Terrestrial and Aquatic Environmental Toxicology ©2009 Global Science Books

Pollution Monitoring in Urban Semi-Arid Environment Using Throughfall Variability in Chemical Composition and Total Particulate Matter

Goni A. Dimari[1] • Stephen S. Hati[2*] • Babagana Kolo[1]

[1] Department of Chemistry, University of Maiduguri, Maiduguri, Nigeria
[2] Department of Chemistry, Gombe State University, Gombe, Nigeria

Corresponding author: * stevehati@yahoo.com

ABSTRACT

Three major aspects of pollution monitoring from throughfall collected under different trees formed the specific objectives of this study: (1) monitoring total particulate matter (TPM) trapped by the vegetation of this environment at a period when the influence of Harmattan is isolated, (2) assessing trees of this environment proficient in trapping particulate matter (PM) and (3) the chemical composition and alterations of throughfall against precipitation caught under the open field. *Acacia nilotica*, *Eucalyptus* sp., *Mangifera*, *Azadirachta indica*, *Tamarindus indica* and *Terminalia catappa* are common trees found in Maiduguri, Nigeria and were used for this study. Results showed a record high values of TPM (2.54 gm^{-2}), Cl^- (36.40 ± 4.72 mgL^{-1}), NO_3^- (1.11 ± 0.23 mgL^{-1}) and SO_4^{2-} (5.45 ± 0.82 mgL^{-1}) in throughfall. The general order of metal concentration found in throughfall was: Pb (1.422 ± 0.62 mgL^{-1}) > Cr (0.547 ± 0.16 mgL^{-1}) > Cd (0.216 ± 0.05 mgL^{-1}) > As (0.102 ± 0.06 mgL^{-1}). There were mostly statistically significant ($p<0.05$) variations of these values amongst the different trees. *Mangifera* and *Azadirachta indica* were more proficient in intercepting and trapping PM amongst the six tree species studied in this work. The alterations of chemical compositions of throughfall against precipitation caught in the open field were observed to be significant in certain trees with an influence of dilution effects due to a higher amount of rainfall.

Keywords: air pollution, anions, heavy metals, particulates, rainwater, urban trees interception

INTRODUCTION

The key objectives of atmospheric air pollution monitoring include: assessment of population exposure and health impact, natural ecosystems threats identifications, identifying and apportioning sources, determining compliance with national or international standards, raising public awareness of air quality and establishing alert systems, providing objective input to air quality management and to transport and land-use planning, policy development and setting priorities for management action based on quantified trends from past to feature problems, developing and validating monitoring and management tools such as analytical methods, models and geographical information systems (WHO 1999; APHEIS 2000).

Analytical method development in atmospheric air pollutant monitoring in urban and rural environments has received intensified efforts from international organizations such as the United Nations Development Programme (UNDP) and the International Atomic Energy Agency (IAEA) Markowicz *et al.* (2002). There have been varying approaches and dimensions, and amongst the newest is the air pollution monitoring system based on geosensor network using wireless sensor networks (Manahan 2005; Jung *et al.* 2008). This will continue to receive modifications based on specific needs, validity of analytical method data, peculiarity of environment and cost of implementation amongst several other factors.

A mixture of pollutants, including sulfur oxides (SOx), nitrogen oxides (NOx), carbon monoxide (CO), organic compounds such as benzene, toluene, xylene and benzo (a)pyrene and particulate matter (PM) are the main causes of urban air pollution, which are very toxic and/or carcinogenic. These are mostly emitted by local sources but some fraction of the pollution is also transported through the atmosphere from the sources located outside of the city, sometimes at a far distance from it. These pollutants are a major threat to human health in cities of developed and especially of developing countries (WHO 2000, 2003).

Trees are known to improve air quality efficiently and inexpensively by providing the following eco-services: reducing air temperatures, increasing oxygen levels, intercepting and trapping PM air pollution, absorbing gaseous pollutants, binding or absorbing water soluble pollutants on leaf surfaces and reducing ozone levels (CGTG 2008).

