Volume XV, Issue (1) (2019) 331-339

International May Conference on Strategic Management

RISKS OF ATMOSPHERIC AIR POLLUTION BY FORMALDEHYDE IN URBAN AREAS FROM MOTOR VEHICLES

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Abstract: The work is devoted to the issue of risk management for the health of the population in urban areas in case of atmospheric air pollution by motor transport. In this study, the level of risk is determined on the basis of concentrations of formaldehyde molecules, which are formed as secondary air pollution as a result of photochemical transformations in the air under steady meteorological conditions. In the estimation of the amount of hydrocarbon emissions from road transport, which is simultaneously at the traffic junction, a mathematical model which is based on the theory of a convective jet on a warm surface and which allows obtaining parameters of the contaminated dome of air formed over this area was used. The proposed risk management scenario allows searching for optimal managerial decisions at the municipal level for a number of scientific and practical tasks of the city in shaping its environmental policy.

Keywords: atmospheric air pollution, hydrocarbon, formaldehyde, the health of the population, risk management

1. INTRODUCTION

According to the World organization of health protection (WOHP), as a result of emissions of components of the exhaust gases each year dies 7 times more people than in traffic accidents. Lung cancer, asthma, allergic diseases - all this is directly related to the exhaust gases of vehicles. According to expert estimates of the Ministry of Infrastructure of Ukraine, man-made environmental pressures bring losses of 20-30 million hryvnias [1,2].

Today, in the European Union and the world at all, the standards of environmental indicators of cars that work on gasoline and diesel fuel are being improved. However, the gradual increase of personal vehicles on the background of the gradual temperature rise of global climate change requires an integrated approach to solve the problem of air pollution by automobile transport and estimation of the possible consequences for public health.

Particularly for Ukraine, special attention should be paid to the implementation of Directive 2008/50 / EC, which defines the framework requirements for control and estimation the quality of atmospheric air, and sets the basic limits for the protection of public health. As a result, the issue of managing the health risk of people in urbanized areas where there is a risk of regulatory boundary exaggeration from motor vehicle emissions is extremely topical. To support the adoption of managerial decisions, the authors propose an algorithm for calculating the risks, which was tested in Kyiv, where atmospheric air pollution is formed by 70% of emissions from motor vehicles.

2. FORMULATION OF THE PROBLEM

The problem of atmospheric pollution by emissions from vehicles and their impact on the human's body has been considered by many authors, including post-Soviet countries. Typically, such articles contain the determination of the level of air pollution by motor vehicle emissions on the basis of the analysis of monitoring observations and determination of the level of risk for people in the study area and recommendations for the improvement of atmospheric air of cities. As noted in the literature [3-7], one of the components of the air quality control system in urban areas is the improvement the monitoring system for the estimation and forecast unit, an integral part of which are methods of mathematical modeling. The estimation of the health risks of the population from atmospheric air contaminated by chemicals (carcinogenic and non-carcinogenic) was made according to the national standards and regulatory documents of the countries where monitoring of the air of the urban environment was considered.

The analysis of the monitoring data of a number of major transport cities has shown that with the increase of hydrocarbon emissions from motor vehicles, an increase of one of the most powerful pollutants of atmospheric air - formaldehyde (secondary pollution due to chemical transformations in the atmosphere) is observed, the formation of which depends on the meteorological conditions of the area. Formaldehyde pollution of the atmosphere is an indicator of the appearance of photochemical smog of a number of major metropolises in the world. Confirmation of this fact is the appearance of smog over motorway overpasses, which is observed under neutral atmospheric conditions and high temperature indices. It was found that concentrations of formaldehyde and benzene in areas of unacceptable risk in urban areas in developing countries are formed mainly through motor vehicles [8]. On these territories there is a tendency to increase the number of personal vehicles, therefore the urgent issues of air quality management and environmental risks for the health of the population is to increase the network of monitoring observations with simultaneous improving existing monitoring points.

