Original article

Magnitude and variation of traffic air pollution as measured by CO in the City of Addis Ababa, Ethiopia

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Abstract

Background: Air pollution level in Addis Ababa is presumed to be high due to the prevalence of old vehicles and substandard road infrastructures. This study assessed CO concentration as a measure of traffic air pollution.

Materials and methods: a total of 80 road side and 24 on-road daily traffic air samples during wet and dry seasons of 2007 and 2008, respectively, were taken using CO data logger. A structured checklist was used to document related data. Downloaded data from the CO sampler was used to generate summary statistics and data presentations. Data quality of CO measurement was ensured using calibration checks.

Results: The mean for 15 minutes CO concentration was 2.1 ppm (GM=1.3) and 2.8 ppm (GM=2.2) for wet and dry seasons, respectively. The concentrations from season to season varied statistically. The CO temporal and spatial profiles among the two seasons were similar. The overall mean on-road CO concentration was 5.4 ppm (GM=5.3). Fifteen percent of roadside samples and all on-road samples exhibited more than 50% of the 8-hr CO WHO guideline.. Daily CO maxima were observed in early mornings and late afternoons.

Conclusions: The consistency in spatial and temporal profiles and the variation on both on-road and road side traffic lines imply that vehicles are the main source of traffic air pollution. There is a concern that the CO 8-hr World Health Organization guideline might be exceeded in future. [*Ethiop. J. Health Dev.* 2010;24(3):156-166]

Introduction

Increasing demand on transportation service and challenges of the prevailing poverty are basic problems in emerging cities of developing countries, such as Addis Ababa. More than 50% of cities with increased level of ambient urban air pollution are found in developing countries (1). Urban air pollutant as measured by particulate matter (PM_{10}) and volatile organics were found to exceed international limits in cities of developing countries (2-5). The presence of poorly maintained old cars on one hand, and limited and slowly expanding urban road net works on the other hand are challenges that could not sustain clean urban air around traffic zones in many developing countries (6). PM_{10} and Carbon Monoxide (CO) measurements along the roadsides in developing countries commonly exceeded the local and international guidelines (7-10). Data inventories from world wide mega cities indicated that urban air pollution due to vehicular emissions is evident in developing countries (5). On-road transportation, fore example, for 1970-1975 in the United States of America (USA) was about 70% of the total CO emissions (11), whereas, this was 57% in European countries in 1999 (5). Proximate factors such as distance between motorway and home, traffic density of cars and lorries were associated with reduced lung functions and respiratory diseases among children living near major motorways (12,13). Traffic density within distance of 90 to 150 metres was found to be related with increased respiratory illness (14-17). A 150 meters distance from a roadside was used as a cutoff for measuring traffic air pollution in Jimma, Ethiopia (18). Distance, as small as 50m, was found to increase risk of birth outcomes (19). Other study used a distance of 20-150m that indicated CO concentrations in the near-road areas had a factor of 1.2 to 1.8 higher than farer from road areas (20).

There is a limited source of evidence describing urban air pollution in Ethiopia. There is only one study that has undertaken the measurement of PM_{10}, CO, airborne lead, ozone, and SO_2 in the ambient environment (21) and concluded the likely of increasing these pollutants in future. The study, however, had air-sampling sites that were 50-100 meters away from the main arterial roads and thus had limitations regarding the magnitude of the measured pollutants within the vicinity of the traffic zone.

The present study focused on the exploration of the level, temporal, spatial variations of traffic air pollution as measured by CO in selected air sampling sites along the road side of the City of Addis Ababa.

Methods

Study setting

The City of Addis Ababa, with an area of 54 thousands hectares, is located at the foot of Mountain “Intoto”. The area approximates a circular shape with a diameter of about 30-40 kms. The elevation varies between 2,200 and 2,800 meters above sea level (masl) with an average of 2,400 masl. The average maximum and minimum temperatures were 23.8°C and 11.1°C, respectively (22). The City had annual rainfall of 1175.8mm rainfall. The climate is characterized by three continuous months of

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rainy season (June-August) and nine months of dry season. A relatively colder nights ("Wurch") exists between October and January.

Sampling strategy

There were three sampling approaches in this study. Roadside CO measurements were performed from July 7 to 27, 2007 representing the wettest month, and from January 1 to 26, 2008 representing the driest month of the year. On-road sampling was made from March 31 through April12, 2008. Sampling was done on six days of the week (i.e. Monday to Saturday) between 7 AM to 18 PM. During the rainy season (July) sampling generally started later in the morning (at approximately 8 am) due to the seasonally delayed opening time of the shops used as sampling locations.

Forty roadside sites along 20 major road networks were purposely selected as sampling locations. Each sampling site was selected using of the following criteria:

- Roadside distance less than 10 meters from the edges of the road side.
- Presence of shopping centers or kiosks with substantial presence of pedestrians.
- Presence of adequate traffic density in order to characterize the significant CO exposures in the city.
- Absence of physical barriers that could impair the air sampling process.
- Locating the sample site in industry free zone: this is used to exclude the industrial source of CO.
- Ensuring the absence of any cooking or smoking activities that might bias the CO concentration coming from vehicular sources.
- Willingness of the owner of the sampling site to host the CO monitor for the sampling time.

