Land Use and Ambient Air Quality in Bahir Dar and Hawassa, Ethiopia

Authors: Kasim, Oluwasinaayomi Faith, Abshare, Muluneh Woldetisadik, Mukuna, Truphena Eshibukule, and Wahab, Bolanle

Source: Air, Soil and Water Research, 11(1)

Published By: SAGE Publishing

URL: https://doi.org/10.1177/1178622117752138

Land Use and Ambient Air Quality in Bahir Dar and Hawassa, Ethiopia

Air, Soil and Water Research
Volume 11: 1–10

DOI: 10.1177/1178622117752138
SAGE

Oluwasinaayomi Faith Kasim[1], Muluneh Woldetisadik Abshare[2], Truphena Eshibukule Mukuna[1] and Bolanle Wahab[3]

[1]Organisation for Social Science Research in Eastern and Southern Africa, Addis Ababa University, Addis Ababa, Ethiopia. [2]Department of Geography and Environmental Studies, Addis Ababa University, Addis Ababa, Ethiopia. [3]Department of Urban and Regional Planning, University of Ibadan, Ibadan, Nigeria.

ABSTRACT: Land use, air pollution, and climate change are closely related. This article analysed the contributions of urban land use to ambient air quality in Bahir Dar and Hawassa cities. A total of 32 geo-referenced locations, 16 each in Bahir Dar and Hawassa, representing different land uses, were assessed for carbon monoxide (CO), carbon dioxide (CO_2), and volatile organic compound (VOC). CO_2 concentration (ppm) for Bahir Dar and Hawassa ranged from 385.10 ± 15.34 ppm (recreational land use) to 555.50 ± 80.79 ppm (commercial land use) and 388.07 ± 19.79 ppm (recreational land use) to 444.50 ± 54.05 ppm (industrial land use), respectively, whereas mean concentration of CO was 0.01 ± 0.01 ppm (recreational land use) to 2.59 ± 0.69 ppm (circulation land use) and 0.12 ± 0.11 ppm (recreational land use) to 4.66 ± 1.41 ppm (circulation land use), respectively. The VOC values were 882.10 ± 147.05 ppm (residential land use) to 1436.00 ± 932.06 ppm (institutional land use) and 1377.30 ± 233.23 ppm (institutional land use) to 2132.33 ± 739.71 ppm (circulation land use). Inadequate monitoring, occasioned by dearth of equipment, poor urban management strategy, fossil fuel combustion, and aged vehicles were some of the factors responsible for the observed concentrations. Elevated levels of CO, CO_2, and VOC in the atmosphere have a significant impact on global warming, with adverse effects on human health. Capacity for monitoring, analysis, reporting, and validation of air quality data in the cities should be strengthened.

KEYWORDS: Land use, ambient air quality, climate change, public health, Bahir Dar and Hawassa

RECEIVED: July 20, 2017. **ACCEPTED:** December 13, 2017.

TYPE: Original Research

FUNDING: The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This research was supported by funding from the Department for International Development (DFID) under the Climate Impact Research Capacity and Leadership Enhancement (CIRCLE) programme.

DECLARATION OF CONFLICTING INTERESTS: The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

CORRESPONDING AUTHOR: Oluwasinaayomi Faith Kasim, Organisation for Social Science Research in Eastern and Southern Africa, Addis Ababa University, Addis Ababa 1176, Ethiopia. Email: kasimfaith@gmail.com

Introduction

The continents of the world are connected through the 4 spheres (lithosphere, hydrosphere, biosphere, and atmosphere). In terms of gaseous emission, the atmosphere is mostly the transportation medium. According to Ramanathan and Feng,[1] air can be transferred thousands of kilometres from one continent to another, for example, from Asia to North America, in about a week. With the free movement of air from one continent to another, people are not immune to the reality of air pollution. It affects the earth's climate by trapping energy from the sun and distorting global solar energy balance. The earth's surface temperature is a function of the balance between incoming and outgoing solar radiation. This relationship has implication for air pollution, human health climate change, and ecosystems. US Environmental Protection Agency (USEPA) issued a report under the Clean Air Act indicating that greenhouse gases (GHGs) has implications for human health and climate change. The report concluded that warming of the climate system is apparent and it is important to note that most of the observed global warming since the mid-20th century is due to the anthropogenic increase in GHG concentrations.[2]

Carbon monoxide (CO) is a colourless, odourless, non-irritating gas produced as a byproduct of incomplete combustion of carbonaceous materials (petroleum products, coal, natural gas, wood, and plastics).[3] Toxic CO can be produced by burning, for example, through internal combustion engines, fires outbreaks, industrial operations, and domestic heating or cooking.[3] Most of CO emissions (95%-98%) in a region can be related to anthropogenic activities.[4–9] Carbon dioxide (CO_2) is a dominant GHG.[1,10–12] Poor air quality in the atmosphere and its relationship with global climate change have attracted interests from scientific communities, becoming a topical issue posing both political and economic challenges worldwide.[1,8] CO_2 has drawn global attention as a major driver of global warming. It is generated mainly from combustion of carbonaceous materials from power, transport, and household activities. CO_2 and a wide range of short-lived air pollutants influence directly or indirectly climate change with adverse effects on human health and ecosystem.[3] Volatile organic compounds (VOCs) from both anthropogenic (human-induced) and natural sources contain one or more carbon atoms that evaporate readily to the atmosphere. Examples of many compounds meet this definition abound. The definition excludes methane, ethane, and the chlorofluorocarbons.[13]

Land use, air pollution, and climate change are closely linked.[1,5,7,8,14] Air pollution is a clear marker for sustainable development, as sources of air pollution also produce climate pollutants. In providing a sustainable pathway to address climate change challenges, the United Nations Climate Conference

Figure 1. Bahir Dar and Hawassa in Ethiopia Context.
Adapted from Department of Geography and Environmental Studies, Addis Ababa University, 2016.

in December 2015 adopted the Paris Agreement. The Agreement provides a multilateral framework for low-carbon transformation of the world economy. Almost all countries have defined national climate change mitigation targets and pledged to take measures to achieve them. The targets can only be achieved if there are transparent and monitoring mechanisms in place to ensure that countries' development agenda is measured in line with global ambition of achieving an emissions pathway that keeps global warming to less than 2°C. For several decades, research on climate change in the developing countries has focused on agriculture and rural environment. However, contribution of city to climate change and its effects on health has been a disturbing issue for governments in developed and developing world.[15] This article examined the contributions of urban land use to ambient air quality and its implications for climate change and city livability in Bahir Dar and Hawassa cities in Ethiopia.

Materials and Methods

The setting

Bahir Dar is located north of Addis Ababa at the southern periphery of Lake Tana, the source of the Blue Nile. Hawassa is located south of Addis Ababa at the shore of Lake Hawassa, as shown in Figure 1.

