Criteria for optimising air quality monitoring in Ukrainian cities (by example of Kyiv)

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SUMMARY

The purpose of the study is to analyse the current state of air quality monitoring in Ukrainian cities, particularly in Kyiv, identify the critical problems in the state monitoring system and substantiate the criteria for optimal air quality monitoring station (AQMS) arrangement to achieve strategic city development goals. Presently, monitoring stations, as usually, are located close to sources of harmful atmospheric emission. This is not helpful in improving the representativeness of the results obtained. Critical social and environmental criteria, which are generally accepted worldwide, are not accounted for. We analysed the demographics statistics, data on atmospheric pollution levels in different Kyiv districts, and regulatory documents. We compared population density indicators with locations of existing monitoring networks where contaminated air has the most adverse impact on public health. The comparison also included the greenness level in all locations and found that the spatial air quality monitoring networks distribution fails to meet modern criteria. With account of absence of a single methodology for determining spatial AQMS representativeness, its chosen key criteria were as follows: average annual concentrations of main air pollutants, population density and urban green spaces distribution within city boundaries. These criteria and the results obtained allowed substantiating the scheme for optimal AQMS arrangement.

Introduction

Poor air quality is one of the challenges of modern cities. In 2015, air pollution caused the death of 6.4 million people worldwide (Landrigan, 2017). Air pollution has a detrimental effect not only on the health of people, but also on the natural components of urban ecosystems (Fowler et al., 2009). This also translates into huge economic expenditures on implementing measures to reduce pollution (Samoilenko and Dibrova, 2019). Monitoring studies in atmospheric air quality are an important instrument in long-term and short-term strategies for controlling its pollution (Puliafito et al., 2011). In the majority of big world cities, especially those in the developed countries, air quality monitoring networks (AQMN) have been established up. However, the criteria for establishing AQMN are usually defined by different goals, and so they are incapable of performing several functions. The key factors for choosing a location for an air quality monitoring station (AQMS) is population density, pollution levels and spatial variation of concentrations of air pollutants. The AQMN structure in big cities should ensure acquisition of data on the state of atmospheric air with a high spatial-time representativeness (Munir, 2019). Recently, big cities have started to increase the use of low-cost sensor devices for assessing the impact of air pollution on public health. However, scientific studies in real time mobile air quality monitoring with the help of smart sensors are yet scarce (Mihăiţă et al., 2019).

Method and/or Theory

Usually, the concentration of air pollutants across a city is evaluated by interpolation of data from operating monitoring networks (Ballesta et al., 2008). To expand the functionality of monitoring stations, monitoring networks are integrated by using different assessment techniques (Bilous et al., 2020). Measurement results at separate stations do not always represent the situation in the city or district because the concentrations of pollutants can vary dramatically within distances from dozens to hundreds of meters (Puliafito et al., 2011). Presently, scientific studies and European regulatory acts have no single methodology for determining spatial AQMS representativeness (Munir et al., 2019).
In the last few years, Ukraine's capital has been experiencing a critical degradation of atmospheric air quality due to population and vehicle growth, destruction of green zones earmarked for development, and ineffective monitoring. With account of this, we analysed statistical demographic data, levels of atmospheric pollution in different Kyiv districts, and regulatory and program documents. Next, we compared the locations of existing monitoring networks with population density indicators where polluted air has the most detrimental effect on public health. Then we analysed the levels of greenness in all locations and their spatial distribution. Based on the results, we chose the average annual concentrations of main air pollutants, the population density and the urban green spaces (UGS) distribution within the city boundaries as the key criteria for determining the spatial AQMS representativeness. This helped to develop a scheme for optimal arrangement of a network of sensors across the entire city.

Results

The first step towards reducing air pollution in big city districts is to create an all-round monitoring network. Since its conventional tools are costly, it is impractical to use them for creating a tight-spaced local network. The emergence of low-cost compact platforms for assessing air pollution helps conducting real time observations with high spatial coverage. This improves existing monitoring systems, with involvement of the public in this process. The main drawback yet is an ambiguous accuracy of data generated by these platforms (Castell et al., 2017). The critical parameter for choosing a monitoring station site is its spatial representativeness, depending on the varying concentration of pollutants (Righini et al., 2014). A maximum content output can be obtained from an integrated network that combines different levels and methods of atmospheric air monitoring. The most accurate reference instruments and cheap IoT (Internet of Things) sensors are installed at fixed stations and on vehicles (mobile monitoring). The chief criteria for choosing monitoring sites are population density and concentration of air pollutants. Each sensor sends data to a cloud server using GPRS, allowing monitoring atmospheric air in countries with low and average income. The purpose

