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Impact of urbanization on CO2 and TVOC in an oasis city in Saudi Arabia

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Abstract: *In the last decade, urbanization in the oasis city of Al-Hofuf, Saudi Arabia has considerably increased in terms of urban population, urban housing and the number of personal automobiles. Al-Hofuf is located in an arid region where different sources of atmospheric pollution occur including heavy oil combustion, suspended soil, industrial emissions, and traffic emissions. Air pollution in terms of carbon dioxide (CO2) and total volatile organic carbon (TVOC) was investigated to examine the impact of urbanization. Four key urban locations were selected for CO2 and TVOC measurement and results were compared with a rural site. Variation of population, housing units and number of cars were reviewed using available data and the trend of air pollution was observed. Results show that CO2 and TVOC are within the allowable limit in Al-Hofuf in spite of rapid urbanization in the last decade. The measured CO2 at all the sites varied in the range of 330-430 ppm and TVOC varied between 153 and 341 ppb. CO2 and TVOC showed an increasing pattern between 2014 and 2018, which is 1.1 times and 3.9 times higher respectively, in the four-year period. Based on the monitored data in five locations, spatial distribution of pollutants is proposed, which can be used to identify pollution hotspots in Al-Hofuf city.*

***Keywords**: Al-Hofuf; Oasis city; Urbanization; Air pollution; Greenhouse Gas (GHG).*

1. Introduction

Air pollution is one of the major issues in rapidly growing regions due to its impact on atmosphere and human health. Air pollution may be sourced because of natural, anthropogenic or secondary reasons. Natural sources are not associated with any human activities, i.e. dust, volcanic eruptions, wildfire. Anthropogenic sources are associated with human activities, i.e. urbanization, industrialization, deforestation, construction of roads and houses, burning of fossil fuels etc., whereas secondary sources are formed by both natural and anthropogenic activities (Hickey et al., 2014).

In arid regions, urbanization contributes to the increase of carbon dioxide in natural ecosystems, resulting in less precipitation and increased temperature due to a 'heat island' effect (Koerner and Klopatek 2002). The heat island effect refers to the phenomenon of a warmer area being created compared to its surrounding because of human activities. Higher levels of CO_2, as much as 50%, can occur in urban areas compared to surrounding non-urban areas (Koerner and Klopatek 2002). CO_2 is regarded as a greenhouse gas (GHG), resulting from the combustion of fossil fuels. In urban areas, the combustion of fossil fuels mainly occurs from the transport sector. Automobile emissions released are highly dependent on the type of fuel and the process itself, however, CO_2 and volatile organic carbon (VOC) are among some important pollutants (EEA, 2011). The product of the combustion of hydrocarbons yields CO_2 and H_2O. Carbon monoxide is generated in all hydrocarbon reactions with oxygen as an intermediate, which then further reacts with oxygen to form CO_2. The reaction requires appropriate temperature and availability of oxygen for complete oxidation. If complete oxidation is not met either due to lack of reaction activation energy, low temperature or poor oxygen presence, substantial emissions of carbon monoxide (CO) may occur (EEA, 2011). In Saudi Arabia, in the year 2000, the total emissions of CO_2 were estimated as 2.6 x 10^5 Gg, of which 92.1% were attributed to the energy sector, and the contribution made by transport sector was 21% (Rahman et al., 2017). The impact of urbanization on air quality is also reported by several other researchers (e.g. Zhang et al., 2017; Gately et al., 2015; Al-Mulali et al., 2013; Bereitschaft and Debbage, 2013; Gratani and Varone, 2005; Cole and Neumayer, 2004).

Total volatile organic compound (TVOC) on the other hand is a group of organic chemical compounds and may be found in ambient air or in the emission of some substances such as natural gas or man-made materials. It can be either gas or vapour and can enter a human body by breathing. VOC concentration exceeding the recommended limit may hamper eyes and the respiratory tract of humans, induce distortions, and can even cause cancer (USEPA, 1998). Also, it may have an effect on animals and plants. TVOCs are considered as one of the causes of smog and it may have impacts on water and soil (Deng et al., 2018). TVOCs have effects on the environment depending on the VOCs composition and its concentration (Kettrup and Risse, 1997).

