Study the effectiveness of different actions and policies in improving urban air quality: Dammam City as a case study

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ABSTRACT
Traffic-related air pollution abatement will remain a challenge because of increasing demand for transportation. This study was aiming to assess the effectiveness of different actions and policies in improving urban air quality. Levels of five air pollutants were simultaneously measured at three locations with different human activities for continuous six years starting from 2010 to 2015 at Dammam City in Saudi Arabia. Data of road traffic policies and administrative actions was obtained from several governmental authorities. Levels of the five pollutants were gradually reduced from year to year with different percents and trends. As for PM10 and VOCs, levels of the industrial and commercial areas were still higher than their recommended air quality guidelines (AQGs) (150 µg/m3 and 0.24 ppm respectively). The traffic management policies and administrative actions appear to be effective to produce significant decreases in traffic-related air pollution concentrations and improve the air quality of urban areas.

1. Introduction

Worldwide, there are a huge number of people exposed to the extreme level of air pollution particularly those emitted from the activity in urban areas [1,2]. Several dangerous diseases such cardiovascular and cardiopulmonary events, asthma and cancer are correlated to the exposure to air pollutants from the traffic activity [3–7]. Several epidemiological studies revealed that there is a direct correlation between the severity of these disease and living in urban traffic congestion areas, particularly those are living near the busy traffic roads [8]. The Traffic-related air pollution not only has its adverse effect on the human health, but also it has a bad impact on the environment. For example, nitrogen oxides together with volatile organic compounds are responsible for the formation of photochemical smog and ground-level ozone in the presence of sunlight [9]. The airborne black particles (soot) is responsible for staining of building as a result of its deposition after emission from the vehicle tailpipe [10]. In addition, the formation of acid rain is caused by the combination of sulphur and nitrogen dioxide with the water content of the atmosphere. Acid rain or deposition has its adverse effects on plants and soil, surface water and aquatic life [11]. The accelerated population increase is accompanying by increasing demand for transportation and increasing in levels of the ambient air pollution [12]. Reducing levels of air pollutants from traffic activity becomes a recent challenge for most urban areas in the worldwide. This can be accomplished by several methods include improvements in vehicle technology, implementation of transportation control measures, reducing congestion by encouraging off-peak period travels or driving under more optimal conditions, and by encouraging the use of public transportation rather than single occupant vehicles. It can also result from better vehicle maintenance practices, retrofitting older vehicles with newer emissions control technology and replacing existing vehicles with lower-emitting vehicles [13]. Redesign of the heavy traffic roads is also considered an important control procedure for reducing levels of traffic air pollution in the road environment [14]. Several recent researches revealed that the above policies and procedures have positive impacts in the improvement of road traffic activity [15,16]. On the other hand, traffic management solutions such as introducing and enforcing variable speed limits, installing local-express lanes or reversible lanes, imposing differentiated road pricing and optimizing traffic signal timing have been conducted to improve air quality levels in the urban atmosphere [17].

Dammam is the capital, the major seaport and one of the largest cities with highest population in the Eastern Province of Saudi Arabia. There is an increase in the migration of people to Dammam City for getting job and studying because of the presence of large number
of industries, universities and different governmental centers. Due to the rapid population growth in the city, number of vehicles is also increasing which lead to changes in air quality level due to the continuous emissions from their engines directly in the street environment. Few studies were conducted to assess the level of the urban air pollution levels in Dammam [18]. This research was aiming to study the road traffic management policies and procedures during the last five years and study their impacts in improving the urban air quality level in Dammam City.

2. Methods

2.1. Sampling stations and duration

Three locations were selected in Dammam City represented three areas with different activities; industrial, commercial and residential. These locations were considered as steady air monitoring stations during a period from year 2010 until year 2015. As shown in the maps (Figure 1), the industrial area was represented by First Industrial Dammam Region which contains more than 200 factories with different activities. The commercial area was represented by the Prince Mohammed Bin Fahd Street which is characterized by the presence of several shopping malls and restaurants. The residential area was represented by Al Tobaishi District which is far from any industrial or commercial activities. Air pollutants levels were measured at the day morning rush hour period, from 6:00–8:00 am, of the 5 working days (Saturday–Wednesday) during the spring season of the six years. This period of the day represents the most traffic rush one in Dammam City because most educational and industrial activities start at this time.

