Identification of Indoor and Outdoor Particulate Concentration and its Chemical Composition in Kathmandu Valley

A.Manandhar[b], S.C.Lee[a], K.F.Ho[a] , W.T Hung[a] , G.R.Joshi[b] ,P.KC[b]

a. Dept. of CSE, The Hong Kong Polytechnic University, Hong Kong

b. Clean Energy Nepal/Clean Air Network Nepal, Nepal

ABSTRACT

The indoor and outdoor particulate concentration and its chemical composition in six monitoring stations and selected residential dwellings were studied in May 2010 in Kathmandu valley. The six stations were strategically located to measure the air quality of the valley viz. -urban roadside, urban hospital, urban residential, urban background and valley background. Particulate concentration was collected for 12 hours from 8 am to 8 pm. The outdoor PM_{10} concentrations at the urban roadside, urban hospital and urban residential stations were found to be higher. The PM_{10} concentrations at the urban roadside station exceeded the National Ambient Air Quality Standard (NAAQS). The indoor PM_{10} concentrations in the urban background and valley background stations were higher due to burning of biomass for cooking. Except for urban roadside station, the I/O ratios for all the sites were greater than 1 which indicates the presence of indoor sources. The average outdoor organic carbon (OC) and elemental carbon (EC) were 30.1 μg/m^3 and 11.1 μg/m^3 respectively. OC and EC were correlated (R^2= 0.88, outdoors), likely indicating common sources for both species, as well as for the precursors that led to the formation of secondary organic carbon (SOC). The highest average outdoor calcium ion (Ca^+) concentration of 22.5 μg/m^3 at the urban roadside station indicates the presence of suspended roadside dust particles. High concentrations of Potassium ion (K^+) observed in the urban and valley background stations (8.5 μg/m^3 and 8.3 μg/m^3 respectively) show the excessive use of biomass burning.

Keywords: Particulate Matter; Carbonaceous aerosol; Water soluble ion; six monitoring stations

Contact Details: Anjila Manandhar, Clean Energy Nepal/Clean Air Network Nepal, 140 Bulbule Marga, Thapagaun, Kathmandu, Nepal. Telephone: 977-1-4464981. Email: anjila@cen.org.np

1. INTRODUCTION

Air pollution is considered to be one of the serious and prominent types of environmental pollution that is prevalent in most industrial towns and cosmopolitan cities of the world. It had been a general impression in the past that air pollution is exclusively a problem of the industrially developed nations; however, recent studies have shown that air pollution is a growing problem in developing countries as well, and hence, attention should be paid to this evil before it is too late.

Nepal, a relatively small country with 147, 181 sq km area inhabited by 22 million people, is known for exquisite environment. However, the real scenario is quite different because urban areas are environmentally degrading due to rapid unplanned urbanization and industrialization. Kathmandu, the capital of Nepal, has a land area of 395 km^2, a rapidly increasing population of 1.08 million, and a vehicle usage rate that is growing by approximately 10 percent per year (CBS, 2005; Faiz et al., 2006).

The valley is especially vulnerable to air pollution due to an exploding population inflow, rapid urbanization, valley centric industrialization and significant increase of vehicular transport in narrow streets. Furthermore, the bowl like topography of the valley restricts wind movement and retains the pollutants in the atmosphere. This is especially bad during winter season when thermal inversion persists. Cold air flowing down from the mountains is trapped under a layer of warmer air and acts as a lid. As a result, the pollutants are kept within the valley.

The main problem in Kathmandu's air quality is the high concentration of particulate matter. Among the major air pollutants released to the atmosphere, suspended particulate is considered as one of the major health impact and therefore numerous studies have been undertaken especially in developing countries in the last decade. In recent years, particulate matter has been recognized as the most dangerous and widely spreaded air pollutant. WHO, the U.S. Environmental Protection Agency, the Europe Union and many other international agencies choose particulate matter as an indicator of air pollution when evaluating the health impact of air pollution on human.

According to an inventory conducted by Environment Sector Program Support (ESPS) in 2001 and World Bank in 1997, there has been a 60 percent increase in the PM_{10} over the past five years or so. The main cause of this increase is the remarkable increase in the number of vehicles. The World Health Organization (WHO) estimates that ambient air pollution causes over half a million premature deaths in Asia per year, leaving the

Contact Details: Anjila Manandhar, Clean Energy Nepal/Clean Air Network Nepal, 140 Bulbule Marga, Thapagaun, Kathmandu, Nepal. Telephone: 977-1-4464981. Email: anjila@cen.org.np

urban poor particularly vulnerable since they live in air pollution hotspots, have low respiratory resistance due to bad nutrition, and lack of access to quality health care. Estimates by the Ministry of Environment, Science and Technology in 2005 showed that ambient air pollution is responsible for the premature deaths of 1600 people per year in Kathmandu Valley.