Typically, TVOCs may consist of VOCs of different chemical classes including aliphatic hydrocarbon, halogenated hydrocarbon, carbonyl compounds, alcohols, aromatic hydrocarbons and chlorinated hydrocarbons, terpens, glycol, ketones and esters (Al Khulaifi et al., 2014; Tanaka-Kagawa et al., 2005). In many oil rich middle east countries, VOCs may result from flaring activities and crude oil facilities, refineries, petrochemical plants, power and desalination plants and from the traffic and transport sector (Al Khulaifi et al., 2014). Also, outdoor VOCs may be sourced from waste disposal areas and wastewater treatment plants. Outdoor VOC levels can be affected by seasonal meteorological conditions (i.e. temperature, humidity and wind speed), and types and nature of surrounding emission sources (Tong et al., 2013; Jia et al., 2008).

In Saudi Arabia, during the last five decades, a considerable shift towards urbanization was observed. According to Abdelatti et al. (2017), the urban population in Saudi cities has increased from 49% in 1974 to 74% in 1992 and to 80% in 2004, of the total population; the urban population in Saudi Arabia reached 25,612,976 in 2014, with annual growth rate of 2.5 %, and the proportion of the people living in the largest city reached to 24.2%. According to the World Bank (2016), the rural population in Saudi Arabia decreased from 23.4% in 1990 to 17.1% in 2014. Reasons for this urbanization may be that urban residents get better education, healthcare facilities, easy access to social services, as well as social and cultural participation (Abou-Korin and Al-Shihri 2015), which are not easily accessible by rural residents. With the increase of the urban population, the number of passengers, as well as commercial vehicle sales have increased. According to Statista (2019), the number of vehicle sales in Saudi Arabia increased more than 45% in a decade from 563,000 in 2005 to 830,000 in 2015. Shift of population and thus urbanization caused the increased number of automobiles and industries in the cities, which may have impact on urban air pollution.

Air quality in big cities of Saudi Arabia was monitored by different researchers and organizations, i.e. Al Harbi et al. (2014) monitored O_3, CO, NO_2, SO_2 and H_2S at five air quality monitoring network stations of King Abulaziz City for Science and Technology (KACST), in Riyadh city. The authors concluded that Riyadh city air was in good condition for 71% of the time during the study period. Al-Jeelani (2009) investigated air quality for similar parameters in Makkah city and found that concentrations of nitrogen oxides and carbon monoxide increased at the starting hours of the day. Salama et al. (2017) investigated air quality in the Eastern Province for CO_2 and VOC in addition to the other stated parameters and concluded that the pollutants exceeded the recommended exposure limit during morning and noon time. Radaideh and Shatnawi (2015) investigated the air quality in Al-Hofuf city in the Eastern Province and reported a strong correlation between indoor and outdoor air quality. Most of the mentioned research reported overall ambient air quality, however more research is needed to examine the relationship between urbanization and air quality in the Al-Ahsa region. Therefore, specific aims of this research were to (a) monitor ambient air quality in terms of CO_2 and TVOC using ground-based air quality monitoring device at five locations of Al-Hofuf city and (b) evaluate the impact of urbanization on air quality.

2. Methodology

2.1 Study Area

The study was conducted in five different places in Al-Hofuf city (Figure 1). Two site-types, urban and rural were selected for this study to carry out air quality measurements and to assess varying air quality. Four of the places were selected from urban areas and one from a rural area. All selected sites are residential areas except the rural area. The selected urban sites were Village Market, Riyadh road (near Al-Rumansiah), Riyadh Road (near Al-Mujjammah), Qaisariyah Market and the rural site was in Al-Jaffer. The rural site was selected far away from the urban areas.