Bahir Dar is sited approximately 580 km northwest of Addis Ababa, the capital of Ethiopia and it is located within on latitude 11°36′N and longitude 37°23′E. The city is the capital of Amhara National Regional State. According to the 2007 census, the total population of Bahir Dar metropolitan area was 180 174 and projected to become 212 785 in 2015. The city's topography is characterised by flat plain. However, there are pockets of conical hills, rugged and undulating features dotting the city's landscape. The average elevation of Bahir Dar is estimated to be between 1786 m above sea level (near the lake shore) and 1886 m above sea level on the summit of Bezawit Hill. The city temperature fluctuates from January to December. The annual mean temperature for the city ranged from 16°C to 21°C, whereas annual mean temperature for 2016 was 20.85°C, as shown in Figure 2. The highest mean monthly maximum temperature occurs in the month of April, which is about 29.7°C, and the lowest is in the months of July and August, which is about 23.3°C. The mean monthly minimum temperature ranges from 7.1°C in January to 14.2°C in May. There is a significant seasonal variation in the amount of rainfall. About 60.3% of the mean annual rainfall occurs in 2 rainy months of July and August with maximum mean value of 432 mm.

Hawassa is one of the major cities in Ethiopia and the capital of the Southern Nations, Nationalities, and Peoples' Region (SNNPR). It is located about 270 km south of Addis Ababa. The city lies on trans-African highway, an international road, connecting Cairo (Egypt), North Africa, Addis Ababa, and Nairobi, through a number of countries, to Cape Town (South Africa). The population of Hawassa based on the 2007 census

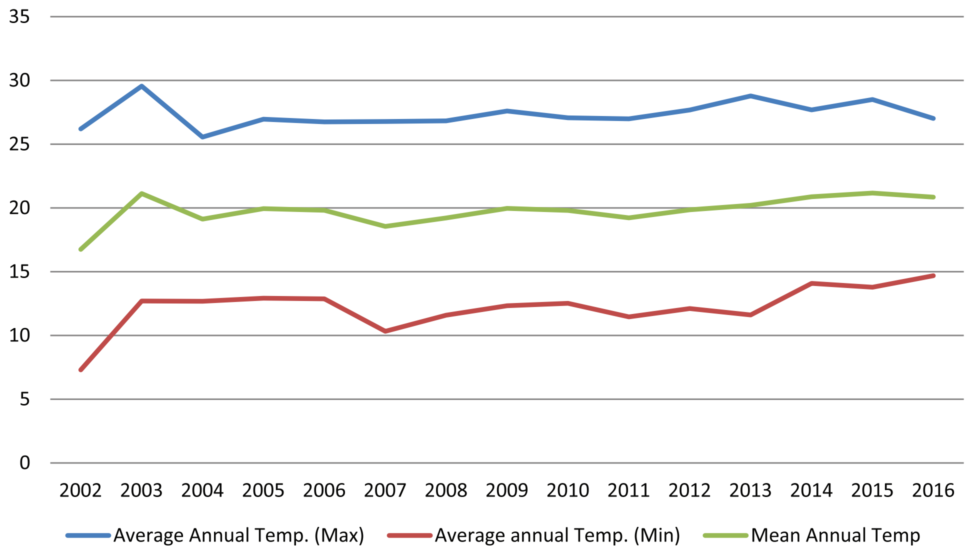


Figure 2. Variation of annual maximum and minimum temperature in Bahir Dar (2002-2016).
Adapted from National Meteorological Agency (NMA) of Ethiopia, 2017.

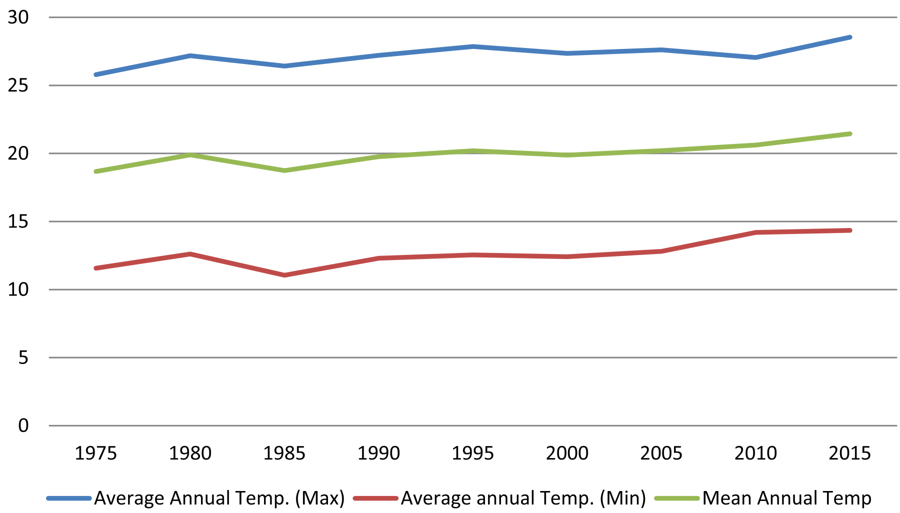


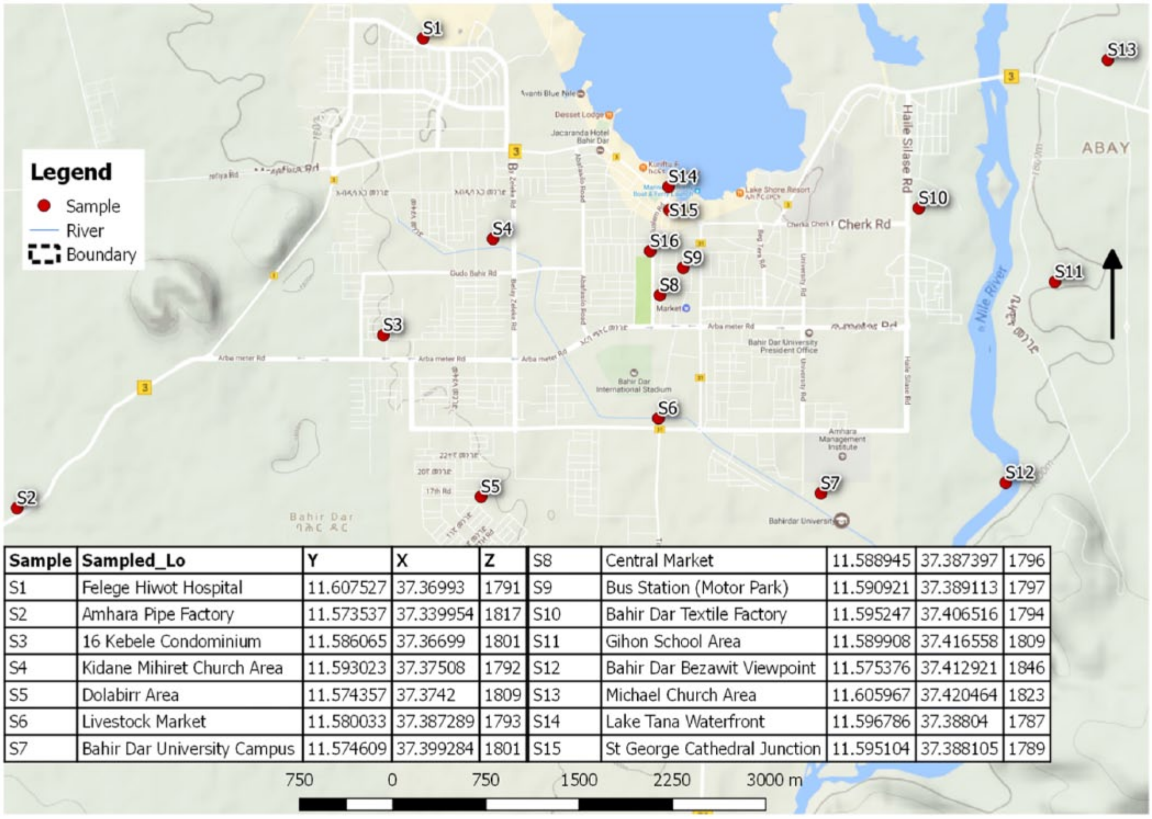
Figure 3. Variation of annual maximum and minimum temperature in Hawassa (1975-2015).
Adapted from National Meteorological Agency (NMA) of Ethiopia, 2017.