Figure 1 indicates Addis Ababa's road networks and locations of air sampling sites. Exact locations were identified using Global Positioning System (GPS) taking (GPS 12 XL, Garmin 12 channel) that were embedded in the City's road network using AutoCad 2007 software (Autodesk Inc).

In addition, four traffic lights ("Olympia", "Legehar", "Urael", and Post office traffic light posts) were selected to explore the on-road CO concentration. One of them lies on the route to the Bole' international airport; two of them lie on the main artery running from East to West of the City, the fourth one is a location entering this artery. These sites have heavier traffic densities than other traffic line sites (judged by observation and interviewing traffic polices).

CO measuring

Two portable CO USB real data loggers (23) were used to measure the level of CO in each sampling site at a rate of two samples per day. These monitors conform to NIOSH Method 6604 for CO, which specifies the use of a data logging electrochemical sensor with a detection limit of 1 ppm (24). Manufacturer provided software was used to set-up the CO monitor, set the logging rate and specify the starting time and date. Sampling intervals of 10 seconds (10s) were set in order to pick any varying levels of CO. A data sheet was used to record the date, USB ID code, name of site of sampling, and the time at which the air sampling in the field was set and stopped.

At each site, the CO monitors were set 2 meters height in a visible location after ensuring the free flow of air from the immediate traffic towards the sampler. Permission for sampling was secured from the local traffic authorities. Consent for sampling was obtained after explaining the purpose of the survey to each owner of sampling sites. The traffic light post sampling is located at the center of the road serving vehicles in both directions.

Data management and Analysis

Immediately after sampling, the logged data was downloaded into MS Excel © format using the USB software. The data was then truncated to include only the 7:00 am to 18:00 pm sampling interval. Daily sample data were compiled into a master data set for each of the three sampling approaches. The 10-second sampling interval results were used to calculate 15 minute, 30 minute, 1 hour and 8 hour moving average CO concentrations for each site. These averaging times correspond to the World Health guidelines of 90 ppm, 50 ppm, 25 ppm, and 10 ppm, for each time interval, respectively (25). Microsoft Office Excel 2003 and SPSS (version 15, SPSS Inc., Chicago, IL, US) were used to for graphical and statistical processing of data.

CO data quality evaluation

The CO sensors have a factory calibration reported to be valid for four years. To ensure the further validity of CO measurement, three strategies of data quality assurance were employed.

1. Field side-by-side measurements during sampling campaigns

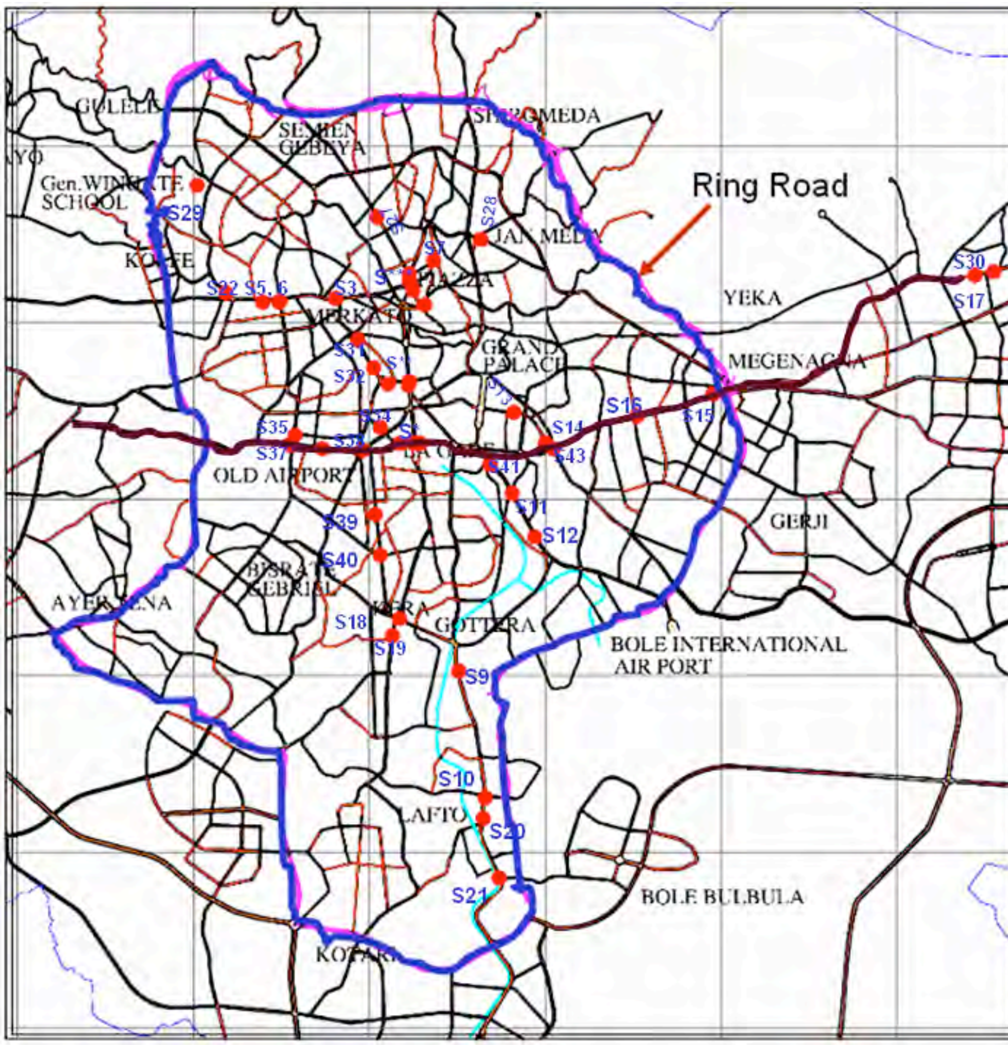
Side-by-side measurements (n=29) were taken using two monitors that were purchased at the same time. When the results from the two monitors were compared, the 10s average concentrations had a Pearson's r of > 0.90 and the 1 minute average concentrations had an r > 0.95.

