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Influence of Meteorology on Ambient Air Quality in Morogoro, Tanzania

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ABSTRACT

The influence of meteorological parameters on air quality was investigated for a rural background site in Morogoro. Precipitation, temperature, relative humidity and wind speed were measured during wet and dry seasons of 2005 and 2006 period and their relationship with reported mass of particles of aerodynamic diameter smaller than 10 µm (PM10) for the site was assessed. The results show that higher PM10 mass concentrations (45µg/m^3) were obtained during the 2005 dry season and the lowest (13 µg/m^3) during the 2006 wet season. It is interpreted that reasons for the higher levels of the particulate matter mass in the dry season are due to temperature inversions and absence of rain wash-down. The observed particulate matter levels are also affected by the variations in sources strengths and in meteorological conditions such as mixing height, precipitation, relative humidity, wind speed and direction as supported by air mass trajectories.

Keywords: Air Quality, PM, Meteorology, Seasons, Trajectory

1. Introduction

Aerosol particles in the atmosphere consist of a mixture of natural and anthropogenic occurring materials. Particles of aerodynamic diameter smaller than 10 µm (PM10) and those smaller than 2.5 µm (PM2.5), have been found to be associated with health problems (Pope, 2000; Afroz et al., 2003) and ambient air quality problems, such as visibility reduction (Watson, 2002). Atmospheric aerosols, especially the submicrometer-sized particles, also affect the Earth's climate in two ways. Firstly, by scattering and absorbing incoming solar radiation and outgoing terrestrial infrared radiation. Secondly, by influencing the properties and formation processes of clouds (IPCC, 2007). In this way, aerosols can affect the concentration and size distribution of cloud droplets. In turn, they can alter the cloud radiative properties, cloud lifetime, the nature and allocation of rain clouds and as a result they interfere with the hydrological cycle (Toon, 2000). Also aerosol particles influence many atmospheric processes, acidification of clouds, rain and fog (Khoder, 2002) and impacts on climate and ecosystems.

Concern about atmospheric particulate pollution in urban areas is growing worldwide. Abundances and chemical compositions of aerosols differ due to physical processes and their origin. These also influence their spatial and temporal variability. It is apparent that urban areas differ from rural areas due to differences in physical obstacle characteristics that affect aerosol movements. The aim of this study was to address the dependence of air quality on meteorological parameters in Morogoro to better understand the pollution levels of the Municipality. The influence of the meteorological parameters on particulate matter (PM) collected close to the meteorology station at different seasons was investigated.

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2. Materials and Methods

Meteorological parameters were collected between May 2005 and May 2006 at the Tanzania Meteorological Agency (TMA) synoptic station located at main campus of Sokoine University of Agriculture (SUA) in Morogoro about 200 km west from Dar es Salaam. Morogoro is a small town (300,000 inhabitants, 2010 estimate) located at an altitude of about 500 – 600 m above sea level on the western foothill of Uluguru Mountain ranges, which rise to 2648 meters above the mean sea level. The influence of meteorological processes on atmospheric PM mass was done for samples collected 600 m from this meteorological station and the details for the study site can be found in Mkoma et al., 2010 (and the reference therein).

3. Results and Discussion

3.1 Local meteorology and air mass climatology

The temporal and spatial variability of the PM and its components are influenced by meteorological parameters such as rainfall, temperature, relative humidity, and air flow patterns (Bardouki et al., 2003). Aerosol particles are removed from the air by a combination of wet and dry deposition processes. Wet deposition (precipitation scavenging) occurs in rain events; it is a process, which is rather independent on the particle size, although larger and smaller particles can be removed sequentially during a single rain event. In contrast, dry deposition is a continuous process in which the fall-out of aerosol particles is strongly determined by particle size (Özsoy and Saydam, 2000). Long-range transport of air masses has an impact upon the aerosol composition at a sampling site, as it brings in particles from distant source areas. Air mass backward trajectories are useful to determine possible sources of aerosol particles and have been extensively used in the literature (Brankov et al., 1998).

