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METHOD OF JUSTIFICATION OF THE NECESSARY NUMBER OF ENVIRONMENTAL MONITORING TOOLS AND OPTIMIZATION OF THEIR LOCATION PLACES

Introduction. *In modern conditions, an urgent issue for Ukraine is the development of a methodology for substantiating the locations of mobile ecological laboratory bases and their composition, which will allow for limited time monitoring of territories affected by hostilities, potentially dangerous objects (PDO) and about objects of critical infrastructure (OCI).*

Purpose*. Mobile environmental laboratories in the region should be located to minimize the costs of monitoring and responding to time-limited emergencies.*

Methodology*. The existing bases of environmental monitoring means should be considered as initial conditions for creating a methodology for solving this problem of optimizing the placement of mobile environmental laboratories in the territories immediately adjacent to the areas of hostilities.*

Findings*. The results of the research can be used in the development of recommendations for choosing the optimal placement of unmanned aircraft complex (UAC) and their infrastructure on the territory of Ukraine in the context of reforming and reducing the number of aviation. A well-grounded choice of a section of the region's territory for the deployment of UAC will increase the level of technogenic and environmental safety during work on the prevention, monitoring and elimination of emergencies of a natural and technogenic nature.*

Originality*. The results of the research can be used in the development of recommendations for choosing the optimal placement of UAC and their infrastructure on the territory of Ukraine in the context of reforming and reducing the number of aviation. A well-grounded choice of a section of the region's territory for the deployment of UAC will increase the level of technogenic and environmental safety during work on the prevention, monitoring and elimination of emergencies of a natural and technogenic nature.*

Practical value*. Thus, the example of the practical application of the method of substantiating the required number of forces and means of environmental monitoring of operational zones and areas of hostilities is carried out according to the criterion of the minimum number of forces and means used, provided that the full scope of monitoring works is performed. The article provides a mathematical formulation of the problem for the development of the methodology and an example of its calculation for determining the location of mobile ecological laboratories using unmanned aerial vehicle complexes.*

Keywords*: methodology; environmental monitoring; unmanned aircraft complex; optimization; potentially dangerous objects; objects of critical infrastructure.*

Introduction. The ecological assessment of regional factors of threats from natural and man-made emergencies in the conditions of warfare showed that it is necessary to take into account the significant dependence of the response speed of mobile ecological laboratories depending on the location of their bases, the level of natural and man-made threats, the number of PDO and OCI, the dynamics of emergency situations [1–3].

Mobile environmental laboratories in the region should be located to minimize the costs of monitoring and responding to time-limited emergencies. This can be achieved by:

1) autonomy of use of UAC;
2) observance of safety measures during flights;
3) ability to maneuver take-off and landing points during response to emergency situations;
4) multifunctionality of monitoring equipment.

From a mathematical point of view, this problem belongs to combinatorial problems. A meaningful statement of the problem is as follows: among the many possible plans for the deployment of air defense systems in the region, find a plan that minimizes the costs of monitoring, responding and liquidating emergencies of a natural and natural nature, of military and man-made origin, while meeting the time limit for responding to emergency situations.

To determine the extent of the threat of natural and man-made emergencies, information on the number of potentially dangerous objects, statistics of dangerous hydrometeorological processes, and statistics of natural and man-made emergencies is required.

The existing bases of environmental monitoring means should be considered as initial conditions for creating a methodology for solving this problem of optimizing the placement of mobile environmental laboratories in the territories immediately adjacent to the areas of hostilities.

Presentation of the main material. The main criteria for the effectiveness of the environmental monitoring system are efficiency and economy, i.e. minimization of time and resources spent on environmental monitoring in the combat zone, detection and localization of potentially dangerous objects, etc. This can be done by deploying mobile episodic networks (MEM) using telecommunication aerial platforms (TA) (Fig. 1), which will collect, partially process and transmit information to specialized coordination centers for environmental monitoring [16]. Subscribers of such networks (military ecologists, rescuers, environmental sensors or vehicles of mobile ecological laboratories) can connect with each other (or with the coordination center) based on temporary links with relaying through intermediate ground or air-based nodes. Not only emergency services aircraft (An-32P aircraft, Mi-8 and ES-145 helicopters), but also mini- and micro-class unmanned aerial systems can be used as aerial repeaters.