result (projection) is more than 300 000. The city is located within the geographical latitude 07°15′N and longitude 38°45′E with an average elevation of 1708 m above sea level. The city enjoys a prolonged period of wet season (March-October with mean monthly rainfall varying from 85 to 133 mm) with the June to September rainfall contributing 44% of the mean annual precipitation. The climate of Hawassa can be classified as dry to sub-humid. The annual temperature ranges from 9°C to 29°C, whereas the mean monthly temperature is 19.7°C (National Meteorological Agency [NMA] of Ethiopia, 2017) (Figure 3).

Sampling methods

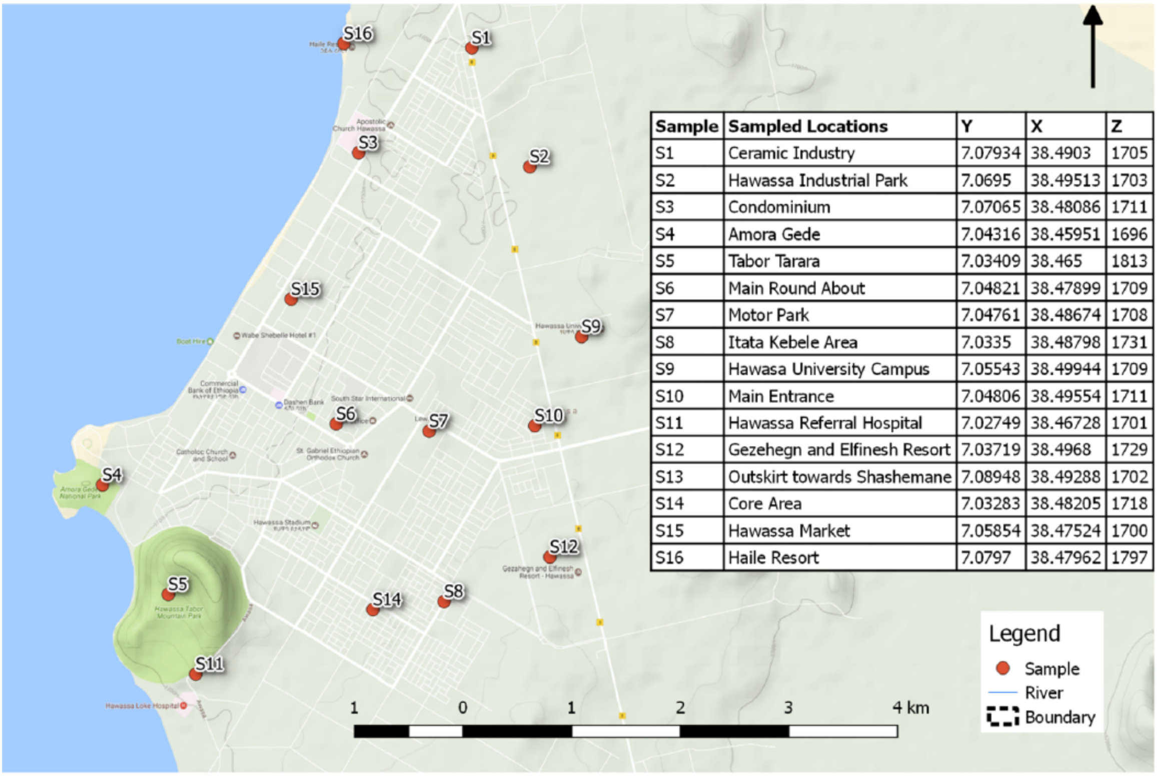
Aeroqual Series 500 portable gas monitor with attached temperature and relative humidity sensor and YuanTe SKY 2000-M4 handheld multi-gas detector were used for the study. Data were collected from 7:00 to 17:00 daily. An average of 15-minute readings for each location was recorded and the locations where measurements were obtained were geo-referenced, as shown in Figures 4 and 5. The measurements were done in the open space to minimise obstructions to wind parameters. The sampled locations' coordinates and altitudes were obtained with handheld automated Garmin GPSMAP 64 GPS. Data were collected from 7:00 to 17:00 daily.

For quality assurance, the equipment and metres were all pre-calibrated before use. The correlation coefficient between *Aeroqual Series 500* portable gas monitor and YuanTe SKY 2000-M4 handheld multi-gas detector was 0.986. The locations and daily data measurements were recorded in Excel spreadsheet for reference and further analysis. Mean concentration values and standard deviation from the sampled locations were calculated from the spreadsheet. Standard deviations presented were day-to-day and time-of-the-day variations in



Sample	Sampled_Lo	Y	X	Z	S8	Central Market	11.588945	37.387397	1796
S1	Felege Hiwot Hospital	11.607527	37.36993	1791	S9	Bus Station (Motor Park)	11.590921	37.389113	1797
S2	Amhara Pipe Factory	11.573537	37.339954	1817	S10	Bahir Dar Textile Factory	11.595247	37.406516	1794
S3	16 Kebele Condominium	11.586065	37.36699	1801	S11	Gihon School Area	11.589908	37.416558	1809
S4	Kidane Mihiret Church Area	11.593023	37.37508	1792	S12	Bahir Dar Bezawit Viewpoint	11.575376	37.412921	1846
S5	Dolabirr Area	11.574357	37.3742	1809	S13	Michael Church Area	11.605967	37.420464	1823
S6	Livestock Market	11.580033	37.387289	1793	S14	Lake Tana Waterfront	11.596786	37.38804	1787
S7	Bahir Dar University Campus	11.574609	37.399284	1801	S15	St George Cathedral Junction	11.595104	37.388105	1789

Figure 4. Sampled locations' coordinates in Bahir Dar.
Adapted from GIS Analysis from Google Earth Imagery.



