Ambient Air Pollution Status of Addis Ababa City; The Case of Selected Roadside

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Abstract: The Objective of the present study was to determine the concentration level, spatial and temporal variation of air pollutants (Carbon monoxide, Volatile organic carbon, Nitrogen dioxide, and Sulfur dioxide) from vehicular emission in ambient air of Addis Ababa city. Measurements were taken at sixty five roadsides sites for all the above selected pollutants. The overall (mean ± SD) of Addis Ababa city roadsides Carbon monoxide, Volatile organic carbon, Nitrogen dioxide, and Sulfur dioxide concentration level were 4.82 ± 3.60 ppm, 317.52 ± 221.52 µg/m³, 0.12 ± 0.16 ppm and 0.23 ± 0.20 ppm respectively. Spatial variation were observed for all the pollutants; the highest Carbon Oxide, Volatile organic carbon, Nitrogen dioxide, and Sulfur dioxide concentration were recorded at SS16, SS34, SS39 and SS6 sites whereas the lowest at SS6, SS36, SS6 and SS19 respectively. At most of the sites high Carbon Oxide and volatile organic carbon concentrations were also observed at early in the morning and late afternoon. The temporal variation of Nitrogen dioxide and Sulfur dioxide were not significant at all sites under the study at p<0.05. The morning and the late afternoon peaks indicate that those pollutants were emitted where vehicular traffic was high. The roadside concentrations of all the pollutants under the study were high and needs continuous monitoring and exploring of mitigation techniques.

Keywords: Ambient Air Pollution, Roadsides, Air Pollutants, Addis Ababa, Volatile Organic Carbon

1. Introduction

Air pollution generated from vehicles has become a major cause of worldwide scientific and public concern. The estimate of the air pollution to global mortality based on World Health Organization (WHO) indicates even million deaths worldwide in the year 2012. However, 3.7 and 4.3 million are only due to Ambient Air Pollution (AAP) and Indoor Air Pollution (IAP) respectively [1, 2]. Population growth, limited emission control technology, substantial scale of urbanization, increased demand of transportation service, land use without planning, low quality fuels, age of vehicles, increased road congestion and lack of effective transport are among the factors contributing to enhanced vehicular urban air pollution [2-6]. The combined effects of urban air pollution factors create adverse air pollution by forming traffic air pollution. If it is not controlled or monitored effectively and timely, the deterioration will increase continually in cities of developing countries [6, 7].

Therefore, air pollution is one of the leading global public health threats. The following health problems like cardiovascular disease (stroke and ischemic heart disease), respiratory disease (asthma, lung cancer, acute respiratory infections in children and chronic obstructive pulmonary disease) are mainly linked with traffic air pollution exposure. The impact of air pollution is severe for sensitive population subgroups (children and elders), pedestrians who walk along busy roads, traffic police and street retailer who spend their time on and along congested roads, work or occupations like taxi and truck drivers [1, 8, 9].

Urban environment of both developed and developing countries like Ethiopia, vehicular emission pollution are a major source of emissions of ultrafine particles in ambient/outdoor air both at national and local level [3, 4, 5, 9, 10]. Ninety (90%) urban air pollution is rapidly growing and expanding in cities like Addis Ababa is due to motor vehicle emission.

WHO identified range of pollutants such as particulate
matter (PM), Carbon Monoxide (CO), Sulfur dioxide (SO$_2$), Nitrogen dioxide (NO$_2$) and Ozone (O$_3$) air pollutants that have a greatest human health importance and The United States (US) National Ambient Air Quality Standard (NAAQS) also include airborne lead (Pb) to the above mentioned air pollutants although more than three thousand substances are known to potentially contaminate urban ambient air [11, 12, 13].

Addis Ababa is among the cities currently undergoing rapid urbanization having considerable investment on buildings, road and transport sectors [14]. The number of vehicles is increasing annually without an expansion of roads in the city which is the main possible factor of the traffic congestion, therefore increasing in traffic pollution level of Addis Ababa. According to NMA, the air quality data of Addis Ababa is not available and data is provided based on the request [15]. Though this subject was extensively studied in cities of developed countries, to the best of our knowledge there are limited research conducted on vehicular pollution level and status in cities of developing countries like Addis Ababa. Therefore, there is a need to set information on the status and level/concentration of vehicular air pollution on roadside of Addis Ababa. Therefore, the present study was undertaken to fill the knowledge gap mentioned above aiming at exploring the concentration level of CO, VOC, SO$_2$, and NO$_2$, their spatial and temporal variation at selected sites of Addis Ababa main roadsides.