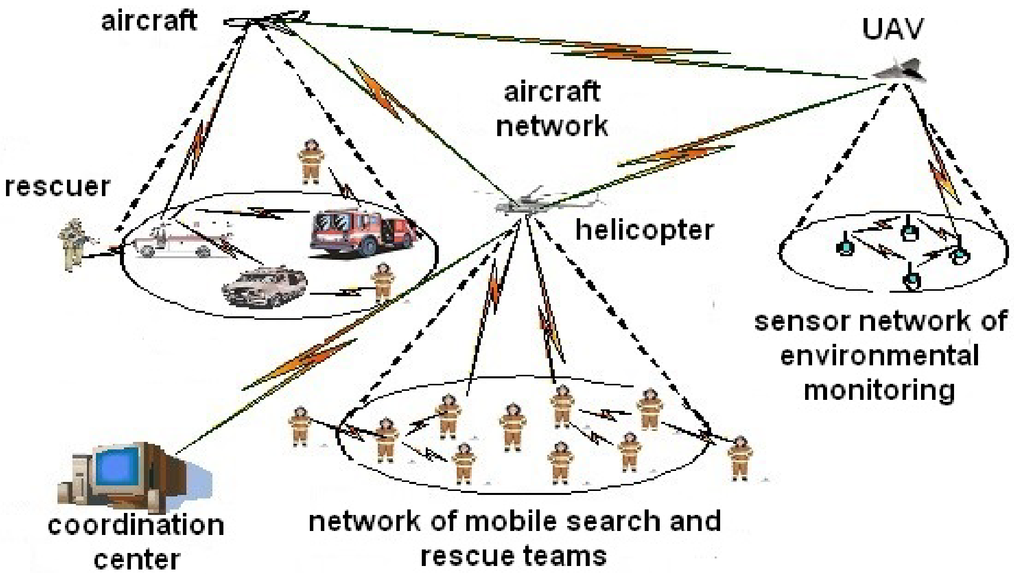

Figure 1. **An example of the organization of a mobile episodic network using aerial repeaters**

To determine the magnitude of threats of emergencies of natural and man-made origin, information is needed on the number of potentially man-made objects, statistics on hazardous hydrometeorological processes, statistics on emergencies of natural and man-made origin.

For the region, the vector of the composition of unmanned aircraft complex is known according to the characteristics of the threats of emergency situations for the region – $Z_j = \|z_j\|_n$, areas of the territory (airfields, airports, helipads) of the region where, subject to the implementation of aerodrome technical support and flight safety measures, unmanned aircraft complex (UAC) can be deployed – $T_i = \|t_i\|_m$, the area of zones of occurrence of natural and man-made emergencies – $S_{TOi} = \|s_{TOi}\|_m$, the density of the location of potentially dangerous objects (PDO) and the intensity of emergencies in the relevant areas of the region – $Y_j = \|y_j\|_n$, and the contingent costs of carrying out measures to eliminate emergency situations and restore the environment $C_{ij} = \|c_{ij}\|_{m\times n}$.

In general terms, these initial conditions can be written as

$$C=\left(\begin{array}{c|c:c:c:c:c|c} & z_1 & \ldots & z_j & \ldots & z_n & \\ \hline t_1 & c_{11} & \ldots & c_{1j} & \ldots & c_{1n} & \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \\ t_i & c_{i1} & \ldots & c_{ij} & \ldots & c_{in} & \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \\ t_m & c_{m1} & \ldots & c_{mj} & \ldots & c_{mn} & \\ \hline & y_1 & \ldots & y_j & \ldots & y_n & \end{array}\right). \quad (1)$$

Also known are the permissible levels of risks of occurrence of man-made and natural emergencies (density of emergency situations) for the corresponding zone of possible location of the UAC:

– risk zones of possible aviation incidents [units/day] – $ar_j,\ j=\overline{1,m}$;

– zones of point potentially dangerous objects [units/day] – $vpr_j,\ j=\overline{1,m}$;

– zones of linear extended potentially dangerous objects [units/day] – $vgr_j,\ j=\overline{1,m}$;

– zones of planar potentially dangerous objects [units/day] – $gr_j,\ j=\overline{1,m}$.

