Cloud service ThingSpeak for monitoring the surface layer of the atmosphere polluted by particulate matters

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Abstract. The article describes the cloud service ThingSpeak as a tool for monitoring and estimates the atmospheric air pollution. The main components of open instruments of environmental monitoring were implemented via microcontroller development system – Teensy 3.2, sensor module (temperature, humidity, pressure) BME280, SenseAir S8 carbon dioxide sensor module, PMS3003 air pollution sensor, Wi-Fi module ESP-01 and online ThingSpeak platform for storing and processing data. The prototype of an open source software system is developed, which, due to its openness, integration capabilities, ease of design and informativeness, provides monitoring of the human respiratory zone in two districts of the city of Ternopil on the content of suspended particulate matter PM_{10} and $PM_{2.5}$. The estimation of the influence of sources of pollution on the level of content suspended particulate matter in the atmospheric air was carried out with the help of multidimensional statistical methods, in particular using statistical procedure by principal component analysis, which allowed to process a large set of data and to obtain information on quantitative indicators and the nature of pollution. The analysis of particulate matter contents in the context of the cloud computing concept reflects the real-time monitoring metrics through the ThingSpeak services, which serves as a place not only for collecting, analyzing data, but also for discussing the results, thereby training students-biologists to monitor the quality of the surface layer of the atmosphere.

Keywords: ThingSpeak, Luftdaten.info, microcontroller, sensors, particulate matter.

1 Introduction

Today, the problem of contamination of the surface layer of atmosphere, especially by particulate matter (PM) of dust, is actual. The State Sanitary and Epidemiological Service of Ukraine (SES), which existed before March 2017, carried out the analysis and provided information on a large group of harmful substances, including the content of atmospheric air, the amount of substances in the form of solid suspended particles (fine particles and fibers) or suspended particles (TSP) [7]. A systematic analysis of atmospheric air relative to the content in it differentiated by the composition of dust is not carried out, although today the functions of the SES have been entrusted to the Ministry of Health and the State Committee for Supervision of Civil Service and Ukraine has undertaken liabilities [10, p. 51] concerning the reduction of emissions of the main substances polluting the atmospheric air.

To understand the objective picture of air pollution by particles of different aerodynamic diameters, there is a need for obtaining and using real observational data. One of the promising approaches to solving the problem of monitoring of suspended particles with a diameter of less than 10 μm is, first of all, the development of open-source environmental monitoring tools (open hardware, software, etc.) that are as reliable as professional ones. As a result, it provides an opportunity to attract a wide range of volunteers from among citizens, to address issues of atmospheric air pollution in the region, popularize the concept and implement the basic principles of "Civic Science" at a wide range of people. Examples of the integrity and success of such an approach are the Luftdaten (Germany), Exploring Salt Lake City's Air Quality (USA), etc., in which enthusiasts provide measurements from different parts of the world.

However, most scientific tools and systems developed on their basis require deep technical knowledge make them inaccessible to the public and limiting the likelihood of their use. Apart from the fact that such means are fairly expensive, their original data is stored locally in special, patentable formats, which limit their exchange for the purpose of analysis and comparison of the results. Therefore, in order to improve communication, one should focus on creating or using an existing open, easy-to-use on-line platform that provides visualization, data sharing, contributing to the formation of a community of users that stimulate its continuous improvement.

2 Analysis of recent research and publications

Research on the theory and practice of pollutant monitoring is supported with the works of domestic and foreign scientists. Iryna F. Voitiuk, Taras M. Dyvak, Mykola P. Dyvak, Andrii V. Pukas [15] dedicated their work to the identification of the real concentrations of harmful emissions. Among them firstly the measuring instruments of the SES to determine the concentrations of harmful substances are noted with a rather low accuracy – 20–50%; secondly, the measurement process is carried out by taking air in certain points of the city and at different moments of time can be significantly different, due to the impact of the intensity of transport flows, weather conditions, intensity of air flow, etc.; thirdly, the measurement process is highly expensive, so it is conducted in separate parts of the city and quite rarely.

The Air Quality Index, or AQI, was developed by the U.S. Environmental Protection Agency (EPA) to provide a simple, uniform way to report daily air quality conditions. Minnesota AQI numbers are determined by hourly measurements of five pollutants: fine particles ($PM_{2.5}$), ground-level ozone (O_3), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO) [1].

Andriy I. Herts, Nataliia V. Herts, Ivan M. Tsidylo studied the possibility of using intelligent measuring instruments on the basis of microelectronic sensors in solving atmospheric air pollution problems [3].