2. Side-by-side sampling with a different model CO monitor

HOBO model CO data loggers (MicroDAQ.com, Ltd., Contoocook, NH 03229, U.S.A) are used by Gaia Association in Addis Ababa to evaluate the efficiency of clean ethanol stove project through the measurement of CO. Data was collected for 24 hours on December13-14/2008. The correlation coefficient between the instruments was 0.967 (95% CI: 0.965, 0.968).

3. **Calibration check with a transfer standard**

The calibration of data loggers that remained in Ethiopia for data collection was confirmed two-years after their initial purchase. This was done by side-by-side sampling using new monitors that had been calibration checked in USA for use as a transfer standard. When sampling side by side the results between the monitors used for data collection in Addis Ababa and the transfer standard were correlated, r> 0.95, and had a slope not statistically different from 1.0 and an intercept not statistically different from zero.



Sample	UTMX	UTMY
S1	472863	995952
S2	472660	996938
S3	471416	998417
S4	472315	996962
S5	470463	998360
S6	470454	998362
S7	548816	1546076
S8	472939	998309
S9	473522	992078
S10	473971	989923
S11	474051	995592
S12	474814	994357
S13	474463	996479
S14	474999	995958
S15	477855	996793
S16	476560	996417
S17	482325	998813
S18	472508	992968
S19	472387	992681
S20	473939	989571
S21	474207	988558
S22	469548	998515
S23	470177	998354
S24	551205	1547784
S25	548547	1545935
S26	551475	1547870
S27	549781	1546759
S28	547493	1545566
S29	469057	1000341
S30	482647	998872
S31	472066	997242
S32	471800	997712
S33	472518	995950
S34	472182	996227
S35	470724	996089
S36	471192	995863
S37	470633	995927
S38	471880	995830
S39	472099	994742
S40	472180	994047
S41	474431	995099
S42	472746	995958
S43	475133	995861
S44	472676	997004

Figure 1: **GPS location of sampling sites for CO monitoring embedded in Addis Ababa Road network, Addis Ababa, July 2007 and January-March 2008**
(Note: S stands for sample; CO concentrations for each sample is indicated in Table1)

Results

Carbon Monoxide Characteristics

The average CO concentrations during the roadside sampling campaigns are indicated in Table 1. The profiles of weighted mean and highest averaged CO concentration based on 15 minutes moving averages for the two multiple sampling periods (n=40) are indicated in Figure 2. Typical patterns of CO concentrations throughout the day are shown in Figure 3.

Overall, the mean roadside CO concentration for the dry season was 2.8 ppm with a GM of 2.2 and GSD of 2.1. During the wet season, the overall roadside average was 2.1 with a GM of 1.3 and GSD of 1.0. Transformed CO data showed statistical difference between the two seasons ($p<0.05$). The average CO levels during the wet season were generally characterized by elevated peaks during rush hours in the morning (8:00-9:00 am local time), early afternoon (15:00 -16:00 pm), and late afternoon (17:15 -18:15 pm). Similar patterns were observed for the dry season although high levels were observed over wider range in afternoon time.

The study indicated the presence of spatial variation in CO concentration. Twelve sites had average CO levels 2 - 4 times of the aggregated mean of the 40 sites. Five sampling sites (S1,S12,S16,S18,S39 locations indicated in Figure 1 and Table 1) consistently showed relatively increased level of CO for both months, while four sites (S11,S12,S35,S38) exhibited higher level of CO in the dry month. All these sites were located in high traffic zones of Addis Ababa. Three sites (S5,S6,S19) had high level of CO during the wet month compared to the dry month. The horizontal sampling distance between the sampler and edge of the road did not correlate with the measured CO concentration in both months.

CO concentrations Vs WHO guidelines

Moving average CO concentrations for 15 minutes, 30 minutes, 1 hour, and 8 hour intervals were calculated using the ten seconds sampling interval data. These results are shown in Tables 2-4. No exposures were found that exceeded the 2000 WHO guidelines.

On Road CO Concentrations

The 15 minutes averaged and its highest averaged CO concentrations for the four on-traffic sites are indicated in Figure 4. An increased trend was observed during early morning and from early to late afternoon. Low level of CO concentration during lunch time was the characteristic of temporal variation for both highest and averaged CO concentrations. The time trend was almost similar with the samples taken from road-sides, except the presence of difference in the rate of variability and the overall weighted averages. The overall averaged traffic line CO concentration (5.4 ppm) was more than twice that of July and January samples taken together (2.3 ppm averaged for both). “Olympia” and “Legehar” Traffic Lights showed increased level of CO concentration all along the days. Post Office site had the least CO level.

