. On other hand, Majengo Street is located near the Majengo market where there are different human activities as well as incineration of urban waste water treatment sludge and urban waste. Moreover the area is close to the main roads of Dodoma and hence reflects the composition of chemical inputs associated to fuel combustion through vehicle emission.

Sample collection and preservation

Samples were collected on the event basis from December 2012 to April 2013 during rainfall at three

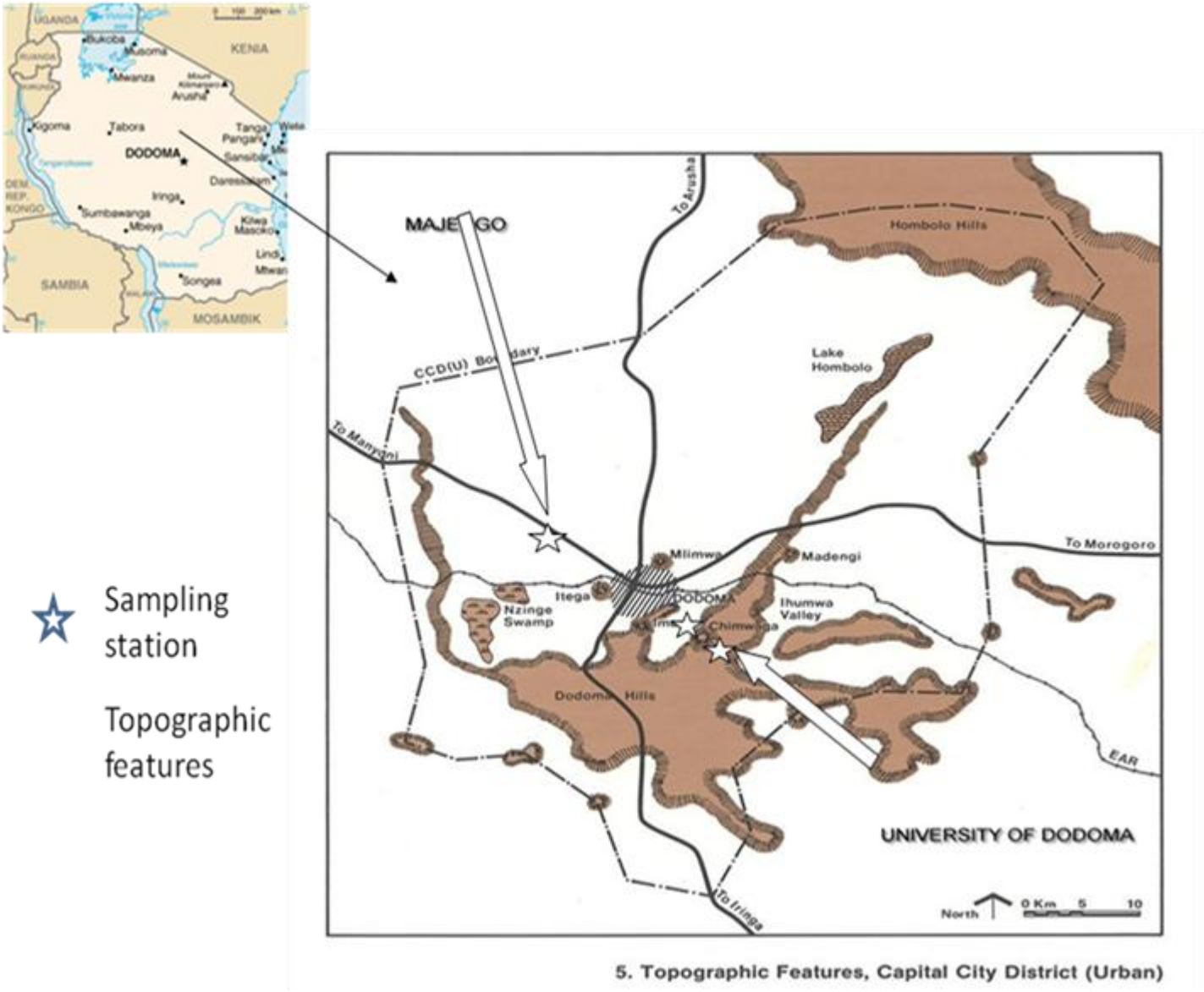

Figure 1. Map of Dodoma Municipality showing sampling area.