At present, there are a number of free resources for atmospheric air data visualization that have a fairly convenient interface where anyone can add a sensor and publish data. In particular, the Open-SenseMap.org has a user-friendly interface, an API, the ability to visualize data through interpolation and visual overview of data in time, etc. The Luftdaten.info server, the Madavi.de server, and a number of others that provide data storage in CSV format and data visualization.

An analysis of literary sources has shown the need to create a prototype of hardware with open source software, which, due to openness, integration capabilities, ease of design and information access, will allow monitoring of the surface layer of the atmosphere (human breathing zone) and send them to the above-mentioned resources.

Little or no attention is has been paid to the problem of integrating the application of monitoring system design tools into the educational process of preparing students of biology. In particular, in our case, the use of intelligent sensors, transmitters, means of microelectronics, etc., analysis and assessment of air pollution included as a requirement of time, to the methodology of scientific and / or professional activities and provided by the educational curriculum of student biologists. This, in the long run, will allow to increase the number of involved people from ordinary citizens to monitoring, exchange of data on the state of the air environment of urbanized areas in order to improve the air quality management system.

To substantiate and implement the prototype of the monitoring system using intelligent metering and cloud services for training students-biologists in the analysis and assessment of air pollution by suspended particles PM_{10} and $PM_{2.5}$, for example, at two monitoring stations in the city of Ternopil.

3 The results of the research

In order to control air pollution in real time, we have implemented an inexpensive air quality monitoring system using the Wireless Sensor Network (WSN), which is deployed in two monitoring air quality control systems. These are: Post 1 – the intersection of the streets of Dovhaya, Halytska, Zbarazka, Brodivska; Post 2 – a crossroads of streets of Zhyvova, Mykulynetska, Hayova, Zamonastyrska, Ostrozka. The proposed air quality monitoring system uses the air quality index, which can be easily interpreted. In addition, the public can access the results of air quality monitoring in real time. The assessment of atmospheric air condition in the city of Ternopil is carried out at the average monthly concentrations in multiplicity of the excess of average daily limit-permissible concentrations (LPC) by priority pollutants [7, p. 803].

3.1 Hardware for use with ThingSpeak services

The measurement system we have built up consists of intelligent, in most cases, digital sensors or measuring transducers connected to the signal processing system (see

Figure 1). To do this, we used the capabilities of the microcontroller of the hardware computing platform Teensy 3.2 [13].

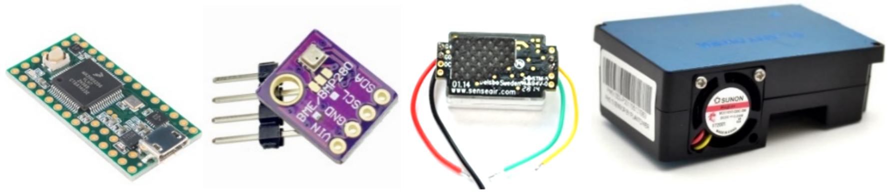


Fig. 1. The main components of the prototype for ThingSpeak

All data coming from the central system (Figure 2) contains temperature information (–40 to +85 °C, ±0.5 °C), relative humidity (0–100%, ±3%), atmospheric pressure (300–1100 hPa, ± 1.0 hPa), the level of CO_2 (0.04% to 2%), the concentration of the suspended particles ($PM_{2.5}$, PM_{10}, μg/m^3) in the surface layer of the atmosphere. This data is being output and analyzed real time, by means of cloud computing service Thingspeak [4].