Consider the existing problem on the example of Kyiv. Observation of air pollution in Kiev is carried out on 16 stationary posts with a periodicity of selection at least 4 times at compulsory selection at 1, 7, 13 and 19 hours local time, 21 harmful impurities are determined. The observation points are located mainly in the area of highways, road junctions and crossroads with intensive traffic, which provides the basis for using monitoring data for statistical estimation and forecast of atmospheric air pollution by motor vehicle emissions. As many researchers point out, the existing network is imperfect, equipment for most observation points is outdated. In the context of city infrastructure development, there is an urgent need to increase the number of stationary observation posts for the possibility of obtaining a real picture of pollution [9,10].

Within the framework of the program "Kyiv city environmental protection program for the period up to 2007" ASEMA - the automated system of environmental monitoring of the atmosphere was created, which now needs updating and further development of separate information modules in accordance with all existing requirements of the World organization of health protection, the Ministry of natural resources of Ukraine and the directives The European Union. The Kyiv City State Administration (KCSA) department of ecology and natural resources together with the Department of information and communication technologies KCSA also plans to develop a system for alerting the public about dangerous situations related to the deterioration of air quality, based on data obtained from the established network of monitoring and GIS technologies.

Systems of forecasting and management of traffic flows and ecological situation in the city are very relevant. The procedure for making managerial decisions on mass flows of vehicles is very expensive, and in other cases it is impossible. This state of affairs indicates the importance and urgency of such works. The complexity of their solution is related to the existing approach to them as secondary ones, with insufficient financing of environmental problems and an outdated legal framework for the use of a car park [11, 12].

Under such conditions, in the monitoring system according to the atmospheric air condition in the calculation and forecast block, which allows, depending on the number of vehicles that are simultaneously at the crossroads or overpasses, to calculate the concentration of hydrocarbon emissions and secondary pollution with formaldehyde air, and have a block of calculating the risk of population stays on this territory.

3. MATERIALS AND RESULTS OF RESEARCH

The risk management of the health of the population in urban areas from motor vehicles is proposed by the authors according to the algorithm shown in figure 1.