Vehicle emission is a major source of air pollution in Kathmandu. This is mainly because of the large number of vehicles on congested streets, poor quality vehicles, poor quality fuels and weaknesses in the emission inspection system. Due to unmanaged urban development, infrastructure, a growing number of vehicles, polluting industries and population growth, Kathmandu's air is getting dirtier day by day. The concentration of particulate matter in the ambient air is already several times higher than WHO guidelines and increasing. This growing air pollution is having an adverse impact on human health and the economy of the Valley. About NRs. 3, 00, 00000 (30 million) of hospital costs every year could be saved by reducing Kathmandu's PM_{10} level to meet World Health Organization (WHO) guideline values. (The Clean Energy Nepal/Environment and Public Health Organization, 2003)

Indoor air quality on the other hand has generally gained great attention in rural areas in recent years. According to WHO comparative risk study 28 percent of all deaths is caused by indoor air pollution in developing countries. Jerkins et.al (1992) showed that urban people spend on average 87 percent indoors and only a mere 6 percent outdoors. The study efforts in North America and Europe have included indoor as well as outdoor environments. The study has shown that pollutants emitted from building materials, consumer products, tobacco, and appliances using gas or kerosene may degrade air quality in residence and other buildings. Exposure to pollutants indoors may pose a greater health risk than exposure outdoors: individuals typically spend about 80-90 percent of their time indoors, and peak concentrations of some pollutants in buildings often exceed ambient levels.

Due to the fact that the air pollution has become a major environmental issue in Kathmandu, there have been some efforts for the air quality management. In 2002, Ministry of Population and Environment established six permanent air quality monitoring stations in Kathmandu Valley. It is the only air quality monitoring system in Nepal. These stations monitor daily PM_{10} concentrations; & other key parameters such as sulphur dioxide (SO_2), oxides of nitrogen (NO_X), benzene, lead, polycyclic aromatic hydrocarbons (PAH) are monitored through passive samplers and such monitoring is not carried out on a regular basis.

Contact Details: Anjila Manandhar, Clean Energy Nepal/Clean Air Network Nepal, 140 Bulbule Marga, Thapagaun, Kathmandu, Nepal. Telephone: 977-1-4464981. Email: anjila@cen.org.np

However, due to erratic power cuts, the six monitoring stations are defunct since mid 2008. After the machine broke down, air quality in the Valley remains unknown. The machines are not equipped with alternative backup system to cope with the load-shedding, thus, they are not functioning. Besides, there have been very few indoor and outdoor air pollution studies in Kathmandu valley. Therefore, the main objective of the study is to supplement the data deficiency through analyzing indoor and outdoor air quality at six sites located at strategic locations of the Kathmandu valley. The results of this study hopefully may help government officials in their efforts to improve policies regarding air pollution control in the city.

2. MATERIALS AND METHODS

2.1 Study Area

The sampling sites were identified by group of experts after rigorous procedure for collecting air samples representative of Kathmandu Valley's air quality. The monitoring stations are located strategically to capture the typical micro-environments in the valley viz. -urban roadside place (Putalisadak), urban hospital place (Patan Hospital), city core residential place (Thamel), urban background place (Tribhuvan University, TU and Bhaktapur) and valley background location (Matsyagaon).

Among the six sites, Putalisadak, Thamel and Patan Hospital are in the city core area with large commercial buildings and heavy vehicular traffic. Tribhuvan University (TU) is close to the urban center in Kathmandu but located in outskirts. Matsyagaon, a valley background station is close to the urban background station in TU, Kritipur. Bhaktapur is a different city about 13 km towards east from Kathmandu, however within the valley precincts. The general description of the area and the type of fuel used in the surveyed residential building are shown in the table below.

Sampling Sites	**Area Type**	**Type of Cooking fuel used**	**Level of the building from the ground**
Thamel	Urban Residential	LPG Gas	Third floor
Putalisadak	Urban Roadside	No cooking	Fifth floor
Patan	Urban Hospital	No cooking	Second floor
Tribhuvan University	Urban Background	No cooking	Second floor

Contact Details: Anjila Manandhar, Clean Energy Nepal/Clean Air Network Nepal, 140 Bulbule Marga, Thapagaun, Kathmandu, Nepal. Telephone: 977-1-4464981. Email: anjila@cen.org.np

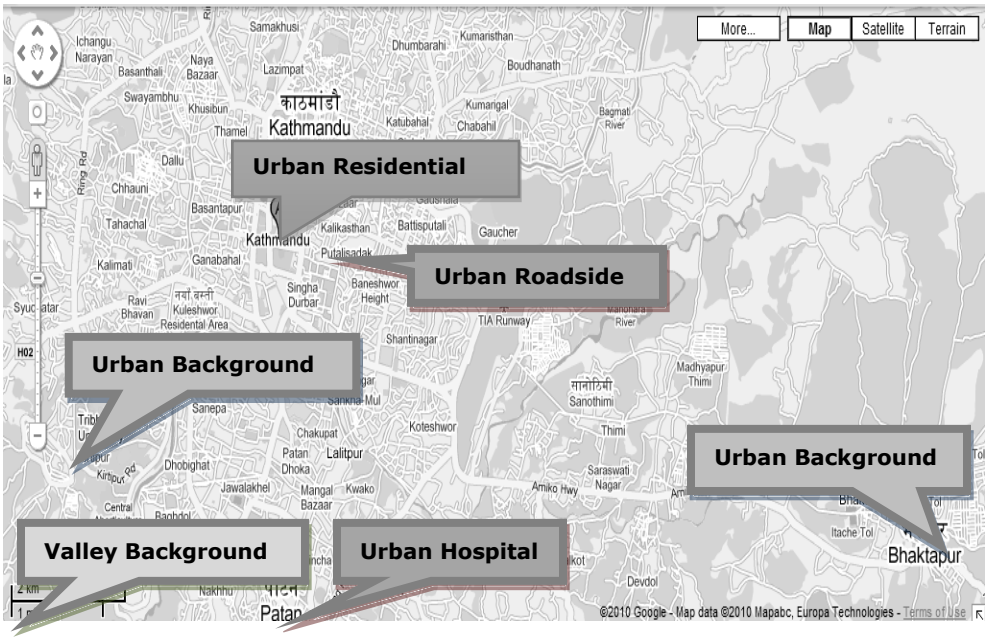
Bhaktapur	Urban Background	Fuel wood	Roof top of two storey building
Matshyagaon	Valley Background	Fuel wood	Ground Floor