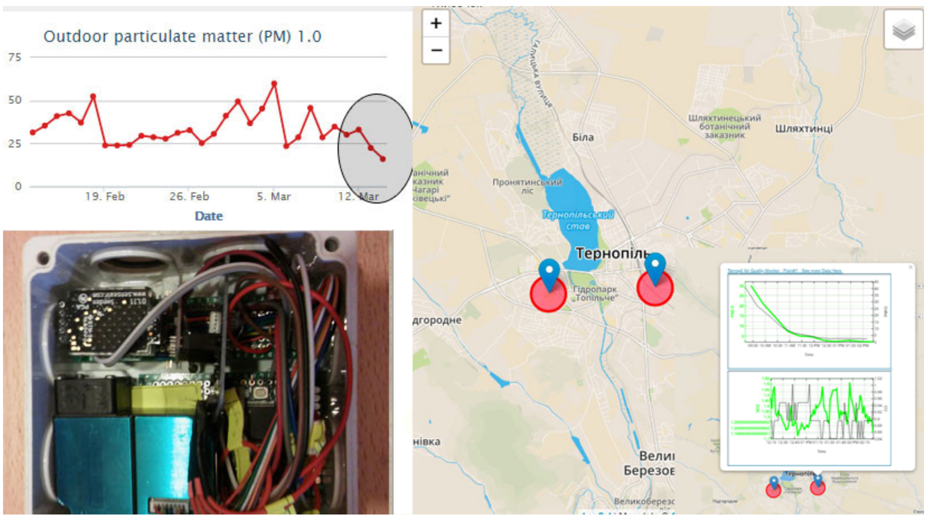


Fig. 2. General view of the system of analysis of suspended particles in the surface layer of the atmosphere

All data (and over the period of research in 2017 and 2018 there have been more than 500,000 measurements at Post 1 and 120,000 at Post 2) was accumulated in the system of cloud computing, collection and analysis of data Thingspeak, where a selection of trends can be set for the defined period.

Between the cycles, that is every 2 minutes, a request was made to the Thingspeak server and the data was sent via ESP8266 (ESP-01 module), from the above-mentioned sensors to the external data storage and visualization services.

In addition to the Thingspeak site's capabilities for analyzing and outputting data, the R-Studio software was used. A correlational analysis was carried out with the drawing of a heatmap on which the data was graphically represented so that the individual values contained in the matrix were presented in the form of colors.

Estimates of the contribution of pollution sources to the level of PM in the atmospheric air, were carried out with the help of multidimensional statistical methods, in particular, the method of the main components. This allowed us to process a large set of data and to receive information on the quantitative parameters and the nature of the pollution.

3.2 Hardware to use the services of Luftdaten.info

Since 2000, the Federal Government of Germany has carried out regular measurements of dust pollution with PM_{10} particles (aerodynamic diameter of 10 µm or less) throughout the country. And since 2008, measurements have been made with particles $PM_{2.5}$. At present, in Germany, the content of PM_{10} dust must not exceed 50 $\mu g/m^3$, which can be exceeded for a maximum of 35 days per year. For our research, we, along with the above-mentioned hardware, used the recommendations of the project.

To carry out measurements, we used the following hardware (see Figure 3): NodeMCU ESP8266; dust sensor SDS011; temperature and humidity sensor DHT22; short tube with diameter of 6 mm; distribution box OBO; Bettermann T 60 IP66; micro USB + power cable; Dupont cable set.

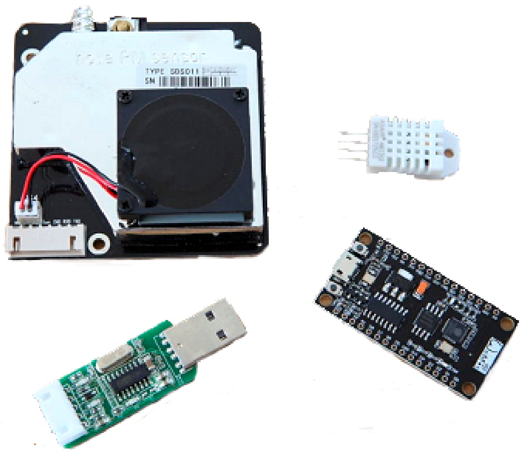


Fig. 3. The main components of the prototype for Luftdaten

The main component is the NodeMCU ESP8266 card [8] with the installed SoC and the WLAN module. SoC called ESP8266, complemented by 128 KB of RAM and

4 MB of flash memory. The operating system called XTOS is adapted to work with the SDS011 dust sensor [6].

The sensor of PM is a laser sensor, which, by means of photometry, determines the amount of suspended dust particles. The effect of attenuation or dispersion of a laser beam is used to do the measurements. The measurement range of SDS011 is from 0 to 999.9 μg/m^3. The sensor can detect particles with a diameter of 0.3 microns and larger, including $PM_{2.5}$ and PM_{10} with an error of 10%. The sensor drains the air through the vents, and then outputs the result in a few seconds. In our study, we read the sensor values every 145 seconds. The operating temperature range is –20 to +50 °C.

Results of the sensor SDS011 depend on temperature and humidity, therefore, for the interpretation of the correct values we measured them as well. To do this, a humidity and temperature sensor DHT 22 or BME280 was used. The sensors determine the humidity in the range from 0 to 100% with an error of 2–5% and the temperature in the range from –40 to +80 °C with an error of 0.5 °C.