2. Materials and Methods

2.1. Study area Description

Present study was conducted in Addis Ababa, a capital city of Ethiopia and working center of African Union. Geographically, Addis Ababa has a total land of over 54,000 hectares and of more than four million populations. Addis Ababa, a heart of the country having an altitude ranging between 2,200 - 2,800 meter above sea level with latitude of 9.0300 degree north and longitude 38.7400 degree east. It has 10 sub-cities and 116 woreda's. The sampling sites under the study touch the corridors of the 10 sub-cities corridor.
2.2. Study Approach

Cross-sectional, environmental ambient air sampling approach was followed for the measuring the roadside pollutants gases mainly due vehicles (traffic congestion); CO, VOC, SO$_2$ and NO$_2$ at Addis Ababa city main roadsides from 03 June - 30 August, 2016.

2.3. Sampling Method

The sampling sites were selected by a walk through survey on the main roads of the City to assess the vehicle flow from 7:30 - 8:30 am (peak busy hours), 12:00-1:30 pm and 05:30-06:30 pm (peak busy hours) on working days of the week. Based on the survey sixty five (65) relatively busy roadside sites were selected. Then ambient air measurement was carried out at one hour interval from 7:00 am - 6:00 pm to quantify the concentration of the pollutants (CO, VOC, SO$_2$, and NO$_2$) at each selected sites. Real time measurement of VOC, SO$_2$, NO$_2$, and CO$_2$ were done using digital aeroqual instrument (portable gas sensor model 500 series, made in USA). GPS (GPS 60 Garmin, made in Taiwan) was used to take the x, y and z coordinates of the sampling/measuring points.

### Table 1. Sampling Site Code/ID.

| Sampling Sites                        | Sampling Site Code/ID | Sampling Sites                        | Sampling Site Code/ID |
|---------------------------------------|-----------------------|---------------------------------------|-----------------------|
| Arat kilo Commercial bank Selassie branch | SS1                   | Kality Meseltegn adelabey             | SS34                  |
| Piassa Hermon Hotel                    | SS2                   | Kality KAFDEM                         | SS35                  |
| Megenagna square                       | SS3                   | Legehar, around Medin insurance       | SS36                  |
| Selmiret Mariam Square                 | SS4                   | Ethio-post office main branch         | SS37                  |
| Summit yetebaberut fuel station        | SS5                   | Taklehaannat bruk photo              | SS38                  |
| Summit Condominium last                | SS6                   | Merkato big bus Station              | SS39                  |
| Arat kilo Minilik School               | SS7                   | Merkato Near Telle, small (Taxi and Bus Station) | SS40                  |
| Sidist kilo Dibab Cafe and Restaurant  | SS8                   | Mesalemania (Yekatit 23 Secondary School) | SS41                  |
| Shiromeda Condominium                  | SS9                   | Kolfe Taxi Station                   | SS42                  |
| Red Terror, Flamingo                  | SS10                  | Sebategna (Cross Road)               | SS43                  |
| Shoa super market                     | SS11                  | Ayer Tena Taxi Station               | SS44                  |
| Bole millennium taxi station           | SS12                  | Kara Kore (Absiniya bank)            | SS45                  |
2.4. Data Collection and Analysis

From all sampling sites all the pollutants i.e parameters under the study were collected in one hour interval starting from 7:00 am in the morning to 6:00 pm in the evening to maximize presence of high vehicular activities on road during the study period. All measurements were made at a range of 0.5-2.0 meter distance from the main road and 1 m height. The collected data entered to Microsoft excel database for further analysis and interpretation. The graphs were drawn using Origin Pro 8 software. For summarizing all the pollutant concentrations descriptive statistics was used. Mean pollutant concentrations were compared between selected sampling sites by t-tests and a p-value of 0.05 was considered for the statistical significance.