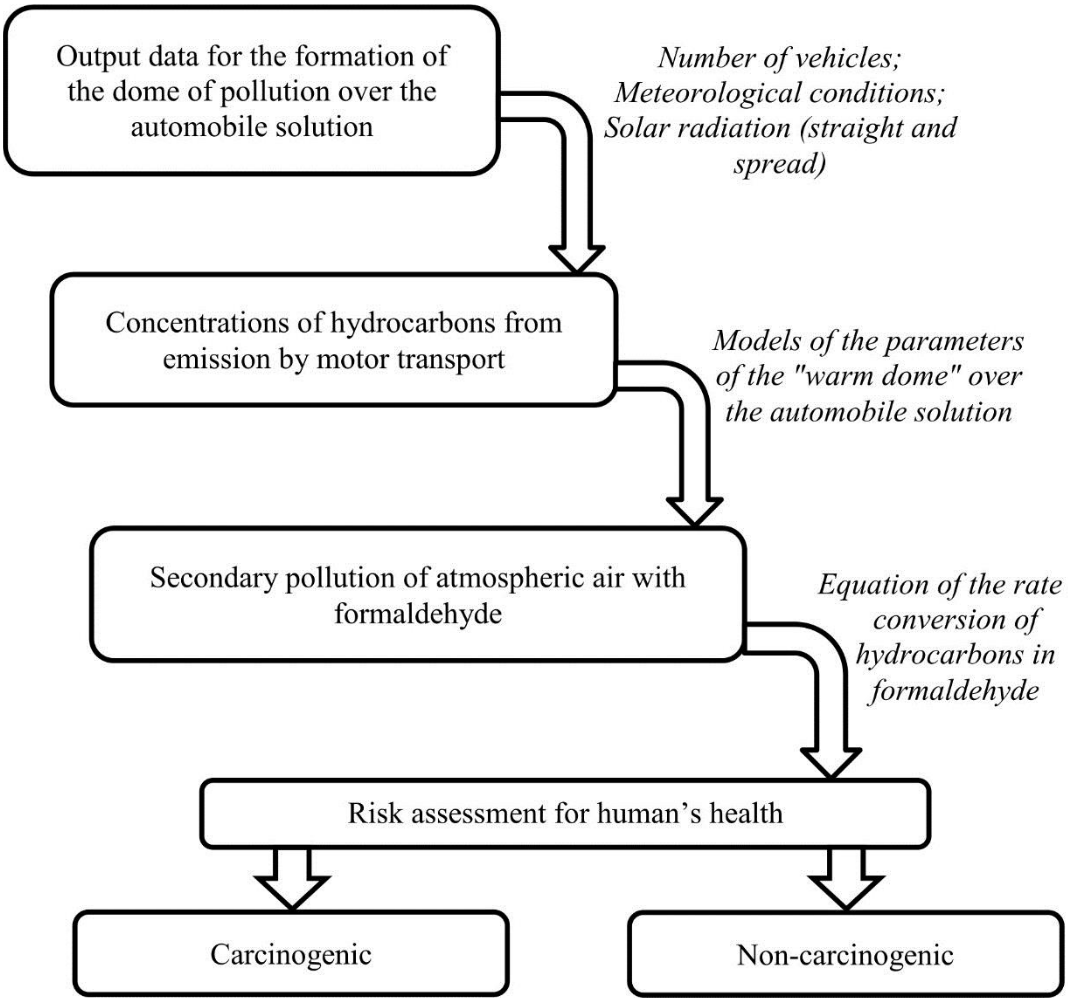

Figure 1. Risk management scenario for public health from motor vehicles (sequence of events)

The scenario of the impact of emissions from vehicles on the human body should be considered as a sequence of certain events, each of which can be described by a corresponding model with characteristic specific parameters. Consider each block of sequence of events.

Output data for the formation of incoming information - the area of the vehicle solution, which focuses a certain number of vehicles, which are in the so-called "pull" or traffic jams; direct and spread solar radiation of the area, meteorological conditions for a certain period of the year for which calculations are carried out, etc. As shown by the analysis of previous numerous monitoring observations of the state of atmospheric air of large transport cities, the greatest pollution from motor vehicles by formaldehyde is observed in steady meteorological conditions during the warm period of the year, which is explained by the direct dependence between the temperature conditions of the environment and photochemical transformations. To determine the concentration of hydrocarbons from transport emissions, the authors of the study proposed to use a mathematical model of estimation of the formation of formaldehyde in the transformation of hydrocarbon emissions at the considered automobile overpasses and large crossroads for the receiving the operational information. The mathematical model consists of a dynamic and kinetic blocks. The basis for the formation of formaldehyde are hydrocarbons. Two of them have a natural origin – methane and isoprene. The third kind represents the emission of automobile engines. Natural emission forms the background level of concentrations of formaldehyde, ethylene gives the variable component. In the first block of the model, based on the equations of the convective jet over the warm surface, we calculate the concentrations of hydrocarbon emissions from the total number of vehicles in the overpass and determine the parameters of the contaminated jet and the amount of heat coming from the warm source into the environment (spread and direct solar radiation, heat, which stands out from motor vehicles in the "traffic jam"). This block of the model is described in detail by the authors [13].

Here are the main dependencies of this calculation.

The amount of heat in the area of the crossroads or overpass S, m^2, with the conditional diameter D, is determined by the dependence:

Equations should be centred, in line with text, with the number indicators to the right, as shown:

$$Q_s = \pi D^2 / 4 \cdot \left(R_a + R_c + R_t \right), \quad (1)$$

where R_a, R_c and R_t – spread and direct radiation of the area considered for a given calendar month and the heat emitted from automobile emissions at the transport junction, MJ/m².

We find the heat from cars according to dependence:

$$Q_a = q_a \cdot N \cdot 40000 \text{, J} \quad (2)$$

where q_a - fuel consumption for one car per 1 m way, l.

By the amount of stripes, we determine the number of cars N on the roadway during peak times (peak hours).

