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OVERVIEW OF THE METHODS AND TOOLS FOR ENVIRONMENTAL COMPONENTS MONITORING

Monitoring of environmental components is an important process for determining the level of pollution and tracking changes in the environment, and plays a key role in ensuring the health and comfort of residents, as well as in preserving the environment. Continuous monitoring of environmental components is key to ensuring human health, protecting nature and reducing the negative impact on the climate and ecosystems, as well as achieving sustainable development. In order to combat environmental pollution, it is necessary to implement effective measures to limit emissions of harmful substances, use environmentally friendly technologies and green solutions in all sectors of the economy, and raise public awareness of the problem of environmental pollution.

From the analysis of the sources reviewed, a pattern was identified that the information technologies mainly used to monitor environmental components are either Internet of Things (IoT) technologies using modern sensors and data transmission components or artificial intelligence technologies such as computer vision. Less commonly, the use of robots, UAVs, and digital twins is being traced.

Based on a critical analysis of methods and tools for environmental components monitoring, there is a need to develop such methods and tools for environmental components monitoring that would: perform cheaper and more versatile environmental components monitoring than existing analogues, but at the same time have no less accuracy and speed; monitor the state of the environment; identify sources of environmental pollution; warn of environmental disasters; assess the state of natural resources; support environmental decision-making; collect and analyze various environmental indicators in real time; assessed the level of quality and safety of environmental components, which will allow immediate response to quality changes and promptly take the necessary measures, etc., which will be the focus of the authors' further efforts.

Keywords: monitoring of environmental components, methods of monitoring environmental components, tools of monitoring environmental components, Internet of Things, artificial intelligence technologies.

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ОГЛЯД МЕТОДІВ ТА ІНСТРУМЕНТІВ МОНІТОРИНГУ КОМПОНЕНТІВ ДОВКІЛЛЯ

Моніторинг компонентів довкілля є важливим процесом для визначення рівня забруднення та відслідковування змін у навколишньому середовищі, відіграє ключову роль у забезпеченні здоров'я та комфорту мешканців, а також у збереженні навколишнього середовища. Постійний моніторинг компонентів довкілля є ключовим для забезпечення здоров'я людей, охорони природи та зменшення негативного впливу на клімат та екосистеми, а також для досягнення сталого розвитку. Для боротьби з забрудненням навколишнього середовища необхідно впроваджувати ефективні заходи з обмеження викидів шкідливих речовин, використання екологічно чистих технологій та зелених рішень у всіх галузях господарства, а також збільшення обізнаності суспільства щодо проблеми забруднення навколишнього середовища.

З аналізу розглянутих джерел було визначено закономірність, що інформаційні технології, які в основному застосовуються для моніторингу компонентів довкілля – це або технології Інтернету речей (IoT) із застосуванням сучасних давачів та компонентів для передачі даних, або технології штучного інтелекту, такі як комп'ютерний зір. Рідше прослідковуються такі засоби як використання роботів, БПЛА та цифрових двійників.

Виходячи з критичного аналізу методів і засобів моніторингу компонентів довкілля, виникає необхідність в розробленні таких методів і засобів моніторингу компонентів довкілля, які б: виконували були дешевшими та універсальнішими, ніж наявні аналоги, але при цьому мали не меншу точність та швидкість; відстежували стан довкілля; виявляли джерела забруднення довкілля; попереджали про екологічні катастрофи; оцінювали стан природних ресурсів; підтримували прийняття екологічних рішень; виконували збір та аналіз різноманітних показників довкілля в режимі реального часу; здійснювали оцінку рівня якості та безпечності компонентів довкілля, яка дасть змогу негайно реагувати на зміни якості і швидко вживати необхідних заходів тощо, на що й будуть спрямовані подальші зусилля авторів.

Ключові слова: моніторинг компонентів довкілля, методи моніторингу компонентів довкілля, засоби моніторингу компонентів довкілля, Інтернет речей, технології штучного інтелекту.

Introduction

Environmental pollution is the presence of various harmful substances in the environment that can be released as a result of industrial, transport, agricultural and other human activities [1-3]. Environmental pollution is a serious environmental problem in our daily lives, as it can have a harmful effect on human, animal and plant health, etc.

Environmental pollution (air pollution, soil pollution, water pollution, and ecosystem damage) can have serious consequences for human health, affect biodiversity, climate change, and ecosystems in general, and lead to global warming, changing climatic conditions, and rising sea levels. In order to combat environmental pollution, it is necessary to implement effective measures to limit emissions of harmful substances, use environmentally friendly technologies and green solutions in all sectors of the economy, and raise public awareness of the problem of environmental pollution [4, 5].