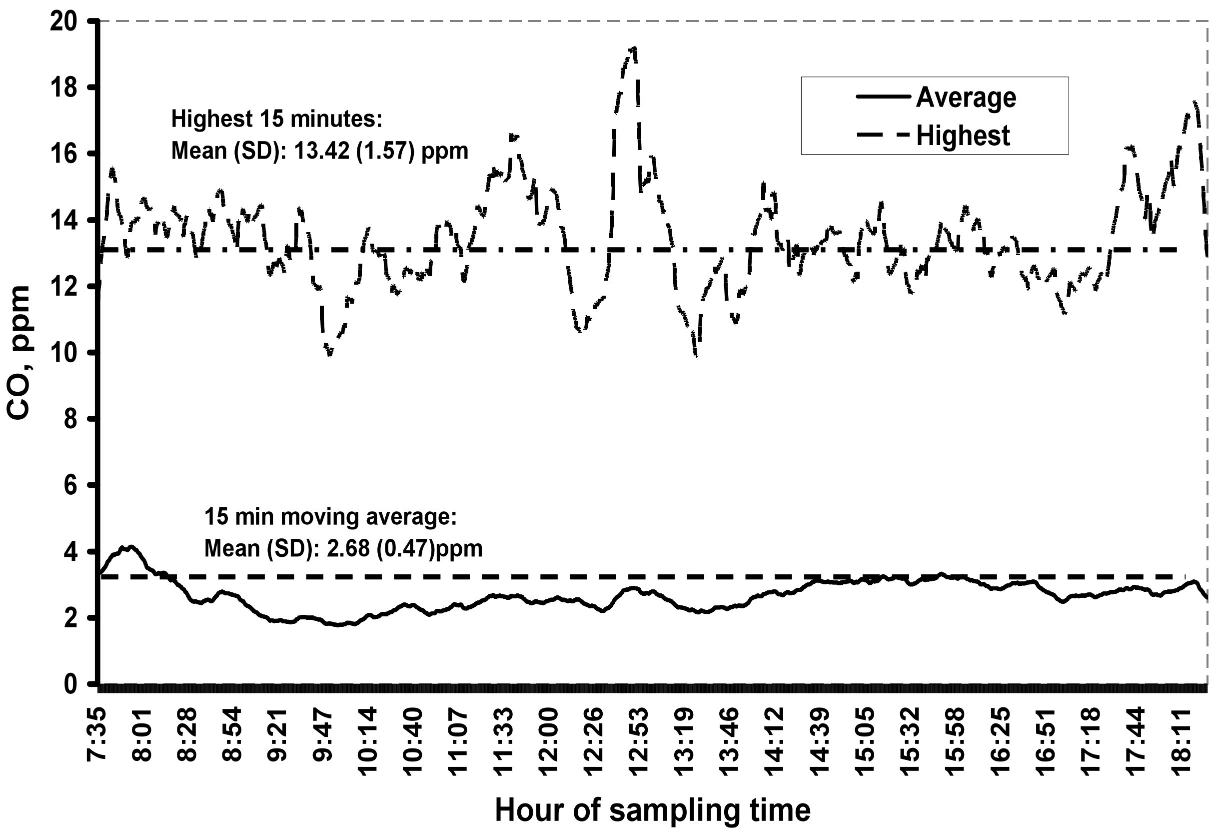


Figure 2: **CO concentrations averaged by 15 minutes measured during dry season of Ethiopia, January 2008 (n=40)**

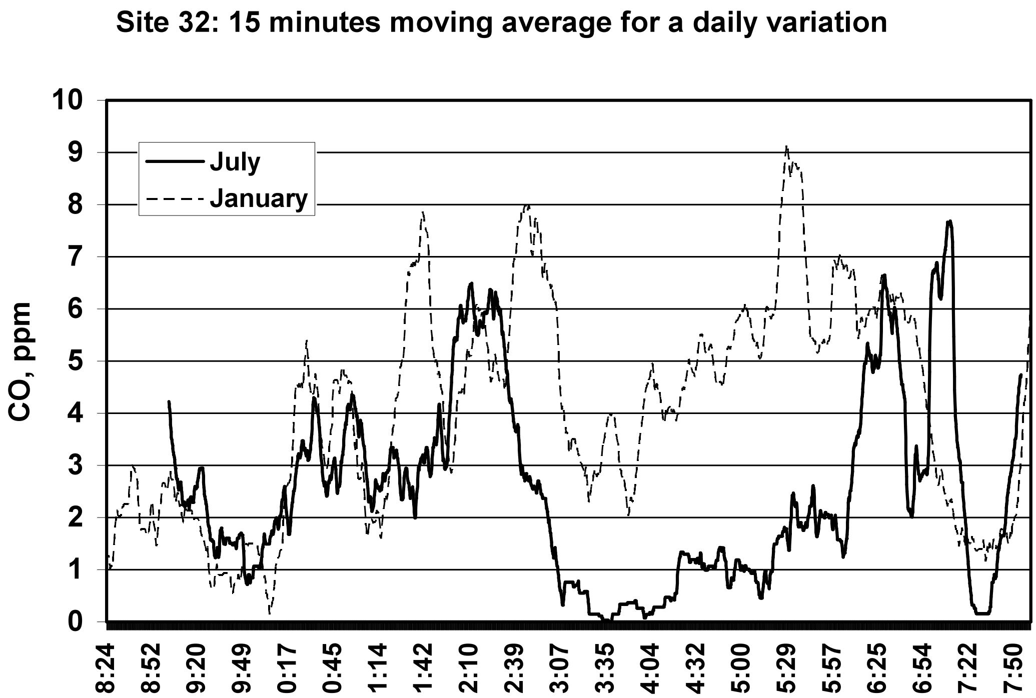


Figure 3: **Typical daily CO patterns for Site 32 ("Teklehaanot-Tsion spare part shop")**