2.2 Sampling and Analysis

Indoor and outdoor air samples were collected from six sites and six residential buildings which represent predominant urban areas associated with high, medium and, low human activities. Sampling was conducted in the month of May 2010, just a starting of the monsoon period. Indoor and outdoor air samples were collected simultaneously for 12 hours starting from 8 am in the morning to 8 pm in the evening to catch pollutants at the highest peak hours. The samples were collected continuously for two days in each location. During sampling floor/height of the building and cooking fuel type were also recorded.

The air sampling locations, both indoor and outdoor, were at the respiratory level (i.e., 1.5 m above the ground). Particulate matter was measured using TSI Dust Trak at 1 minute interval for 12 hours (8am to 8pm).

Map Showing sampling sites in Kathmandu Valley



Contact Details: Anjila Manandhar, Clean Energy Nepal/Clean Air Network Nepal, 140 Bulbule Marga, Thapagaun, Kathmandu, Nepal. Telephone: 977-1-4464981. Email: anjila@cen.org.np

The PM_{10} samples were also taken with two collocated Mini Volume PM portable air samples (Model-3156, Airmetrics) for 12 hours operated at 5.0 liter/min. The particles were collected on 47mm quartz fiber filters (QMA, Whatman International Ltd., Maid-stone, England). In order to remove carbonaceous contaminants, the filters were heated in air at 500 ºC-800 ºC for 4 hours, kept in a room at 20 ºC and 50% relative humidity for 48 hours, and then weighed 2-3 times before use. Filters were transferred to petri dishes so as to avoid contaminations and kept in desiccators at 20 ºC and 50% relative humidity before shipping them to Nepal. The filters used for gravitational sampling was kept in the refrigerator with petri dish in 4 ºC before and after sampling in Kathmandu. Similar procedures were applied after transporting the samples to the laboratory in the Hong Kong Polytechnic University for analysis. The blank and actual sampled filters were weighted at least three times using an electronic micro-balance (Model A200 S-DIB, Sartorius Ltd.).

2.3 Particulate Matter Analysis

2.3.1 Carbonaceous aerosol analysis

All the loaded filters were analyzed for Organic Carbon (OC) and Elemental Carbon (EC) using a DRI Model 2001 Thermal/Optical Carbon Analyzer. The IMPROVE thermal/optical reflectance (TOR) protocol (Ho et al., 2001; Chow and Watson, 2002) was used for the carbon analysis. The protocol heats a 0.526 cm^2 punch aliquot of a sample quartz filter stepwise at temperatures of 120 ºC (OC1), 250 ºC (OC2), 450 ºC (OC3), and 550 ºC (OC4) in non-oxidizing helium (He) atmosphere, and 550 ºC (EC1), 700 ºC (EC2), 800 ºC (EC3) in an oxidizing atmosphere of 2% oxygen in a balance of helium. The carbon that evolves at each temperature is oxidized to carbon dioxide (CO_2), and then reduced to methane (CH_4) for quantification with a flame ionization detector. As the temperature increases in the inert helium, some of the OC pyrolyzes to black carbon, resulting in darkening of the filter deposit. This darkening is monitored by the reflectance of 633 nm light from a He-Ne laser. When oxygen is added, the original and pyrolyzed black carbon combusts and the reflectance increases.

The amount of carbon measured after oxygen is added until the reflectance achieves its original value is reported as Optical Pyrolyzed Carbon (OPC). The eight fractions OC1, OC2, OC3, OC4, EC1, EC2, EC3 and OPC are reported separately in the data sheet. The IMPROVE protocol defines OC as OC1+OC2+OC3+OC4+OPC and EC as EC1+EC2+EC3-OPC. The analyzer was calibrated with known quantities of Methane (CH_4) every day. Replicate analyses were performed at the rate of one per group of 10 samples. The detection limits

Contact Details: Anjila Manandhar, Clean Energy Nepal/Clean Air Network Nepal, 140 Bulbule Marga, Thapagaun, Kathmandu, Nepal. Telephone: 977-1-4464981. Email: anjila@cen.org.np

for Elemental Carbon (EC) and Organic Carbon (OC) were below 1.0 μg/m^3 (about 0.2 μg/m^3 for Elemental Carbon(EC) and 0.5 μg/m^3 for Organic Carbon (OC). The repeatability determined from analyses was better than 5 % for total carbon (TC) and 10 % for Organic Carbon (OC) and Elemental Carbon (EC) (Cao et al., 2003).