3. Result and Discussion

Measurements were taken for parameters under study at sixty five (65) sampling sites during the study period 03 June - 30 August, 2016 which falls in the wet season. The average (mean ± SD) concentrations of all parameters under study are presented in Table 1. The daily variation patterns of the pollutants (CO, VOC, SO$_2$ and NO$_2$) at (SS42) Merkato; busy business center and country cross Bus Station site of particular day was also indicated in Figure 2.

![Figure 2](image-url)
3.1. Roadsides CO Concentration

The arithmetic mean and standard deviation (mean ± SD) concentrations of CO at all the sampling sites of roadside presented in the Table 2. The overall mean ± SD CO concentration during the sampling period was 4.82 ± 3.60 ppm. The overall trends of CO concentration at all sites during the study period were similar. All the sites (SS16, SS40, SS3, SS41, SS33, SS39, SS38, SS26 and SS35) with high CO concentration (mean ± SD) are sites located in the high congestion traffic zones of Addis Ababa. The finding of this study is higher than the value reported (2.8 and 2.1 ppm in dry and wet seasons respectively) by [3] which was studied in the same city (Addis Ababa) and lower than the one reported by [16]. The higher concentration of CO recorded in this research work was may be due to the indirectly increased vehicle congestion in the city. Figure 3 below indicate the trends of CO concentration at site with highest and lowest roadside CO concentration.

The results obtained from the present study revealed that there is a spatial (site to site) variation (p<0.05) of CO concentration even though the overall concentration trend of CO concentration at all sites was analogous. The highest and lowest CO concentration was recorded at Merkato, which is very busiest business center and country cross bus Station (10.83 ± 3.3.27 ppm) and Summit Condominium square; south-eastern peripheral of Addis Ababa city (1.20 ± 1.40ppm) sampling sites respectively. It was indicated in recent study [1] that there is a spatial variation of CO concentration in Addis Ababa City. Lowest (0.2 ppm) and highest (23.2 ppm) CO concentration in Addis Ababa city at Entoto St. Mary Church and Teklehaimanot square respectively were reported [17].

The geographical location of sampling site and average (mean ± SD) concentration of all the parameters under study at all study sites is shown in Table 2.

![Figure 3. Typical daily CO concentration trends at sites with highest and lowest concentration.](image)

Table 2. Geographical Location of Sampling site and Average (mean ± SD) n= 12 Concentration of all the parameters under study at all study sites.