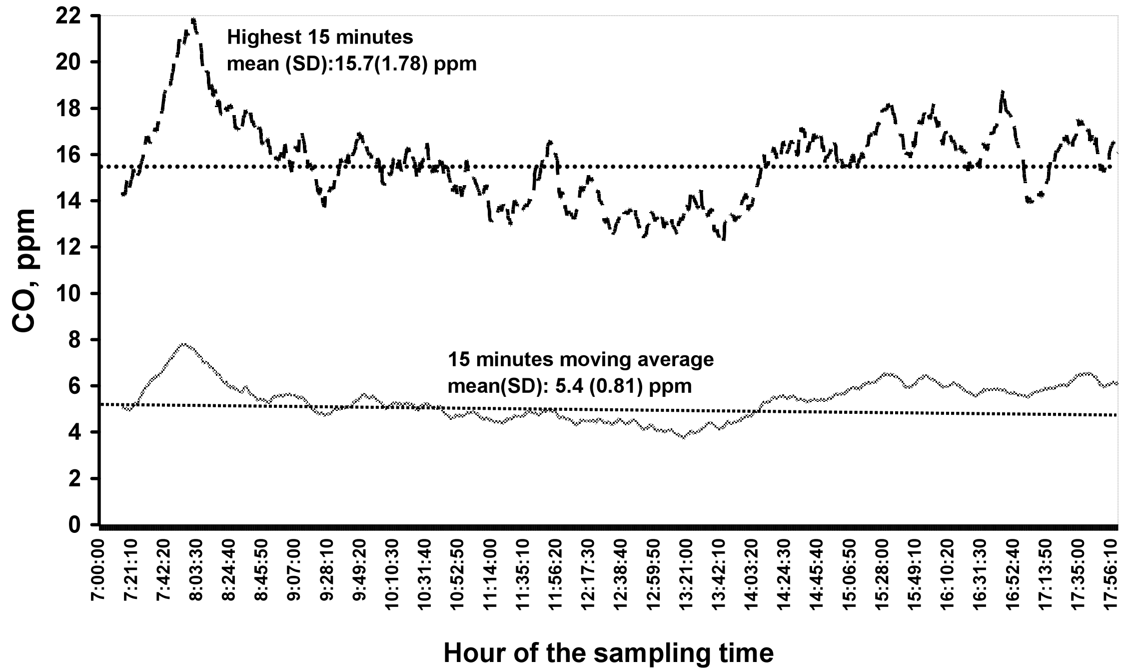


Figure 4: **CO concentration averaged by 15 minutes in four traffic sampling points, Addis Ababa, April 2008 (n=24)**

Table 1: **Average CO concentrations for the two sampling periods, July 2007 and January 2008, Addis Ababa**