2.3.2 Water-soluble ion analysis

Quarter sections of the filters were extracted by using 10 ml of ultra-pure water (specific resistance ≥18.1 MΩ cm). The extraction solutions were filtered and stored in plastic vials in the refrigerator at 4º C until chemical analysis. Water-soluble ions were measured using ion chromatography (DIONEX 500) with an electrochemical detection (DIONEX ED40). Uncertainties were ±6% for ions of Chlorine (Cl^-) and were ±12% for Nitrate (NO_3^-), Sulfate (SO^{2-}_4) and Ammonium ion (NH^+_4).

3. RESULTS AND DISCUSSION

3.1 Indoor and Outdoor Particulate Matter concentrations

The study presents the indoor and outdoor concentrations of particulate matter less than ten micron within the Kathmandu Valley. Figure 1, Table 1 and Table 2 summarize the results of indoor and outdoor particulate matter concentration in six different locations with high, medium and low human activities. Indoor PM_{10} concentrations varied from 103.6 μg/m^3 in the urban roadside station (Putalisadak) to 373.1 μg/m^3 in the urban background (Bhaktapur). The outdoor PM_{10} concentrations varied from 60.6 μg/m^3 in valley background station (Matshyagaon) to 199.2 μg/m^3 in urban roadside station (Putalisadak). The indoor concentrations in the urban roadside station (Putalisadak) was lower however the outdoor concentration was higher compared to the other stations (Urban Residential and Urban Hospital) with large commercial buildings and vehicular traffic congestion. This shows the predominant effects of vehicular emission. This was the tallest building among the other two buildings. PM_{10} concentration decreases with increasing vertical height (Lee et al., 1999).This could be explained by the fact that major sources of PM_{10} were from the ground level rather than at higher levels. Therefore, vehicle exhaust and other sources like re-suspension dust are the major sources of outdoor pollution in the urban roadside station.

Contact Details: Anjila Manandhar, Clean Energy Nepal/Clean Air Network Nepal, 140 Bulbule Marga, Thapagaun, Kathmandu, Nepal. Telephone: 977-1-4464981. Email: anjila@cen.org.np

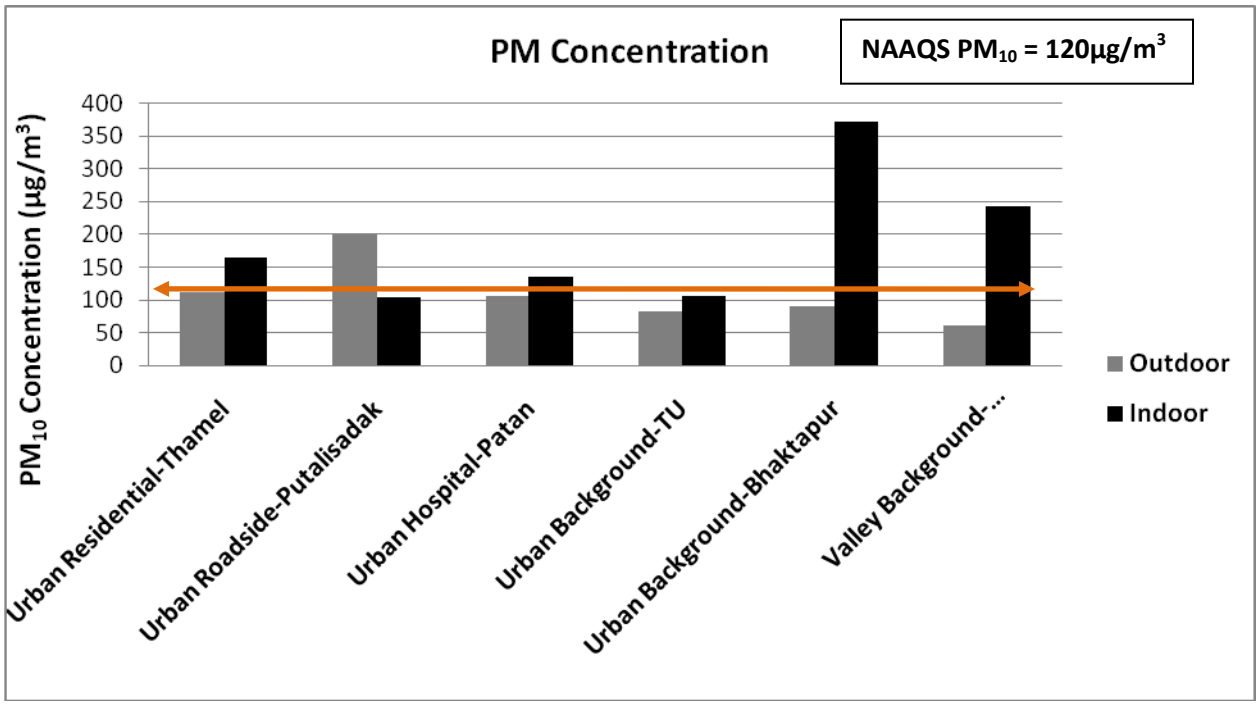


Figure 1: Indoor and Outdoor PM_{10} Concentration

The indoor concentration was higher in the urban residential building than urban roadside and urban hospital station. The possible reason is cooking during the sampling period. The LPG gas was used for cooking in a particular site however no cooking activities were done in the other two sites. The indoor concentration in urban background (Bhaktapur) and valley background (Matshyagaon) was found to be extremely high with 373.1 µg/m^3 and 243.6 µg/m^3 respectively. The major reason is the biomass burning for cooking. Only these two residential buildings used biomass for cooking during the sampling, leading to higher indoor concentration of particulate matter. However, the outdoor concentrations are lower compared to the heavily trafficked areas which exceeded the National Ambient Air Quality Standard (NAAQS).

