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Multiple pollution effects in urban areas on the environment and living organisms

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Abstract. The urban environment faces multiple pollution from various sources, resulting in the presence of different pollutants simultaneously. These pollutants can be chemical, radioactive, electromagnetic, acoustic etc. The paper begins by analyzing the general issue of multiple loads on technical structures and extends to the environment and living organisms. It introduces the concept of deterioration, a dimensionless concept important in analyzing the effects of pollution.
One analyzes the relationships for deterioration of environment and living organisms, due to pollution by simultaneous action of different pollutants. One presents urban pollution sources, both mobile and stationary and their effects on living organisms.

Keywords: multiple pollution, deterioration caused by pollutants, effects of pollution on living organisms, urban pollution sources, pollution monitoring.

Introduction

Simultaneous action or multiple loads refers to the superposition of similar or different types of loads (chemical, radioactive, mechanical, thermal, electromagnetic, sound etc.). Loads of the same nature can be of different types (e.g., mechanical: force, pressure, bending moment, torsion moment etc.) or from different origins (e.g., various classes of chemical substances).
The problems of multiple loads in the case of nonlinear behavior of matter, function of power, or in the case of linear behavior of matter, have been solved and are extensively presented in works [1-3], based on the principle of critical energy and on the concept of specific energy participation.

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Numerous cases of multiple loads in technical structures, with or without deterioration, have been solved and are presented in works [4-9]. The calculation method for the critical state in the case of multiple pollution of matter, based on Energonics, has also been extended to the evaluation of pollution effects on the environment and living organisms in works [1;10-15].
It should be noted that, at present, the calculation of the critical state in the case of multiple pollution with pollutants of different natures, in the case of nonlinear behavior of pollutants in interaction with their effect on the environment or on living organisms, can only be carried out using the principle of critical energy, based on the dimensionless concept of specific energy participation.
The concept of deterioration of technical or natural structures plays an important role in defining the critical value of specific energy participation, known as critical participation [1-3;10].
This paper examines: - the problem of environmental and living organism deterioration due to pollution; - mobile and stationary pollution sources in urban environments.

2. Deterioration of the environment and living organisms due to pollution

The nonlinear behavior of matter — as a power function — is considered in its general form [2;16],

$$Y = C \cdot X^{k}, \tag{1}$$

where Y represents the load; X - the effect of the load; C and k are material constants.
Deterioration depends, among other factors, on the behavior of the loaded material.

- *Environmental deterioration*. The causes of environmental deterioration can be natural (e.g., natural disasters) and anthropogenic (e.g., resource overuse, deforestation, agriculture, pollution etc.). These pathways of deterioration do not operate in isolation in space and time; rather, they typically affect various environmental components simultaneously.

For instance, *total deterioration in relation to the critical state*, caused by the simultaneous action of multiple chemically and, respectively, radioactive pollutants, under nonlinear behavior as described by relationship (1), is expressed as follows [10]:

- for chemical pollution,

$$D_T(c) = \sum_i \left(\frac{c_i(t)}{c_{i,cr}} \right)^{\alpha_{c_i}+1},$$

- for radioactive pollution,

$$D_T(A) = \sum_j \left(\frac{A_j}{A_{j,cr}} \right)^{\alpha_{A_j}+1}, \tag{2}$$

in which $D_T(c)$ is the total deterioration in relation to the critical state, resulting from the action of multiple chemical pollutants, i, of concentrations $c_i(t)$; $c_{i,cr}$ – the

critical concentration of pollutant *i*; this may be the value that is destructive to the environment.; $\alpha_{c_i} = 1/k_{c_i}$, where k_{c_i} is the exponent in the environmental behavior law (1) interacting with pollutant *i*;

$D_T(A)$ is the total deterioration in relation to the critical state, caused by the action of multiple radioisotopes with activity A_j, whereas $A_{j,cr}$ is the critical activity of the radioisotope; $\alpha_{A_j} = 1/k_{A_j}$, where k_{A_j} is the exponent in the law of the living organism's behavior resulting from the interaction between the radioisotope and the living organism (1). Similar relationships are written for *deteriorations in relation to the allowable state*,

$$\left.\begin{aligned} D_T^*(c) &= \sum_i \left(\frac{c_i}{c_{i,al}}\right)^{\alpha_{c_i}+1}, \\ D_T^*(A) &= \sum_j \left(\frac{A_j}{A_{j,al}}\right)^{\alpha_{A_j}+1}. \end{aligned}\right\} \tag{3}$$