According to existing literary sources [14] you can find a typical composition of exhaust gases (hydrocarbons $CH_{1,85}$) by type of engine.

The difference between the average air temperature on the surface of the transport node and the narrowest section of the warm jet which rises up, as well as the average air velocity, is found by the convective heat transfer formulas:

$$\Delta T_{avr} = 41 Q_k^{2/3} \big/ \left(y - y_0 \right)^{5/3}, \text{ K}; \quad (3)$$

$$V_y = 0.56 \left(Q_k \big/ \left(y - y_0 \right) \right)^{0.33}, \text{ m/s}, \quad (4)$$

where $Q_k = R_a + R_c + R_t$, MJ/m²; $y - y_0$ – the distance from the surface of the earth to the narrowest jet of convective heat that rises up, m; 41 – dimensional factor, $m^3 \cdot K/MJ^{2/3}$; 0.56 – dimensional factor, $m^{1.99}/(MJ^{0.33} \cdot s)$.

The concentration of hydrocarbons from a given amount of vehicles C_{CH} is found in the narrowest section of the contaminated jet.

The second block of the model under consideration describes the process of photochemical transformations in the air of the city and allows us to find the coefficient of speed of the transformation of ethane in formaldehyde (secondary pollution) in the narrowest section of the convective jet. On this height above the surface of the earth there are photochemical reactions of smog formation with the corresponding stable meteorological conditions. In the city of Kyiv, on the basis of the calculator developed by this method of atmospheric air pollution, 33 motorized crossroads and motorways were calculated. Calculations for the most polluted Kiev overpasses have shown that the concentration of hydrocarbons in the narrowest section of the contaminated jet does not exceed 1 mg/m^3 and, compared with the monitoring data, gives satisfactory results of no more than 5% (at the maximum measured values). As for the average monthly concentrations, the calculated values give somewhat overestimated results compared with the experimental ones, especially in the summer. Exaggerated calculation data is explained by the fact that monitoring at observation posts is carried out in the surface layer of atmospheric air, while the calculation of secondary pollution is carried out in the transition section of the contaminated warm jet at a distance of more than 200 m from the surface.

The rate of reaction of the conversion of hydrocarbons to the formaldehyde molecules is determined by a formula that takes into account the frequency of collisions and the share of excess of required energy. According to [14], the dependence of the reaction rate constant on temperature in the general case is described by the differential equation of Vant-Hoff-Arrhenius, which allows to determine the effective activation energy of the process of transformation of C_2H_4 molecules into the CHOH molecule, depending on the given meteorological conditions of the area.

Linear approximation of the solution of the Vant-Hoff-Arrhenius equation on the basis of experimental data on automobile solutions, which allows us to find the mean value of the integration constant and determine the analytic form of the dependence of the constant of speed K [14].

For Kyiv, the analytical form of the dependence of the constant of speed a has the form:

$$\ln K = -3784.6/T + 8.96 \quad (5)$$

where T – temperature of environment, K.

The calculations of the average monthly concentrations of formaldehyde and non-carcinogenic hazard indices on 33 motorway overpasses and major crossroads in Kyiv showed a significant excess (in average 2.5-5.0 times threshold limit value), which characterizes the risk of secondary contamination by formaldehyde as an average and requires additional control points in the system of monitoring of atmospheric air and corresponding measures on reduction of pollution on the boundary of residential development.

Recently, domestic and foreign scientists increasingly use a safety criterion instead of a comparison of concentrations of pollutants from the threshold limit value as a possible risk to the health of the population. Existing standard risk assessment methods allow estimating and predicting risks only in cases where the researcher has all the necessary information for performing certain calculations.

Guided by the methodical ukrainian recommendations of MR 2.2.12-142-2007 [15], the risks to public health from non-carcinogenic and carcinogenic influence of toxic substances are determined.

Non-carcinogenic quality assessment of the air is carried out at reference concentrations. Non-carcinogenic risk is calculated on the basis of the general criterion of the hazard index (HI), which is defined as the sum of the factors of the hazard of substances (NQ). For formaldehyde, the minimum risk of a pollutant occurs at a reference dose of 0.003 mg/m^3.