Contact Details: Anjila Manandhar, Clean Energy Nepal/Clean Air Network Nepal, 140 Bulbule Marga, Thapagaun, Kathmandu, Nepal. Telephone: 977-1-4464981. Email: anjila@cen.org.np

Table 1: The average indoor and outdoor Particulate Matter concentration in different sites in Kathmandu Valley (I=Indoor, O=Outdoor)

Sites	Outdoor PM_{10} concentrations Ranges (µg/ m^3)	Average Outdoor PM_{10} concentrations (µg/m^3)	Indoor PM_{10} concentrations Ranges (µg/ m^3)	Average Indoor PM_{10} concentrations (µg/m^3)
Urban Residential-Thamel	107.8-114.4	111.1±9.4	162.2-167.8	165.0±7.9
Urban Roadside-Putalisadak	185.6-212.8	199.2±38.5	93.3-113.9	103.6±29.1
Urban Hospital-Patan	58.9-151.7	105.3±131.2	132.2-138.9	135.6±9.4
Urban Background-TU	76.1-87.8	81.9±16.5	102.2-108.9	105.6±9.4
Urban Background-Bhaktapur	61.1-117.8	89.4±80.1	256.1-490.0	373.1±330.8
Valley Background-Matshyagaon	47.8-73.3	60.6±36.1	83.3-403.9	243.6±453.3

Table 2: The differences between Indoor and Outdoor particulate matter

Sites	I/O Ratio Ranges	Average I/O Ratio
Urban Residential-Thamel	1.5-1.5	1.5±0.1
Urban Roadside- Putalisadak	0.5-0.5	0.5±0.05

Contact Details: Anjila Manandhar, Clean Energy Nepal/Clean Air Network Nepal, 140 Bulbule Marga, Thapagaun, Kathmandu, Nepal. Telephone: 977-1-4464981. Email: anjila@cen.org.np

Urban Hospital- Patan	0.9-2.4	1.6±2.1
Urban Background- TU	1.2-1.3	1.3±0.1
Urban Background- Bhaktapur	4.2-4.2	4.2±0.04
Valley Background- Matshyagaon	1.7-5.5	3.6±7.3

The indoor/outdoor (I/O) ratio is an indicator for evaluating the differences between indoor and outdoor levels, and their correlation. The indoor and outdoor correlation can be used to imply a source relationship between indoor and outdoor environments (Lee et al., 1999). When average I/O ratio is less than or equal to 1, the sources of PM_{10} come from outdoors, especially from diesel motor vehicle exhaust (Lee et al., 1999). The study result showed that only in the urban roadside station (Putalisadak), the I/O ratio is less than 1 which is from the outdoor source. The remaining five sites however has I/O ratio greater than 1 which indicate that there is some sources indoor.

3.2 OC and EC concentrations in indoor and outdoor environments

The average indoor and outdoor Organic Carbon (OC) and Elemental Carbon (EC) concentrations in PM_{10} as well as the ratios of Organic Carbon to Elemental Carbon (OC/EC) and Indoor to Outdoor (I/O) ratios of Organic Carbon and Elemental Carbon in the six monitoring stations in Kathmandu valley are shown in table 3. (The average I/O and OC/EC ratios were calculated by averaging I/O ratios or OC/EC values of all corresponding samples).The average outdoor total carbon (TC) was 41.2 $\mu g/m^3$ and the average indoor total carbon concentration was 72.9 $\mu g/m^3$.

The outdoor OC concentration ranged from 16.85 $\mu g/m^3$ to 57.82 $\mu g/m^3$ and the outdoor EC concentration ranged from 4.11 $\mu g/m^3$ to 32.56 $\mu g/m^3$ .The average outdoor Organic Carbon and Elemental Carbon concentration were found to be 30.1 $\mu g/m^3$ and 11.1 $\mu g/m^3$ respectively which is higher compared to those measured during winter in other urban Asian cities. Average OC and EC during winter of 2005 in Guangzhou, China, were 23.9 $\mu g/m^3$ and 4.2 $\mu g/m^3$ and in Hong Kong were 12.4 and 2.5 $\mu g/m^3$, respectively (Duan et al., 2007), and during winter of 2006 in Xian, china were 23.7 and 4.6 $\mu g/m^3$, respectively (Shen et al., 2009). Carrico et al. (2003) observed EC of 1.0± 0.7 during October 1999 to January 2000 in Nagarkot, a site inside Kathmandu valley that is approximately 20 kilometers from the sites of the current study.

Contact Details: Anjila Manandhar, Clean Energy Nepal/Clean Air Network Nepal, 140 Bulbule Marga, Thapagaun, Kathmandu, Nepal. Telephone: 977-1-4464981. Email: anjila@cen.org.np

Similarly, the indoor OC concentration ranged from 16.21 μg/m^3 to 187.38 μg/m^3 and the indoor EC concentration ranged from 4.23 μg/m^3 to 82.02 μg/m^3 . The PM_{10} chemical composition is dominated by organic carbon (OC) in both the indoor and outdoor environment of Kathmandu.