Relations (3) are derived from relations (2), where the denominators have been replaced with their allowable values, namely $c_{i,al}$ – the maximum allowable concentration of pollutant *i*, and $A_{j,al}$ – the maximum allowable activity of the radioisotope, *j*,

$$c_{i,al} = \frac{c_{i,cr}}{c_c}; A_{j,al} = \frac{A_{j,cr}}{c_A}, \tag{4}$$

where $c_c > 1$ and $c_A > 1$ are safety coefficients.

- *Deterioration of living organisms due to pollution.* The deterioration of living organisms can be caused by both external factors (ecological factors, traumatic injuries, surgical interventions) and internal imbalances such as nutritional deficiencies, excessive use of medications or alcohol, or parasitic infections. Often, it results from a spiral of adverse events, a successive or simultaneous combination of multiple stress factors. Based on the concept of specific energy and according to *the principle of critical energy*, the critical state is reached when [1-3; 16],

$$P_T(t) \geq P_{cr}(t), \tag{5}$$

where $P_T(t)$ represents the total participation in relation to the critical state, and $P_{cr}(t)$ is the critical participation. Both participations depend on time, *t*, and are dimensionless.

For living organisms, *the critical participation at a given moment*, *t*, is given by the relation [10],

$$P_{cr}(t) = P_{cr}(0) - D_T(t) + P_{\arg} + P_{tr}(t), \tag{6}$$

where $P_{cr}(0)$ represents the initial value of the critical participation, at t = 0;

P_{arg} – the specific energy participation corresponding to the organism's adaptive self-regulation through homeostasis (reluctance to changes in the values of the organism's physiological constants) [3];

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$D_T(t)$ – the total deterioration of the living organism at the moment *t*;

$P_{tr}(t)$ – the specific energy participation corresponding to medical treatments, which can be positive if it helps increase the organism's resistance, zero if it has no effect on the organism's resistance and negative if it decreases the organism's resistance under the stress to which it is subjected.

If a deterministic value of the involved physical characteristic is considered, then $P_{cr}(0) = 1$, and the relation (6) becomes [10],

$$P_{cr}(t) = 1 - D_T(t) + P_{\arg} + P_{cr}(t). \tag{7}$$

Total deterioration $D_T(t)$, corresponding to living organisms, which appears in the expression of critical participation in relations (6) and (7), is calculated using the relation [3],

$$D_T(t) = \sum_k D_k(t), \tag{8}$$

where $D_k(t)$ represents the individual deterioration at the moment of *t*. Total deterioration $D_T(t)$ is a dimensionless quantity as a function of time, *t*, and results in the deterioration of the living organism.

Total deterioration for living organisms is composed of the deterioration caused by certain external actions, denoted by $D_T^{(ex)}(t)$, from the total deterioration caused by internal imbalances within the organism, denoted by $D_T^{(in)}(t)$, and aging, denoted by D(t) [3],

$$D_T(t) = D_T^{(ex)}(t) + D_T^{(in)}(t) + D(t). \tag{9}$$

In the case of living organisms, natural deterioration (e.g., through aging) causes to a continuous decrease in critical participation.

- *Deterioration of living organisms caused by external factors*. In reality, the behavior of matter is nonlinear in most cases, and the relationship between load (Y_i) and effect (X_k) can be expressed by the general power function law (1).

Deterioration of living organisms caused by external factors, in the case of nonlinear behavior of living matter, can be calculated using the following relations [10]:

- $D^{(ex)}(n) = P(n)$ – under cyclic load of the living organism, or one of its organs, with *n* successive cycles;
- $D^{(ex)}(J) = P(J)$ – under exposure of the organism to an electric field *J*;
- $D^{(ex)}(\Phi) = P(\Phi)$ – under exposure of the organism to a radiation flux Φ;
- $D^{(ex)}(c_i) = P(c_i)$ – under the action of a chemical pollutant with concentration c_i on the organism.

Total deterioration caused by the actions of external influences is calculated using the relation [3],

$$D_T^{(ex)}(t) = \sum_j D_j^{(ex)}(t), \tag{10}$$

where $D_j^{(ex)}$ is the individual deterioration caused by a specific external influences.