Sample	Sampled Locations	Y	X	Z
S1	Ceramic Industry	7.07934	38.4903	1705
S2	Hawassa Industrial Park	7.0695	38.49513	1703
S3	Condominium	7.07065	38.48086	1711
S4	Amora Gede	7.04316	38.45951	1696
S5	Tabor Tarara	7.03409	38.465	1813
S6	Main Round About	7.04821	38.47899	1709
S7	Motor Park	7.04761	38.48674	1708
S8	Itata Kebele Area	7.0335	38.48798	1731
S9	Hawasa University Campus	7.05543	38.49944	1709
S10	Main Entrance	7.04806	38.49554	1711
S11	Hawassa Referral Hospital	7.02749	38.46728	1701
S12	Gezehegn and Elfinesh Resort	7.03719	38.4968	1729
S13	Outskirt towards Shashemane	7.08948	38.49288	1702
S14	Core Area	7.03283	38.48205	1718
S15	Hawassa Market	7.05854	38.47524	1700
S16	Haile Resort	7.0797	38.47962	1797

Figure 5. Sampled locations' coordinates in Hawassa.
Adapted from GIS Analysis from Google Earth Imagery.

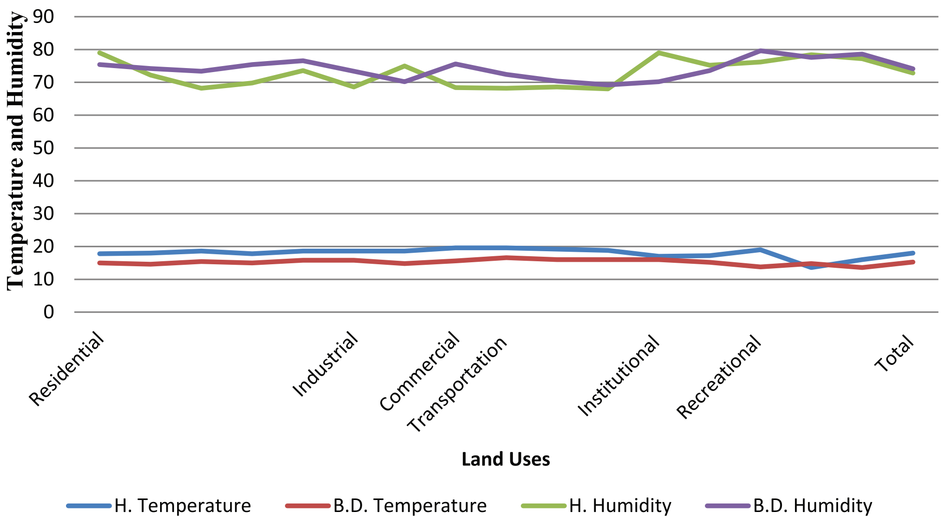


Figure 6. Temperature and humidity in Bahir Dar and Hawassa cities, Ethiopia.

the recorded concentrations from the sampled locations. Recorded temperature of the cities, one of the important elements of climate, was obtained from the NMA of Ethiopia Statistical analyses employed, which were descriptive (mean and standard deviation) and inferential (regression analysis) statistics. Microsoft Office Excel 2007 and Statistical Package for Social Science (SPSS) were used for statistical processing of data. Geographic information system was used to produce digital elevation and sampled location maps for the 2 cities.

Results

Meteorologic parameters

During data collection exercise in the cities, rains fell on 2 days in Bahir Dar (Wednesday and Friday), whereas rainfall was recorded only on Tuesday in Hawassa. Temperature results indicated a low variation among the sampled locations. Temperature variations ranged from 13.6°C ± 2.07°C to 16.6°C ± 2.51°C, with a mean value of 15.25°C ± 0.82°C (Figure 6). From the results, it could be deduced that temperature was relatively constant and there was no significant variation across locations at $P > .05$ in the recorded temperature values. Relative humidity in Bahir Dar ranged from 69.2% ± 8.70% to 79.6% ± 6.99% in main motor park and Bahir Dar University Campus, respectively. The mean value for all sampled locations was 74.11% ± 3.13%. Relative humidity from the city was relatively high. This is understandable because the study was conducted at the peak of the rainy season and the cities were located at the shores of Lake Tana (Bahir Dar) and Hawassa. Much of the water that evaporates from these lakes will be injected into the atmosphere. This, to a larger extent, affects humidity of the cities.

Mean temperature in Hawassa was 18.0°C ± 1.52°C. High temperatures were recorded from Main Roundabout (19.6°C ± 2.07°C), Hawassa market (19.6°C ± 1.82°C), Bus Station (19.2°C ± 2.59°C), and Amora Gedel (19.0°C ± 2.24°C). The temperature of other sampled points ranged from 13.6°C ± 1.82°C (Tabor Tarara), 16.0°C ± 1.22°C (Haile Resort) to 18.8°C ± 2.29°C at the main entrance. The highest temperature recorded was from transportation activities. One can then infer that there is an association between vehicular activities and temperature in the city. Relative humidity mean value for all sampled locations was 72.85% ± 4.32% and it ranged from 68.0% ± 7.07% to 79.0% ± 9.46%. The highest values for relative humidity within the city were recorded from the university campus and the condominium (79.0% ± 9.46%). The lowest value (68.0% ± 7.07%) was recorded at the main entrance. Humidity was fairly high, with about 12% difference in all the locations sampled.

Levels of emission from sampled locations

Results of emissions from the sampled carbon dioxide (CO_2), CO, and VOC for Bahir Dar and Hawassa are shown in Table 1. Carbon dioxide emission levels across all sampled points in Bahir Dar, as shown in Table 1, ranged from 383.6 ± 17.36 ppm at Bezawit Hill Summit to 583.8 ± 93.38 ppm at Central Marketplace with a mean value of 463.56 ± 55.10 ppm. This was higher than the American Society for Heating Refrigerating and Airconditioning Engineers Incorporated (ASHRAE)[16] guideline of 400 ppm. The highest level of emission was generated from Bahir Dar Central Market (583.8 ± 93.38 ppm), followed by Livestock Market, with concentration value of 527.2 ± 62.94 ppm. Other high CO_2 generation points were Felege Hiwot Specialist Hospital (509.4 ± 31.75 ppm), St. George Cathedral Roundabout (508.0 ± 79.89 ppm), and the Central Bus Station (507.2 ± 104.46 ppm). Relatively high concentrations of CO_2 emissions were recorded from Amhara Pipe Factory (491.4 ± 84.83 ppm), Bahir Dar Textile Factory (484.0 ± 21.62), and Dolabirr residential area (450.6 ± 20.91). The lowest level of CO_2 concentration (383.6 ± 17.36) was recorded at Bezawit (Bahir Dar Viewpoint). There was a

Table 1. Classification of sampled locations into land uses.