The above-mentioned inexpensive sensors, in comparison with the existing professional ones, have a number of shortcomings. Nowadays such sensors cannot replace the professional ones, but they are capable of acting as an additional source of information about air quality. Most of them are generally less sensitive and accurate, but the data from the PM sensors show a rather high correlation (r^2 = 0.7–0.9) with measurements obtained with the help of the equipment used by the US Environmental Protection Agency (USEPA) [2].

On the other hand, such an inaccuracy of the sensors can be offset by an increase in the spatial density of the measurements achieved through the creation of their network. It should be borne in mind that in the case of the use of identical base components of the sensors, the results obtained may differ and be different in the light of differences in approaches to data correction and calibration. Therefore, the need for data normalization and calibration of hardware remains relevant.

Among the advantages of building a sensor system integrated through a web-platform into a single network is that in this case it serves as a place not only for the accumulation, analysis of data, but also for the place of discussion of the results. Such a policy, open access and open data, facilitates the exchange of data with interested parties, the community and local authorities, research institutions, etc.

3.3 Analysis of data concerning the content of PM in the air by means of cloud computing

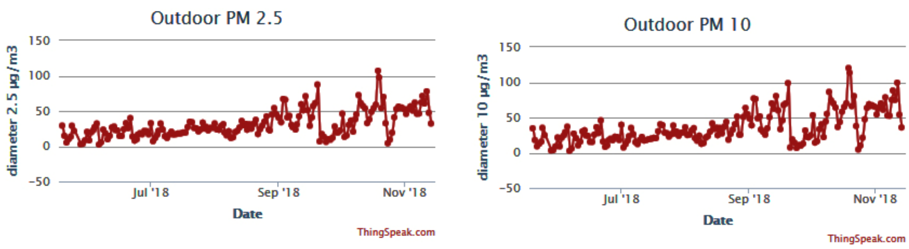
The system, which we offer is capable of displaying real-time data that is available through the cloud-based ThingSpeak or Luftdaten.info service for any user who is connected to the Internet.

To analyze the data, we used data from our Post 1, which covered the area of the East-Center massif and came from February to November 2018. At the Post 2 sensors received data concerning the content of PM in the massif Center-Druzhba. During the research period, more than 500,000 measurements were obtained. Duration of measurements – 24 hours a day, the frequency of data acquisition was every 2 minutes.

Along with obtaining data describing the content of PM in the air, the proposed system is able to accumulate data on relative humidity and air temperature. On the one hand, this makes it possible to assess the presence or absence of a temperature dependence between the content of PM and the physical characteristics of atmospheric air; on the other hand, it allows to detect the measurement errors associated with the work of the sensor itself.

Post 1 was additionally equipped with sensors that described such parameters of the air pool of Ternopil City as the content of CO_2, NO_2, NH_3 and CO in the air.

Using ThingSpeak cloud services (see Figures 4 and 5) we made graphs and calculated the average values of each of the parameters that were evaluated and output in the on-line mode.



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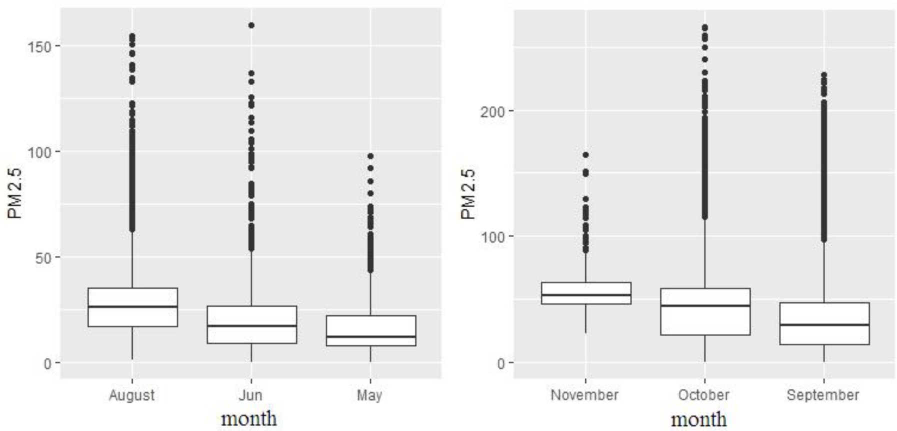


b)

Fig. 4. Dynamics of changes in $PM_{2.5}$ and PM_{10} in the Ternopil air pool (Post 1): *a* – each point as the average for a certain time period; *b* – Box Diagram of Dynamics of $PM_{2.5}$

For a more detailed analysis, we used RStudio. This allowed us to obtain data in a format that made it possible to calculate and evaluate their statistical reliability. Generalized data from Post 1 is presented in Table 1, where the average values for three months and annual values are calculated. For data analysis, we have taken European yearly standards for content of $PM_{2.5}$ and PM_{10}, which are 10 and 20 μg/m^3, respectively.