2.2. Sampling method and equipment

Five air pollutants were measured at the three selected sites in Dammam City included particulate matter less than 10 microns (PM$_{10}$), carbon monoxide (CO), sulphur dioxide (SO$_2$), nitrogen dioxide (NO$_2$), and volatile organic compounds (VOCs).

Samples of PM$_{10}$ were collected gravimetrically [19] by using the Staplex MiniVol® Tactical Air Sampler (TAS). Each PM$_{10}$ sample was collected once during the two hours period on a membrane filter carried in a filter holder assembly based on the required size, and then transferred to the lab for further analysis and calculations. After further weighting of the filters, concentrations of PM$_{10}$ were calculated in micrograms of the particulate mass per cubic metre of the sampled air volume (µg/m$^3$). About 200 samples were collected yearly at each selected location during the overall period of study.

Levels of the selected gaseous air pollutant were measured directly by three different instruments; the Gray Wolf’s DirectSense® mobile PC based products AdvancedSense™ with Wolf Pack™ area monitor, the AQM 60 Ambient Air Quality Monitor and the TSI’s Q-Trak IAQ Monitor. At each measuring point, several readings in parts per million (ppm) were recorded for each gaseous pollutant during the two-hour period (a reading per 15–30 min). For quality assurance, the instruments were calibrated and adjusted to record and save directly a reading each 30 min.

![Figure 1. Sampling stations at different areas in Dammam City.](image-url)
2.3. Actions and policies survey data

Data of any efforts, policies and administrative actions that were inserted to improve road traffic in Dammam City were collected from several governmental authorities, agencies and stakeholders including; the General Department of Traffic, Presidency of Meteorology and Environment, the Municipality of Eastern Province, the Ministry of Transportation, the Ministry of Industry, and the Ministry of Culture and Information. For accepting the obtained data, several criteria were considered such as; it should be provided with formal signatures or agency stamp, it must be updated numerical data or published studies and researches. Examples of these data included details numbers and types of cars that were registered in the General Department of Traffic, periodical city boom reports [20] and Knowledge City: Case Study of Dammam Metropolitan – Kingdom of Saudi Arabia [21].

2.4. Attitudinal social survey

An attitudinal survey was conducted in the last year of study (2015) to measure people’s knowledge and satisfaction with air quality improvement policies in Dammam City. A direct interview was done with 150 respondents with different ages and sexes using a pre-designed questionnaire having a total of 14 straight-forward questions including personal information of the respondents, their opinion about the magnitude of air pollution problem in Dammam City and the efficiency of the corresponding policies and management actions to mitigate its levels and effects.

3. Results

3.1. Air pollutant monitoring results

Figures 2–6 represent mean levels of the five measured air pollutants at the three selected locations for each year of the six-year studies. The highest mean levels ± standard deviation of PM$_{10}$ (413.7 ± 83.7 $\mu$g/m$^3$), CO (7.9 ± 5.2 ppm), VOCs (0.47 ± 0.23 ppm), NO$_2$ (0.025 ± 0.006 ppm) and SO$_2$ (0.017 ± 0.003 ppm) were found at the industrial area, followed by the commercial (227.6 ± 101.1 $\mu$g/m$^3$, 7.4 ± 3.9 ppm, 0.47 ± 0.23 ppm, 0.022 ± 0.004 ppm and 0.016 ± 0.005 ppm, respectively) while the lowest levels were recorded at the residential area (151.1 ± 49.6 $\mu$g/m$^3$, 1.8 ± 0.08 ppm, 0.19 ± 0.16 ppm, 0.007 ± 0.0 ppm and 0.008 ± 0.002 ppm, respectively).

Statistically, means of pollutants were compared at the three selected locations by applying the ANOVA test as shown in Table 1. It is evident that there are

![Figure 2. Mean levels of PM$_{10}$ at different locations and different years in Dammam City.](image2)

![Figure 3. Mean levels of CO at different locations and different years in Dammam City.](image3)
strong statistical significant differences for levels of PM$_{10}$ between the three locations ($p < .001$). For levels of CO and VOCs, there are also strong statistical significant differences between the residential area and the other two areas ($p < .005$), while there is no differences between the commercial and industrial areas ($p > .05$). For other pollutants, there is no any difference between their levels in the three areas ($p > .05$).