LAND USE	LOCATIONS	CO_2	CO	VOC
Bahir Dar	16th Condominium	408.4 ± 59.28	1.17 ± 0.24	847.2 ± 254.80
Residential	Kidane Mehret Church	439.8 ± 48.23	0.84 ± 0.20	936 ± 20.65
	Dolabirr area	450.6 ± 20.91	1.32 ± 0.29	946.8 ± 87.46
	Gihon School	432.8 ± 33.60	0.91 ± 0.19	850.2 ± 230.07
	Michael Church	436.2 ± 31.57	0.88 ± 0.17	873.4 ± 111.11
	04 Kebele	446.6 ± 22.38	0.85 ± 0.17	839 ± 66.39
	Mean	435.73 ± 37.68	0.99 ± 0. 27	882.10 ± 147.05
Industrial	Amhara Pipe Factory	491.4 ± 84.83	3.32 ± 0.62	1225.6 ± 251.56
	Bahir Dar Textile Factory	484.0 ± 21.62	1.18 ± 0.23	725.2 ± 198.46
	Mean	487.70 ± 58.49	2.25 ± 1.21	975.40 ± 339.39
Commercial	Livestock market	527.2 ± 62.94	2.20 ± 0.23	1416.6 ± 274.13
	Central market	583.8 ± 93.38	1.78 ± 0.42	1293.8 ± 562.14
	Mean	555.50 ± 80.79	1.99 ± 0.39	1355.20 ± 421.94
Circulation	Central Motor Park	507.2 ± 104.46	3.21 ± 0.27	1530.2 ± 142.19
	St. George Cathedral	508.0 ± 79.89	1.97 ± 0.15	1258.2 ± 123.08
	Mean	507.60 ± 87.67	2.59 ± 0.69	1394.20 ± 190.45
Institutional	Felege Hiwot Specialist Hospital	509.4 ± 31.75	0.92 ± 0.18	2304 ± 144.75
	Bahir Dar University	421.4 ± 113.81	0.00 ± 0	568 ± 223.91
	Mean	465.40 ± 91.41	0.46 ± 0.05	1436.00 ± 932.06
Recreational	Bezawit Viewpoint	383.6 ± 17.36	0.01 ± 0.01	911.6 ± 88.84
	Lake Tana waterfront	386.6 ± 14.91	0.01 ± 0.01	868.2 ± 110.67
Grand mean		385.10 ± 15.34	0.01 ± 0.01	889.90 ± 97.34
Hawassa City	Condominium	403.80 ± 17.23	1.55 ± 0.46	1668.8 ± 518.23
Residential	Itata Kebele	407.80 ± 22.33	1.68 ± 0.63	2001.2 ± 680.36
	Gezahegn Resort	429.00 ± 20.69	1.79 ± 0.92	1442.8 ± 30.34
	Outskirt	417.40 ± 18.00	1.40 ± 0.64	1447.8 ± 53.69
	Core area	429.4 ± 21.13	1.21 ± 0.38	1488.2 ± 12.36
	Mean	417.48 ± 21.16	1.51 ± 0.61	1609.76 ± 411.79
Industrial	Ceramic factory	467.60 ± 69.37	4.03 ± 1.07	2092.0 ± 646.42
	Industrial park	420.40 ± 19.14	5.30 ± 1.53	1731.4 ± 661.45
	Mean	444.50 ± 54.05	4.66 ± 1.41	1911.70 ± 645.21
Commercial	Market	416.2 ± 16.27	1.03 ± 0.22	1443.4 ± 81.72
Circulation	Roundabout	426.00 ± 30.95	3.44 ± 1.30	2655.8 ± 591.59
	Bus station	421.80 ± 9.68	2.23 ± 1.16	2095.0 ± 906.75
	Main entrance	435.80 ± 17.60	4.32 ± 0.58	1646.2 ± 321.35
	Mean	427.87 ± 20.64	3.33 ± 1.32	2132.33 ± 739.71

Table 1. (continued)

LAND USE	LOCATIONS	CO_2	CO	VOC
Institutional	Hawassa University	386.80 ± 8.41	0.17 ± 0.03	1243.0 ± 253.48
	Hawassa Referral Hospital	394.8 ± 17.54	0.18 ± 0.04	1511.6 ± 114.23
	Mean	390.80 ± 13.63	0.18 ± 0.03	1377.30 ± 233.23
Recreational	Amora Gedel	408.20 ± 11.84	0.24 ± 0.13	2010.6 ± 725.86
	Tabor Tarara	380.40 ± 16.44	0.07 ± 0.03	1634.2 ± 29.50
	Haile Resort	375.6 ± 13.64	0.06 ± 0.04	1231.0 ± 269.88
Grand mean		388.07 ± 19.79	0.12 ± 0.11	1625.27 ± 529.31

Abbreviations: CO, carbon monoxide; CO_2, carbon dioxide; VOC, volatile organic compound.

significant variation in the amount of CO_2 emission at $P < .05$ across the sampled land use locations. From the analysis of coefficient of variation for CO_2 across the land uses, the standard deviation was 12.5% of the mean.

Analysis of CO emission indicated that concentration of the gas ranged from 0.00 ppm at Bahir Dar University Campus to 3.32 ± 0.62 ppm at Amhara Pipe Factory, with a mean value of 1.29 ± 1.01 ppm, which was lower than World Health Organization (WHO)[17] and USEPA[18] guidelines of 9 ppm. Low values (0.00 to 0.01 ± 0.01 ppm) were recorded from Bahir Dar University Main Campus, Lake Tana waterfront, and Bezawit Viewpoint. Amhara Pipe Factory generated the highest emission (3.32 ± 0.62 ppm) in the city. Central Bus Station and Livestock market emitted 3.21 ± 0.27 ppm and 2.20 ± 0.23 ppm of CO, respectively. Emission levels from St. George Cathedral Roundabout, Central market, and 16th Condominium ranged from 1.97 ± 0.15 to 1.17 ± 0.24 ppm. There was no significant variation at $P > .05$ in CO emission concentration from industrial, commercial, and circulation land uses.