Site ID	Sampling sites	Sampling distance, m	July 2007			January 2008		
			Mean	GM	GSD	Mean	GM	GSD
S1	Legehar Megenagna Mini bus stop	2	**7.1**	4.2	3.4	**5.1**	3.2	3.2
S2	Churchil, Pepsi Kiosk infront of Post Office	4	0.9	0.8	2.5	0.5	0.7	2.0
S3	Autobus Tera-Andnet shop near Mesgid	4	0.4	0.6	1.9	2.9	1.9	3.1
S4	Black Lion Hospital gate, in front of SIM	10	<0.5	0.5	1.0	<0.5	0.5	1.0
S5	Autobus Tera shop, next to Z music	4	4.4	3.0	2.9	1.8	1.2	2.9
S6	Autobus Tera Ismael shop near Z Music	5	4.3	2.9	3.0	1.0	0.8	2.6
S7	Piassa Awash Stationary	5	2.2	1.2	3.2	0.9	0.7	2.2
S8	Paissa in front of Commercial Bank	3	2.9	1.5	3.5	0.1	0.5	1.3
S9	Gotera intersection, bread retailer	4	1.5	1.0	2.8	0.5	0.6	2.0
S10	Gotera, in front of 3F, General shop	5	1.0	0.8	2.4	0.7	0.7	2.1
S11	Bole road near Flamingo, Electronic shop	9	2.1	1.1	3.3	**10.6**	**10.4**	1.2
S12	Bole Printing Press Coka Cola Kiosk	10	4.0	2.0	3.6	**7.3**	**6.8**	1.5
S13	Kazanchis, Grocery, near Awash Bank	5	1.1	0.8	2.5	4.3	2.8	3.0
S14	Kazanchis, ceramic shop, Urael direction	3	2.3	1.1	3.3	0.1	0.5	1.5
S15	Megenagna, Yaekob Mobile center	7	0.3	0.6	1.8	1.6	1.1	2.7
S16	Haya Hulet Mazoria, general shop	3	**7.7**	3.7	4.2	4.7	3.4	2.7
S17	Kotebe College in front, dairy kiosk	2	0.2	0.5	1.5	0.1	0.5	1.3
S18	Gofa intersection, Kokeb Fashion	4	**5.2**	3.2	3.3	**5.4**	4.2	2.4
S19	Gofa intersection, Mebrat Hail	3	**5.6**	2.8	3.9	0.8	0.8	2.4
S20	Saris, Blue Nile shoes, in front of Red Cross	5	0.2	0.5	1.5	2.3	1.5	3.0
S21	Fruit shop named Harer, Saris Chimad	4	1.0	0.8	2.4	1.9	1.3	2.8
S22	Mesalemia Mimi Bakery shop	5	2.3	1.4	3.1	4.7	3.3	2.8
S23	Autobus Tera, Alfa public book	4	0.5	0.6	2.0	2.6	1.5	3.2
S24	Giorgis intersection Pepsi kiosk	2	1.6	1.0	2.9	1.2	0.9	2.6
S25	Giorgis, Ato Teklu Barber Verandah	5	1.7	1.0	2.9	0.3	0.6	1.7
S26	Giorgis Church translation and PC service	3	0.3	0.6	1.7	0.1	0.5	1.4
S27	Dej. Bela Road, Marvlous PC center	5	0.7	0.7	2.2	<0.5	0.5	1.0
S28	Sidist kilo total, Hiwot stationary	4	0.2	0.5	1.6	0.8	0.7	2.2
S29	Medhanialem School, MN shoe repair shop	5	0.4	0.6	1.8	3.5	2.2	3.1
S30	Kotebe College end of fence, Harer shop	7	0.1	0.5	1.3	0.1	0.5	1.2
S31	Teklehamanotu Tyre shop	5	1.7	1.2	2.9	3.0	2.0	3.1
S32	Teklehaimanot, Tsion Spare parts	4	2.5	1.4	3.3	4.1	2.6	3.1
S33	Leghar, Watch and eye glass kiosk	2	3.0	1.7	3.4	3.1	2.1	3.1
S34	Sengatera, electric shop	4	2.1	1.3	3.0	4.0	2.6	3.0
S35	Lideta, Tele Center	5.5	0.4	0.6	1.9	**6.0**	**5.0**	2.2
S36	Lideta, Temesgen shop, in front of Balcha	7.5	1.2	0.8	2.6	3.0	2.1	2.8
S37	Lideta, near Desse Hotel Pepsi kiosk	3.5	1.0	0.8	2.5	3.3	2.4	2.7
S38	Mexico Square Pepsi kiosk	7.5	0.5	0.6	1.9	**7.6**	**7.2**	1.4
S39	Kera Discovery shop near Genet Hotel	2.5	4.4	2.4	3.7	**5.8**	4.6	2.4
S40	Kera, Teka shop near Bulgaria Mazoria	5	2.9	1.6	3.5	0.2	0.6	1.7
	Overall mean (SD)	**4.7 (2.0)**	**2.1 (1.95)**	**1.3 (1.0)**	**2.6 (0.8)**	**2.8 (2.5)**	**2.2 (2.1)**	**2.3 (0.7)**

Bolded Numberss: CO ppm>50% of 8-hr WHO guideline of 10 ppm; GM-Geometric Mean; GSD-Geometric SD

Table 2: **Distribution of highest CO concentrations on the road sides, July 2007, Addis Ababa, Ethiopia**

Sampling sites ID	**15 minute average. ppm**	**30 minute average, ppm**	**1-hr average, ppm**	**8-hr average, ppm**
S1	18.2	14.5	12.1	**7.2**
S2	5.9	3.4	2.3	1.3
S3	3.9	3.3	1.7	0.4
S4	<0.5	<0.5	<0.5	<0.5
S5	9.2	7.5	7.4	**5.1**
S6	9.5	8.1	7.5	4.6
S7	6.4	5.7	4.7	2.3
S8	11.0	8.2	7.0	3.0
S9	5.0	4.3	3.3	1.8
S10	4.3	3.6	3.2	1.1
S11	9.7	8.4	8.2	2.3
S12	31.0	22.0	**14.9**	4.2
S13	6.8	4.3	2.3	1.1
S14	9.0	6.2	4.6	2.4
S15	2.5	2.0	1.4	0.4
S16	25.1	19.6	**17.7**	**8.2**
S17	1.8	0.9	0.5	0.3
S18	16.6	14.1	**12.8**	**5.1**
S19	21.9	19.6	**15.1**	**6.1**
S20	0.5	0.4	0.3	0.2
S21	3.8	2.9	2.5	1.1
S22	7.5	6.7	5.5	2.5
S23	4.1	2.4	1.4	0.5
S24	4.5	3.9	3.3	1.6
S25	9.4	7.0	4.1	1.7
S26	3.4	2.2	1.2	0.2
S27	3.9	3.2	2.3	0.7
S28	3.3	1.9	1.2	0.2
S29	2.4	1.3	1.1	0.4
S30	1.0	0.5	0.3	0.09
S31	4.4	3.5	3.4	1.8
S32	7.7	6.4	5.2	2.6
S33	7.7	6.7	6.1	2.9
S34	6.1	5.2	4.6	2.5
S35	4.1	4.0	2.8	0.5
S36	7.5	4.4	3.0	1.2
S37	6.8	5.1	4.6	1.1
S38	5.0	3.3	2.0	0.5
S39	12.8	11.6	10.8	**5.1**
S40	11.4	10.6	8.9	3.0
No (%) exceeding 100% of the WHO guideline	**None**	**None**	**None**	**None**
No (%) exceeding 50% of the WHO guideline	**None**	**None**	**4 (10)**	**6 (15.0)**

*WHO guidelines for CO: 15 minutes: 90 ppm; 30 minutes: 50 ppm; 1hr: 25ppm; 8hr: 10 ppm; bolded numbers indicates values more than 50% of WHO guidelines.