On the other hand, levels of the five air pollutants were compared during the 6 years (2010–2015) at the same selected locations. The overall mean levels of PM$_{10}$, CO, VOCs, NO$_2$ and SO$_2$ in the ambient air of Dammam City were gradually reduced from...
Table 2. ANOVA test for mean levels of pollutants during different years.

| Years        | CO    | PM10  | VOCs  | NO2   | SO2   |
|--------------|-------|-------|-------|-------|-------|
| 2010–2011    | .482  | .872  | .135  | .867  | .445  |
| 2010–2012    | .089  | .416  | .010  | .648  | .420  |
| 2010–2013    | .063  | .218  | .008  | .482  | .123  |
| 2010–2014    | .047  | .144  | .004  | .431  | .108  |
| 2010–2015    | .011  | .125  | .003  | .268  | .101  |

381.4 µg/m³, 10.9, 0.72, 0.023 and 0.019 ppm, respectively, in year 2010–2012 µg/m³, 2.1, 0.21, 0.013 and 0.011 ppm, respectively, in year 2015. Statistically, the mean levels of these pollutants were compared between the six-year periods (2010–2015) by applying the ANOVA test as shown in Table 2. It is clear that there are statistical significant differences for levels of VOCs and CO between the first and the last two to three years ($p < .05$), while there are no differences between the other pollutants ($p < .05$).

### 3.2. Attitudinal survey results

Figure 7(a–c) represent the answer of some questions that were directed to assessment of urban management.
procedures. Only 45% of the respondents were feeling with a considerable improvement in the air quality levels around them, while the other 55% do not have the same feel. About 38% of the respondents decided that actions and policies engaged with the traffic roads (repairing, inspection, construction of bridges or tunnels, etc.) were the apparent effective actions to reduce air pollution level in Dammam City, while 37% decided that cultivation of more green areas were the most apparent one. On the other hand, about 100% of them were convinced with importance of public awareness for actual reducing of air pollution problem.

4. Discussion

Traffic intensity is considered one of the most important determinants of ambient anthropogenic PM concentrations, but its contribution varies between PM size fractions. Based on several studies, the contribution of traffic to PM$_{10}$ has been estimated to be 32% [22]. Comparison of PM levels in several European cities demonstrated a positive correlation between ambient PM$_{10}$ concentrations on the one hand and population and traffic density on the other hand [23]. In addition to the traffic pollution source, the industrial activity is also considered a main source of ambient PM which emitted from stacks and fugitive dust emissions from several industries such as cement and fertilizer industries [24]. Results of our study confirmed this fact in which, levels of PM were found in the industrial areas higher than those of the commercial ones. Similarly, levels of SO$_2$ and NO$_2$ gases were the highest at the industrial area because of the presence of many sources of these pollutants inside the industrial sector.

In contrary, CO is emitted from incomplete combustion of carbonaceous material. Emissions from vehicles contribute about 60% of all CO emissions, and thus, high concentrations of CO generally occur in areas with heavy traffic intensity and congestion [25]. Similarly, traffic is a predominant source of ambient VOCs in many urban areas of the industrialized countries. Traffic-related VOC pollution has frequently been demonstrated to be a more serious problem in the developing countries than in the United States and Europe, as indicated by the VOC data obtained in Karachi, Pakistan and India [26]. For this reason, the mean levels of both CO and VOCs in this study at the commercial area were close to their levels in the industrial area because of the heavy traffic activity and the presence of a large number of food processing shops that are using different types of fuel.

During the past six years, most of governmental authorities and agencies in the Eastern Province of Saudi Arabia were keen to develop their policies and administrative actions to improve roads and minimize traffic congestion and accidents from one side and to reduce the emission of air pollutants from other side. Based on the personal contact with the formal governmental authorities, a lot of documented data were obtained representing the actual actions and policies that are conducted and evaluated periodically to improve the traffic movement on the roads and reduce levels of the air pollution in Dammam Urban Cities (Dammam, Khobar and Dahran). Table 3 represents the population growth rate for Dammam Cities during the period from 201-2014. Consequently, several actions were done for accommodating the annual increase in population such as construction of about 600 km roads (12.3% highways, 72.9% Regional roads and 14.9% main roads) in addition to about 500 km railway lines with more passenger capacity [20]. The Municipality of Eastern Province has been concerned with upgrading health and environmental issues by increasing the awareness of people in the eastern province community and implementing training, health education programmes and conducting a project for continuous monitoring of air quality levels in the city. The General Department of Traffic in the city developed new techniques and tools in the vehicle periodical inspection stations to improve the vehicle mileage emissions. It also took all the necessary measures to meet the huge and continuous increase in the number of vehicles. The General Agency for Roads conducted a plan for paving and repairing most traffic roads and construction of new bridges and tunnel in main roads. The Presidency of Meteorology and Environment issued environmental law which included air quality criteria and standards to inspect strongly the industrial and other air pollution source emissions, particularly the unplanned small workshops. The Ministries of Education and Higher Education set several awareness planes to educate all staff, teachers, students, decision-makers and public with the air pollution problems and the responsibility of each one to abate or reduce its magnitude. From the socio-economic point of view, based on the official statements of the Head of the Eastern Province Municipality, more than 4.5 billion Saudi riyals were spent for projects implemented during three years included: reconstruction of streets and main roads, development of plans and residential neighbourhoods, establishment of fields and improvement of bridge intersections, and the establishment of bridges and tunnels for intersections, gardens and pedestrian paths and yards. In addition, the government issued several decisions to reduce fuel consumption by cars such as application of the fuel economy card tire specifications to increase awareness of drivers and car owners and help them to reduce consumption of fuels.