different sampling sites. The samples of wet deposition only were collected using ten liters poly-ethylene buckets with opening of about 25cm diameter. The poly-ethylene buckets were set at the top of the building blocks at the College of Education (10m height above the ground), College of Humanities and Social Science (9m height above the ground) and at the City centre was set on the roof of the house 6m height above the ground to ensure direct entrance and hence prevent contamination. The sampler was placed at the beginning of rain and removed immediately after rainfall to collect only wet deposition. The samples for nutrients analysis were preserved by freezing, while for aluminum and silicon analysis were preserved by using concentrated analytical grade hydrochloric acid at a pH below 2.

Sample Analysis

The volumes of water samples, temperature, Electrical conductivity (EC), Total Dissolved Solid (TDS) and pH were measured immediately before filtration at the University of Dodoma Chemistry Laboratory by using Measuring cylinder and Multi-parameter pH meter (Eutech model CON 110). The filtered samples were analyzed for; NH_4-N, NO_3-N, PO_4^{3-} at the Environmental Engineering Laboratory of the Ardhi University. Nitrate nitrogen was measured by cadmium-reduction method, while ammonium nitrogen was measured by Nessler method and phosphate phosphorous was measured by ascobic acid method (Parsons et al., 1984). Trace metals, Al and silicon were measured by inductively

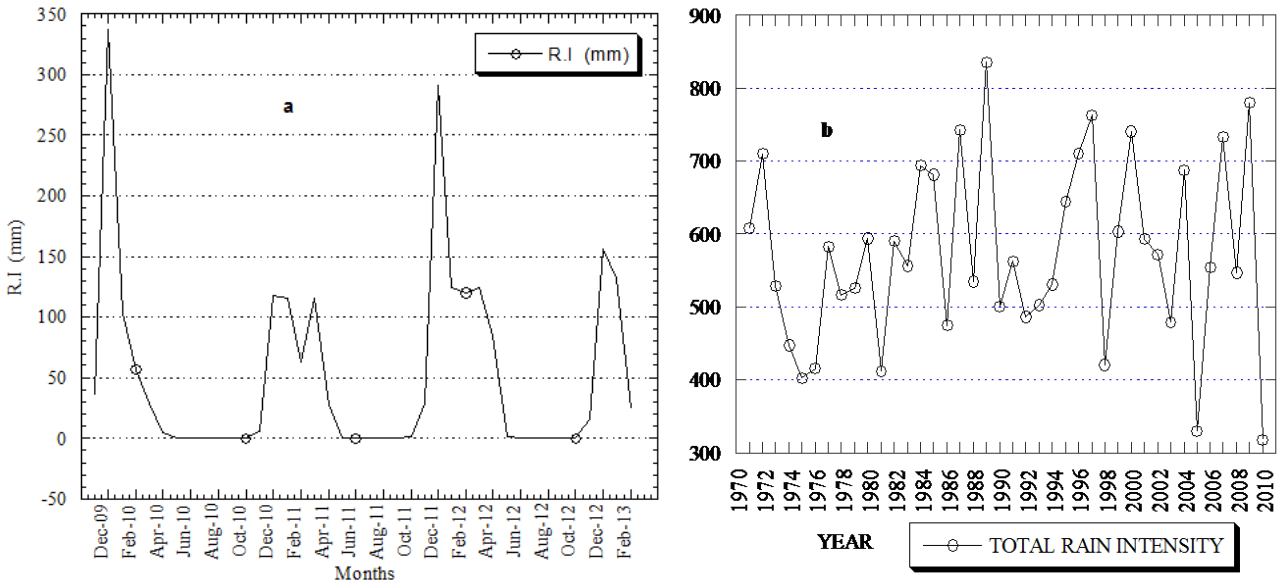

Figure 2. Rainfall characteristics in Dodoma Region. Monthly trend showing the unimodal trend (2009-2013), Figure 2a and Fourty years Annual rainfall trend (Figure 2b).