Meteorology: The climate of Tanzania is mainly tropical on the coast and temperate inland. It is characterised by a warm, humid wet season and a somewhat colder dry season. In the eastern part of the country, the rainfall is mainly bimodal, with two rainy seasons. The 'short rains' or '*Vuli*' last from October to December and the 'long rains' or '*Masika'* extend from March through June (the wet season). A dry season (July-September) separates the 'short rains' and 'long rains' and is characterised by the lack of precipitation. The wet and the dry seasons can be distinguished due to the passage of the inter-tropical convergence zone, with the north-east East-African monsoon between March and October, and the south-east East-African monsoon between October and March (Trewartha, 1961).

Morogoro experiences a sub-humid tropical climate characterised by an annual average rainfall of 870 mm, which ranges between 610 and 1180 mm. It has a mixture of cool and warm temperature, ranging between 16 and 28 °C in the cold dry season and 21 and 31 °C in the warm wet season. The average relative humidity is 63–88% in March through May (the wet season) and 46–82% from July to September (the dry season). The annual mean temperature is 25 °C and the relative humidity is, on average, 80% in the morning and 61% in the afternoon. As for the study period Table 1 shows the measured meteorological parameters.

Table 1: Average (or total amount) of meteorological parameters and ranges during the study periods.

Parameter	Minimum	Maximum	Total/Mean
2005 wet season			
Precipitation (mm)	0	3.3	6.2
Relative humidity (%)	73	87	81 ± 4
Temperature (^{o}C)	23	26	25 ± 0.8
Wind speed (m/s)	0	1.6	0.5 ± 0.5
Pressure (mmHg)	953	956	955 ± 0.9
2005 dry season			
Precipitation (mm)	0	0.23	0.23
Relative humidity (%)	50	86	69 ± 11
Temperature (^{o}C)	21	25	23 ± 6
Wind speed (m/s)	0	3.6	1.3 ± 1.0
Pressure (mmHg)	956	960	958 ± 0.97
2006 wet season			
Precipitation (mm)	0	39	248
Relative humidity (%)	72	90	83 ± 5
Temperature (^{o}C)	21	27	26 ± 1.2
Wind speed (m/s)	0	2.5	0.6 ± 0.5
Pressure (mmHg)	950	954	952 ± 0.95

Since meteorological conditions influence the aerosol PM concentration, the wet (March - May) and the dry (July - September) seasons were investigated separately. Data for precipitation, temperature and relative humidity (Figure 1) are given for all days of the years because the atmospheric aerosol levels are highly controlled by the relative humidity and precipitation of the days before sampling. The average values for temperature and wind speed are presented only for the days were Mkoma et al., (2009, 2010 a,b) did aerosol sampling (Fig. 2). It can be observed from Figure 1 that there is a seasonal cycle of local precipitation, however, the 2005 wet season was rather dry. The local ambient temperature also exhibited a seasonal cycle with highest temperatures during the wet season and lowest temperatures during the dry season.

Air Mass Climatology: Measurements of the ambient PM and its constituents, whether as part of a long-term monitoring or of a short-term intensive sampling, show that concentrations vary on time scales from days to years. Some of these variations can be related to seasonal changes in the transport of the chemical constituents or their precursors and seasonal variation in meteorological parameters. But the daily variability is closely related to the immediate history of the air before arriving at the sampling site. Therefore the origin of the sampled air is one of the approaches for the categorisation of the measured data to understand the different processes which contribute to the changes in aerosol chemical composition. The approach relies on some measure of the direction and past history of the air mass arriving at the sampling site.

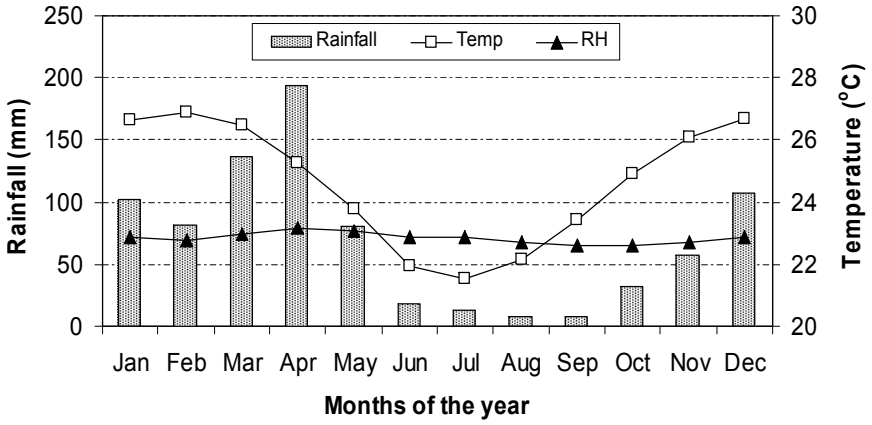


Figure 1: Relative humidity (RH, in %) and precipitation (mm) recorded for all days in 2005 and 2006 in Morogoro.