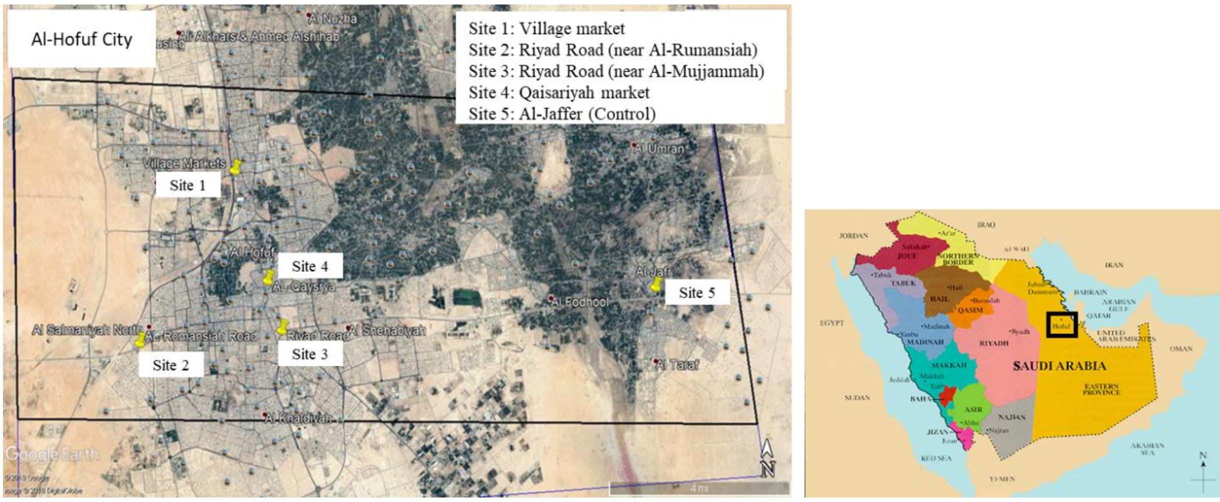

Figure 1. Monitoring sites in Al-Hofuf city

2.2 At site monitoring and spatial distribution

The measurement at the sites were conducted beside the road during the peak hour. Peak hour was assumed to be after 4 pm in week days. Peak hour was selected to measure the maximum pollution due to increased number of cars compared to off-peak times. In this study, no off-peak hour reading was taken. The monitoring was conducted two times in each location (except Al-Jaffer) during November and December 2018 (Table 1). GrayWolf® analyzer was used to monitor CO_2, TVOC, temperature, and relative humidity. GrayWolf® is a mobile analyzer which provides fully integrated systems for measuring air quality using probes (Wolf sense, 2012). The analyzer was set in a place from where it was easy to monitor the number of cars; most of the time near the traffic signal. The analyzer was powered by a portable DC converter. The height of the analyzer was maintained as close as possible to the average height of human noses. This was done to simulate the pollution exposure to human. A wooden table was used to raise the height of the analyzer. The number of cars were counted manually. Traffic was counted in one way, which was closer to the monitoring location. In this study, geographic information system (GIS) was used to present spatial distribution of the collected data and to pinpoint the air pollution hot spot. Contour lines gave better understanding of the pollution exposure covering the Al-Hofuf city from on-site measurement data of five sites.

2.3 Statistical analysis

The results obtained were statistically analysed using the SPSS Statistics 19.0 package. One-way ANOVA and the t-test was carried out to explain the result. Pearson's correlation coefficient was determined to evaluate correlation between pollutant and meteorological parameters, which is widely considered as the degree of intensity and the direction of correlation by many researchers. The probability value (p-value) less than 0.05 are considered significant results (Kim et al., 2007; Han et al., 2006).

The measured CO_2 at all the sites varied between 330-430 ppm, which is within usual limit of ambient air. Generally, 0.03% CO_2 in the ambient air is considered safe for human health (Cetin and Sevik 2016). In all the sites, the level of CO_2 was about 50% less than a frequently polluted place, i.e. bus terminal (Salama et al., 2017, shown in Table 1). A similar pattern was observed for TVOC. It should be noted that TVOC in all urban sites was almost double than the control site (Al-Jaffer), except Qaisariyah Market site. This may be because of the very minimal or non-existent traffic near the control site compared to urban sites. However, no correlation was observed with the number of automobiles passing the monitoring stations and the level of TVOC. On an average, number of automobiles passing the monitoring point of Sites 1, 2, 3, and 4 were 48, 42, 41 and 36 vehicles/min, respectively. Therefore, it could not be confirmed that automobiles were solely responsible for the measured level of CO_2 and TVOC in the urban sites. Another source of the ambient air pollutants may be the smoke dispersed from date palm farms in Al-Hofuf. Al Ahsa oasis caters an estimated 25,000 to 27,000 acres of date palm gardens (Vidal, 1954). It is a common practice in Al-Hofuf to burn dry date tree branches, which was observed during the monitoring events.