Carcinogenic risk according to the accepted method is defined as the product of a specific carcinogenic risk of formaldehyde multiplied by the average annual concentration. In case of inhalation, the average daily hit m (dose rate), assigned to 1kg of body weight, is determined by the formula:

$$m = \left(C \cdot V \cdot f \cdot T_0\right) / P \cdot T \tag{6}$$

where C – the concentration of carcinogen in the environment - in the air, mg/m^3; V – the volume of air that gets into the lungs for a long time, m^3/ day.; f - the number of days in a year, the duration of which is the effect of carcinogens; T_0 - the number of years the carcinogenic effect continues; P – average body weight of an adult, kg; T – averaged time of possible carcinogen effect, day.

HQ hazard index is calculated taking into account the average daily hit m (attributed to 1 kg of body weight):

$$HQ = m / H_d \tag{7}$$

where H_d - coordinated limit dose; m – daily average non-carcinogenic exposure to air, attributed to 1 kg of body weight, mg/kg · day. If $HQ < 1$, then there is no risk to the health of the population and there is no danger. If $HQ \geq 1$, then there is a danger according to the normative gradation.

The authors calculated the concentrations of secondary pollution by formaldehyde from road transport near the main overpasses at maximum monthly concentrations and calculated non-carcinogenic risks for the health of the population located in the area of influence of motorway overpasses. The results of calculations for some of the most polluted solutions in Kyiv are visually represented in figure 2.

According to the classification of risk levels [16], the average monthly estimated data in the summer period are the excess of concentrations of formaldehyde in the range of 2.5-5.0 threshold limit value at the crossroads in Kyiv, which is the average value of the levels of risk, which under conditions of influence on all the population needs the necessary dynamic control and in-depth study of sources and possible consequences of harmful impacts on the population. The significance of the risks calculated by this methodology suggests that the location of residential buildings along motorway overpasses does not always correspond to the norms of the Ministry of health of Ukraine regarding atmospheric air pollution. Therefore, there is an urgent need to reduce the level of carcinogenic risk in the locations of large road crossroads and overpasses.