- *Deterioration caused by internal imbalances* within the organism is correlated with deficiencies in nutrients (carbohydrates, proteins, lipids, vitamins, minerals). Deficiencies in multiple nutrients, through a synergistic effect, can lead to an increase in deterioration $D_T^{(in)}(t)$ and, implicitly, a decrease in the organism's resistance [10].

3. Sources of pollution and pollutants in urban areas

- *The main sources of pollution in urban areas*, though not limited to these, are: - road transport; - industrial facilities; - power plants; - residential heating; - commercial activities; - telecommunications antennas; - construction sites; - the waste sector.

It is also important to note indoor pollution, given that people spend a substantial amount of time indoors (over 90% [17]). The most harmful indoor pollutant is *radon*. Epidemiological studies show that exposure to radon levels around 100 $Bq \cdot m^{-3}$ in homes can increase the risk of developing lung cancer [18].

- There are two main categories of atmospheric pollution sources – mobile sources and stationary sources:
  - *mobile sources* include automobiles, buses and trucks. Road traffic contributes to urban pollution both through noise and through pollutants emitted during combustion processes, especially in areas with heavy traffic (Fig. 1);
  - *stationary sources* refer to thermal power plants, residential heating, dry cleaners, industrial installations, landfills, construction sites etc. The main pollutants emitted by stationary sources are largely generated by power generation plants, residential heating and industrial activities (Fig. 2).

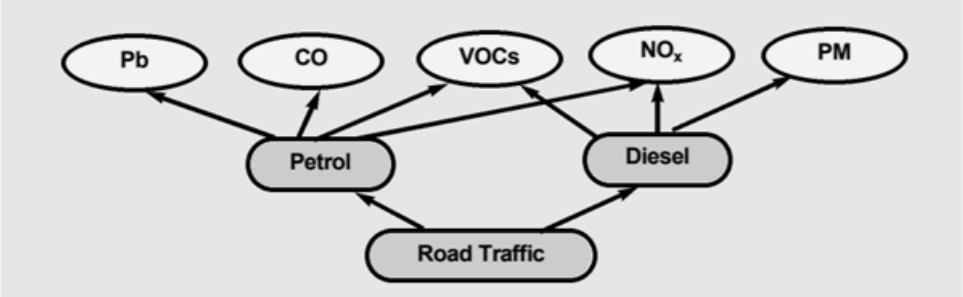

Fig. 1. The main atmospheric pollutants from mobile sources [19]: Pb (lead); CO (carbon monoxide); VOCs (volatile organic compounds); NO_x (nitrogen oxides); PM (particulate matter).

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Fig. 2. The main atmospheric pollutants from stationary sources [19]: SO_2 (sulfur dioxide); PM (particulate matter); NO_x (nitrogen oxides); VOCs (volatile organic compounds); Pb (lead).

These sources generate both *primary pollutants* and *precursor pollutants*, which participate in chemical reactions in the atmosphere to form *secondary pollutants*. The main processes for the formation of secondary pollutants are: the formation of ozone (O_3), the formation of secondary aerosols and the oxidation of nitrogen monoxide (NO) to nitrogen dioxide (NO_2). The impact of these pollutants on the environment and human health depends on the duration of exposure, the concentration and toxicity of the pollutant and the susceptibility of the environment or exposed individuals.

4. The effects of pollution from mobile sources in urban areas

Approximately one-fifth of the total greenhouse gas emissions in the European Union come from road transport, a significant mobile source [20].
Traffic particles result from two sources: *exhaust sources* (incomplete combustion of fuel) and *non-exhaust sources* (road surface, brakes, tires). It is estimated that exhaust and non-exhaust sources related to traffic contribute almost equally to the total PM10 emissions [21].
Globally, traffic contributes 25% of urban air pollution with PM2.5, compared to industrial activities, which contribute 15% and domestic fuel combustion, which contributes 20% [22]. Road traffic is also responsible for high levels of CO emissions, a pollutant that can accumulate to dangerous levels during periods of atmospheric calm.
Another form of urban pollution from mobile sources is *noise pollution*, caused by vehicles, public transport, aircraft and trains. The World Health Organization's noise guidelines recommend reducing traffic noise to below 53 dB during the day and 45 dB at night, with levels exceeding these thresholds associated with adverse health effects [23]. Traffic noise, as a major pollution factor in urban areas, impacts human health in various ways, both psychologically and physiologically. Studies also indicate that noise can affect plant growth, both in the short term and long term [24;25].