The term "throughfall" has mainly been used in connection with forest ecosystem studies in which the canopy effect is also associated. Throughfall is one of the copious phenomena that occur when precipitation (rainfall) interacts with forest treetops that form a kind of ceiling (canopy). Consequent upon this interaction is canopy interception (rainwater evaporates from the canopy of standing vegetation) or drips from leaves, twigs and stems (throughfall) or runs down the stem (stemflow) to the forest floor (Enloe *et al.* 2000; Helvey and Patric 2007).

Canopy effects have been well recognized (Myburgh 2004) over several decades (Madgwick and Ovington 1959; Pressland 1976; Qualls and Haines 1992), and studies on throughfall have been conducted with the aim of investigating the modifying effects of throughfall on intensity-duration-frequency relations using a stochastic model to extrapolate measured rainfall and throughfall expected during extreme events (Keim *et al.* 2004), the effects of water and solute inputs to the subcanopy, including understory vegetation, soil moisture, soil solution chemistry, and the fate of atmospheric dryfall (Levia and Frost 2006). The subject is however unclear when the term "throughfall" is applied in a non-forest environment. In the context of this

Received: 22 April, 2009. Accepted: 19 June, 2009.

Original Research Paper

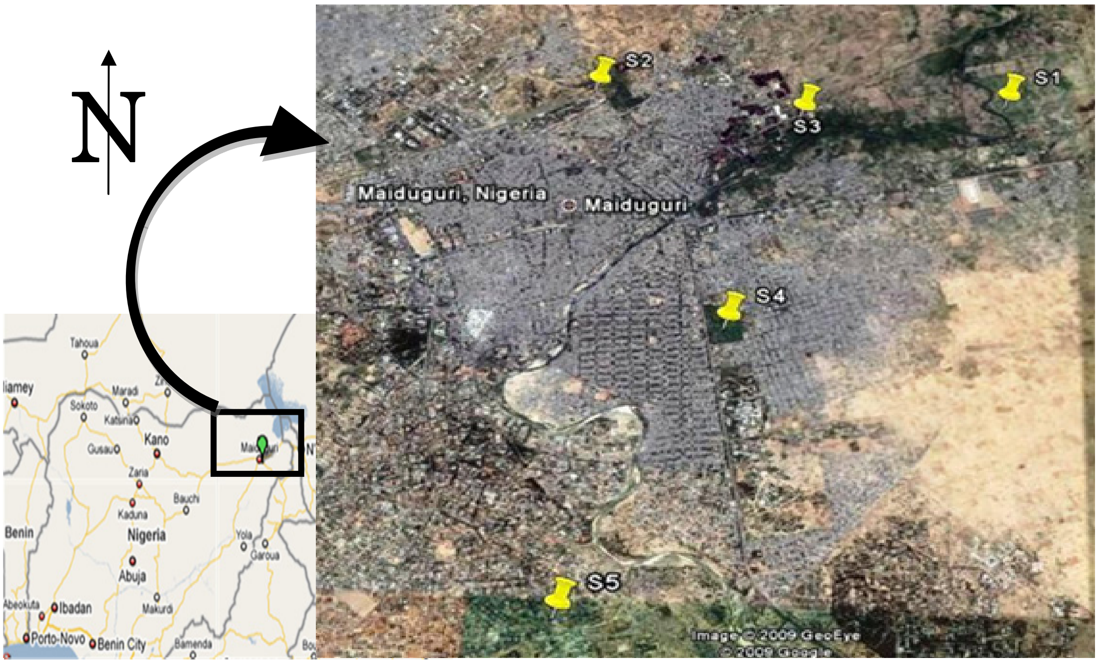

Fig. 1 Map of Maiduguri, Nigeria showing sampling stations for the collections of throughfall..

work, the term is used to refer to rainwater samples collected under trees of different types in an urban semi-arid environment for possible use as pollution monitoring tool, which is the aim of this work. However, three major aspects of pollution monitoring from the throughfall obtained forms the specific objectives: (1) monitoring total particulate matter (TPM) trapped by the vegetation of this environment at this period, when the influence of Harmattan is isolated, (2) assessing trees of this environment proficient in trapping PM and (3) the chemical composition and alterations of throughfall against precipitation caught in the open field.