Table 1. At-site monitoring results of pollutants and meteorological parameters

Site description	**Month of sampling**	**CO_2 (ppm)**	**TVOC (ppb)**	**RH(%)**	**Temp (^{0}C)**
Village Market (25°23'25.7"N 49°32'45.5"E)	November 2018	*415.84±8.22	336.69±50.93	32.33±0.09	29.48±0.1
Riyad road (Rumansiah) (25°21'29.6"N 49°32'50.0"E)	November 2018	434.1±11.34	304.04±43.63	31.62±0.09	26.27±0.27
Riyad road (Mujjammah) (25°21'53.2"N 49°35'06.1"E)	November 2018	331.68±11.72	341.4±41.49	62.89±0.51	25.76±0.08
Qaisariyah Market (25°22'39.4"N 49°35'20.3"E)	November 2018	396.24±8.18	177.43±25.73	43.32±0.58	26.86±0.48
Jaffer (Control site) (25°22'43.7"N 49°44'33.8"E)	December 2018	328.26±3.95	152.96±30.52	49.18±1.49	25.05±0.31
Salama et al. (2017)	Feb 2014-Jun 2014	664-791	170-450	49-51	20-25

*Mean ± SD

Table 2. Testing the statistical significance of the observations by t-test

Parameters	**Compared site**	**p-value**	**Differences between measurements**
CO_2 (ppm)	Site1-Site5	< 0.001	Extremely significant
	Site2-Site5	< 0.001	Extremely significant
	Site3-Site5	0.003	Significant
	Site4-Site5	< 0.001	Extremely significant
TVOC (ppb)	Site1-Site5	< 0.001	Extremely significant
	Site2-Site5	< 0.001	Extremely significant
	Site3-Site5	< 0.001	Extremely significant
	Site4-Site5	< 0.001	Extremely significant
Temperature (^{0}C)	Site1-Site5	< 0.001	Extremely significant
	Site2-Site5	< 0.001	Extremely significant
	Site3-Site5	< 0.001	Extremely significant
	Site4-Site5	< 0.001	Extremely significant
RH (%)	Site1-Site5	< 0.001	Extremely significant
	Site2-Site5	< 0.001	Extremely significant
	Site3-Site5	< 0.001	Extremely significant
	Site4-Site5	< 0.001	Extremely significant

Note: Site 1: Riyad Road (near Al-Mujjammah); Site 2: Riyad Road (near Al-Rumansiah);
Site 3: Village market; Site 4: Qaisariyah market; Site 5: Al-Jaffer (Control)

The at-site monitoring results confirmed higher pollutant levels in urban sites than the control, however, since the monitoring was not conducted continuously, statistical analyses could be an appropriate way to provide statistical significance of the observations made in this study between the urban and control sites. For this purpose, a t-test was carried out between pairs of urban as well as control sites, for all the parameters (Table 2). Table 2 statistically compares the differences between the selected two sites and identifies whether it is extremely significant ($p < 0.001$), significant ($p < 0.05$) or insignificant ($p > 0.05$). Results show that all the observed parameters in urban sites were significantly different than that of the control site, which confirms the acceptability of monitoring results. In addition, Pearson's correlation coefficient was evaluated between measured pollutants and meteorological parameters. It was found that CO_2 is highly correlated to RH ($p < 0.001$) and temperature ($p < 0.001$) and TVOC is highly correlated to temperature ($p < 0.001$). Poor correlation was found between TVOC and RH (p-value = 0.062). Similar observation was made by Tong et al. (2013) and Jia et al. (2008).

At-site pollutant measurement of five sites were used to generate spatial distribution of CO_2 and TVOC over the whole study area. This was done using contour lines by GIS software. The distribution is shown in Figure 2. The spatial distribution of pollutants will help to identify the overall extent and direction of pollution hot spots in the study area. In the case of CO_2 (Figure 2*a*), more pollution was observed on north of Riyadh Road towards Village Market and less pollution towards the control site at Al-Jaffer. The present data sets provide an idea of the average status of the measured pollutants, however, more data points are needed for an accurate representation of the CO_2 distribution in this area. Similar observation was made for TVOC (Figure 2*b*).