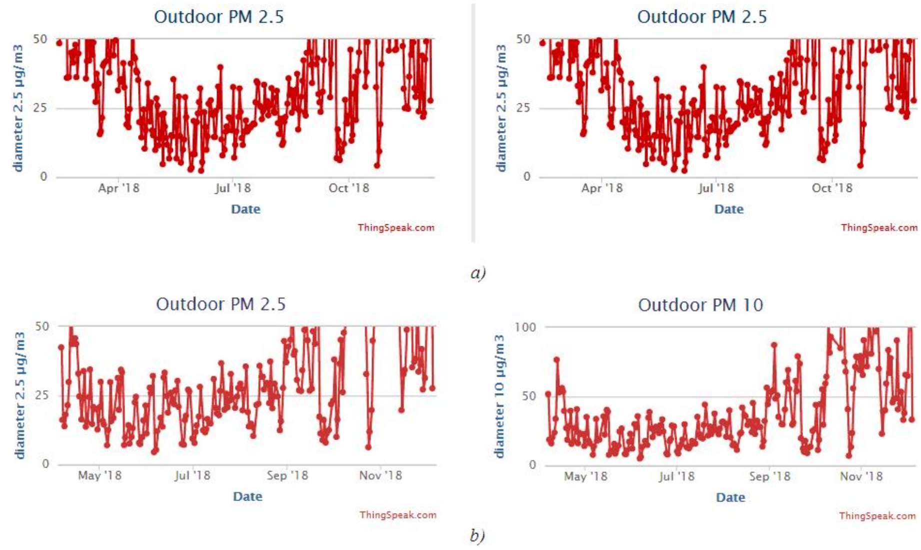


Fig. 5. Dynamics of the content of $PM_{2.5}$ and PM_{10} in the air pool of Ternopil, (μg/m^3);
a – Post 1; *b* – Post 2

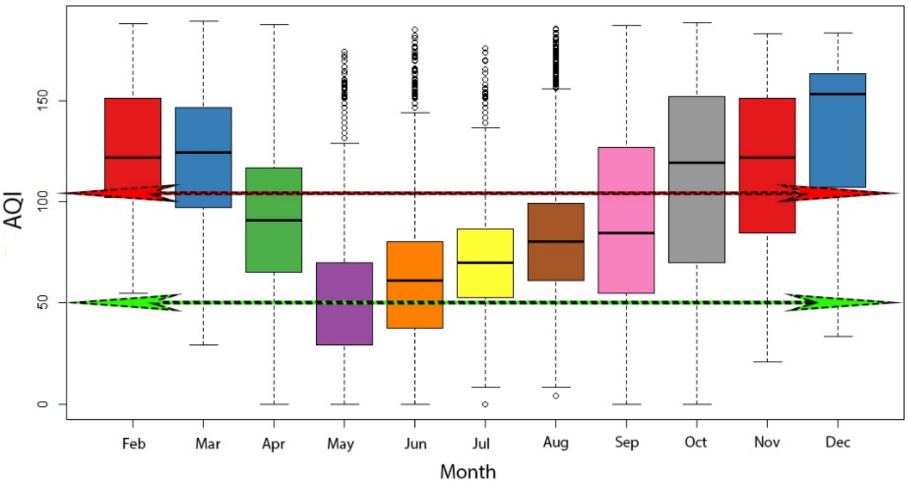
Table 1. The content of carbon monoxide and carbon dioxide in the atmosphere of the city of Ternopil (May–November 2018)

Month / Parameter	**May**	**July**	**August**	**September**	**October**	**November**
PM_1, μg/m^3	10±0.06	12.5±0.05	19±0.06	23±0.11	29±0.12	35±0.08
$PM_{2.5}$, μg/m^3	16±0.08	19±0.07	28±0.09	36±0.21	45±0.10	54±0.12
PM_{10}, μg/m^3	18±0.11	20±0.09	31±0.10	41±0.2	52±0.2	66±0.18
$PM_{2.5}$, μg/m^3 in 3 months	21.56±0.07			42.98±0.12		
Annual readings	29.72±0.08					
PM_{10}, μg/m^3 in 3 months	24.11±0.06			50.37±0.14		
Annual readings	35.21 ±0.10					
CO_2, pmm	428±0.70	422±0.13	436±0.21	429±0.13	424±0.11	429±0.12
Air temperature, °C	20±0.03	21±0.02	24±0.02	18±0.03	13±0.02	11±0.11
Relative humidity, %	55±0.12	67±0.09	65±0.07	67±0.07	69±0.08	82±0.06