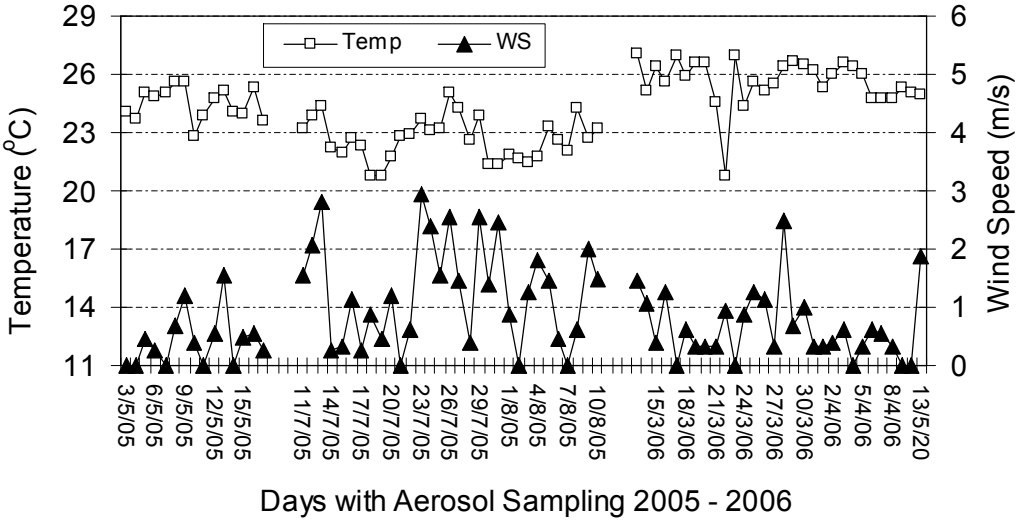
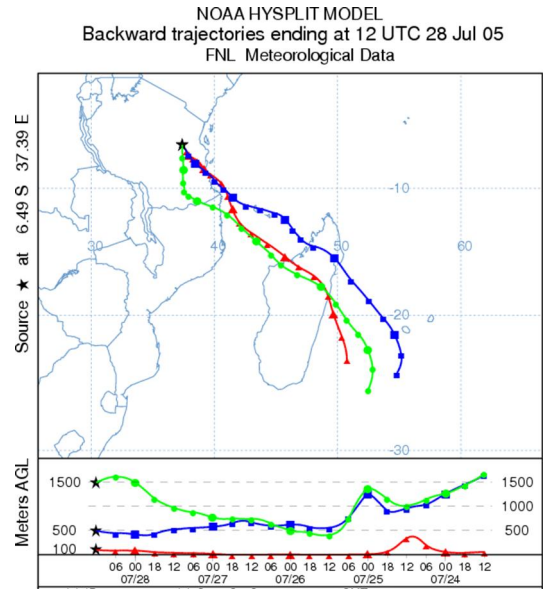


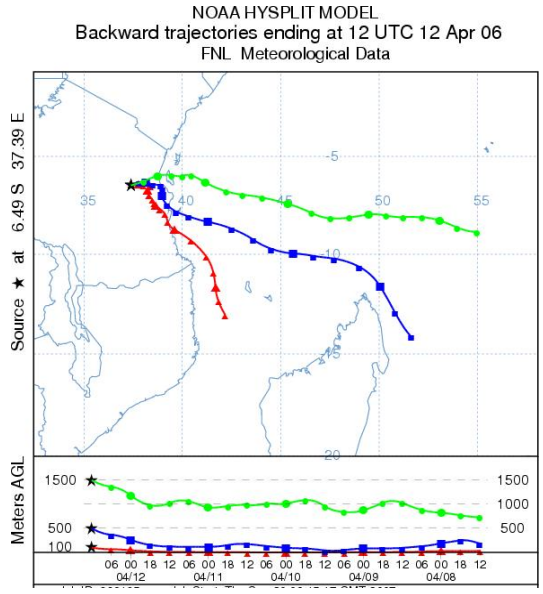
Figure 2: Daily average temperature (^{o}C) and wind speed (m/s) recorded for days with aerosol sampling.

