ORIGINAL PAPER

Long-term spatial and temporal variability of ambient carbon monoxide in Urmia, Iran

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Date of submission: 25 Jun 2017, ***Date of acceptance:*** 31 Jul 2017

ABSTRACT

One of the pillars of epidemiologic research on the long-term health effects of air pollution is to estimate the chronic exposures over space and time. In this study, we aimed to measure the intra-urban ambient carbon monoxide (CO) concentrations within Urmia city in Iran, and to build a model within the geographic information system (GIS) to estimate the annual and seasonal means anywhere within the city. We collected more than 5,000 measurements from 53 locations during July 2010 to July 2011 in four seasons to calculate the annual and seasonal means in Urmia. The Universal Kriging was used to predict the spatial and seasonal concentrations of CO. The annual mean and annual peak CO concentrations were respectively 2.5 and 4.4 ppm. The results of the spatial analysis showed that the north-eastern parts of the city were more polluted than the other areas. The mean and peak seasonal spatial patterns were consistent over time. This is the first study that monitored and predicted the long-term CO concentrations with a dense measurement network in Urmia, providing a foundation for future epidemiological studies on the health effects of air pollution. The spatial estimates can also be used for a variety of other purposes, such as evidence-based air quality management and urban planning. Overall, the CO levels in Urmia were lower than the values recommended by the World Health Organization. However, further research is required on other important pollutants, such as particulate matter, nitrogen dioxide, air toxics and so forth.

Keywords: Air pollution, carbon monoxide variability, intra-urban, long-term, spatial

Introduction

Air pollutants comprise one of the leading risk factors, which have a huge impact on the burden of diseases.[1, 2] The adverse health effects of acute and chronic exposure to ambient air pollution have been documented for a variety of outcomes and consequences on public health.[3] It is important to mention that each air pollutant has its specific effects on various health endpoints. Till date, many studies have reported the elevated mortality and morbidity risks associated with different air pollutants, such as particulate matter, sulfur dioxide, nitrogen oxides, ozone, carbon monoxide (CO), etc.[4–7] Although most studies evaluated the detrimental effects of exposure to high levels of air pollutants, however, interestingly, the recent findings suggested beneficial effects of exposure to specific air pollutants on the health outcomes. Tian et al. (2013) reported that exposure to low levels of exogenous CO (0.6 to 1.0 parts per million–ppm) may reduce hospital admissions due to respiratory tract infections and CO might play a modulator role in chronic

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Citation: Hamed Aghdasi, Rahim Aali, Nabiollah Mansouri, Heresh Amini. Long-term spatial and temporal variability of ambient carbon monoxide in Urmia, Iran. J Adv Environ Health Res 2017; 5(2): 78-84

respiratory illnesses.[8] This is consistent with the experimental studies, which suggest the anti-microbial and anti-inflammatory effects of exposure to CO.[9–11] However, on the other hand, numerous studies have pointed out the adverse health effects of exposure to CO.[12–14]

Studies on the spatial and temporal variability of air pollutants revealed that certain species have substantial gradients within cities.[15–18] Various approaches have been used so far to capture the small-scale spatial variability of intra-urban air pollutants for epidemiologic research.[19] These include proximity models, dispersion models, land use regression, chemical transport models, integrated meteorological emission models, hybrid models, interpolation models and so on.[20] Each of these methods has its own pros and cons, which are described elsewhere,[19, 20] but one of the methods most used is interpolation.[21] In the interpolation models, generally the stochastic and deterministic geo-statistical techniques are exploited to estimate the pollutant from a network of real measurements in the study area. Meanwhile, it has been demonstrated that in the air pollution studies, the universal Kriging method provides reasonable predictions over the study areas.[20]

Urmia city is located in the north-west of Iran near Urmia Lake. Till date, there has been no published report on the long-term levels of ambient CO in the city, and the work that we are reporting here is the first study to measure and estimate the long-term ambient CO concentrations in Urmia. It is noteworthy that Urmia experiences several dusty days in a year, flowing mainly from Iraq,[22] and there are reports about the air quality suggesting that there were about 25 unhealthy days in 2011.[23] In this research, we aimed to monitor the intra-urban CO concentration levels within Urmia city with a dense network to increase the spatial representative strength over four seasons within a year to increase the temporal coverage, and to build a model within the geographic information system (GIS) to estimate the annual and seasonal means anywhere within the city.