The formula 1 [1] was used to calculate the air quality index (Figure 6)

$$I = \frac{I_{high} - I_{low}}{C_{high} - C_{low}} \left(C - C_{low} \right) + I_{low} \quad (1)$$

where: I – air quality index (AQI), C – concentration of pollutant, C_{low} – lower concentration limit when ≤C, $Chigh$ – upper concentration limit when >C, I_{low} – index point corresponding to C_{low}, I_{high} – index point corresponding to the C_{high}.



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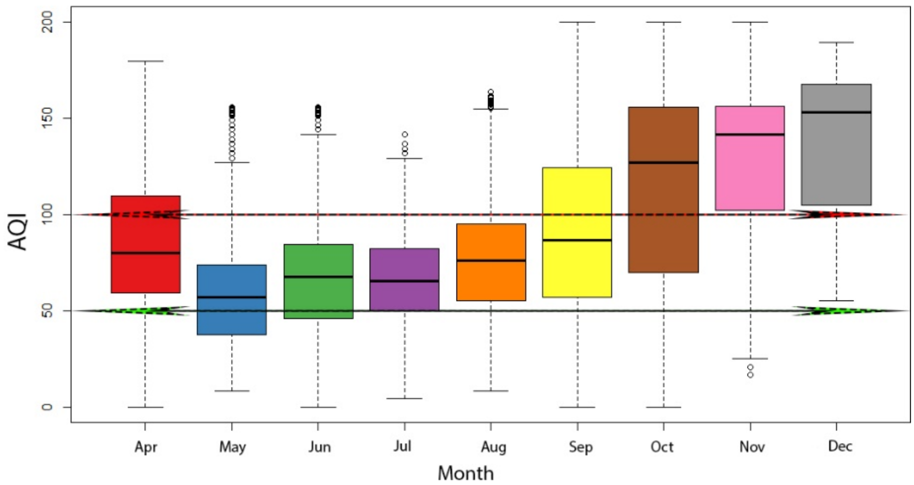


b)

Fig. 6. The air quality index (AQI) for the indicators of $PM_{2.5}$ in Ternopil city in the period from February till December 2018 (green line – 0-50 – AQI – good, above the red line – 101-150 AQI – harmful to risk groups): *a*) – Post 1; *b*) – Post 2

Consequently, the average annual content of PM of 2.5 and 10 μm in the air of the city of Ternopil (see Table 1) exceeds the approved European standards [11] in 3 and 1.5 times, respectively.

The maximum permissible concentration for Ukraine is determined according to the existing normative documents [7] at the level of 150 μg/m^3. However, this value refers to the undifferentiated sum of substances in the form of solid suspended particles (microparticles and fibers) or particulate matter. That is, all the particles in the air are taken into account. Based on WHO recommendations, we used the following relationship between TSP and PM_{10}: PM_{10} = 0.55TSP. That is, 82 μg/m^3 is the average daily maximum permissible concentration which in 1.5 times exceeds the European and world standards in general.

The air quality index (AQI) that we calculated varies within 50–140, that is within the scale of "satisfactory – harmful for the risk group". Thus, the winter-autumn period is critical for people with chronic diseases.

Comparing the daily and nightly average monthly values of the PM content in the air pool of Ternopil (see Table 2), it was found that the content of the PM at night always exceeded the one in the daytime. If in the spring-summer period this difference can be partially neglected, then in the autumn period it becomes significant and reliable.