| Table 3. Population growth rate for Dammam Cities. |
|-------------|----------|----------------|
| City        | 2010     | 2014           | Annual growth rate |
| Dammam      | 903,312  | 986,397        | 2.22               |
| Khobar      | 457,745  | 510,544        | 2.77               |
| Dahran      | 120,221  | 134,423        | 2.77               |
Evaluations of the effectiveness of air pollution policy interventions are scarce. As shown in Figures 2345–6, levels of the five studied pollutants were gradually reduced from year to year with different percents. As for PM10 and VOCs, although their levels decreased considerably at all locations, but at the industrial and commercial areas these levels were still higher than their recommended air quality criteria (AQGs) (150 µg/m³ and 0.24 ppm, respectively) [27]. This may due to expansion in the industrial sector and increasing number of cars in Dammam City which needs more efforts and administrative actions in the future. Levels of CO reduced to lower than its AQG (9 ppm) [28] at all locations in the city which reflects the success of the administrative policies, particularly those are directed to car maintenance and driving behaviour. The reduction in levels of the other two pollutants (SO2 and NO2) was minimal because the mean concentrations of these pollutants were already very low and much lower than their AQGs (0.14 and 0.08 ppm, respectively) [28]. These results are in accordance with the results of similar researches in the world. A recent study has been conducted in China [29] revealed that significant emission reductions have occurred largely through robust administrative power, especially when emission reductions were tied to the performance evaluations and promotion of government officials. Another recent paper reviewed the effectiveness of traffic management strategies (TMS) for mitigating emissions, ambient concentrations, human exposure, and health effects of traffic-related air pollution in urban areas. The objective of this paper was to summarize the evidence base for a range of moderate-scale strategies broadly relevant to municipal and regional government decision-making [30]. In Spain, a recent study was aiming at understanding the micro scale spatio-temporal variation of ambient concentration levels in areas with high pollution values to study the effect of urban trees on particulate matter concentrations. Results of this study showed a reduction in the concentrations of PM10 and PM2.5 and black carbon with considerable percents (50%, 50% and 20%, respectively) [31]. The study that had been conducted in five Dutch cities to investigate air pollution at street level before and after implementation of local traffic policies including low emission zones (LEZ), revealed that all pollutant concentrations were lower in 2010 than in 2008 [16]. Another study was achieved in Oporto Metropolitan Area and indicated that levels of CO, PM10 and SO2 have been continuously decreasing in the respective metropolitan area and the implementation of some policy measures led to significant decrease of these pollutants levels in the atmosphere [11].

The attitudinal survey revealed that nearly 100% of people were convinced with the importance of public awareness for actual reducing of air pollution problem. Ministry of Culture and Information in Saudi Arabia should issue more actions and policies to increase awareness of people with the environmental pollution through all media.

5. Conclusions

The traffic restrictions policies and administrative actions appear to be effective to produce significant decreases in traffic-related air pollution concentrations, and hence improving the air quality of urban areas, particularly those of high traffic and population density. Training of managers and decision makers through professional programmes, increasing awareness of all people through different media tools with the environmental pollution problems and enhancing the cooperation and coordination between all authorities who are dealing with the traffic roads are very important administrative actions that should be considered to improve the air quality level of the urban or industrial cities.

Disclosure statement

No potential conflict of interest was reported by the authors.

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