MATERIALS AND METHODS

Study site and target trees

The study site was the Maiduguri metropolis (13° 10′ E; 11° 50′ N; Google Earth 2008). It is known to be underlined by sediments of the Chad basin and a semi-arid climate characterized by a long dry season and a short rainy season (Papka 1984). The metropolis has an estimated population of 521,492 (FRN 2007) with high commercial activities, which include high traffic and the use of electricity generating plants, but few industries such as the bottling plants and asphalt plant. A total of 5 sampling stations (S1, S2, S3, S4, S5), selected on the basis of predominance of target trees, were used in this study. These sampling stations were located on the satellite map (**Fig. 1**) using Geko 101 (2003) with a position accuracy of 15 m (49 ft) RMS. Target trees consisted of six commonly grown trees in this region (**Table 1**).

Throughfall collections

Throughfall was collected according to the method described by Levia and Frost (2006) in pre-cleaned plastic jugs placed on an elevated wooden stump that was inserted in the ground to which the jug was affixed by a screwed clip, about 36 cm above ground level. Three jugs were place under each tree species, within the diameter of tree canopy at an approximate equidistance, which varied according to tree size. An average range of 48–60 cm from the tree trunk was used. Four of each tree species were randomly selected in a sampling station and treated as a composite sample. Throughfall was collected within the main four months (June, July, August and September) of the rainy season in Maiduguri (HKO 2003; Gwary *et al.* 2006), for the years 2007 and 2008.

Table 1 Target trees of throughfall collection.

Common name	Scientific name
Acacia	*Acacia nilotica*
Eucalyptus	*Eucalyptus Sp*
Mango	*Mangifera*
Neem	*Azadirachta indica*
Tamarind	*Tamarindus indica*
Umbrella	*Terminalia catappa*

Throughfall analysis

Sample preparations and determinations of throughfall were carried out according to standard analytical methods described by Radojevic and Bashkin (2006), in addition to instructions in the manuals of instruments used. Each analysis run was carried out in duplicate.

Determination of total particulate matter (TPM)

Throughfall samples from the jugs were filtered in large glass beakers using funnel and Whatman filter paper No 2. Samples contaminated with insects and leaves were removed by floatation and decantation procedures. Filtered PM was dried at about 80°C, weighed and calculated as total mass weight of TPM per unit area (g/m^2), while filtrate subjected to the determinations of ions and metal contents.

Determination of pH and ions [Cl^-, NO_3^-, SO_4^{-2}]

The pH of throughfall was determined using a model 3310 pH meter (Jenway Ltd., Dunmow, UK). The pH meter and electrode were calibrated with buffer solutions of pH 7 and 4 for pH determinations. Samples were run on site. A HACH® DR/890 colorimeter (HACH 1997-2007) was used for the determinations of ions in the throughfall samples. Chloride was determined by the DPD method 10069, nitrate by the mid-range cadmium reduction method 8171 and sulphate by the SulfaVer 4 method 8051.

Determination of metals [As, Cd, Cr, Pb]

A standard method of flame atomic absorption spectroscopy (FAAS) was used to determine the heavy metal content. A Shimadzu AA-6800 (SC 2000) equipped with ASC-6100 auto sampler and air-acetylene atomization gas mixture was used for the analysis. About 10 ml of throughfall sample was extracted into 40% acidified (nitric and hydrochloric acid) distilled water and heated to a clear solution. A similar treatment was made on samples from open field and blanks as described by SC (2000).