The mean concentration of VOC was 1087.13 ± 417.89 ppm. Concentration levels of VOC ranged from 568 ± 223.91 to 2304 ± 144.75 ppm. The highest concentration (2304 ± 144.75 ppm) was recorded at Felege Hiwot Specialist Hospital premises, followed by Central Bus Station (1530.2 ± 142.19 ppm). Concentration from 4 other locations (Livestock market, Central market, Amhara Pipe Factory, and St. George Cathedral Roundabout) exceeded 1000 ppm. Levels of VOC concentration from Dolabirr, Kidane Mehret Church, and Bezawit Viewpoint were 946.8 ± 87.46, 936 ± 20.65, and 911.6 ± 88.84 ppm, respectively. Relatively low concentrations were recorded from the Gihon School area (850.2 ± 230.07 ppm), the 04 Kebele area (839 ± 66.39 ppm), and Bahir Dar Textile Factory (725.2 ± 198.46 ppm). The lowest value (568 ± 223.91 ppm) was recorded within the Bahir Dar University Main Campus premises. There was a significant variation across locations at $P < .05$ in VOC concentrations.

Table 1 also presents the concentrations of CO_2, CO, and VOC recorded in Hawassa. As seen in the table, the mean concentration recorded for CO_2 was 413.81 ± 23.04 ppm, slightly higher than the ASHRAE guideline of 400 ppm. CO_2 emission values ranged from 375.6 ± 13.64 ppm in Haile Resort, a high-end secluded environment, to 467.60 ± 69.37 ppm from Ceramic Factory along trans-African highway linking Cairo (Egypt) to Cape Coast (South Africa). Other locations that emitted higher CO_2 concentrations included the main entrance to the town via trans-African highway adjacent to the University (435.80 ± 17.60 ppm), Gezahegn and Elfinesh Resort along trans-African highway, the high-density (core) area of the city, Main Roundabout, Bus Station, and Hawassa Industrial Park premises. CO_2 concentrations in the listed locations ranged between 420 and 430 ppm. Lower concentration levels were recorded from the condominium (403.80 ± 17.23 ppm), Hawassa Referral Hospital (394.8 ± 17.54 ppm), and Hawassa University Campus (386.80 ± 8.41 ppm). The lowest concentrations were recorded from Tabor Tarara, the highest point in the city, with a concentration value of 380.40 ± 16.44 ppm, and Haile Resort (375.6 ± 13.64 ppm)

Recorded concentration levels of CO ranged between 0.06 ± 0.04 and 5.30 ± 1.53 ppm, with a mean value of 1.79 ± 1.66. The mean value was lower than the WHO and USEPA guidelines of 9 ppm. The highest concentration level (5.30 ± 1.53 ppm) for CO was recorded from Hawassa Industrial Park. Heavy construction activities and closeness to trans-African highway may be responsible for the reading. The major roundabout at the centre of the city, the Ceramic Industry, and the sampled point at the main entrance to the city also emitted high concentration of CO with recorded value of 3.44 ± 1.30, 4.03 ± 1.07, and 4.32 ± 0.58 ppm, respectively. The level of emissions from Bus Station, residential areas, and marketplace ranged between 1.0 and 2.40 ppm. The lower concentrations were recorded from the institutional land use (Hawassa Referral Hospital and Hawassa University) and recreational land use (Tabor Tarara, Amora Gedel, Hawassa Lake waterfront, and Haile Resort). There was a significant difference in CO at $P < .05$ across the sampled locations.

The overall mean for VOC concentration was 1708.94 ± 376.22 ppm. The highest concentration value of 2655.8 ± 591.59 ppm was recorded at the main roundabout.

Other points that recorded above 2000 ppm concentration of VOC were Bus Station, Ceramic Industry, Amora Gedel, and Itata Kebele residential area. Concentrations of VOC in Industrial Park, condominium, main entrance to the city, and Tabor Tarara were 1731.4 ± 661.45, 1668.8 ± 518.23, 1646.2 ± 321.35, and 1634.2 ± 29.50 ppm, respectively. Relatively lower readings were recorded for residential areas and the institutional land use, with the lowest concentration recorded from Haile Resort. The VOC concentration level was high in Hawassa and there was no significant difference at $P > .05$ across sampled points. However, in terms of coefficient of variation, the standard deviation was 17.1% of the mean.

Discussion

Emission level, according to land use classification in Bahir Dar and Hawassa, is shown in Table 1. Carbon dioxide emissions from same land use were relatively similar. There were differences across different land uses. For instance, CO_2 emissions ranged from 408.4 ± 59.28 to 450.6 ± 20.91 ppm within residential land use in Bahir Dar with a mean value of 435.73 ± 37.68. However, mean values of emissions from recreational and commercial land uses were 385.10 ± 15.34 and 555.50 ± 80.79 ppm, respectively. The difference between the listed land use is significant at $P < .05$. In Hawassa, mean concentration of CO_2 from land uses ranged from 388.07 ± 19.79 ppm emitted from recreational land use to 444.50 ± 54.05 ppm from industrial land use. Mean contributions of circulation (427.87 ± 20.64 ppm), residential (417.48 ± 21.16 ppm), and commercial (416.20 ± 16.27 ppm) land uses were above the ASHRAE guidelines. Inadequate monitoring from emissions and uncoordinated land use placed pressure on the city's environmental conditions. Air pollution has been claimed to be responsible for increase in the incidence of diseases and ill health in several developing countries.[9] As air quality declines, the threat of exposure to stroke, heart disease, lung cancer, and chronic and acute respiratory diseases increase for the people who live in cities.

Carbon dioxide is a dominant GHG.[3,6,8,10] About 95% of total CO_2 emissions in United States is attributable to fossil fuel combustion.[18] CO_2 emissions from vehicular activities in Bahir Dar and Hawassa were high (507.60 ± 87.67 and 427.87 ± 20.64, respectively). However, in the cities, CO_2 emission from vehicular activities is not a function of the number of vehicles on the road. Just like any other Ethiopian city, vehicle ownership rate and the number of vehicles are significantly low (owing to high cost of purchasing a vehicle informed by high import duties imposed on vehicles by the government) compared with the population of urban dwellers.[19] Most of the vehicles on the roads are aged used vehicles imported from developed countries with reduced ability to achieve complete combustion, thereby emitting more obnoxious gases into the atmosphere.[5,7,19] According to Tiwari,[19] over 50% of the automobile in Addis Ababa were more than 20 years old and about 30.0% were more than 30 years old. Situations in the secondary cities in Ethiopia are worse off. Elevated levels of CO_2 in the atmosphere have a significant impact on global warming, constituting directly or indirectly to climate change, with adverse effects on human health and city livability. Except for recreational land use, where natural habitats are still maintained with lower human interventions, the mean values of emissions from other land uses were above ASHRAE guidelines.