The highest average indoor and outdoor Organic Carbon (OC) concentrations were observed in Matshyagaon, valley background station with 103.7 μg/m^3 and Putalisadak, urban roadside station with 54.6 μg/m^3 respectively. The highest average indoor and outdoor Elemental Carbon (EC) concentrations were observed in Bhaktapur, urban background station (54.9 μg/m^3) and in Putalisadak, urban roadside station (30.2 μg/m^3) respectively.

The highest average indoor OC and EC concentrations were observed in two homes in Matshyagaon, valley background station and Bhaktapur, urban background station. Similar trends were also seen in the case of PM_{10} concentration and this is due to burning of firewood for cooking in these two respective houses during the sampling period. In the urban roadside station, Putalisadak, the average outdoor OC and EC concentrations were higher which is consistent with particulate concentration due to high vehicular exhaust.

In general, OC to EC ratios depend on emission sources and secondary organic aerosol formation. OC/EC ratios exceeding 2.0 (Chow et al., 1996) or 1.1 (Castro et al., 1999) have been used to indicate the presence of secondary aerosols. Hildemann et al.(1991) found that OC/EC in fine particles of 2.2 for light-duty gasoline vehicles and 0.8 for heavy-duty gasoline vehicles. The average OC/EC ratios varied from 2.70 μg/m^3 in the outdoor to 2.86 μg/m^3 in the indoor environment. Cao et al. (2005) found an average OC/EC ratio of 4.1 for vehicle exhaust, a value close to that observed in most stations in Kathmandu. Thus, the common source is most likely vehicular emissions. The variation of OC/EC during the sampling period and the values larger than 3.01 indicate the importance of secondary OC, assuming no fluctuations in emission ratios. Emission from vehicles appears to be one of the most important sources of aerosols. Kondo et al. (2005) also concluded that the transportation-related emissions are the main sources of air pollution in Kathmandu valley, which is further corroborated by the observations of Panday and Prinn (2009) that showed peaks in concentrations of PM_{10} during the mornings from 2004 to 2005. The strong relation between OC and EC (R^2= 0.88 in outdoor environment) and (R^2= 0.89 in the case of indoor) indicate that any secondary OC likely was derived from volatile organic compounds co-emitted with primary OC and EC.

Contact Details: Anjila Manandhar, Clean Energy Nepal/Clean Air Network Nepal, 140 Bulbule Marga, Thapagaun, Kathmandu, Nepal. Telephone: 977-1-4464981. Email: anjila@cen.org.np

Table 3: The average concentration of OC and EC as well as OC/EC and I/O ratios in different indoor and outdoor environments of Kathmandu

Sites		OC Conc. Range	OC Conc. (µg/m3)	EC Conc. Range	EC Conc. (µg/m3)	OC/EC	I/O Ratios OC	I/O Ratios EC
Urban Residential-Thamel	Indoor	35.19-39.24	37.2±2.9	10.15-12.37	11.3±1.6	3.32±0.21	1.18±0.39	1.11±0.31
	Outdoor	27.03-39.04	33.0±8.5	9.35-11.41	10.4±1.5	3.16±0.38		
Urban Traffic-Putalisadak	Indoor	31.11-33.65	32.4±1.8	14.69-15.12	14.9±0.3	2.17±0.08	0.59±0.02	0.50±0.04
	Outdoor	51.31-57.82	54.6±4.6	27.93-32.56	30.2±3.3	1.81±0.04		
Urban Hospital- Patan	Indoor	20.23-26.47	23.3±4.4	6.27-11.86	9.1±4.0	2.73±0.70	1.00±0.12	0.64±0.91
	Outdoor	18.54-28.83	23.7±7.3	0-4.88	2.4±3.4	1.90±2.69		
Urban Background-TU	Indoor	16.21-21.23	18.7±3.5	4.23-6.90	5.6±1.9	3.45±0.53	0.93±0.23	0.68±0.27
	Outdoor	19.44-21.20	20.3±1.2	7.96-8.68	8.3±0.5	2.44±0		
Urban Background-Bhaktapur	Indoor	61.58-125.60	93.6±45.3	27.79-82.02	54.9±38.3	1.87±0.48	3.76±0.85	5.42±1.59
	Outdoor	19.50-28.85	24.2±6.6	6.48-12.54	9.5±4.3	2.66±0.50		
Valley Background-Matshyagaon	Indoor	20.07-187.38	103.7±118.3	4.91-60.10	32.5±39.0	3.60±0.69	3.46±3.21	4.65±4.89
	Outdoor	16.85-32.71	24.8±11.2	4.11- 7.42	5.8±2.3	4.25±0.22		
Average Indoor			51.5±37.2		21.4±18.9	2.86±0.72	1.82±1.40	2.16±2.24
Average Outdoor			30.1±3.4		11.1±1.4	2.70±0.91		

Contact Details: Anjila Manandhar, Clean Energy Nepal/Clean Air Network Nepal, 140 Bulbule Marga, Thapagaun, Kathmandu, Nepal. Telephone: 977-1-4464981. Email: anjila@cen.org.np

3.3 Water soluble ions in indoor and outdoor environments

The water-soluble ion analysis results using ion chromatography are shown in table 4. The highest average outdoor calcium ion (Ca^{+}) concentration of 22.5 µg/m^3 was found in the Putalisadak area, urban roadside station. This indicates the presence of suspended roadside dust particles. Yin et al. (2005), also pointed that fine calcium concentrations were higher in urban areas than in non-urban areas. Harrison et al., (2001) also explained that these results support the use of calcium as a marker for re-suspended materials with traffic contributing significantly to particle re-suspension in urban areas.