Data analysis

Results obtained were expressed as mean ± SD (standard deviation) and statistically analysed for significance in variations between sampling stations and tree species by analysis of variance (ANOVA) with the Bonferroni *post hoc* test using coupled Microsoft Excel + Analyse-it v. 2.10 (Analyse-it® 2007). Variations were considered significant at $P<0.05$.

RESULTS AND DISCUSSION

The trees selected for this study play a significant role to the natives of this study area, ranging from food with economic value such as mango and tamarind, to the provision of useful shade against the hot sun such as the neem and umbrella trees. Intercepting and trapping PM air pollutants and binding or absorbing water soluble pollutants on leaf surfaces are amongst the several significant ecological roles of trees, especially in an urban environment (CGTG 2008). **Fig. 2** shows the result of the TPM trapped in the leaves of different trees that were eventually washed down in throughfall collected and analysed in this work. It is evident from the result that the mango tree played a significant role in the interception and trapping of PM, with the highest average TPM of 2.54 gm^{-2}. The least was recorded in throughfall collected under the eucalyptus tree (0.51 gm^{-2}). The variations in TPM were markedly statistically significant ($P<0.05$), which is also very obvious from the data on the plot. In summary, from this study, the order of competing efficiency of trees in interception and trapping TPM can be outlined as follows: mango > neem > tamarind > umbrella > acacia > eucalyptus. Leaf size, number and texture have been attributed to the efficiency of trees to intercept and trap particulate matter in air. The combined effects of leaf number and texture of the mango tree may have contributed significantly to the observed high values of TPM recorded, while neem and tamarind showed a high leaf number on individual stems. However, in comparison with the data collected by NUFU (1999), the TPM trapped by leaves of this region was higher than that recorded in a non-arid environment due to less dust laden air observed there.

A sand storm usually accompanies rainfall in this study area, therefore it is also anticipated that PM blown in air may interfere with the throughfall collected. However, PM is also intercepted in the precipitation. The variations of alteration of chemical compositions of throughfall are presented in **Tables 2** and **3**. Alterations of the chemical composition of throughfall may be caused by solubility of certain solutes (PM) adsorbed on leaf surface and/or the solubility of leaf material after being soaked in rain water (Levia and Frost 2006). **Table 2** shows the variation of some ion concentrations and pH in throughfall and rainwater collected in the open field. The result shows significant alterations of chemical compositions which were dependent on tree type.

Chloride, nitrate and sulphate ions measured in throughfall showed increases in concentration, which were higher than that measured in rainwater measured in the open field. Neem (36.40 ± 4.72 mgL^{-1}) > mango > tamarind > umbrella tree > acacia > eucalyptus > open field (15.80 ± 1.67 mgL^{-1}) in chloride concentrations of throughfall. The concentrations in the first three trees were statistically significant to