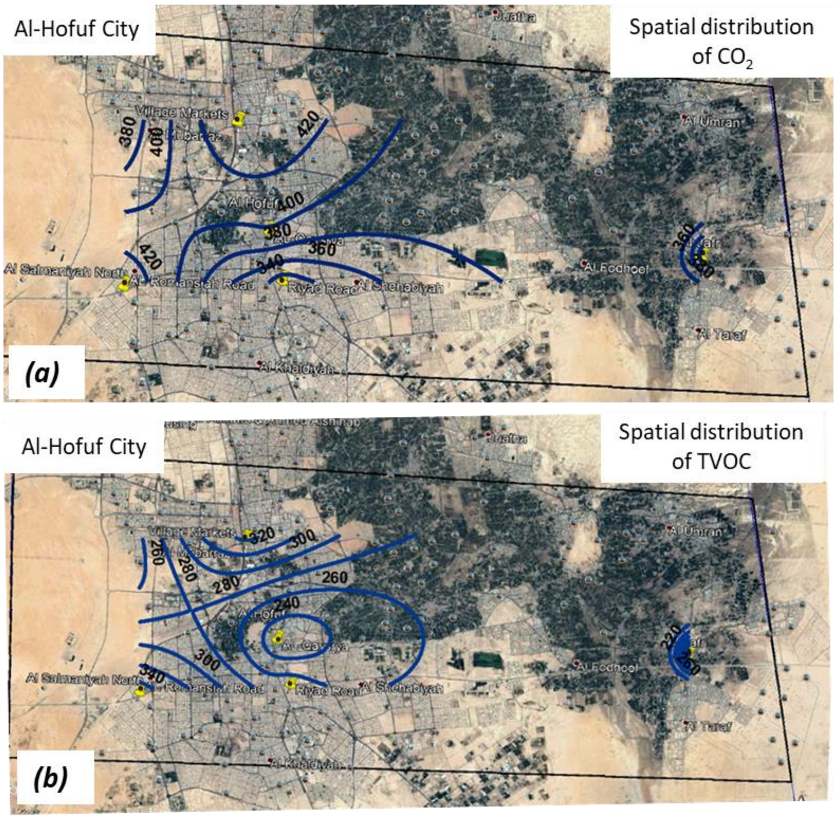

Figure 2. Spatial distribution of (*a*) CO_2 and (*b*) TVOC in the study area along with the control site

3.2 Urbanization and air quality

Impact of urbanization in Al-Hofuf on air quality was assessed based on population, number of vehicles and number of houses. The data was collected from the General Authority for Statistics (GAS). According to GAS (2019), the population of Al-Ahsa in 2004 was about 907,734 people, including Saudis and non-Saudis. In addition, the population of Al-Ahsa in 2010 was about 1,067,691 people, including Saudis and non-Saudis. This was an annual increase of 2.94%. Based on this, the growth rate projected population in Al-Ahsa in 2014 and 2018 was 1,174,329 and 1,280,967, respectively. In the Al-Ahsa province, a major portion (62-63%) of the population live in Al-Hofuf and Al-Mubarraz city (Abdelatti et al., 2017). According to Abdelatti et al. (2017), in Saudi Arabia, the number of people living near urban centers increased from 49% in 1974 to 80% in 2004. As a result, the number of traditional houses in this area reduced and to cope with the demand, the number of urbanized accommodation (i.e. two and three floors apartments) increased. From 1994 to 2011, the proportion of the apartments increased from 66.2% to 85.8% (Al-Ahsa Municipality, 1998) of the total houses. According to GAS (2019), the number of apartments in 2004 and 2010 was 28,043 and 58,395, respectively. The projected number of apartments in 2014 and 2018 are shown in Figure 3. An important aspect of urban housing related CO_2 can be attributed to the use of grid-electricity for electric stoves and heaters, lighting, air conditioning and other electric appliances. The remainder of household emissions are due to the on-site burning of fuels. With the increase of urban population and housing, the number of cars have also increased from 99,479 in 2004 to 2,388,49 in 2018 (Figure 3). In reality, automobiles are the most important urbanization factor causing more air pollution due to its direct production of GHG. According to Rahman et al. (2017), a strong correlation ($r^2 > 0.995$) was observed between the number of registered cars and energy consumption, thus production of GHG. The authors also found a considerable correlation among GHG production, urban population and Gross National Income. Overall, the registered car ownership in Saudi Arabia is 209 vehicles per 1000 people. In Al-Ahsa, car ownership increased from 110 vehicles in 2004 to 149 per 1000 people in 2010 (GAS, 2019). This increase of car ownership represents the broad scenario in Saudi Arabia, where only 2% of the total population uses public transport, while 85% relies on personal vehicles for commuting purposes (Al-Fouzan, 2012).