coupled plasma mass spectrometry (ICP-MS) at Southern and Eastern Africa Minerals Center (SEAMIC) laboratory.

Data analysis

The values of rain intensity were calculated by using equation 1.

Rain Intensity (R.I) = V/A..... (1)

where V is the volume of total collected rainfall and A is the area of opening of the sampler.

Volume weighted mean (VWM) concentration was calculation using equation 2

$$VWM = \frac{\sum_{i=1}^{n}(V_i C_i)}{\sum_{i=1}^{n} V_i} \quad \text{..... (2)}$$

C_i = measured concentration of individual species and V_i= volume of rain water recorded during each sampling.

Annual deposition flux (A.D Flux) was calculated using equation 3 using 40 year average annual rainfall provided by Tanzania Metrological Agency.

$$A.\,D\ Flux = \frac{\text{Vol of deposition (L)}}{\text{Area (ha)}} x \text{Average deposition} \left(\frac{mg}{L}\right)$$

.... (3)

RESULTS

Rainfall distribution and physico-chemical characteristics

Dodoma region experience unimodal rainfall pattern (Figure 2a) with an average of 570mm of precipitation per year. The lowest rainfall during the past 40 year was 318mm (Figure 2b), while the highest was 836mm, the bulk of which occurs during its wet season between November and April. The remaining months of the year are completely dry. The precipitation amount also varies within a studied area in intensity and frequency.

The highest rainfall frequency producing measurable volume was found at the COED with six rainfall events compared to the other two sites with only four rain events (Table 1). These represent total collected rainfall amounts of 302.88, 143.60 and 127.77 mm, respectively. The annual rainfall recorded by TMA at the beginning of the rain season in November up to April, 2013 was 498.6mm, giving the total collections of rain water equivalent to 60.74%, 28.80% and 25.63% at College of Education, College of Humanities and Social Sciences and City Centre, respectively. All three sites showed similar rainfall pattern during the sampling course with high precipitation intensity on December 12th, January 3rd and February 1st.

The concentration of chemical species as depicted by TDS values showed generally low concentration during high rainfall intensity for the college of education suggesting the influence of dilution (Figure 3). Electrical conductivity values followed similar trend to that of TDS. The pH value did not show a definite pattern probable because of the observed range (4.8-7.9) is sensitive to both direct and indirect influences such as equilibration with atmospheric carbon dioxide.

Nutrients and trace metal characteristics of precipitation

Chemical composition of precipitation in Dodoma Municipality showed that it contained significant amount

Table 1. Rainwater characteristics at three sampling stations

Station	Precipitation events	Collection per station (mm)	Annual rainfall (mm)	Collection (%)
COED	6	302.88	498.60	60.75
CHSS	4	143.60		28.80
City Centre	4	127.77		25.63

of nitrogen and phosphorous species with the following general trend NO_3^->NH_4^+>PO_4^{3-}. However the concentrations of trace metals were generally below detection limit with exception of silicon and aluminum. This is concomitant with the level low industrial activities in the municipality hence the pollution is mainly derived from natural and domestic activities.