of such a network is collecting data for cartography and modelling with a high resolving power on a local scale (Munir et al., 2019).
Kyiv has updated the Development Strategy up to 2025. Its main goal is improving the wellbeing and comfort of life in the capital. The Life Comfort Index includes the sector "Environmental policy and control". One of its operational goals is introducing an advanced environmental control system that would provide refining the environment monitoring system in Kyiv by using advanced information and communication technologies and monitoring devices (The Kyiv City Development Strategy Until 2025, 2018). The Borys Sreznevsky Central Geophysical Observatory (CGO) is responsible for state monitoring of atmospheric air pollution in Kyiv. Sixteen stationary stations in eight districts of the capital determine the content of main pollutants: particulate matter PM_{10} and $PM_{2,5}$, sulphur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2). The composition of specific substances (hydrogen sulphide (H_2S), phenol (C_6H_5OH), hydrogen fluoride (HF), ammonia (NH_3), formaldehyde (CH_2O), etc.) is monitored by separate stations close to industrial enterprises and the city's most crowded thoroughfares (Fig. 1). Air pollution is assessed by its comparing with the relevant threshold limit value (TLV) of substances in the air of inhabited locations and calculating the Air Pollution Index (API).
The main drawbacks of stationary CGO monitoring stations are their high maintenance costs and outdated equipment, making it impossible to identify pollution "hot spots" timely across the city. Such a method of collecting and processing information can be used only for statistical analysis, but not for making operational management decisions. With account of this, a Concept has been developed for introducing and maintaining a system for monitoring the atmospheric air quality in Kyiv. In late 2019, the Kyiv City Council had supported the creation of a municipal system for monitoring atmospheric air quality in the capital. The plan is to install a network of twenty-seven stationary stations for integrated air quality assessment in each city district (Fig. 2). They will measure the concentration of PM_{10} and $PM_{2,5}$, SO_2, nitrogen oxides (NO_2, NO, NO_x), CO, benzene (C_6H_6), lead (Pb), CH_2O, ozone (O_3) in the air. If needed, a mobile laboratory will investigate the state of atmospheric air in a concrete location.

Figure 1 CGO Air pollution monitoring network in Kyiv

Figure 2 Planned municipal Air quality monitoring network in Kyiv

The Darnytskyi and Dniprovskyi administrative districts are those earmarked for starting to install the stations. The Concept developers are explaining this priority by the substantial industrial impact and lack of green spaces, making the air quality the worst in these districts.

The current outdated state monitoring system denies the residents of Ukrainian cities the possibility of receiving real information about the state of atmospheric air. Hence, recent years have been witnessing the emergence of public and commercial projects focused to eliminating this drawback. One of these is the EcoInfo project launched in the Dnipropetrovsk Region. Another one is the LUN City project in Kyiv, which collects and analyses information on the quality of life in different residential districts of the city. Data on the concentration of $PM_{2,5}$ and PM_{10} in the air as well as air temperature and humidity are received by a proprietary network of sensors, which has been set up with involvement of specialists from Taras Shevchenko National University of Kyiv.

Mobile applications are being developed for receiving updated information about the state of atmospheric air. In 2019, the capital launched an air quality monitoring platform within the framework of the Smart Environment public project. Air is sampled daily in ten locations in all city districts. One monitoring station is located near the "Energia" refuse incineration plant. According to the recommendations of EU Air Quality Directive 2008/50/EC, air quality is assessed by eight pollutants, as well as air temperature, atmospheric pressure and humidity are measured.

The emergence in Ukrainian cities of municipal and public projects for air quality monitoring is a positive step forward on the path of improving the overall environmental situation. However, the key parameter for choosing a monitoring station location, as before, is its closeness to enterprises (sources of hazardous effluents) or transport junctions responsible for the highest concentrations of air pollutants. Presently, such a critical social indicator as population density is not accounted for, though it is responsible for the impact of polluted air on human health. In addition, during AQMN structuring, such an environmental indicator as provision of urban population with green spaces should be considered.

In other words, the key criteria for choosing sites for installing sensors should be the annual average concentrations of main air pollutants, population density and the urban green infrastructure. We analysed all these indicators and developed an optimal variant of spatial AQMS arrangement in addition to that planned by the city administration (Fig. 3). Of course, substantiating more precise AQMS locations calls for follow up studies. The new draft Kyiv Development Master Plan provides for expanding the network of stations for controlling and monitoring the state of atmospheric air.

Figure 3 *Optimal AQMS locations (additional) in Kyiv*

Conclusions

The system for air quality monitoring in Ukrainian cities is in a critical condition, therefore it has to be refurbished and recommissioned, rather than being refined. Due to the incapacity of monitoring entities to coordinate their actions to provide valid information on the state of atmospheric air, it is impossible to foresee the impact of its pollution on human health and plan actions for improving the state of atmospheric air. Installing a high-density network of sensors across the city will enable identifying air pollution "hot spots" in real time. The criteria of their siting should be the present pollution levels, population density, and green infrastructure. AQMS should not be installed close to only one pollution source – a transport junction or an industrial enterprise. Other factors should also be taken into accounted, for instance, construction sites, petroleum filling stations, railway stations, and so forth. Besides, background level stations should be installed in recreation zones, this being especially vital for districts with the biggest development density and the least provision of residents with green zones. The number of sensors depends on the municipal budget; hence, public and commercial organisations should be involved more broadly in the development of an air quality monitoring network.

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