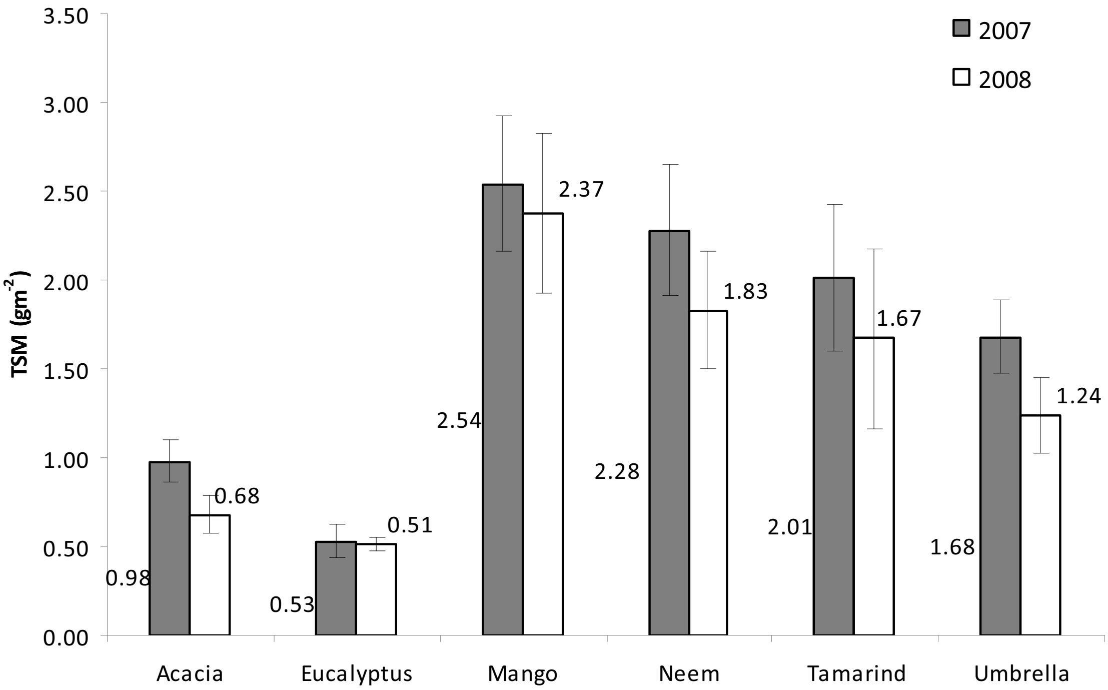

Fig. 2 Total Solid Matter (TSM) in throughfall collected under different trees in Maiduguri, Nigeria in 2007 and 2008.

Table 2 Anion concentrations and pH values of throughfall caught under different trees and in open field of Maiduguri Metropolis.

Trees	Ion conc. (mg L^{-1})						pH	
	Cl^-		NO_3^-		SO_4^{2-}			
	2007	2008	2007	2008	2007	2008	2007	2008
Acacia	18.40 ± 2.12	17.20 ± 1.87	0.39 ± 0.08	0.56 ± 0.08*	4.01 ± 0.26	4.12 ± 0.38	6.22 ± 0.12	6.14 ± 0.15
Eucalyptus	17.60 ± 2.43	24.60 ± 2.54*	0.87 ± 0.04	1.11 ± 0.12	4.23 ± 0.47	4.86 ± 0.45*	6.24 ± 0.11	5.86 ± 0.21
Mango	30.20 ± 5.11†	28.40 ± 2.67	1.24 ± 0.41†	2.04 ± 0.30	6.67 ± 1.20†	7.12 ± 1.24	5.12 ± 0.32†	5.53 ± 0.42*
Neem	36.40 ± 4.72†	34.20 ± 3.98	0.96 ± 0.11	1.12 ± 0.13	5.12 ± 0.94	5.87 ± 0.82	5.00 ± 0.21†	5.21 ± 0.31
Tamarind	24.20 ± 4.12†	26.40 ± 4.22	0.67 ± 0.04	0.89 ± 0.07	4.12 ± 0.76	4.65 ± 0.65	5.67 ± 0.12	5.66 ± 0.89
Umbrella tree	22.40 ± 3.22	18.20 ± 2.34*	1.11 ± 0.23†	2.45 ± 0.48*	5.45 ± 0.82†	6.23 ± 0.83*	5.82 ± 0.33	6.00 ± 0.65
Open field	15.80 ± 1.67	16.20 ± 2.11	0.34 ± 0.06	0.56 ± 0.07	3.87 ± 0.44	4.46 ± 0.52	6.66 ± 0.17	6.21 ± 0.43*

Mean ± SD (standard deviation), n=28
*significant $P<0.05$ (*t*-test) between years for a tree
†significant $P<0.05$ (ANOVA) higher than two other values within single column

Table 3 Anion concentrations and pH values of throughfall caught under different trees and in open field of Maiduguri Metropolis.