DISCUSSION

Spatial Variation in atmospheric inputs

Sampling of precipitation was conducted to reflect different characteristics of locations found in Dodoma municipality. This selection was carried out to qualify and quantify the effects of respective activities on atmospheric pollution around the municipality. The volume of rain recorded was different among sampling sites with highest record at the College of Education followed by the College of Humanities and Social Sciences and last at the City Centre with values of 302.9mm per six samples, 143.6mm and 127.8mm per four samples for COED, CHSS and City Centre, respectively. This variation in rainfall intensity can be due to different geographical location of sampling site inducing different niches of micro-climatic conditions. College of Education and Social Sciences were located at similar altitude separated by hill at a distance of about four kilometers, as compared to City Centre found at a flat land with high density of residential buildings. The influence of spatial variation of rainfall was also reflected in nutrient content. City center found to have high concentrations of all nutrients species, followed by the College of Humanities and Social Sciences and the lowest concentration at the College of Education. All nutrients species shows inversely proportional to the rainfall volume (Figure 4) suggesting dilution effect. City Centre recorded lowest rainfall (127.17mm), consequently the concentrations of nutrients were the highest while the College of Education recorded highest rainfall (302.87mm) and lowest concentrations of nutrients. Effect of dilution on the concentration of chemical species in precipitation was also reported by Andreae et al. 1993 and Vuai et al. 2011.

The volume weighted mean pH was 6.1, 5.1 and 6.6 for the College of Education, College of Humanities and Social sciences and City Centre, respectively. Despite City center having higher concentration of acid precursor (NO_3^-), the value of pH was the highest. This can be explained by presence of high concentration of neutralizing species especially ammonium. Sakihama et al. 2008 showed that pH of precipitation was controlled by neutralization process in Okinawa Island involving ammonium ions.

In addition to the dilution effect, land cover/use may influence atmospheric pollution around the municipal. City Centre station is located near the Majengo market where there are different human activities as well as incineration of urban waste water treatment sludge and urban waste. Moreover, the area is close to the main roads of Dodoma and population density is high. The combination of these activities may contribute to the observed high concentrations of nutrients. Similarly, variation in nutrients in two sites located at the University of Dodoma might be attributed to the population density and nature of settlement. College of Humanities and Social Sciences host nearly half of all students of University of Dodoma and its hostels are clustered together. Consequently there is concentration of waste emissions. On the other hand, College of Education has relatively less students and the hostels are spread over the wide area subjecting dilution of waste emission by turbulent wind. Sazakli et al. (2007) reported that rain water quality depending on the atmospheric pollution of the individual area and the proximity to pollution sources. In a similar study variability of elemental composition was observed among sampling points and study location (Morrow et al., 2010)

The results of spatial variation of volume weighted mean concentration of metals are presented in Figure 5. Concentrations of crustal elements (Al and Si) measured in College of Humanities and Social Science is high relative to the other sites. The pH is the most influential factor on the dissolution of these metals and they generally show high values at low pH. The average weighted pH values for three locations were reported as 6.1, 5.1, and 6.6 for College of Education, College of Humanities and Social Sciences, and City Centre, respectively. Thus the higher concentration of Al and Si at College of Humanities and Social Science might be attributed to this lower pH.