Table 2. The content of PM in the atmospheric air of the city of Ternopil dependending on time of day (daytime / night), (May-November 2018), μg/m^3, m ± se

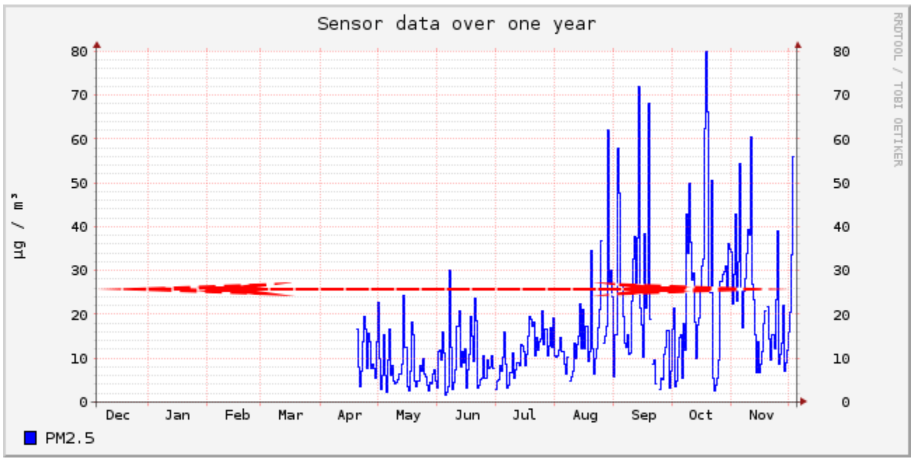
	May		July		August		September		October		November	
	Daytime	Night	Daytime	Night	Daytime	Night	Daytime	Night	Daytime	Night	Daytime	Night
$PM_{2.5}$	14,05 ±0,09	19,41 ±0,16	15,83 ±0,08	21,88 ±0,12	20,59 ±0,09	34,20 ±0,13	24,31 ±0,16	46,40 ±0,32	39,57 ±0,25	49,93 ±0,26	24,31 ±0,16	56,31 ±0,16
PM_{10}	16,06 ±0,11	22,55 ±0,20	16,88 ±0,09	24,18 0,14	22,47 ±0,11	39,08 ±0,16	24,31 ±0,16	53,55 ±0,36	46,09 ±0.30	58,69 ±0,31	64,10 ±0,27	68,53 ±0,24

The obtained data confirm the opinion of other authors [9], which argue that for some parameters such as CO, benzene and toluene, there is a different "behavior" over the course of a day than for PM_{10}. This suggests that the concentration of CO, gasoline and toluene is mainly related to transport systems, while PM is mainly influenced by a number of factors. They associate 90% of the data variance with the movement of vehicles, especially private ones. Our analysis indicates the presence of a string of other sources of these pollutants.

Similar results during the first decade of December are presented using the Luftdaten service (see Figure 7).

In order to find out whether the parameters of the prototype proposed by us are independent of temperature and relative humidity of the air, we carried out a correlation analysis, which was visualized as a heat map (see Figure 8).

As shown on the heat map, there is a weak (from 0.25 to 0.5, depending on the observation point (observation post)) positive correlation between the content of the PM and the relative humidity of the ambient air. It is known that in the fog, the concentration of particles in the air can greatly increase due to surface inversion and high humidity. Fogs are often associated with winter smogs, in which over a long period of time there occur high concentrations of harmful substances contained in the surface air layer [12].



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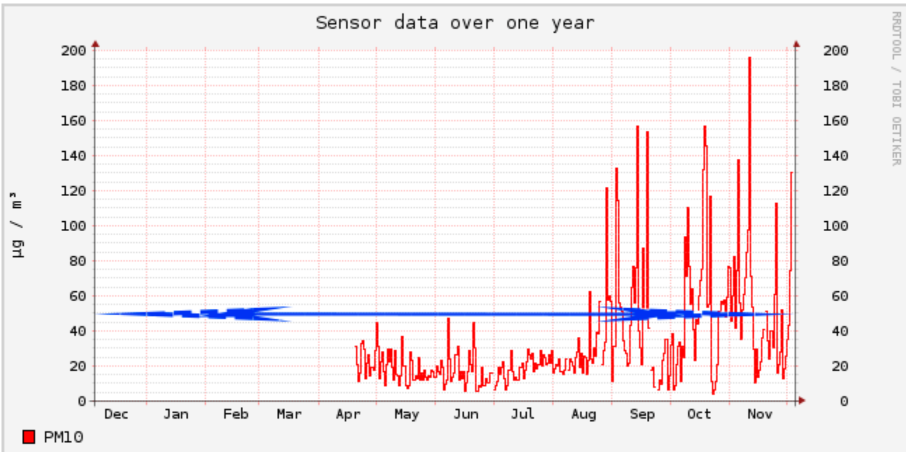

b)

Fig. 7. Dynamics of the content of $PM_{2.5}$ and PM_{10} in the air pool of the city of Ternopil in the period from April till December 2018 a) the red line – 25 µg/m^3 – the average daily norm for $PM_{2.5}$; b) the blue line – 50 µg/m^3 – the average daily norm for $PM_{2.5}$

The air temperature and atmospheric pressure, which vary during the day and depending on the season, are negatively correlated with the content of fine particles in the air. There is a slight (r^2 = 0.21) positive correlation between NO_2 and PM_{10}, although, in our opinion, the accuracy of measurements of CO, NO_2 and NH_3 is significantly influenced by the temperature factor.