Potassium ion (K^{+}) was found in small concentrations in most of the indoor and outdoor environments in Kathmandu, however, very high concentrations of potassium ion (K^{+}) was found in the urban and valley background stations (8.5 µg/m^3 and 8.3 µg/m^3 respectively). Potassium ion (K^{+}), a tracer of biomass burning seems to have a great influence on aerosol mass loadings in indoor households in Kathmandu.

Carrico et al., 2003 reported that influence of dust transport inside Kathmandu valley from a Saharan region; however correlation of calcium ion (Ca^{2+}) with Magnesium ion (Mg^{2+}) is insignificant which suggests aerosols in Kathmandu is not from crustal sources.

Sulfate was significantly correlated with ammonium ion (NH_4^{+})(R^2= 0.90, p≤0.05). The average sulfate (SO^{-2}_4) concentration in Kathmandu (8.1 µg/m^3) was similar to the annual mean sulfate (SO^{-2}_4) observed in Seoul (8.70 µg/m^3) (Lee et al., 1999) and larger than in Nagarkot, Kathmandu valley (2.5 µg/m^3) (Carrico et al., 2003). This showed that ammonium ion (NH_4^{+}) was sufficient to neutralize the aerosols, which were most likely acidic in nature.

Contact Details: Anjila Manandhar, Clean Energy Nepal/Clean Air Network Nepal, 140 Bulbule Marga, Thapagaun, Kathmandu, Nepal. Telephone: 977-1-4464981. Email: anjila@cen.org.np

Table 4: The average concentrations of water soluble ions in PM10 in different indoor and outdoor environments in Kathmandu

Sites		Na^{+} ($\mu g/m^3$)	NH^{+}_4 ($\mu g/m^3$)	K^{+} ($\mu g/m^3$)	Mg^{+2} ($\mu g/m^3$)	Ca^{+2} ($\mu g/m^3$)	Cl^{-} ($\mu g/m^3$)	NO^{-}_3 ($\mu g/m^3$)	PO^{+}_4 ($\mu g/m^3$)	SO^{-2}_4 ($\mu g/m^3$)
Urban Residential-Thamel	Indoor	11.0±2.0	1.0±0.6	1.9±0.8	1.3±0.1	10.4±2.7	1.9±1.0	7.0±0.4	13.4±4.6	10.8±1.5
	Outdoor	9.3±1.3	1.3±0.7	1.3±0.4	1.2±0.1	10.7±0.4	1.4±0.5	7.9±1.7	6.8±0.5	8.7±3.3
Urban Roadside-Putalisadak	Indoor	8.8±0.9	0.3±0.0	0.8±0.1	1.2±0.0	10.5±0.3	1.4±0.3	5.2±0.7	14.0±3.1	6.0±1.4
	Outdoor	8.8±0.6	0.2±0.0	1.3±0.0	1.3±0.1	22.5±1.8	12±0.0	7.2±2.7	13.6±2.9	6.9±2.0
Urban Hospital-Patan	Indoor	11.0±2.3	0.4±0.4	0.9±0.2	1.0±0.3	9.1±1.7	2.0±1.5	5.9±1.8	16.2±5.4	7.2±4.8
	Outdoor	10.1±0.4	0.4±0.0	0.9±0.1	1.2±0.0	7.6±0.5	2.8±2.6	5.4±1.7	10.1±6.4	5.9±3.8
Urban Background-TU	Indoor	8.9±0.6	1.4±0.8	0.7±0.1	1.1±0.0	5.7±0.8	0.9±0.0	5.8±0.7	12.9±6.3	9.4±2.4
	Outdoor	9.9±0.7	1.7±0.6	1.0±0.1	1.3±0.2	7.6±0.0	1.3±0.6	7.4±0.6	13.0±1.0	12.8±0.9
Urban Background-Bhaktapur	Indoor	11.9±0.8	0.7±0.0	8.5±3.8	2.7±0.9	11.2±2.3	15.1±2.1	6.0±0.3	13.3±4.3	12.8±6.9
	Outdoor	9.3±1.0	0.3±0.3	1.2±0.1	1.1±0.0	6.6±0.4	1.6±0.4	5.1±0.6	10.8±3.6	7.3±2.3
Valley Background-Matshyagaon	Indoor	9.9±2.0	0.6±0.8	8.3±10.6	1.6±0.4	8.3±1.4	7.6±9.5	6.5±2.1	16.1±5.0	9.1±7.2
	Outdoor	9.1±0.3	0.5±0.5	1.3±0.5	1.4±0.1	7.7±0.2	1.7±0.7	5.5±1.5	16.1±6.5	7.0±2.0

Contact Details: Anjila Manandhar, Clean Energy Nepal/Clean Air Network Nepal, 140 Bulbule Marga, Thapagaun, Kathmandu, Nepal. Telephone: 977-1-4464981. Email: anjila@cen.org.np