Deposition flux of nutrients and trace elements in wet precipitation

The quantity of nutrients and other precipitation

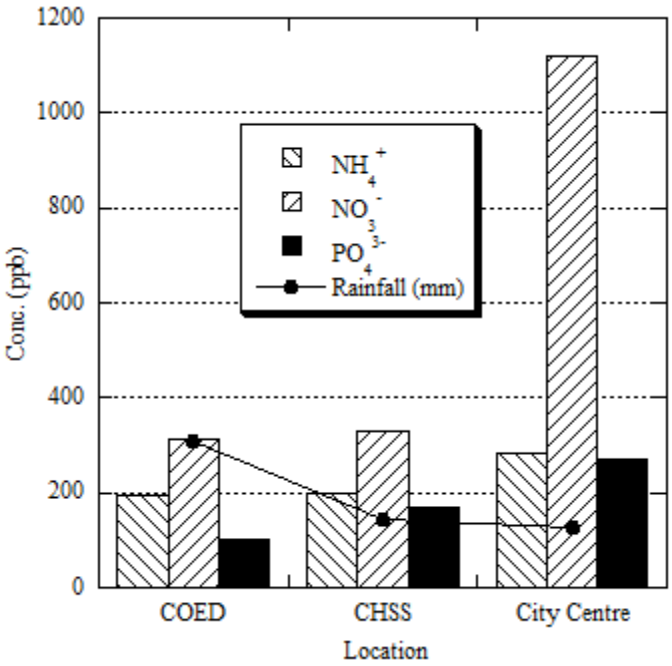

Figure 4. Spatial variation of rainfall and nutrient species in Dodoma Municipality.

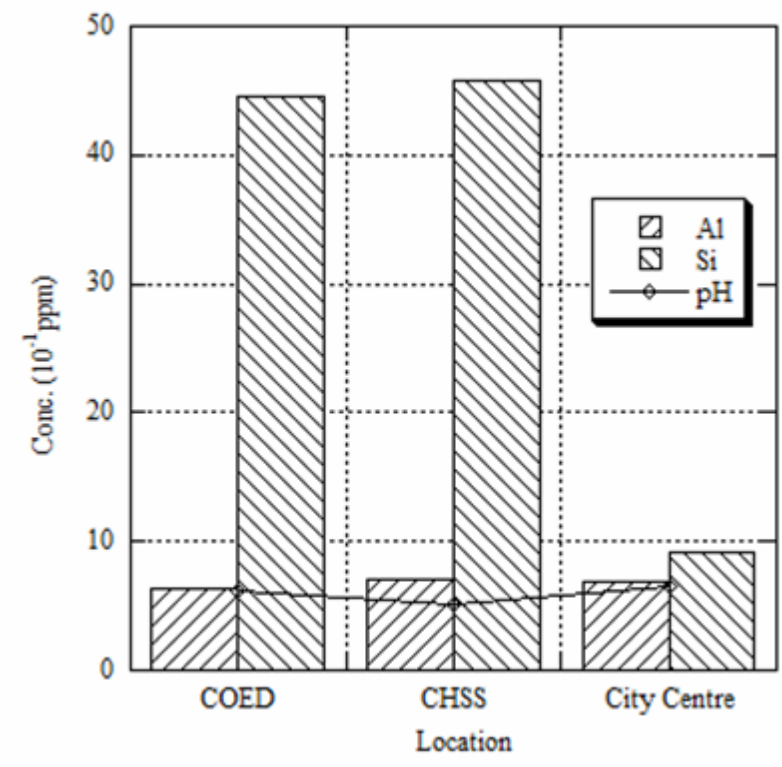

Figure 5. Concentration of metals and pH in the sampling sites.

components may be affected by a number of factors including meteorological such as wind speed and direction, rainfall intensity, proximity to source and human activities (Andreae et al., 1993). The volume weighted mean concentrations over the intere municipality were NO_3-N: 500 µg/L; NH_3-N: 210µg/L, and

PO_4^{3-}: 160 µg/L for COED, CHSS and City Centre respectively which is lower than those reported for Mwanza Region, Tanzania (Vuai et al. 2011). Nitrate contributes the first largest fraction to the nitrogenous content of precipitation at the three measurement sites. The average value measured in this study is similar to those measured at the South African semi-arid savanna sites of Louis Trichardt and Skukuza (0.496 and 0.506mg/L, respectively) (Mphepya, 2005, 2006), the rural Indian site of Iqbalpur (0.53mg/L) (Monika et al., 2000), the wet savanna site of Lamto (0.48mg/L) (Yoboué et al., 2005) but higher than those reported for the equatorial forest site of Zoetele (0.43mg/L) (Sigha-Nkamdjou et al., 2003). The concentrations at the three sites investigated here are also lower than those at Amersfoort, South Africa (dry savanna site located near industrial areas; 1.55mg/L) (Mphepya et al., 2005).