5. The effects of pollution from stationary sources in urban areas

In major cities, the most significant sources of pollution, in terms of their impact on the environment and, specifically, human health, include thermal power plants, industrial installations, residential heating and telecommunication antennas.

Residential heating using wood and coal is a major source of pollution, primarily due to *incomplete combustion*.

Thermal power plants are the main sources of nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and particulate matter (PM). The production of energy in thermal power plants relies on fossil fuels and is a major cause of air pollution. Technological advancements and improvements in power and thermal plants have led to a significant reduction in emissions; between 2004 and 2019, emissions of SO_2 decreased by 89%, NO_x by 60% and particulates by 88% [26].

Extended exposure to fine particulate matter has been associated with increased morbidity and mortality rates. According to the National Report on the Health Status of the Romanian Population [27] for 2019, pollution from particulate matter (PM) was ranked 8th out of 22 considered risk factors.

The effects of exposure to *radiofrequency electromagnetic fields* decrease with distance. Exposure to electromagnetic fields has been categorized into two frequency ranges [28]: 450 MHz – 6 GHz (2G-4G technology) and 6 GHz – 300 GHz (>5G technology).

- *Biological effects* resulting from the interaction between electromagnetic waves and the human body include:

- *thermal effects* – the electromagnetic energy absorbed by tissues and converted into heat can lead to localized increases in temperature;

- *non-thermal effects* – microwave radiation can affect the body due to possible interference between the body's electrical biological activities and the incident microwave radiation through its oscillatory characteristics [29].

Numerous studies have highlighted the following effects on human health from exposure to electromagnetic fields [30]: - impact on the nervous system, including the brain, with neurological or neuropsychiatric implications (depression, insomnia, headaches, fatigue, attention or memory dysfunction, dizziness, anxiety, etc.), especially from excessive use of mobile phones and wireless smart devices; - impact on the endocrine system; - induction of oxidative stress and effects on free radicals; - damage to human DNA, leading to cancer or mutations in future generations; - contribution to neurodegenerative diseases and infertility.

The new 5G technology, introduced in 2019, uses higher frequency spectra, improving data transmission speed and the ability to overcome physical obstacles and interference. 5G technology enables the simultaneous connection of many more devices compared to existing technologies. As a result, *human exposure to electromagnetic radiation increases due to multiple and simultaneous* frequencies, compounding with the frequencies of existing technologies (2G, 3G and 4G). This creates an electromagnetic radiation network, with cumulative effects resulting in increased electromagnetic pollution. *Electromagnetic hypersensitivity* is a

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condition recognized by European bodies, and the introduction of 5G technology may increase the number of people suffering from this condition.
The International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines for limiting exposure to electromagnetic fields (100 kHz to 300 GHz), issued in 2020 [30], establish "basic restrictions" for exposure to these fields over averaging intervals of ≥ 6 minutes.
In a point in space where electromagnetic radiation from 2G, 3G, 4G and 5G technologies cumulate, the induced energies from each are additive. According to the principle of critical energy [3;10], the total specific energies participation corresponding to electromagnetic field frequencies, $P_T(\nu)$, equals the sum of the specific energies participations of these frequencies,

$$P_T(\nu) = P_2(\nu_{2G}) + P_3(\nu_{3G}) + P_4(\nu_{4G}) + P_5(\nu_{5G}) \tag{11}$$

The influence of the 5G radiofrequency electromagnetic field is between 13.3 ÷ 50 times greater than that of the 2G, 3G and 4G technologies. This causes the overall effect of electromagnetic fields on living organisms to be much greater than before the introduction of 5G technology.

6. Conclusions

In the first part of the paper, the effects of the simultaneous action of multiple pollutants on the environment and living organisms are analyzed. The deterioration of these is examined with consideration of the nonlinear behavior of matter under the influence of pollutants. By analogy with the deterioration of technical structures subjected to multiple loads, relationships for calculating the deterioration of living organisms and the environment exposed to multiple pollution are presented.
In the second part of the paper, the following are presented: - the sources of pollution and pollutants in urban areas; - the effects of pollution caused by stationary and mobile sources in urban areas; - the biological effects of urban pollution.

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