CO_2 emitted from residential land use as a result of fossil fuel combustion for cooking and heating will harm the environment in 2 ways. First, fossil fuel is sourced from the environment thereby depleting the natural vegetation that serves as sinkhole for CO_2. Second, increased CO_2, together with other elements in the atmosphere, triggers global warming and climate change. This, in the long run, will have effects on meteorologic parameter, manifesting, for example, in either rainfall too much (flooding) or too little (drought).

As noted by Etyemezian et al,[5] emissions of CO are influenced by transportation density, type of industry, fuels and solvents used, production process, and level and efficiency of pollution controls that are in place. Therefore, CO levels in urban area could be seen as a function of weather conditions, industrial activities, traffic density, and also open incineration of wastes.[8] As seen in the analysis, circulation activities emitted highest CO concentrations (2.59 ± 0.69 ppm), followed by industrial (2.25 ± 1.21 ppm) and commercial activities (1.99 ± 0.39 ppm). Recorded concentrations are lower than the WHO and USEPA standards. In Hawassa, inability to monitor development compounded by inadequate personnel and equipment, coupled with drive for economic development through industrialisation, and industrial land use, contributed highest (4.66 ± 1.41 ppm) emission of CO into the atmosphere. This was followed by circulation activities (3.33 ± 1.32 ppm), whereas the least value recorded was from recreational land use. There was no significant difference ($P < .05$) in the level of CO emissions from industrial and circulation land uses in Hawassa.

The observed concentration levels of CO in the cities will be appreciated when one considers the level of urbanisation in the cities. Both cities are secondary cities and Bahir Dar economy is largely driven by recreational attractions of Lake Tana (the source of Blue Nile) and numerous monasteries located within Lake Tana's islands. Before the advent of the Hawassa industrial park inaugurated in July 2016, Hawassa economy also depended largely on Hawassa Lake as tourist attraction. The observed trends in CO emissions give credence to the notion that urban development trajectory in Ethiopia and, by extension, Africa in the quest for development will rather trample on the environment than protect it.[20,21] This is further given credence to by the notion that for states in Africa to achieve industrial and economic development, there is justified need to pollute the environment.[20] If countries in Africa are not polluting others, superpowers are still polluting. However, it is important to note that there is no boundary in global atmosphere.[22] Whatever happens in one location will adversely affect another location, no matter the distance.[1] The realisation of borderless global atmosphere, to a larger extent, informed the Paris Agreement on climate change that provides actionable framework for low carbon economic development. The atmosphere as a global envelope transfers pollution from one region to others.

Bahir Dar and Hawassa are beautiful cities with palm and other exotic trees lining streets and walkway, especially along the major roads. Behind the facade, as shown by relatively high contribution of residential land use in the cities to air pollution index, lies poverty, squalor, dilapidated buildings using fossil fuel as major energy source, poor land use planning, and other indices of poor environmental management. To some extent, there is relative improvement in terms of environmental management in Hawassa. However, in the cities, there is obvious poor monitoring and enforcement of environmental standards within the industrial areas. During the course of the study, the regional environmental protection agency of the cities has no equipment to measure air quality to determine the level of emission emanating from different land uses in line with Paris declarations. None of the industries visited has environmental protection and waste management plan. The drive for clean energy (hydro and wind) and other developmental programmes as entrenched in Ethiopia Growth Transformation Plan (GTP) II has been seen and touted as one-size-fits-all agenda to economic and environmental challenges, including pollution.

The mental map embedded in the presumed once-for-all solution of GTP II has overshadowed the monitoring element that should be ingrained into any developmental agenda. The impression and pedestal on which GTP II is hinged is that if industrial and household air pollution generation activities could be run on clean energy (hydro and wind), pollution will be eradicated. Production activities within industrial land use and fossil fuel usage at the household level, due to high cost of electricity to an average poor household, contribute immensely to GHG emission from these land uses. This has implications for global warming and climate change. Therefore, air quality monitoring with required equipment should be done periodically to ascertain whether the required standards for environmental protection are met. Today, the cities may not be contributing much to air pollution, global warming, and climate change. However, if the observed trends continue, coupled with Ethiopia's quest for industrial development, in the near future, the narratives from cities in the country will change drastically and climate change impacts will definitely undermine contemporary developmental gains, bearing in mind the susceptibility nature of Ethiopia to climatic variations.

Another major driver of air pollution in developing countries' urban areas that is receiving less attention is the urban market and related activities. It is usually an important workplace of the urban poor and the urban rich through buying and selling engagements.[23] Constellation of different activities predisposes the market environment to pollution arising from dumping of sewage, dirt and animal dung, spewing of plume from vehicular exhaust, emission from fossil fuel used for cooking, and other emissions from the activities of light (cottage) industries, abutting the market. Uncoordinated planning and management of market environment in the cities influenced the locations in Bahir Dar to emit the highest level (555.50 ± 80.79 ppm) of CO_2, third highest in CO (1.99 ± 039) and VOC (1355.20 ± 421.94) emissions. In Hawassa, commercial activities also contribute significantly to air quality outcomes. The contributions to air quality are evident in stench and offensive smell, that is, dirtiness of the environment. Polluted air within the market environment will adversely impacts on humans' health.

Mean concentration of VOC emission ranged from 882.10 ± 147.05 ppm from residential land use to 1436.00 ± 932.06 ppm within the institutional land use in Bahir Dar. There was a significant difference between emission value of VOC at <0.05 from institutional land use and residential land use. From the outcome of the recorded measurements of VOC from institutional land use, the readings at the Bahir Dar University environment was low. However, readings from Felege Hiwot Specialist Hospital were high. The increase in the values recorded could be attributed to massive construction activities within the hospital premises. High concentrations of VOC were also recorded from commercial and circulation activities with mean values of 1355.20 ± 421.94 and 1394.20 ± 190.45 ppm, respectively. Volumes of emission for VOC were relatively the same for all land uses in Hawassa, with a mean value of 1625.27 ± 529.31 ppm. As revealed in the analysis, vehicular activities generated highest (2132.33 ± 739.71 ppm) emission in the city. This was followed by emission from industrial activities, whereas the least emission was from recreational land use.