Sources of environmental pollution can be classified by type of emissions, origin, and their impact on various components of ecosystems [6, 7]:

1) industrial sources:
   - chemical industry – emissions of toxic substances such as sulfur dioxide, nitrogen oxides, heavy metals (lead, mercury) and organochlorine compounds that pollute air, water and soil;
   - metallurgical industry – pollution by heavy metals and dust particles;
   - energy – burning fossil fuels (coal, oil, gas) causes emissions of carbon dioxide, sulfur dioxide and other greenhouse gases that contribute to global warming;
2) transportation:
   - emissions from road, air and sea transport cause air pollution with carbon oxides, nitrogen, lead and other substances;
   - noise and light pollution;
3) agriculture:
   - pesticides and herbicides – chemicals used to protect plants, often end up in water bodies, soils and the atmosphere;
   - ammonia and methane emissions from livestock farms - affecting air quality and contributing to the increase in greenhouse gas concentrations;
4) household waste:
   - landfills – emit methane, which is a powerful greenhouse gas;
   - plastic waste – accumulates in the oceans, polluting aquatic ecosystems and harming marine organisms;
   - household chemicals (cleaning products, paints and other toxic materials) can enter water systems, causing harm to aquatic organisms and humans;
5) construction and urban infrastructure – water and soil pollution from construction materials, chemical discharges, as well as noise and dust pollution;
6) natural sources:
   - volcanic eruptions – emit huge amounts of sulfur dioxide, carbon dioxide, dust and ash into the atmosphere;
   - forest fires – cause carbon emissions and destroy ecosystems;
   - dust storms – carry significant amounts of dust and toxic particles over long distances.

Monitoring of environmental components is an important process for determining the level of pollution and tracking changes in the environment, and plays a key role in ensuring the health and comfort of residents, as well as in preserving the environment [8, 9].

The main reasons for the importance of monitoring environmental components are [10-12]:

1) human health protection:
   - air pollution – tracking the level of harmful substances (nitrogen oxides, carbon, fine dust) helps protect the population from respiratory diseases and other chronic conditions;
   - water quality – monitoring of water resources allows detecting toxins, harmful chemicals and pathogens that can threaten drinking water supply and cause epidemics;
2) preventing the loss of biodiversity:
   - monitoring the state of ecosystems – it is important to monitor the state of plant and animal populations to detect signs of degradation or destruction of ecosystems caused by anthropogenic factors (deforestation, pollution);
   - species conservation – monitoring allows to respond promptly to changes that threaten endangered species and take measures to preserve them;
3) prevention of climate change:
   - greenhouse gas tracking – monitoring of carbon dioxide, methane and other greenhouse gas emissions helps to assess progress in combating climate change and adjust policies to reduce these emissions;
   - changes in temperature and weather conditions – monitoring global temperature changes, precipitation and other climate indicators helps to predict natural disasters and implement adaptation measures;
4) control over the sustainability of ecosystems:

- restoration of contaminated areas – monitoring allows to assess the level of soil, water and air pollution, as well as the effectiveness of measures to clean up and restore ecosystems;
- management of natural resources – it is important to monitor the condition of forests, rivers and other natural resources for their sustainable use;

5) economy and social benefits:
   - loss mitigation – timely monitoring of pollution and degradation of natural resources can prevent economic losses in agriculture, fishing and tourism;
   - support for sustainable development – environmental monitoring contributes to the implementation of environmentally responsible practices that combine economic growth with environmental protection.

Thus, continuous monitoring of environmental components is key to ensuring human health, protecting nature and reducing the negative impact on climate and ecosystems, as well as for achieving sustainable development.

Overview of the Methods and Tools for Environmental Components Monitoring

Let's review the known methods for environmental components monitoring.

For example, article [13] is devoted to a critical analysis of smart monitoring systems using the Internet of Things, machine learning, and modern sensors to monitor air quality, water quality, radiation pollution, and agricultural systems.

Paper [14] is devoted to the application of artificial intelligence technologies to solve water conservation problems, analyzing five key areas: water management and distribution, precision agriculture, water quality monitoring, drought forecasting and early warning systems, and smart water networks.

The author of [15] argues that the Internet of Things (IoT) paradigm in environmental monitoring can improve our understanding of regional climate through technological solutions, providing dynamic climate elements based on integrated environmental monitoring and communication, which are necessary for assessing the impact of climate change in relevant areas (e.g., environmental quality monitoring, sustainable energy use, agricultural systems, cultural heritage preservation, and sustainable mining).

Paper [16] presents the use of IoT technology to monitor environmental aspects in smart cities. In this review, environmental problems that may arise in any city are classified into four main areas: water, waste, air, and transportation. Based on the research presented in the literature, the paper focuses on the approaches that can be applied in smart city management to address these issues, taking into account the main environmental challenges faced in cities.