Table 3: **Distribution of highest CO concentrations on the road sides, January 2008, Addis Ababa, Ethiopia**

Sampling Site ID	**15 minute average, ppm**	**30 minute average, ppm**	**1-hr average, ppm**	**8-hr average, ppm**
S1	11.4	9.5	7.6	**5.8**
S2	3.8	3.1	1.9	0.5
S3	17.5	13.0	7.8	3.4
S4	<0.5	<0.5	<0.5	<0.5
S5	9.4	8.1	6.3	2.0
S6	8.4	7.4	6.4	1.4
S7	4.5	2.9	1.8	0.8
S8	1.8	1.3	1.2	0.2
S9	5.6	4.4	2.6	0.6
S10	5.9	5.5	4.8	0.9
S11	12.7	12.1	11.4	**10.7**
S12	14.7	14.3	**13.7**	**7.7**
S13	15.1	9.9	6.5	4.2
S14	1.2	0.7	0.6	0.1
S15	4.1	3.6	3.3	1.7
S16	11.0	10.5	8.7	4.8
S17	0.5	0.4	0.3	0.1
S18	14.5	14.0	11.6	**6.0**
S19	5.5	3.6	2.4	1.0
S20	6.3	5.8	5.3	2.8
S21	3.9	3.4	3.0	2.2
S22	10.3	9.4	7.7	**5.2**
S23	11.8	8.2	5.9	3.0
S24	3.8	2.8	2.3	1.3
S25	2.5	1.4	0.8	0.3
S26	1.2	0.9	0.6	0.1
S27	<0.5	<0.5	<0.5	<0.5
S28	4.3	2.5	1.7	0.9
S29	12.0	11.7	10.8	3.8
S30	0.4	0.2	0.1	0.1
S31	7.0	6.1	6.1	3.3
S32	9.2	7.6	6.8	4.7
S33	6.5	5.9	5.2	3.5
S34	7.9	7.2	6.7	4.5
S35	10.0	9.3	8.9	**6.8**
S36	12.4	8.8	5.3	3.3
S37	6.1	5.6	5.2	3.7
S38	13.7	12.5	11.7	**7.5**
S39	10.9	10.4	9.4	**5.9**
S40	3.8	2.3	1.6	0.24
No (%) exceeding 100% of the WHO guideline	**None**	**None**	**None**	**1 (2.5)**
No (%) exceeding 50% of the WHO guideline	**None**	**None**	**1 (2.5)**	**8 (20.0)**

*WHO guidelines for CO: 15 minutes: 90 ppm; 30 minutes: 50 ppm; 1hr: 25 ppm; 8hr: 10ppm. Bolded numbers indicate values more than 50% of WHO guidelines.

Table 4: **Distribution of highest CO concentrations on traffic light posts, March-April 2008, Addis Ababa, Ethiopia**

Sampling Days	Sampling sites	15 minute average , ppm	30 minute average, ppm	1-hr Average, ppm	8-hr Average, ppm
Day 1	1 (Post Office)	9.3	8.4	7.5	4.3
	2 (Post Office)	9.1	7.8	5.9	3.2
Day 2	3 (Post Office)	11.6	10.1	9.2	3.7
	4 (Post Office)	6.8	4.9	4.0	2.2
Day 3	5 (Post Office)	9.5	8.4	6.8	2.9
	6 (Post Office)	4.4	3.3	2.8	1.6
Day 4	7 (Legehar)	10.1	9.8	9.0	**5.5**
	8 (Legehar)	9.1	8.0	7.3	**5.3**
Day 5	9 (Legehar)	10.1	9.7	9.2	**6.1**
	10 (Legehar)	8.6	8.2	7.5	**5.4**
Day 6	11 (Legehar)	10.9	9.7	8.3	4.9
	12 (Legehar)	7.3	6.8	6.2	4.9
Day 7	13 (Urael)	11.0	10.1	9.4	**6.2**
	14 (Urael)	12.1	11.6	11.0	**6.2**
Day 8	15 (Urael)	9.3	8.2	7.4	**5.9**
	16 (Urael)	8.7	8.1	7.7	**5.1**
Day 9	17 (Urael)	8.6	7.8	7.0	4.7
	18 (Urael)	6.3	5.9	4.9	3.9
Day 10	19 (Olympia)	14.0	13.3	11.6	**7.5**
	20 (Olympia)	17.9	16.6	**14.8**	**9.5**
Day 11	21 (Olympia)	16.1	12.4	11.4	**8.3**
	22 (Olympia)	15.2	14.8	**14.1**	**9.7**
Day 12	23 (Olympia)	14.9	14.6	**12.8**	**9.3**
	24 (Olympia)	9.5	8.4	7.9	**5.9**
Number (%) exceeding 100% of the WHO guideline		**None**	**None**	**None**	**None**
Number (%) exceeding 50% of the WHO guideline		**None**	**None**	**3 (12.5)**	**14 (58.3)**

*WHO guidelines for CO: 15 minutes: 90 ppm; 30 minutes: 50 ppm; 1hr: 25 ppm; 8hr: 10 ppm. Bolded numbers indicate values more than 50% of WHO guidelines.