As noted by Jacob and Winner,[6] the 2 major air pollutants affecting public health and climate change are surface ozone and particulate matter. Ozone is generated in the atmosphere by photochemical oxidation of CO, methane, and other non-methane VOCs by the hydroxyl radical (OH) in the presence of reactive nitrogen oxides ($NOx \equiv NO + NO_2$).[1,5,6] The increased level of VOC recorded above the ASHRAE guideline is a portent of danger and it is an indication that development trajectory of the city is not sustainable and has implications for global warming and climate change. The effects of these climate-driven scenarios include warmer air (urban heat island), too much rainfall (flooding), or too little (drought) and more frequent heat waves.[24]

Concluding Remarks

Air pollution control in developing countries has not been given the required attention compared with other environmental issues, such as deforestation, land degradation caused by soil erosion, and water pollution.[25] In the midst of a worsening air pollution situation, the policy response has been slow and tends to be based on command-and-control rather than inclusive management. Ethiopia has developed a number of strategies to address climate change. For example, Ethiopian Climate Resilience Green Economy offers opportunities to transform the country's economy towards sustainable practices. However, Ethiopian cities, similar to major cities in the world, are vulnerable to climate change and climate variability. The relatively low level of contribution to atmospheric GHGs still requires a firm and visible commitment to the principle of mitigating or adapting to climate change. Therefore, appropriate control measures to monitor the rate of emission of GHGs and other pollutants in the atmosphere must be taken. Progress has been made in terms of policy direction; plans and developmental issues are seen as priority. However, poor implementation and enforcement of these policies and plans, especially at the city level, need to be addressed and the mechanism required to achieve this should be strengthened. There is a positive nexus among urban development, air pollution, and climate change challenges. Effective response to the connection requires that capacity for analysis and supporting human resources needed for monitoring, reporting, and verification of air quality data at the city level be strengthened.

Acknowledgements

The authors appreciate the support from Organisation for Social Science Research in Eastern and Southern Africa (OSSREA), Addis Ababa University, Ethiopia, for hosting the fellowship. They are also grateful to the anonymous reviewers for the enlightening, constructive, and useful comments on the manuscript.

Author Contributions

Conceived and designed the experiments: OFK. Analysed the data: OFK, MWA and BW. Wrote the first draft manuscript: OFK. Contributed to the of the manuscript: OFK, MWA and BW. Agree with the manuscript results and conclusions: OFK, MWA, TEM and BW. Jointly developed the structure and argument for the paper: OFK, MWA and BW. Made critical revisions and approved final version: OFK, MWA, TEM and BW. All authors reviewed and approved the final manuscript.

REFERENCES

1. Ramanathan V, Feng Y. Air pollution, greenhouse gases and climate change: global and regional perspectives. *Atmospher Environ*. 2009;43:37–50.
2. US Environmental Protection Agency (USEPA). The benefits and costs of the Clean Air Act, 1990 to 2010 – first prospective study; 1999. https://www.epa.gov/clean-air-act-overview/benefits-and-costs-clean-air-act-1990-2010-first-prospective-study. Accessed October 10, 2016.
3. Ana GR, Ogunseye OO. Spatio-temporal variations in carbon monoxide and carbon dioxide levels in three motor parks in Ibadan, Nigeria. *Int J Environ Monitor Anal*. 2015;3:411–419.
4. Piantadosi CA. Carbon monoxide poisoning. *Undersea Hyper Med J*. 2004;31:167–177.
5. Etyemezian V, Tesfaye M, Yimer A, et al. Results from a pilot-scale air quality study in Addis Ababa, Ethiopia. *Atmospher Environ*. 2005;39:7849–7860.
6. Jacob DJ, Winner DA. Effect of climate change on air quality. *Atmospher Environ*. 2009;43:51–63.
7. Kumie A, Charles K, Berehane Y, Emmelin A, Ali A. Magnitude and variation of traffic air pollution as measured by CO in the city of Addis Ababa, Ethiopia. *Ethiopian J Health Dev*. 2010;24:156–166.
8. Njoku KL, Rumide TJ, Akinola MO, Adesuyi AA, Jolaoso AO. Ambient air quality monitoring in Metropolitan City of Lagos, Nigeria. *J Appl Sci Environ Manage*. 2016;20:178–185.
9. WHO. *Health as the Pulse of the New Urban Agenda: united Nations Conference on Housing and Sustainable Urban Development*. Geneva, Switzerland: WHO; 2016.
10. Canadell JG, Raupach MR, Houghton RA. Anthropogenic CO2 emissions in Africa. *Biogeosciences*. 2009;6:463–468.
11. Intergovernmental Panel on Climate Change (IPCC). Climate change 2007: the physical science basis, summary for policymakers (Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change); 2007. https://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf. Accessed June 20, 2008.
12. IPCC. Climate change 2013: the physical science basis, summary for policymakers (Working Group I Contribution to the IPCC Fifth Assessment Report); 2013. http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf. Accessed July 12, 2016.
13. Environment and Climate Change Canada. Volatile organic compounds in consumer and commercial products; 2015. http://www.ec.gc.ca/cov-voc/. Accessed November 9, 2016.
14. WHO. *Ambient Air Pollution: a Global Assessment of Exposure and Burden of Disease*. Geneva, Switzerland: WHO; 2016.
15. World Bank. *Turn Down the Heat: Why a 4° Warmer World Must be Avoided. A Report for the World Bank by the Potsdam Institute for Climate Impact Research and Climate Analytics*. Washington, DC: World Bank; 2012.
16. American Society for Heating Refrigerating and Airconditioning Engineers Incorporated (ASHRAE). *Selecting CO2: Criteria for Outdoor Air Monitoring*. New York, NY: ASHRAE; 2008. www.ashrae.org.
17. World Health Organization (WHO). *Environmental Health Criteria 213: Carbon Monoxide*. Geneva, Switzerland: World Health Organization; 1999.
18. USEPA. Emissions; 2007. http://epa.gov/climatechange/emissions/usinventoryreport.html. Accessed October 7, 2016.
19. Tiwari A. Urban air pollution caused by automobiles in Addis Ababa, Ethiopia and its health consequences. *J Environ Sci*. 2011;5:49–58.
20. Osuntokun A. Political culture and urban development in Nigeria: an historical overview. In: Osuntokun A, ed. *Dimension of Environmental Problem in Nigeria*. Ibadan, Nigeria: Davidson Press Publisher; 1997:1–11.
21. Agbola SB. Climate change and poverty in Nigeria. *Region Dev Dialogue*. 2011;32:54–79.
22. CARE International Poverty, Environment and Climate Change Network (PECCN). *Understanding Vulnerability to Climate Change: insights from Application of CARE's Climate Vulnerability and Capacity Analysis (CVCA) Methodology*. Bangkok, Thailand: CARE International Poverty, Environment and Climate Change Network; 2011.
23. Ogunbameru K, Rotimi W. *Man and His Social Environment: A Textbook of Sociology*. Ibadan, Nigeria: Spectrum Books Limited; 2006.
24. USEPA. Benefits and costs of the Clean Air Act 1990-2020, the second prospective study; 2011. https://www.epa.gov/clean-air-act-overview/benefits-and-costs-clean-air-act-1990-2020-second-prospective-study. Accessed October 10, 2016.
25. Krupnick AJ. Urban air pollution in developing countries: problems and policies. In: Dasgupta P, Maler K eds. *The Environment and Emerging Development Issues*. Vol 2. Oxford, UK: Oxford University Press; 2000.