Environmental monitoring is a key component of environmental research and protection, as the analysis of the dynamics of natural processes allows us to identify patterns in the organization of ecosystems and the biology of individual species of animals and plants. Physical and chemical parameters of the environment are usually measured using instruments: noise level and spectrum, temperature, characteristics of electromagnetic fields, characteristics of radioactive contamination of the environment, characteristics of geophysical phenomena, concentrations of chemical pollutants in air, water, soil, etc. Paper [17] proposes the use of an information and communication approach to monitoring natural reserves in biosphere reserves.

Paper [18] presents an approach that uses reinforcement learning and takes into account traffic pressure to optimize vehicle travel time through road intersections to reduce CO2 emissions. The proposed method is based on modern approaches to optimizing traffic lights, but with an emphasis on environmental aspects.

Paper [19] presents the concept of an information system for predicting the temperature regime of the earth's surface using machine learning. The forecasting is based on historical data for a certain territory. To improve the accuracy of the forecasting results, the features of climatic zones are analyzed to identify patterns.

To determine the main areas of application of information technology for monitoring environmental components, we analyzed the methods and technical tools used in the publications discussed above. The results of the analysis are presented in Table 1.

From the analysis of the sources reviewed, a pattern was identified that the information technologies mainly used to monitor environmental components are either Internet of Things (IoT) technologies using modern sensors and data transmission components or artificial intelligence technologies such as computer vision, etc. Less commonly used tools include robots, UAVs, and digital twins.

Let's review the known tools for environmental components monitoring.

The functions of environmental monitoring in Ukraine are vested in the State Environmental Monitoring System of Ukraine [25]. The State Environmental Monitoring System is a system of observations, collection, processing, analysis, storage and exchange of information on the state of the environment, its impact, forecasting its changes and development of scientifically based recommendations for making effective management decisions in Ukraine in order to prevent emergency crisis situations. Each of the entities of the State Environmental Monitoring System monitors those environmental objects that are defined by the Regulation on the State Environmental Monitoring System and procedures and regulations on state monitoring of certain environmental components. The functioning of the state system of environmental monitoring is carried out at three levels, which are distributed

according to the territorial principle: the national level, covering priority areas and tasks of monitoring on the scale of the whole country; the regional level, covering priority areas and tasks on the scale of a territorial region; the local level, covering priority areas and tasks of monitoring on the scale of certain territories with increased anthropogenic load.

Table 1

Analysis of methods and tools for monitoring environmental components

№	Author(s)	Year of publication	Country of research	Methods and tools used to monitoring environmental components
1	Ullo S. L., Sinha G. R.[13]	2020	Myanmar	Internet of Things (IoT) and sensors
2	Nova K.[14]	2023	USA	Using AI to monitoring water pollutants
3	Salam A. [15]	2024	USA	Internet of Things (IoT)
4	Sankar K. M., Booba B., & Boopathi S. [20]	2023	India	Internet of Things (IoT)
5	Khang A. [21]	2023	India	Artificial intelligence, robots, UAVs, Internet of Things
6	Arsiwala A., Elghaish F., & Zoher M. [22]	2023	England UAE	Digital twin technology
7	Guerrero-Ibañez A., & Reyes-Muñoz A. [23]	2023	Mexico Spain	Computer vision technology (AI)
8	Ryzhanskyi O., Manziuk E., Barmak O., Krak I., & Bacanin N. [18]	2024	Ukraine Serbia	Reinforcement learning (AI)
9	Pavlova O., & Alekseiko V. [19]	2024	Ukraine	Machine learning (AI)
10	Hovorushchenko T., Baranovskyi V., Ivanov O., & Hnatchuk A. [1]	2024	Ukraine	Internet of Things (IoT)
11	Hovorushchenko T., Voevudskyi Ye., Ivanov O., & Voichur O. [2]	2024	Ukraine	Internet of Things (IoT) and geolocation data
12	Yuan, S., Li, Y., Bao, F., Xu, H., Yang, Y., Yan, Q., & Lin, J. [24]	2023	China	UAVs

Another state environmental monitoring system in Ukraine is the Integrated Automated Radiation Monitoring System [26]. The Integrated Automated Radiation Monitoring System in Ukraine is an important element of the national system for protecting the public and the environment from radiation hazards. This system was created to continuously monitor the radiation background, collect, process and analyze data on radiation levels in the country, as well as to ensure prompt response to cases of increased radiation levels.

During 2016-2020, Ukraine implemented the ENI SEIS II East (Shared Environmental Information System East) project as part of the European Union's initiative in partnership with the Eastern Neighborhood countries, including Ukraine. The project was part of the Pan-European ENPI (European Neighborhood and Partnership Instrument) program, which aims to strengthen cooperation between the EU and its neighbors [27]. The main objective of ENI SEIS II East was to promote better environmental information and transparency in the Eastern Neighborhood countries by implementing the principles of the Common Environmental Information System (SEIS). The project aimed to promote the development of national environmental information systems, ensure their integration with European systems and support environmental decision-making based on reliable data.