Air masses during their motion can be loaded with particles and gases from natural and anthropogenic sources. Backward air mass trajectories are useful to determine possible sources of aerosol particles and have been successfully used in the field of aerosol science (Brankov et al., 1998). To examine the effect of long-range transported air masses on PM and aerosol components, air mass back trajectory analyses were performed daily during the study periods (May 2005 – May 2006) using the Hybrid Single-Particle Lagrangian Integrated Trajectory model (HYSPLIT version 4) (Draxler and Rolph, 2003) utilizing the Final Model Run (FNL) meteorological data set. Five-day isentropic backward trajectories were computed for arrival levels of 100, 500, and 1500 m above ground level (agl) at 00:00 and 12:00 UTC arrival times for night and daylight periods, respectively.

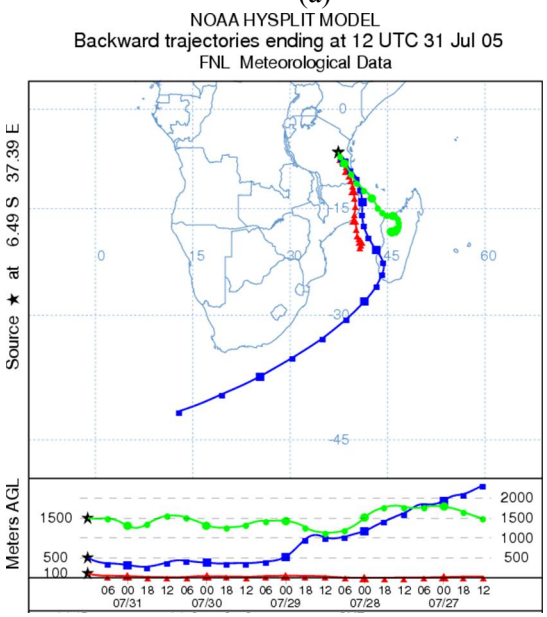
The daily air mass back trajectories for Morogoro were categorized into four different sectors at the arrival levels of 100, 500, and 1500 m agl (Figure 3). The allocated sectors were T1 (Oceanic); T2 (Oceanic, over Madagascar); T3 (Madagascar and/or oceanic over continental, mainly through Mozambique and Tanzania) and T4 (Continental, over Tanzania, Mozambique, South Africa). Allocation to a particular sector was made using criteria similar to those used by Traub et al. (2003). It was observed that there was a fair similarity between the four defined sectors for each of the three arrival levels for the 2005 dry season and 2006 wet season campaigns, but that there is a substantial difference for the 2005 wet season, with T3 clearly most common at Morogoro.



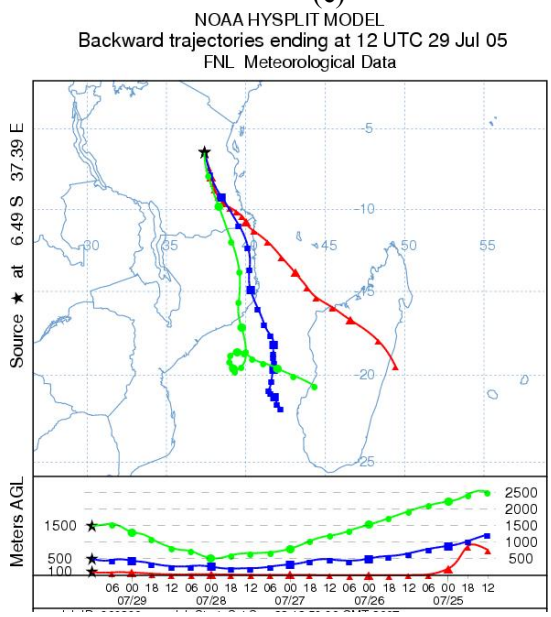
(a)