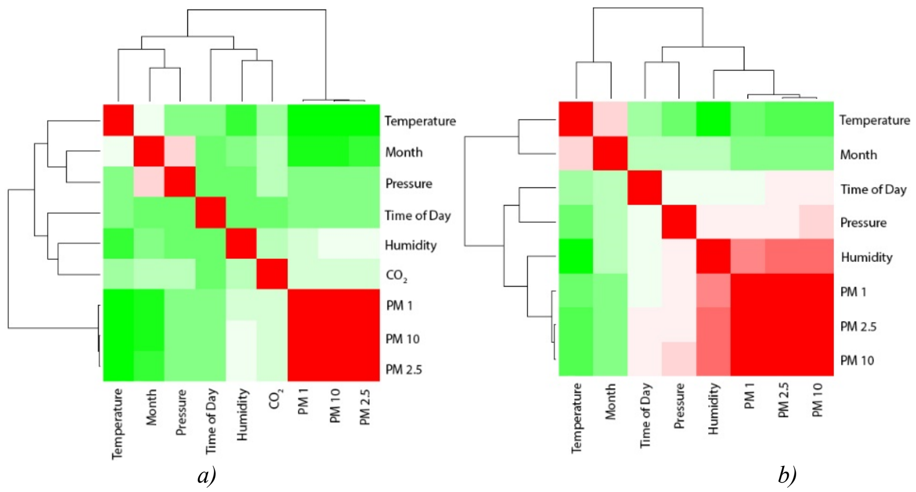

Fig. 8. Heat map and graph of the dependence of the content of PM in the atmosphere on the temperature and relative humidity of air: *a)* – Post 1, *b)* – Post 2

4 Conclusions and prospects for further research

Portable, compact devices for rapid analysis of biological systems, identification and quantitative measurements of their metabolites, analysis of the chemical composition of foodstuffs, soils, etc. have already been developed. They have been widely used in the investigation of biophysical processes of living organisms, in the study of biologically and chemically active substances, in the system of health care, environmental protection, ecology, and in environmental monitoring in particular.

The results obtained from our monitoring system, which includes sensors for determining the level of PM, temperature, humidity, CO_2, show their effectiveness in solving a number of topical issues. First of all, it provides an opportunity to evaluate the inhalation effect of suspended particles with a diameter of less than 10 microns, which is not carried out in Ukraine at all or is carried out non-systematically. Secondly, it changes the strategy of monitoring atmospheric air using cloud services for registration, analysis and interpretation of the data array. Thirdly, it is able to assess the daily, not just monthly or quarterly effects of toxic substances of the air pool on the population, which complies with European norms.

The international monitoring and epidemiological studies [16], which are currently documented and scientifically confirmed, have proven a negative impact on human health (an increase in the proportion of diseases and mortality from respiratory and cardiovascular pathology) caused by aerodynamic PM_{10} and $PM_{2.5}$ [5]. Their presence in the atmospheric air is mainly due to combustion of fuels in stationary plants (40–55%), technological processes in industry (15–30%) and motor vehicles (10–25%) [14].

All this leads to the creation of automated installations, which are a set of means for registration, transmission and processing of data, etc. Together with hardware-based computing capabilities of modern cloud services, and in conjunction with the use of intelligent algorithms based on knowledge bases, new functionalities are created in ecological and biological research and prompt detection of areas where there is an excess of concentrations of harmful emissions.

Such decisions will allow students-biologists to develop the ability to solve complex tasks and problems that require the updating and integration of natural and philosophical knowledge, often under conditions of incomplete / insufficient information and contradictory requirements. Such ability is provided for by the list of general competences in accordance with the requirements of the national qualification framework.

The prospect of further research in the direction of expanding monitoring capabilities and teaching them to students-biologists is seen in obtaining additional data on environmental concentrations of chemically active gaseous substances (CO, NO_x), greenhouse gases of CO_2 and CH_4, non-methane volatile organic substances and so on. All this requires further up-to-date research and the search for inexpensive, high-quality sensors, the market of which is constantly replenished with new samples.

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