| Sampling Site Code/ID | UTM (X)  | UTM (Y)  | Elevation | VOC (µg/m³) | CO (ppm) | SO₂ (ppm) | NO₂ (ppm) |
|-----------------------|----------|----------|-----------|-------------|----------|-----------|-----------|
| SS1                   | 474186   | 998409   | 2431      | 560.17± 137.08 | 5.29± 5.50 | 0.28± 0.09 | 0.08± 0.04 |
| SS2                   | 472997   | 998487   | 2456      | 598.25±78.68  | 7.83±5.62  | 0.23±0.08  | 0.14±0.20  |
| SS3                   | 478054   | 997288   | 2391      | 697.33±295.16 | 9.92±5.23  | 0.29±0.11  | 0.08±0.14  |
| SS4                   | 480720   | 996972   | 2369      | 809.92±233.36 | 3.75±3.89  | 0.24±0.10  | 0.08±0.01  |
| SS5                   | 483798   | 997276   | 2390      | 574.02±120.31 | 3.58±2.81  | 0.24±0.11  | 0.07±0.02  |
| SS6                   | 484043   | 992991   | 2320      | 629.9±72.36   | 1.20±1.40  | 0.21±0.01  | 0.05±0.02  |
| SS7                   | 473941   | 998823   | 2442      | 377.28±159.88 | 7.92±2.97  | 0.23±0.11  | 0.12±0.14  |
| SS8                   | 473807   | 100042   | 2505      | 221.15±43.88  | 5.58±4.54  | 0.18±0.10  | 0.06±0.03  |
| SS9                   | 473819   | 1001585  | 2569      | 207.42±30.38  | 3.42±2.91  | 0.18±0.09  | 0.07±0.01  |
| SS10                  | 474196   | 995768   | 2355      | 255.73±145.07 | 5.08±2.94  | 0.24±0.13  | 0.11±0.04  |
| SS11                  | 474949   | 994487   | 2338      | 196.97±51.97  | 3.50±1.98  | 0.23±0.13  | 0.10±0.05  |
| SS12                  | 476908   | 993584   | 2332      | 208.98±23.35  | 3.57±1.59  | 0.28±0.12  | 0.22±0.31  |
| SS13                  | 474867   | 996734   | 2369      | 363.63±160.37 | 4.17±2.21  | 0.28±0.14  | 0.11±0.10  |
| SS14                  | 476457   | 994679   | 2369      | 305.08±132.08 | 6.25±5.93  | 0.26±0.15  | 0.08±0.03  |
| SS15                  | 477253   | 993821   | 2332      | 264.58±145.10 | 5.58±5.09  | 0.20±0.25  | 0.32±0.31  |
| SS16                  | 477536   | 997525   | 2402      | 375.41±84.46  | 10.83±3.27 | 0.37±0.24  | 0.18±0.17  |
| SS17                  | 484110   | 998745   | 2451      | 270.11±75.36  | 2.83±1.53  | 0.23±0.23  | 0.07±0.02  |
| SS18                  | 472301   | 993299   | 2280      | 277.84±78.85  | 1.58±0.67  | 0.26±0.10  | 0.07±0.02  |
| SS19                  | 486713   | 1001113  | 2448      | 206.83±34.21  | 1.67±0.78  | 0.01±0.03  | 0.02±0.02  |
| SS20                  | 473555   | 996064   | 2334      | 247.89±79.74  | 7.92±6.26  | 0.29±0.16  | 0.14±0.83  |
| SS21                  | 473609   | 993529   | 2306      | 185.94±22.35  | 4.58±1.78  | 0.30±0.13  | 0.12±0.08  |
Figure 4. Typical day CO concentration trends at SS3 (Megenagna train ticket sell).
The result of this study shows there was temporal variation of CO concentration at all sites under study and the variation was significant (p<0.05). Figure 4 below shows the patterns of CO concentration on particular measuring day at Megenagna; thickly crowded road part in Addis Ababa (SS3). There was high CO concentration during the rush hours in the morning (8:00 am- 9:00 am) and early afternoon (04:00-06:00 pm) and lower at 10:00 am -03:00 pm [18, 19, Figure 4]. The daily (hourly) maximum CO concentration recorded during the study period was 18 ppm for SS14 and SS3 sampling sites on rushing hours of the day on 9:00 am and 5:00 pm respectively [Figure 4]. The high CO concentration in the early morning and late afternoon was due to the congested vehicular staging and stagnation of temperature in the city [3, 16]. The low concentration of CO at mid-day was because of the photochemical reaction taking place by sunlight in the presence of hydrocarbons as CO is converted to carbon dioxide [3].

3.2. VOC Concentration

The overall VOC concentration mean ± SD during the sampling period was 317.52 ± 221.52 µg/m³. The arithmetic mean and standard deviation concentrations of VOC at all the sampling site of roadside presented in the Table 2, SS1, SS2, SS3, SS4, SS5, SS6, SS26, SS34 and SS59 are sites with VOC concentration of above the overall mean ± SD [Table 2]. Scholar [20] also reported lower total VOC concentrations of 129 µg/m³ on roadsides of Philippines. The VOC concentration found in this study was higher than the value reported for Ghent city (54 µg/m³), similar with that of Addis Ababa (318 µg/m³) and lower than that reported for Hanoi city (507 µg/m³) [15].

The finding of the present study is indicating that, there is a spatial variation of VOC concentration over the selected study sites. The highest and lowest VOC concentration during the sampling period was 752.88 ± 121.36 µg/m³ and 157.73 ± 39.79 µg/m³ at SS34 and SS36 sampling sites respectively. More than ten (10) sites under study have VOC concentration above mean ± SD and most of the sampling sites have VOC Concentration below mean ± SD [Table 2]. The study by [22] also reported the spatial variation of VOC in urban areas of Dhaka city of Bangladesh.