Calculation of annual wet deposition flux using 40year mean rainfall of 570mm and volume weighted mean concentrations of the municipality was done using equation 4 and results are presented in Table 2.

$$\text{A. D Flux} = \frac{\text{Vol of deposition (L)}}{\text{Area (ha)}} \text{x} \text{Average deposition} \left(\frac{\text{mg}}{\text{L}}\right) \quad \text{..... (4)}$$

The results show that nitrate deposition flux was higher than that of Prades, Spain and Similar to Kamernicki, Yemen but lower than that of Ahmedabad, India. Over the infertile soils of the semi-arid savanna regions of South Africa, Parsons et al. (1996) measured emission fluxes of 2.83kgha^{-1} yr^{-1}, the same order of magnitude in size as the deposition fluxes measured in the Sahelian. Original measurements of NO_3 emission in the Sahelian savanna at Banizoumbou, where natural emissions are perturbed by grazing activities, indicate rates of 1.9 - 0.8 kg N ha^{-1} yr^{-1} (Serça et al., 1998).

The wet deposition fluxes of NH_4-N over Dodoma municipality was significantly lower (1.23 kg/ha/yr) compared to other reported studies. Ammonium content in precipitation is derived from the incorporation of gaseous ammonia and particles containing NH_4^+ in clouds and rainwater. Ammonia originates largely from bacterial decomposition of urea in animal excreta, and from emission by natural or fertilized soils (Schlesinger and Hartley, 1992; Galy-Lacaux and Modi, 1998). Domestic and wild animals also lead to volatilization of ammonia in tropical pastures (Galbally and Gillet, 1988; Schlesinger and Hartley, 1992). Another significant source of ammonia is savanna fires and domestic fuel wood burning (Lobert et al., 1990; Delmas et al., 1995; Brocard et al., 1996). Seinfeld (1986) reported that ammonia generally occurs in the atmosphere as $(NH_4)_2SO_4$, but is also found in the form of NH_4NO_3 (Parmar et al., 2000). Dodoma region is an agro-pastoralism area characterized by long dry season with high temperatures, low soil moisture and bare soils surfaces. This condition favors volatilization of ammonia and hence increases its atmospheric concentration (Delon et al. 2010). McCalley and Sparks, (2008) reported that rates of NH_3 volatilization is sensitive to soil conditions.

Volumes weighted mean concentration of phosphate-phosphorous in Dodoma municipality was 160 µg/L. The corresponding annual flux of entire municipality is 0.9 kg/ha/yr which is higher than for Marina Catchment with rainfall intensity more than four times higher (Table 3). Sources of phosphorus to the atmosphere include re-suspension of crustal materials, vegetation combustion products, and marine aerosols. Anthropogenic sources in addition to burning are typically include fertilizer applications and handling and phosphate mining (Dixon, 1994). The dry climate of April to November in Dodoma region results into drying of vegetation and the land become beard. The season is also accompanied with very strong wind with maximum up 8.7m/s (TMA, 2013). This condition results into suspension of dust particle in the atmosphere. In addition to that land preparation which involves burning of vegetation is being done in October and November prior to rainfall seasons. These characteristics might be responsible for elevated concentration of phosphate in the atmosphere around Dodoma Municipality.