Trees	Metal conc. (mgL^{-1})							
	As		Cd		Cr		Pb	
	2007	2008	2007	2008	2007	2008	2007	2008
Acacia	0.058 ± 0.01	0.042 ± 0.01	0.091 ± 0.02	0.167 ± 0.01*	0.444 ± 0.08	0.420 ± 0.05	1.012 ± 0.41	1.421 ± 0.26*
Eucalyptus	0.067 ± 0.02	0.061 ± 0.01	0.101 ± 0.05	0.146 ± 0.06	0.451 ± 0.12	0.397 ± 0.06*	0.873 ± 0.15	0.917 ± 0.07
Mango	0.086 ± 0.02	0.088 ± 0.03	0.216 ± 0.05†	0.289 ± 0.08*	0.547 ± 0.16†	0.487 ± 0.08*	1.422 ± 0.62†	1.620 ± 0.41
Neem	0.102 ± 0.06†	0.076 ± 0.01*	0.187 ± 0.06†	0.213 ± 0.04	0.489 ± 0.09	0.438 ± 0.06	1.413 ± 0.21†	1.421 ± 0.76
Tamarind	0.062 ± 0.02	0.059 ± 0.02	0.148 ± 0.08	0.142 ± 0.02	0.448 ± 0.06	0.401 ± 0.02	0.992 ± 0.13	0.976 ± 0.19
Umbrella tree	0.091 ± 0.03†	0.076 ± 0.01	0.188 ± 0.04†	0.205 ± 0.07	0.524 ± 0.11†	0.511 ± 0.10	1.213 ± 0.24	1.015 ± 0.20
Open field	0.062 ± 0.01	0.036 ± 0.01*	0.091 ± 0.02	0.102 ± 0.04	0.431 ± 0.08	0.383 ± 0.07	0.826 ± 0.12	1.210 ± 0.22*

Mean ± SD (standard deviation), n=28
*significant $P<0.05$ (*t*-test) between years for a tree
†significant $P<0.05$ (ANOVA) higher than two other values within single column

that of the others. A similar order of concentration in throughfall was observed for nitrate and sulphate, in which the umbrella tree [1.11 ± 0.23 mgL^{-1} (NO_3^-); 5.45 ± 0.82 mgL^{-1} (SO_4^{2-})] showed the highest concentration while the acacia tree followed by the rain water in the open field [0.34 ± 0.06 mgL^{-1} (NO_3^-); 3.87 ± 0.44 mgL^{-1} (SO_4^{2-})] showed the least concentrations for the ions. The results for 2007 rainfall (**Fig. 3**) was used for this comparison due to the generally slightly higher values recorded, but was not statistical significant. However, these ions are indicators of levels of acid rain which are mainly cause by combustion byproducts of automobiles and combustion engines (Radojevic and Bashkin 2006). Thus the pH which also measures the activities of these ions in solution showed significant variations between throughfall from different trees and rainwater in the open field. The highest pH value was recorded in the throughfall of the acacia tree (6.22 ± 0.12), while the least was in the neem tree (5.00 ± 0.21). pH variations was also found to correlate with the ion, especially, chloride ion concentrations.

The heavy metals concentrations (**Table 3**) in the throughfall were also found to be significantly higher than that obtained in the open field for some of the tree species. Pb was found to be the highest metal of the four metals analysed, with a concentration of 0.826 ± 0.12 mgL^{-1} in open field rain water, while the highest concentration was recorded in throughfall of mango tree (1.422 ± 0.62 mgL^{-1}). This is closely followed by that in neem tree (1.413 ± 0.21 mgL^{-1}). The general order of metal concentration found in throughfall was as follows: Pb > Cr > Cd > As. However, the pattern of metal concentrations in the throughfall from tree types tended to be similar with a slight dependency on TPM and was found to be significant as indicated in the table. pH variations may be attributed to the enhanced solubility of the metals (Manahan 2005).

On the whole, variations in the concentrations of both ions and heavy metals recorded, which were higher in throughfall than in rainwater collected in the open field, are largely due to salvation of these analytes in throughfall, sourced from the PM and leaf contents of respective trees.