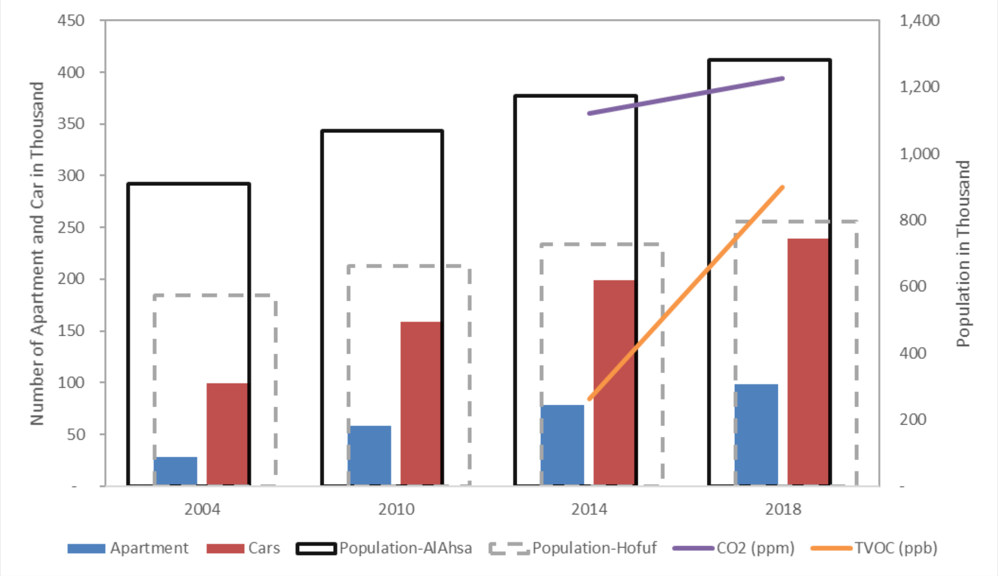

Figure 3. Trend of urbanization and air quality in Al-Hofuf, Al-Ahsa

No doubt, urbanization in Al-Hofuf in terms of population, urban housing and cars has an impact on air quality, but it was not possible to get a clear correlation between factors of urbanization and the air quality due to lack of multi-year data. However, available literature data reported by Radaideh and Shatnawi (2015) was plotted along with this study to get an impression of the trend of CO_2 and TVOC in the study area. It is worth mentioning that Radaideh and Shatnawi (2015) conducted the monitoring in a similar location as the current study. The trend line of CO_2 shows an increase of 1.1 times higher value in four years, which is 3.9 times that of TVOC. Further monitoring at the same location can support such trends of air pollution.

3. Conclusion

Ensuring a clean and sustainable environment is one the goals of Saudi Vision 2030. Urbanization is a positive indicator for a nation's economic and social development; however, this should be commensurate to the national policy for a sustainable environment. Unplanned urbanization in terms of population, housing and transportation may hamper such an environment. It can be concluded from the study that:

- CO_2 and TVOC are within the allowable limit in Al-Hofuf in spite of rapid urbanization in the last decade; the measured CO_2 at all the sites varied in the range of 330-430 ppm and TVOC varied between 153 and 341 ppb;
- CO_2 and TVOC showed an increasing pattern, which is 1.1 times and 3.9 times higher respectively, in a four-year period; and
- Based on the monitored data in five locations, spatial distribution of pollutants is proposed, which can be used to identify pollution hotspots in Al-Hofuf city.

It should be mentioned that air pollution is a process, which is impacted by many other factors in addition to urbanization. In this study only two parameters of air quality are discussed, which can be improved by the monitoring of CO, SO_x, NO_x and Particulate matter (PM_{10} and $PM_{2.5}$). Classification of TVOC is also important to pin point the mitigation measures. Lastly, long-term monitoring is crucial for a comprehensive mitigation plan, which can be ensured by establishing permanent monitoring stations at key points of the city.

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