Aluminum concentrations in the studied area range from 0.64 to 0.71 ppm with an average of 0.67ppm while Si concentration range from 0.9 to 4.6ppm with an average of 3.7ppm. Comparison with other studies the concentration of Al was higher than 0.15-0.3ppm reported by Kombo et al. (2008) but lower than (>2ppm) that reported by Gatz (1981) in Bondville. The concentration of deposited Si was higher than 0.08ppm reported by Huang (2013) in Subtropical China and close to the range (1.5 and 3.3 ppm) reported by Kombo et al. (2008) in Gesashi. Al and Si are purely soil-derived (crustal) elements and they are dominant in the soil distributed in the most of Dodoma Region (GST, 2012). Soil particles and mineral dust from weathered rock re-suspended to the atmosphere by wind may release metals during interaction with rain water. This was suggested to be the source of excess dissolved Al in the rain water (Vuai et al., 2011). The average of wind speed studied between 2000 and 2013 at 0600 GMT was 5.46m/s with the frequency of minimum speed of 0.51m/s occurring between February and March while maximum wind speed of 8.7m/s occurs in August. The wind is high up to November when it is the onset time for rain season at Dodoma region. Thus it is suggested that windblown soil particles, have significant contribution to Al and Si in the rain water. Therefore it may be suggested that the concentrations of crustal elements in the study area are due to inclusion of dust during the long dry summer season associated with the wind blown in the area that increases the atmospheric loading of soil particles which gets washed out by precipitation.

Table 2. Volume weighted mean conc. (VWM) and Flux in precipitation

Depositions	VWM (mgL^{-1})	Flux ($kgha^{-1}y^{-1}$)
TDS	8.85	50.74
[H+]	0.0024	0.014
NH_3-N	0.21	1.23
NO_3-N	0.5	2.84
PO_4^{3-}	0.16	0.9
Al	0.67	3.3
Si	3.7	18.5

Table 3. Comparison of atmospheric deposition of Si, Al and nutrients in Semi arid areas.

Site	Rainfall	Deposition (kg/ha/y)			References
	(mm)	NO_3-N	NH_3-N	PO_4^{3-}	
Dodoma municipality(2012-13)	498.6	2.83	1.23	0.90	This study
Marina Catchment Singapore	2554	6.26	3.39	0.19	J.He et al., 2011
Ahmedad India (2002)	400	4.87	2.97	-	Rastogi and Sarin., 2006
Ahmedad India (2001)	680	5.69	3.92	-	Rastogi and Sarin., 2006
Ahmedad India (2000)	730	3.92	3.64	-	Rastogi and Sarin., 2006
Prades Spain	551	1.70	2.30	-	Roda et al., 1993
Kamernicki Yemen	527	2.70	6.40	-	Pedersen et al., 1992

SUMMARY AND CONCLUSION

Dodoma region is a semi arid area experiencing long dry season accompanied with very strong wind. This condition results into suspension of particles in the atmosphere originating from the blown soil dust which may transport nutrients and other metals and causing negative consequences to the ecosystem during deposition. Contribution of this phenomenon to the atmospheric aluminum, silicon and nutrients has not been studied. The study was conducted to assess atmospheric deposition of aluminum, silicon and nutrients in Dodoma Municipality. The samples of rain water were collected in event basis from three different areas reflecting a combination of natural and anthropogenic activities and analyzed for aluminum, silicon, ammonium, nitrate and phosphate. The results show that there is strong spatial variation in rainfall intensity within Dodoma Municipality caused by niches of micro meteorological factors including wind and altitude. Nutrients deposition also in Dodoma Municipality show clear spatial variation due to nature and intensity of anthropogenic activities. Densely populated area is reflected by high deposition of nitrogen based nutrients. The concentration of nutrients showed that NO_3^- >NH_4^+>PO_4^{3-} with volume weighted mean concentrations 500, 210 and 160μgL^{-1}, respectively. It was also found that annual deposition flux of the nitrogen based nutrient is low compared to the other reported area with similar rainfall intensity reflecting less industrial activities and relatively low population density. However phosphorous deposition is relatively high due to burning of biomass during land preparation and dissolution from soil particles. Silicon and aluminum in the precipitation around Dodoma Municipality was significantly high which could be attributed to the blown soil particles by strong wind prevailing during long dry season with clear spatial variation as results of variation of rainwater pH. It was concluded that strong wind during dry condition disperse nutrients and bring soil dust which results into high concentrations of aluminum and silicon and low concentrations of nutrients in the wet precipitation.

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