Materials and Methods

Urmia is located in the north-west of Iran, neighboring Urmia Lake. The area of the city is about 63 square kilometers, with an annual precipitation of roughly 340 mm.[24] The city is located at a latitude of 37°33′19″ N and a longitude of 45°04′21″ E, with an elevation of about 1,300 meters above the sea level. The population of the city—based on the census report in 2011—is over 963,000 individuals.[25]

As the vehicles are the main culprit responsible for CO pollution, we selected monitoring sites based on the traffic counts over the city. There was no data on the traffic counts, and, so, we conducted a preliminary study and counted the number of cars passing by per minute in different locations. We then stratified these locations based on the traffic counts into four categories: Very low traffic (<5 vehicles/minute), low traffic (5–35 vehicles/minute), high traffic (35–60 vehicles/minute), and very high traffic (60–90< vehicles/minute) sampling sites. Afterward, we selected 53 locations (25% from each traffic category) so as to have a dense network with high spatial representative strength (Figure 1).

We used a diffusion detector for the CO measurement in Urmia called QRAE II, which had one electrochemical-sensor (RAE Systems Inc., San Jose, CA, USA). The range of detection by QRAE II was from 0 to 1,000 ppm, with a resolution of 1 ppm.

The monitoring period was from July 2010 to July 2011, for one year, over four seasons. Overall, we took the measurements on 24 days (six days in each season and two days randomly selected in each month). We had four sampling periods in each measurement day for each location, including 6:30 a.m. to 10:30 a.m., 11:00 a.m. to 15:00 p.m., 15:30 p.m. to 20:30 p.m., and 21:00 p.m. to 00:30 p.m. Overall, we collected 5,088 measurements in the year while attempting to have a reasonable temporal coverage to calculate the annual and seasonal averages. Finally, minimum, mean, and peak concentrations of CO were calculated for each monitoring station.

In order to create the spatial and seasonal surfaces of CO in Urmia, a GIS was established. At first, all the sampling locations were geo-coded. Then, the mean and peak annual and seasonal CO concentrations that were measured were assigned to each location. Next, ArcGIS Spatial Analyst extension was used to interpolate the observed samples to create the spatial surface of CO over the study area. The interpolation was carried out by the universal Kriging method with a horizontal resolution of 50 meters. The final predicted surfaces were cross-validated using the hold-out method, and root mean square error (RMSE) statistic, which was calculated based on the following equation:

$$\mathrm{RMSE} = \sqrt{\frac{1}{N}\Sigma(y-\bar{y})^2} \quad (1),$$

where y is the monitored CO level (ppm) and $\bar{y}$ is the predicted CO value (ppm). Finally, the spatial and seasonal surfaces of the mean and peak CO concentrations in Urmia were created.

Results and Discussion

In this study, we monitored the within-city concentrations of CO for the first time in Urmia, Iran. We collected 5,088 measurements from 53 locations with a somewhat dense network and a reasonable temporal coverage. Furthermore, we interpolated these measurements within a GIS, with a commonly used method to create spatial surfaces of the long-term CO concentrations over the city.

The average concentrations of the mean CO were higher in summer and lower in spring, which were 2.8 and 2.4 ppm respectively. In addition, the average concentrations of the peak CO were higher in summer and lower in winter, which were 5.1 and 3.9 ppm respectively. The minimum concentrations were zero in all seasons. The annual mean and peak CO concentrations were 2.5 and 4.4 ppm respectively. The summary of the statistics of the mean and peak CO concentrations measured are shown in Table 1.

The predicted spatial annual mean and annual peak CO concentrations are shown in Figure 2. As can be seen, the north-eastern part of the city is more polluted than the other areas, which is caused by the high traffic counts in these areas. The north-west, south-west, and eastern areas had lower concentrations, which is evident by the blue and light blue colored areas. Furthermore, the spatial patterns of the annual mean and peak CO concentrations were similar (Figure 2).

Table 1. Summary statistics of measured carbon monoxide concentrations (ppm) in ambient air of Urmia, Iran

	Mean	Min	Max	p25	p50	p75
Annual mean	2.5	0.0	6.6	0.3	2.5	4.1
Summer mean	2.8	0.0	9.0	0.6	2.4	4.6
Autumn mean	2.5	0.0	5.9	0.4	2.4	3.9
Winter mean	2.5	0.0	5.9	0.2	2.6	4.4
Spring mean	2.4	0.0	5.8	0.2	2.5	3.9
Annual peak	4.4	0.0	11.2	0.8	4.3	7.3
Summer peak	5.0	0.0	15.6	1.0	4.2	8.0
Autumn peak	4.4	0.0	11.2	0.8	4.2	6.9
Winter peak	3.9	0.0	9.3	0.5	4.1	6.4
Spring peak	4.1	0.0	9.5	0.5	4.5	7.0