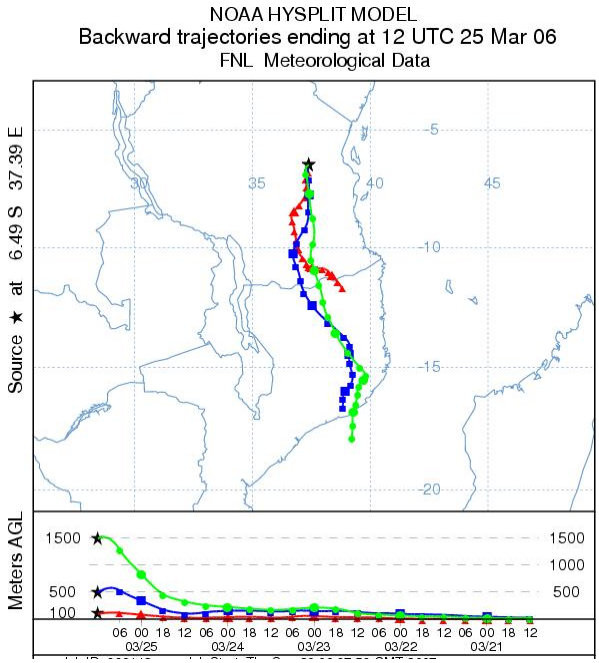
(e)



(b)



(d)



(c)

Figure 3: Typical examples of five-day back trajectories for air masses arriving at Morogoro during the sampling campaigns. In (e) mainly oceanic origin-T1; (a) oceanic origin over Madagascar-T2; (b) and (d) oceanic or Madagascar origin over continental-T3; (c) Continental origin-T4.

3.2 Impact of meteorology on the PM mass

Studies have indicated that the PM10 mass concentrations in the ambient air are affected by various meteorological factors such as temperature, wind speed, rainfall, and relative humidity (Bardouki et al., 2003). In Morogoro the daily average wind speed observed during the study period ranged from 0.0 to 3.6 m/s and winds were predominantly blowing from the south-east. The daily average temperature ranged from 14 °C to 31 °C. The daily mean relative humidity ranged from 50% to 90%, with the lower value typically recorded in the dry season. The cumulative precipitation varied from nearly zero during the 2005 wet and 2005 dry seasons to 248 mm during the 2006 wet season. The relationship between PM10 mass for Morogoro and meteorological parameters were examined. The concentration for PM10 mass for different seasons in Morogoro have reported by Mkoma et al., (2009; 2010a,b). Higher concentrations of the PM10 mass were observed during the 2005 dry season and the lowest median concentration during the 2006 wet season. The variations in ambient PM10 levels observed during the different seasons resulted from variations in sources strengths and in meteorological conditions, such as mixing height and precipitation. But the high aerosol levels during the 2005 dry season at the site may be also attributed by the arrival of the air masses that originated mainly from the southern African subcontinent (see trajectories Figs. 3c).

Relationship with Precipitation: The PM10 mass concentration was systematically low during precipitation events (Figure 4). It never exceeded 20µg/m^3 when the daily precipitation was higher than 5 mm.

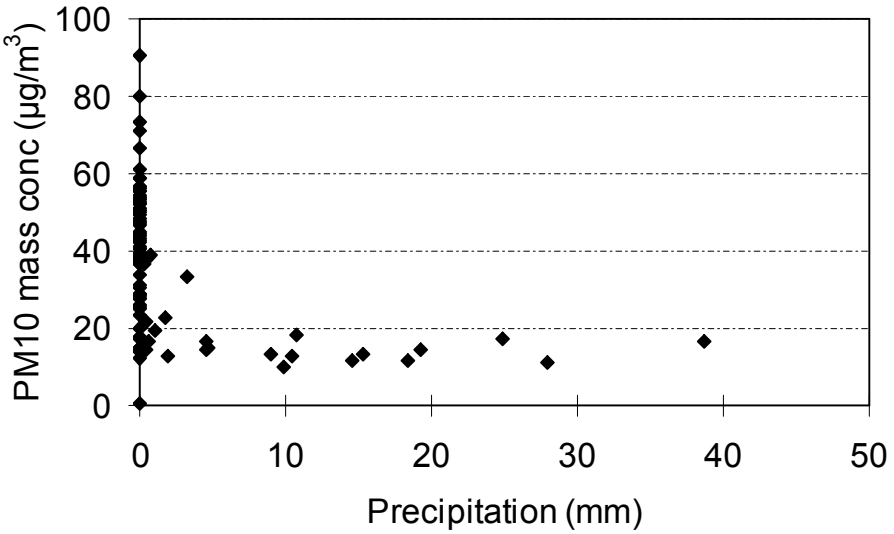


Figure 4: Relationship between PM10 mass and total daily cumulative precipitation