4. CONCLUSION

Among the six monitoring stations located at the strategic locations in the Kathmandu valley, the highest outdoor particulate matter concentration was observed in the urban roadside station due to high traffic congestion. While the indoor concentration of particulate matter in the same station was lower because PM_{10} concentration decreases with increasing height. The height of the building at this station was the tallest among the other residential buildings. Vehicle exhaust and other sources like re-suspension dust are the major sources of outdoor pollution at the urban roadside station. The outdoor particulate concentration at the valley background station was found to be much lower. The indoor concentrations at the valley background and urban background station were found to be extremely high because of biomass burning for cooking. The study result illustrated that only in the urban roadside site; the I/O ratio is less than 1 which is from the outdoor source. The remaining five sites however has I/O ratio greater than 1 which is due to presence of indoor sources.

Correlation of Organic Carbon (OC) and Elemental Carbon (EC) (R^2= 0.88) in outdoor environment, large primary Organic Carbon (OC) contribution to carbonaceous aerosol and secondary Organic Carbon (OC) likely was derived from volatile organic compounds co-emitted with primary OC and EC. The average OC/EC ratio in outdoor environment (2.70 $\mu g/m^3$) imply vehicular emission is most common source of pollution in the valley. Ionic concentrations are approximately a factor of two smaller than those of organic carbon and are dominated by calcium ion (Ca^+) in outdoor samples and potassium ion (K^+) in the indoor which indicate the presence of suspended roadside dust particles and traces of biomass burning respectively. Biomass burning plays a significant role in aerosol emissions in indoor households in Kathmandu (Urban background and valley background station). The neutralization ratio indicated that the aerosols in Kathmandu are not acidic in nature, as ammonium ion (NH_4^+) was sufficient to neutralize the acidity in fine particles.

Kathmandu, the capital of Nepal, experiences a very high level of air pollution due to urbanization and being located inside a valley. Human health is adversely affected. Some good initiatives like banning of the polluting industries and vehicles were implemented but the effects are negligible compared to the magnitude of the problem. The results of this study revealed the indoor and outdoor particulate concentration and its chemical composition at six strategic locations and may hopefully help generate further air quality management programs to alleviate the air pollution problem.

Contact Details: Anjila Manandhar, Clean Energy Nepal/Clean Air Network Nepal, 140 Bulbule Marga, Thapagaun, Kathmandu, Nepal. Telephone: 977-1-4464981. Email: anjila@cen.org.np

ACKNOWLEDGEMENT

This study is supported by Fredkorpset (FK), Norway and Clean Air Initiative for Asian Cities (CAI-Asia), Philippines under Clean Air and Blue Skies Project, Phase II. The authors would like to extend their sincere gratitude to the Hong Kong Polytechnic University for all the technical support and Clean Energy Nepal/Clean Air Network Nepal for logistic support. The authors would also like to appreciate and thank the students from Tribhuvan University, Nepal and the Hong Kong Polytechnic University, Hong Kong for their immense help during the study. Lastly, sincere gratitude goes to the Ministry of Environment for their support throughout the study.

REFERENCES

Giri. D at el, 2006, Ambient air quality of Kathmandu valley as reflected by atmospheric particulate matter concentration

WHO, Indoor Air Pollution: National Estimates of Burden of Diseases

Jekins P.L. at el, 1992, Activity patterns of Californians: use of proximity to indoor pollutants sources, Atmos Environ, Vol 26A, pp 291-297.

National Academy of Sciences Indoor Pollutants; National Academy Press: Washington, DC, 1981

Lee, S.C, 1997, Comparison of indoor and outdoor air quality at two staff quarters in Hong Kong, Environment International, Vol 23, No 6, pp 791-797

Lee, S.C and Chan L.Y, 1998, Indoor and Outdoor air quality correlation and questionnaire survey at the two staff quarters in Hong Kong, Environment International, Vol 24, No 6, pp 729-737

Lee, S.C at el, 1999, Indoor and outdoor air quality investigation at 14 public places in Hong Kong, Environment International, Vol 25, No 4, pp 443-450

Lee, S.C at el, 1999, Indoor and Outdoor air quality investigation at six residential buildings in Hong Kong, Environment International, Vol 25, No 4, pp 489-496

Shrestha R.M at el, Air Quality Management in Kathmandu, Better Air Quality in Asian and Pacific Rim Cities(BAQ 2002)

Contact Details: Anjila Manandhar, Clean Energy Nepal/Clean Air Network Nepal, 140 Bulbule Marga, Thapagaun, Kathmandu, Nepal. Telephone: 977-1-4464981. Email: anjila@cen.org.np

Shakya Kabindra M. at el, Characteristics and Sources of Carbonaceous, Ionic, and Isotopic Species of Wintertime Atmospheric Aerosols in Kathmandu Valley, Nepal

Carrico, C.M. at el, The Importance of Carbon and Mineral Dust to Seasonal Aerosol Properties in the Nepal Himalayan.

Contact Details: Anjila Manandhar, Clean Energy Nepal/Clean Air Network Nepal, 140 Bulbule Marga, Thapagaun, Kathmandu, Nepal. Telephone: 977-1-4464981. Email: anjila@cen.org.np