Again, the variations observed in the chemical compositions between 2007 and 2008 may be linked to the amount of rainfall recorded within the period of study, shown in **Fig. 3**. The amount of rainfall in 2007 was generally higher than in 2008 and hence the impact of dilution effect on the concentration of the chemical compositions of throughfall. Similar observations have been reported by Enloe *et al.* (2000) in their study conducted in a primary forest without specifying tree type. The influence of urban activities on rain water in a semi-arid environment similar to the present study has been reported by Ayodele and Abubakar (1998), in which variation in chemical composition of rainwater collected in the heart of the semi-arid urban metropolis was compared with rainwater collected in an open field of the outskirt of Kano city, Nigeria. In the same manner, though over a decade ago, the concentrations of these potentially toxic metals are within the limits of no problem to biota in this region.

High air pollution episodes may cause economic problems (reduction in agriculture production and loss of revenue from tourism) and adverse health effects. Moreover, the fine particles can easily be transported across national boundaries over long distances creating problems for neighbouring countries (transboundary pollution) (Markowicz *et al.* 2002). Therefore forestation programmes in semi-arid urban environments need to be practiced, and more intense attention is encouraged.

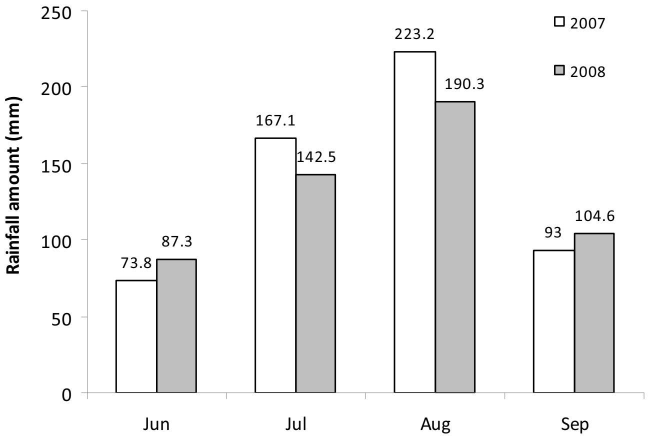

Fig. 3 Average rainfall distribution within the study period of 2007 and 2008 in Maiduguri, Nigeria.

CONCLUSION

The study showed that with consistent improvement, it will be possible to monitor certain air pollutants trapped in trees of an urban semi-arid environment at periods when the influence of the Harmattan (dry dust-laden atmosphere) which occurs from November to March each year as experienced in most parts of West Africa is isolated, thereby indicating basically the influence of anthropogenic source of PM trapped in vegetation.

Mangifera and *Azadirachta indica* were found to be more proficient in intercepting and trapping PM amongst the six tree species studied in this work.

The alterations of chemical compositions of throughfall against precipitation caught in the open field were observed to be significant in certain trees with a significant influence of dilution effects due to higher amount of rainfall.

ACKNOWLEDGEMENT

We thank Dr. Musa Umar and the team of analyst at the NAFDAC zonal laboratory, Maiduguri-Nigeria for supporting the instrumental analysis.

REFERENCES

APHEIS (Air Pollution and Health: a European Information System) (2000) Monitoring the effects of air pollution on public health in Europe. Scientific report, European Commission DG SANCO G/2, pp 2-5

Ayodele JT, Abubakar MB (1998) Trace element contamination of rain water in the semi-arid region of Kano, Nigeria. *Environmental Management and Health* **9**, 176-181

CGTG (City of Golden Tree Guidelines) (2008) *Golden Tree Guidelines*, Institute for Environmental Solutions, Colorado, USA, pp 1-6

Enloe T, Hellstern R, Lee C, McCandless B (2000) What is the canopy effect on rainfall amount and its chemical composition? Woodrow Wilson National Fellowship Foundation Environmental Science Institute Costa Rica. Available online: www.woodrow.org/teachers