Temporal variation of VOC concentration during the study period at the entire study site was not significant as such even though the overall concentration trend of VOC concentration at all sites was similar. The pattern of particular measuring day, Megenagna site (SS3) shown in Figure 2. There was high VOC concentration at most sampling sites during the rush hours in the morning (8:00-9:00 am) and early afternoon (04:00 pm) and lower 10:00 -03:00 pm [Figure 2, 5]. Temporal variation of VOC; low in midnight and high at early in the morning continuously increasing up to 10:00 am was reported in [23].

3.3. NO₂ Concentration

The overall mean ± SD NO₂ concentration during the sampling period was 0.12 ± 0.16 ppm [Table 2]. The highest and lowest NO₂ concentrations were recorded at site SS34 (0.67 ± 0.30 ppm) and SS6 (0.05 ± 0.02 ppm). The study conducted in two Ugandan cities also reported 0.025 ppm NO₂ concentration [1]. Furthermore, the study by [17] conducted in Addis Ababa city, reported that the NO₂ concentration at the sites under their study was not detectable.

The arithmetic mean and standard deviation (mean ± SD) concentrations of NO₂ at all the sampling site of roadside presented in the Table1. The result of this study shows that there is a spatial variation of NO₂ concentration. The overall NO₂ concentration trend at all sampling sites were similar [Figure 6]. Sites such as; SS2, SS26, SS34, SS35 and SS39 have high concentration of NO₂ then mean ± SD and are located in the high congestion of traffic zones in Addis
Ababa [Table 2]. The highest and lowest NO$_2$ concentrations were recorded at sites SS39 and SS6 respectively [Table 2]. Figure 6 below shows the trends of NO$_2$ concentration of SS6 and SS39 during particular day during the study period, which shows directly proportional to traffic and congesting of traffic.

![Figure 6. The daily NO$_2$ concentration Trends in particular day of sites SS6 (Summit Condominium last gate) & SS39 (Merkato big bus Station).](image)

Temporal variation of NO$_2$ concentration at all sites under study was observed. The trend of NO$_2$ concentration at all sites was similar [Figure 6]. There was high NO$_2$ concentration during the rush hours in the morning (8:00 - 9:00 am) and early afternoon (04:00-06:00 pm) and lower 10:00 am -03:00 pm [Figure 6].

3.4. SO$_2$ Concentration

The arithmetic mean and standard deviation (mean ± SD) concentrations of SO$_2$ at all the sampling site of roadside presented in the Table 1. The overall arithmetic mean and standard deviation (mean ± SD) concentration of SO$_2$ during the study period was 0.23 ± 0.20 ppm perhaps the climatic condition of Addis Ababa may facilitate the adsorption of the gaseous pollutants such as SO$_2$ on particulate matter [1]. As reported by [17] the SO$_2$ concentration at the sites under their study in Addis Ababa city was not detectable.

![Figure 7. Trends of SO$_2$ at sites with highest and lowest concentration.](image)

The highest and lowest SO$_2$ concentrations were recorded at site SS33 (0.74 ± 0.31 ppm) and SS19 (0.01 ± 0.03 ppm) respectively [Table 2]. The roadside SO$_2$ concentration of the site with highest and lowest is indicated in figure 7. The results shows that no remarkable spatial and temporal variation of SO$_2$ concentration (not significant at $p<0.05$), but the overall concentration trends of SO$_2$ concentration at all sites were similar [Figure7].

4. Conclusion

The current study was carried out to assess the concentration of four ambient air pollutants in Addis Ababa City focusing on the roadside to understand their distribution and provide the overview of the pollutants concentration. The roadsides concentration (mean ± SD) of CO, VOC, NO$_2$ and SO$_2$ found were 4.52 ± 3.60, 317.52 ± 221.52, 0.12 ± 0.16
and 0.23 ± 0.20 respectively. The result of this study for all air pollutants under study were higher than the previous studies result reported by different researchers. Therefore, air pollution in the city needs to be monitored continuously and exploring mitigation mechanisms should be put in place by concerning government bodies or non-government organization.

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