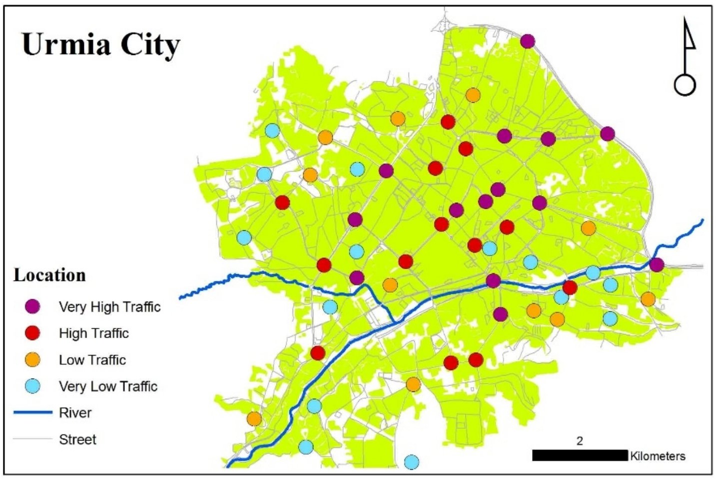

Fig. 1. Map of the 53 sampling sites based on four traffic categories in Urmia, Iran

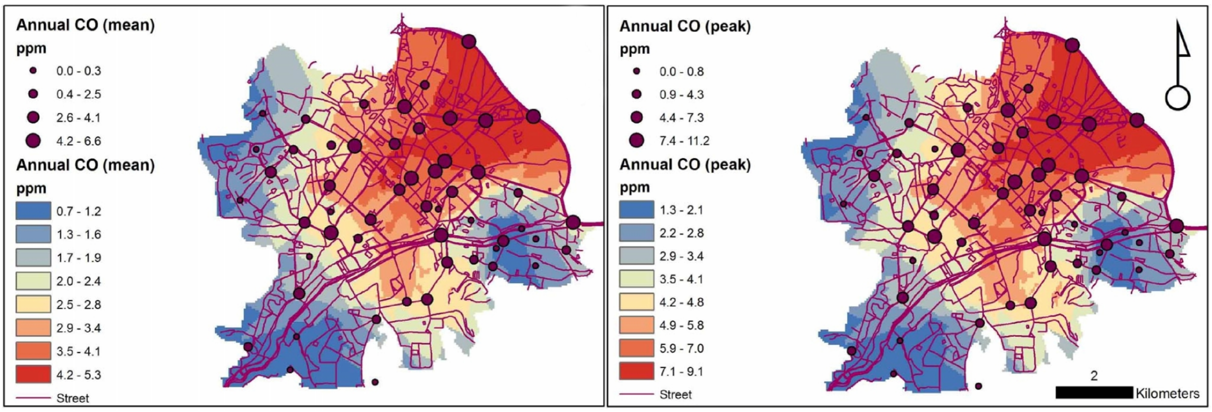

Fig. 2. Spatial pattern of annual mean and annual peak CO concentrations in Urmia, Iran

The seasonal mean and peak spatial patterns were similar to the annual mean and peak patterns and did not change much over time (Figure 3).

The RMSE values for the annual mean and annual peak were respectively 0.4 and 0.7 ppm, which indicate small errors in the predicted surfaces.