FRN (Federal Republic of Nigeria) (2007) Official Gazette. Legal Notice on Publication of the 2006 Census Report **4 (94)**, B47-182

Geko 101 (2003) Personal Navigator®, Garmin International Inc., Kansas, USA

Google Earth (2008) Google earth satellite image of Maiduguri, Nigeria. Available online: http://earth.google.com/

Gwary DM, Saleh B, Gwary SD (2006) Evaluation of new pearl millet lines to Maiduguri pathotype of *Sclerospora graminicola*. *International Journal of Agriculture and Biology* **8**, 597-601

Helvey JD, Patric JH (2007) *Design Criteria for Interception Studies*, Coweeta Hydrologie Laboratory Southeastern Forest Experiment Station Forest Service, USDA, Asheville, North Carolina, pp 3-5

HKO (Hong Kong Observatory) (2003) Climatological Information for Maiduguri, Nigeria. Available online: www.brandhk.gov.hk

Jung YJ, Lee YK, Lee DG, Ryu KH, Nittel S (2008) Air pollution monitoring system based on geosensor network. *IGARRS (International Geoscience and Remote Sensing Symposium)*, Boston, pp 1-5, Available online: www.grss-ieee.org

Keim RF, Skaugset AE, Link TE, Iroume A (2004) A stochastic model for throughfall for extreme events, *Hydrology and Earth System Science* **8 (1)**, 23-34

Levia DF, Frost EE (2006) Variability of throughfall volume and solute inputs in wooded ecosystems. *Progress in Physical Geography* **30**, 605-632

Madgwick HAI, Ovington JD (1959) The chemical composition of precipitation in adjacent forest and open plots. *Forestry* **32 (1)**, 14-22

Manahan SE (2005) *Environmental Chemistry* (8th Edn), CRC Press LLC, Boca Raton, USA, pp 169-180, 687

Markowicz A, Aleta A, Smodis A (2002) IAEA activities in support of air pollution monitoring in Asia and Pacific region, better air quality in Asian and Pacific Rim cities. *BAQ (Better Air Quality), Hong Kong* **16**, 1-7

Myburgh PA (2004) Determining grapevine canopy effects on effective rainfall in vineyards. *South African Journal of Enology and Viticulture* **25 (1)**, 33-35

NUFU (National Urban Forestry Unit) (1999) *The Effects of Urban Woodland on Air Quality*, NUFU, The Science Park, Wolverhampton, UK, pp 1-4

Papka PM (1984) *The Role of Forestry in Integrated Land Use in Borno State, Nigeria*, University Press, Ibadan, Nigeria, pp 4-6

Pressland AJ (1976) Soil moisture redistribution as affected by throughfall and stemflow in an arid zone shrub community. *Australian Journal of Botany* **24**, 641-649

Qualls RG, Haines BL (1992) Biodegradability of dissolved organic matter in forest throughfall, soil solution, and stream water. *Soil Science Society America Journal* **56**, 578-586

Radojevic M, Bashkin VN (2006) *Practical Environmental Analysis* (2nd Edn), RSC Publishing, UK, pp 147-170

SC (Shimadzu Corp.) (2000) *Atomic Absorption Spectrometry Cookbook: Heavy Metal Analysis*, Analytical Instruments Division, Kyoto, Japan, G10, pp 1-32

WHO (World Health Organization) (1999) *Monitoring Ambient Air Quality for Health Impact Assessment*, WHO Regional Publications, European Series, No. 85. World Health Organization Regional Office for Europe Copenhagen, pp 36, 56-115

WHO (2000) Air Quality Guideline, WHO, Geneva, pp 45-47

WHO (2003) *Health Aspects of Air Pollution with Particulate Matter, Ozone and Nitrogen Dioxide*, Report on a WHO Working Group Bonn, Germany, 13-15 January 2003, pp 2-5