Relationship with Temperature: The variation of PM10 mass concentration with temperature is shown in Figure 5. The concentrations were higher at low temperatures (below about 24 °C) and high temperature (above about 27 °C), and reached a minimum for temperatures between 24 and 27 °C. One could make a number of assumptions to explain this observation. The rise in concentration at low temperatures could be due to more frequent inversion events. The altitude of the site (526 m above sea level), as well as the morphology of the foothill of the Uluguru Mountain ranges, make that the site is rather sensitive to the phenomenon of temperature inversion. The higher PM10 mass concentrations at higher temperatures might be caused by more intense formation of secondary aerosols.

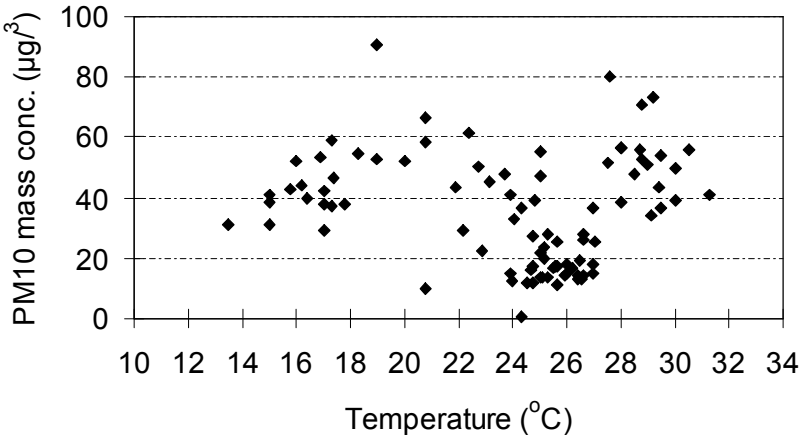


Figure 5: Relationship between PM10 mass and daily mean temperature

Relationship with Wind Speed: The influence of the wind speed (Figure 6) is less clear than that of the meteorological parameters discussed above. Low wind speeds inhibit dilution whereas large wind speeds lead to increased soil dust mobilisation. It seems that the effects of decreased dilution and increased soil dust mobilisation were roughly of equal importance.

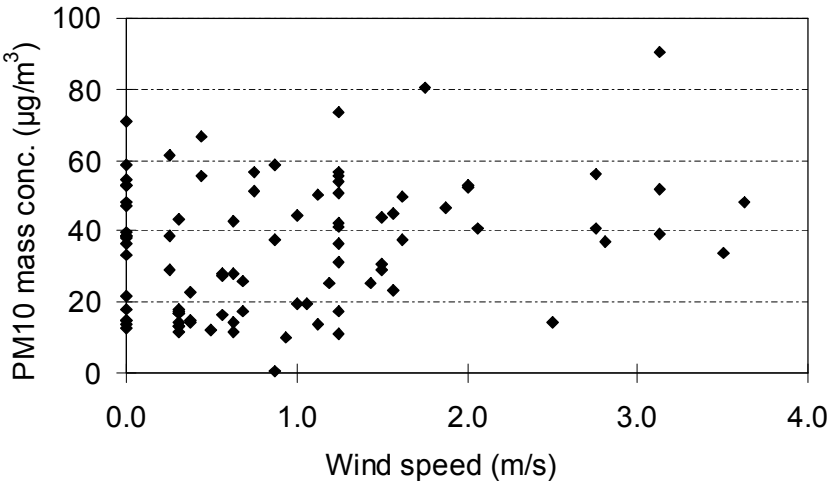


Figure 6: Relationship between PM10 mass and daily mean wind speed

4. Conclusion

This paper provides the first discussion of the influences of meteorology on aerosol concentrations data for the different seasons in Tanzania. The influence of the meteorological parameters on the air quality of Morogoro Municipality was investigated during the dry and wet seasons of 2005 and 2006. Differences on the atmospheric particles levels between the dry and the wet seasons can be attributed to the differences in meteorological conditions. In order to obtain a better picture, other studies along the same lines in several other parts of the country are needed.

5. Acknowledgements

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