Discussion

This study is only the second attempt to look the situation of urban pollution in the rapidly growing city of Addis Ababa. The presence of difference in the weighted averaged CO concentrations between July and January was consistent with the research question our study assumed. Three factors might explain this finding. First, although the traffic density in July is commonly less than that of January (personal observation and communication), the increased moisture and related climate variability might play a role in the dispersion of CO vehicular emission. Secondly, the relatively increased traffic density in January could be a factor. Third, the photochemical reaction that takes place in the daytime might be another factor to explain the high level of CO in January. Sunlight radiation in the day time could act on vehicular emissions to generate both CO and CO_2, thereby biasing the measurement of CO concentrations. However examining whether a photochemical process contributed or not to the low level CO concentration is beyond the scope of this research.

The 1-hour and 8hours averaged CO concentrations for each site was far less than the international practice (5) and the USA National Ambient Air Quality Standard (26). However, there were six sampling sites (15% of total of 40) that demonstrated 55-70% of the 8-hr standard (10.0 ppm) representing a qualitative description of “moderate” air quality based on the USEPA Air Quality Index (27). Those sites were located on “Kera” road (S39), “Gofa” intersection (S18), “Bole” road (S11, S12), and the road to “Megenagna” (S1, S16). Those roads with high vehicle density in general (“Bole sites”), and increased truck densities in some sites in particular (“Kera” and “Gofa” sites), were the major arteries bridging many other road tributaries and explaining the relatively increased CO concentrations. Sampling sites such as “Kera” sites were physically observed to be narrow with dense road side buildings that possibly restrict the ventilation of the vehicular emission.

The low level of CO below the 1-hour and 8 hours standard, which was counter to the research hypothesis of this study, was in agreement with the recent findings (21). The assumption was that there could be high CO concentrations due to the prevailing old vehicles in Addis Ababa and apparent congestion of vehicles in existing narrow roads. The results, however, are inconsistent with those reported by other investigators (8-10). The difference in the roadside CO concentration levels in different studies might be in part due to difference in vehicle density, meteorological conditions, methods of CO sampling techniques and variation in equipment used for CO monitoring.

There is a possible link between the traffic line and roadside sampling sites in CO concentration temporality. Three characteristics in pattern emerged on the traffic line pollution: short duration with highest peak in early morning, low level in lunch time, and extended but weakly plateaued CO concentration in the afternoons. The similarity in this pattern (Figure 2 and 4) explains that the source of roadside traffic pollution samplings was mainly of vehicular nature. Vehicular sources of traffic air pollution were obvious in a similar study in Addis Ababa (21). Elsewhere, vehicles in Toronto contributed about 82% of traffic pollution. Generally, traffic pollution contributes 60-85% of the urban ambient air (28-30). All sampling sites were located in industry free zones and, thus the analyzed CO is predominately from vehicular sources.

Of all traffic lines, "Bole" road at "Olympia" traffic light is notable as its 8-hr mean CO concentration observed in 5 out of 6 days in the daytime was between 7.5-9.8 ppm. These values are below the WHO 10 ppm guideline but closer to the USA EPA 9 ppm CO standard for 8-hr (5,26). The roadside CO concentrations at "Bole" road were also elevated compared to other sampling sites. Traffic Police are always present at this sampling site to watch out and manually instruct the flow of the traffic. Fortunately, their physical location throughout the shift (personal communication) might not expose them above the 8 hr standard level of CO. There is a concern that CO level might very soon exceed this level given the continued traffic density in the city accompanied with 8-12% of annual growth rate.

Traffic count in this study was only used for the selection of sampling point. Associating traffic count with the level of ambient air pollution is a difficult job. The work in Jimma, which had detailed traffic counts, displayed only weak correlations (18). Other studies state that relating traffic levels to ambient concentrations is difficult and/or only explains partly the variability in pollution levels (31,32).

In conclusion, although this study found low levels of CO concentration on both on-road and roadside traffic zones in reference to 15 minutes, 1 hour, and 8 hours standards, it is reasonable to assume that certain road corridors will likely exceed these reported values in future, given the continued increase of vehicles in the city. These corridors have inherently high traffic density. The increased CO concentration in January is reasonably acceptable due to the presence of high level of traffic density.. Future efforts should include the measurement of particulate matter and organic-elemental carbon along the traffic lines since the city is packed with diesel powered and aging vehicles and prevailing gravel roads dispersing organic dust and soil particles along traffic lines. In addition, the measurement of PM and CO on occupationally exposed group of population is another future of direction for research.

Some important limitations must be considered when interpreting the results from this study. The sampling might have missed some high concentration sites of which the investigators were not aware. These locations may exist despite the fact that 40 different sampling sites is assumed to maximize the sampling along the existing high traffic routes. The sampling time was only during the daytime in order to assess the impact of heavy traffic patterns. Moreover, measurements of CO at during two months are not adequate to get the complete picture of traffic air pollution. Limitations go also to the inability to control daily traffic counts at the time of the study and capture climate conditions such as temperature, rainfall and humidity. Yet even given these limitations, the data collected is an important contribution in assessing the level of traffic related air pollution through the measurement of CO concentrations.

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