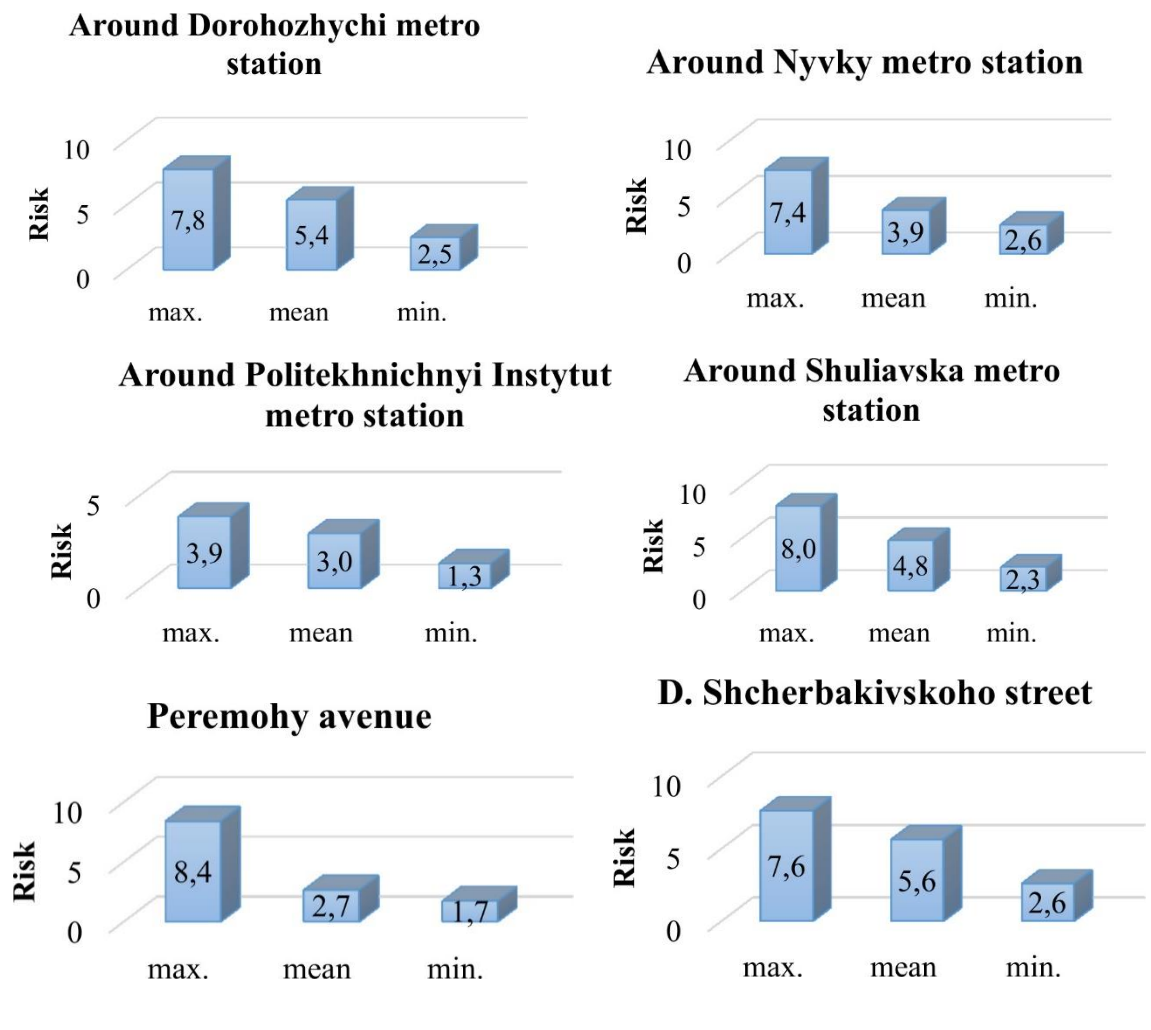

Figure 2. Examples of values of non-carcinogenic risk from the action of formaldehyde in some points in Kyiv

It is also necessary to further improve the system of monitoring of atmospheric air in the area of motorway overpasses and large intersections of the city of Kyiv by the State hydrometeorological service of Ukraine and the State sanitary and epidemiological service of the Ministry of health of Ukraine. It should also be noted that at the last stage, additional studies are conducted in the presence of a need for quantitative risk assessment of carcinogenic effect due to the inhalation effect of formaldehyde on the population, taking into account age distribution.

The achievement of an acceptable level of risk for the population in areas of its maximum value can be achieved through the introduction of such measures as: the organization of optimal traffic flow streets and roads; maximized implementation of environmentally friendly modes of transport and the use of environmentally cleaner fuels; arranging green stripes between highway and residential buildings; the introduction of elements of "green structures" in the reconstruction of residential areas. Under conditions of compacted development, "green roofs" and vertical gardening are promising elements of landscaping. Author`s research has established that one hectare of lawn on "green roofs" consumes CO_2 per year at the level of its release from the motorway for 8.9 days.

4. CONCLUSIONS

On the basis of the analysis of the impact of road transport on atmospheric pollution and on the theoretical model of estimation of hydrocarbon emissions from motor vehicles the risk management strategy for public health has been developed. The proposed approach was tested on the road junctions of the city of Kyiv. The model used to obtain the volumes of hydrocarbon emissions, depending on the number of transport units, is based on solving equations of the theory of convective jets from a warm surface. The concentration at the distance of two conditional diameters of the warm surface of the overpass is determined by the constant of the rate of reaction of the conversion of hydrocarbons to the formaldehyde molecules.

The proposed algorithm for determining the risk provides an opportunity of support for making managerial decisions during the developing the national environmental policy of the city, and provides an opportunity to optimize measures to reduce the impact of urban areas on people's health.

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