One of the projects being implemented in Europe that uses information technology to monitor environmental components is the European Environment Information and Observation Network (EIONET), a network created to collect, process and disseminate environmental information across Europe. It is coordinated by the European Environment Agency (EEA). The main goal of EIONET is to support environmental decision-making in the European Union and partner countries by providing reliable, timely and comprehensive information on the state of the environment [28]. EIONET is a key tool for ensuring environmental sustainability in Europe. By collecting, standardizing and analyzing data, the network ensures high quality environmental information, which is the basis for formulating environmental policy and evaluating its effectiveness. Ukraine, as an EU partner country, also participates in EIONET activities. This allows Ukraine to integrate into the Pan-European environmental monitoring system, exchange data and best practices, and gain access to advanced methodologies and technologies in the field of environmental protection.

The Global Earth Observation System of Systems (GEOSS) is an international initiative created to coordinate and integrate global Earth observation systems. The goal of GEOSS is to provide access to high-quality, integrated and open information on the state of the environment that can be used to make decisions in the field of environmental protection, economics, resource management and emergency response [29].

In the United States, the United States Environmental Protection Agency (EPA) is a key tool in combating environmental threats and supporting sustainable development [30]. The EPA is one of the leading government agencies in the United States responsible for protecting the environment and human health. Within this agency, there are many divisions that deal with various aspects of environmental monitoring and management. One of these divisions is Environmental Monitoring Systems. Environmental Monitoring Systems (EMS) is a division of the EPA that develops, implements, and maintains environmental monitoring systems. These systems are used to collect and analyze data on the state of the environment, including air, water, soil, and other environmental parameters.

Thus, the main tasks of monitoring environmental components are as follows [31-35]:

1) tracking the state of the environment:
   - monitoring the level of pollution of air, water, soil, and other natural resources;
   - assessment of the impact of human activity (industry, agriculture, transportation) on natural ecosystems;
2) identification of sources of pollution:
   - identification of sources of emissions of harmful substances and their impact on various components of the environment (water, air, soil);
   - assessment of potential threats to human health and biodiversity;
3) prevention and response to environmental disasters:
   - timely detection and prevention of environmental accidents, such as chemical releases, radioactive contamination, and oil spills;
   - taking measures to minimize damage from natural disasters, such as floods or fires;
4) assessment of the state of natural resources:
   - monitoring of water, forests, and fisheries resources for their efficient and sustainable use;
   - control over the state of resource recovery and prevention of their depletion;
5) assessment of the effectiveness of environmental protection measures:
   - verification of the effectiveness of government programs and initiatives on environmental protection;
   - assessment of the effectiveness of methods of cleaning and restoration of contaminated areas;
6) support for environmental decision-making:
   - providing scientifically based information for the development of environmental policy and regulation of activities that affect nature;
   - facilitating decision-making at the level of government agencies and enterprises to reduce the negative impact on the environment;
7) control over biodiversity:
   - monitoring the status of populations of rare species of animals and plants;
   - detecting changes in flora and fauna that indicate an environmental imbalance.

These tasks help to maintain ecological balance, ensure sustainable development and protect human health.

Based on a critical analysis of methods and tools for environmental components monitoring, there is a need to develop such methods and means for environmental components monitoring that would: perform cheaper and more versatile environmental components monitoring than existing analogues, but at the same time have no less accuracy and speed; monitor the state of the environment; identify sources of environmental pollution; warn of environmental disasters; assess the state of natural resources; support environmental decision-making; collect and analyze various environmental indicators in real time; assessed the level of quality and safety of environmental components, which will allow immediate response to quality changes and promptly take the necessary measures, etc., which will be the focus of the authors' further efforts.

Conclusions

Monitoring of environmental components is an important process for determining the level of pollution and tracking changes in the environment, and plays a key role in ensuring the health and comfort of residents, as well as in preserving the environment. Continuous monitoring of environmental components is key to ensuring human health, protecting nature and reducing the negative impact on the climate and ecosystems, as well as achieving sustainable development. In order to combat environmental pollution, it is necessary to implement effective measures to limit emissions of harmful substances, use environmentally friendly technologies and green solutions in all sectors of the economy, and raise public awareness of the problem of environmental pollution.

From the analysis of the sources reviewed, a pattern was identified that the information technologies mainly used to monitor environmental components are either Internet of Things (IoT) technologies using modern sensors and data transmission components or artificial intelligence technologies such as computer vision. Less commonly, the use of robots, UAVs, and digital twins is being traced.

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