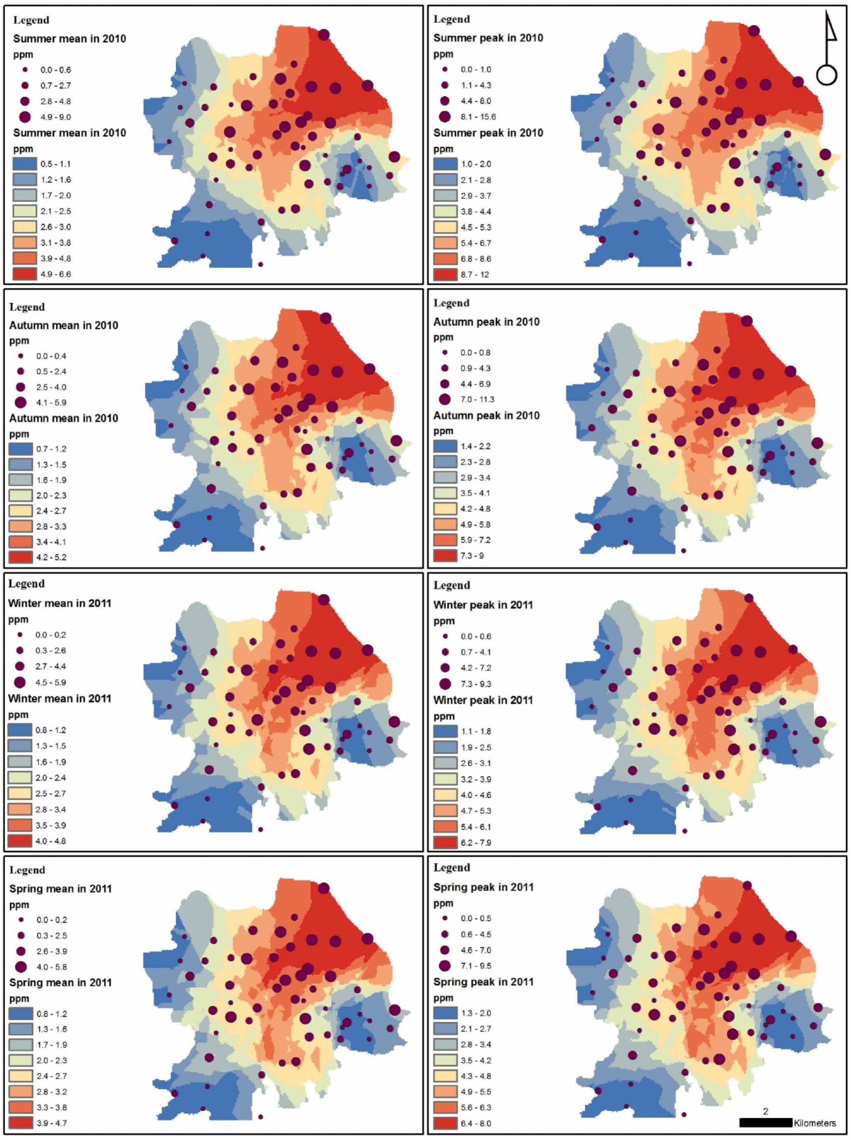

Fig. 3. Spatial pattern of seasonal mean and peak CO concentrations in Urmia, Iran

The examples of CO measurement and mapping are not rare globally. Potoglou and Kanaroglou (2005) predicted the CO concentrations using the universal Kriging in Hamilton, Canada.[26] The values of the predicted CO concentrations in Hamilton were 0.1 to 4.5 ppm and they found hot spots near highways, which had high traffic. The RMSE of the model used by Potoglou and Kanaroglou (2005) was 1.5 ppm, indicating that the predicted values were unbiased. Beelen et al. (2009) applied the universal Kriging to predict the concentrations of nitrogen dioxide (NO_2), fine particles < 10 µm (PM_{10}), ozone (O_3), sulfur dioxide (SO_2), and CO using routine monitoring data over the whole of Europe.[27] Although the universal Kriging could predict the values of NO_2, PM_{10}, and O_3, it could not provide satisfactory results for CO and SO_2. The unsatisfactory result for CO was mainly because of the lack of sufficient monitoring sites in Europe, showing that the presence of a dense monitoring network greatly affects results of the Kriging interpolation. In Urmia, we had 53 monitoring locations over a small area with high spatial representative strength, and, so, we could provide reasonable predictions.

In Iran, the CO concentrations have been measured and predicted mainly in Tehran[28, 29]; in addition, there is no study till date that reports the long-term CO levels in the ambient air of Urmia. Kavousi et al. (2013) analyzed the spatial patterns of CO and PM_{10} in Tehran using universal Kriging and found that the mean CO levels were around 3 ppm. They also found the hot spots of CO in the eastern and northern parts of Tehran with an RMSE of 0.8 ppm, which is a reasonable prediction error. Sargazi et al. (2011) used data from 16 monitoring sites in Tehran and predicted the spatial surfaces with several methods. They reported that Co-Kriging and Kriging were the best techniques among the that were tried methods with smaller prediction errors and so could satisfactorily detect the hot spots of CO in Tehran. However, the temporal coverage of these studies has been low, while in Urmia, we took into account this issue, and monitored throughout the year.

Conclusion

Air pollution monitoring and modeling are crucial in low- and middle-income countries. This report is the first study to monitor and predict the long-term spatial and temporal CO concentrations in Urmia, Iran. The CO levels in Urmia were lower than the values mentioned in the World Health Organization guidelines. However, further research is required on other important pollutants, such as particulate matter, nitrogen dioxide, air toxics, and so on. The results of this study could provide a foundation for future health studies in Urmia.

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