The density of emergency situations, which characterizes the corresponding concentration of the technogenic factor in the environmental components for the corresponding UAC, can be determined by the formula

$$N_{T\,moi}=\frac{y_{moi}(t,x,y)}{s_{moi}}, \quad (2)$$

where $i=\overline{1,n}$ – man-made objects,

s_{moi} – area of risk zone, respectively, for one UAC.

With such initial conditions, it is necessary to find such a plan for the distribution of areas of the region's territory for UAC, which would ensure the minimization of costs in the elimination of emergencies and the performance of recovery work in the region and the implementation of restrictions on the levels of risks, taking into account the response time.

The plan of assignment (distribution) of areas of the region's territory for the placement of UAC:

$$X=\left\|x_{ij}\right\|_{m\times n}=\left(\begin{array}{c|c:c:c:c:c|c} & z_1 & \ldots & z_j & \ldots & z_n & \\ \hline t_1 & x_{11} & \ldots & x_{1j} & \ldots & x_{1n} & \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \\ t_i & x_{i1} & \ldots & x_{ij} & \ldots & x_{in} & \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \\ t_m & x_{m1} & \ldots & x_{mj} & \ldots & x_{mn} & \\ \hline & & & & & & \end{array}\right), \quad (3)$$

where $x_{ij}=\left\{\begin{array}{c}1, when\ the\ \text{UAC}\ is\ located\ in\ the\ region\\ 0, when\ there\ is\ no\ \text{UAC}\ in\ the\ region\end{array}\right\}.$

Then the mathematical statement of the problem of the optimal placement of a UAC in possible risk zones on the territory of the region is formulated as follows: on the set of possible plans for the deployment of UAC (assignment distribution) $\{X\}$ in the territory of the region, each of which $\|x_{ij}\|_{m\times n}$ satisfies the system of restrictions:

– in the accommodation area for the UAC:

$$\sum_{i=1}^{m} z_{ij} \cdot s_{yj} \le s_{xi},\ j=\overline{1,m}; \tag{4}$$

– to permissible levels of risk of emergencies in the area of the UAC

$$\sum_{i=1}^{m} ax_i \cdot y_j \le ar_j,\ j=\overline{1,m}; \tag{5}$$

$$\sum_{i=1}^{m} vpx_i \cdot y_j \le vpr_j,\ j=\overline{1,m}; \tag{6}$$

$$\sum_{i=1}^{m} vgx_i \cdot y_j \le vgr_j,\ j=\overline{1,m}; \tag{7}$$

$$\sum_{i=1}^{m} gx_i \cdot y_j \le gr_j,\ j=\overline{1,m}, \tag{8}$$

find the optimal layout for search and rescue aircraft $X^o = \|x_{ij}^o\|_{m\times n}$ that minimizes the overall cost of maintaining an environmentally sound region

$$CS(X^o) = \min_{\{X\}} \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij} \cdot x_{ij} \cdot y_j. \tag{9}$$

Evolutionary methods are recommended for solving this problem.

The effectiveness of the deployment of UAC on the territory of the region can be assessed by the ratio of its level and the costs of its implementation, including taking into account the costs of responding to emergency situations and restoring the environment

$$ES = \frac{WS^{ПД}}{CS}. \tag{10}$$

Since the considered problem minimizes *CS* costs, the efficiency of using search and rescue aircraft in the region is maximized

$$ES^{ПД} = \frac{WS^{ПД}_{потр}}{\min CS} = \max ES^{ПД}. \tag{11}$$

The results of the research can be used in the development of recommendations for choosing the optimal placement of UAC and their infrastructure on the territory of Ukraine in the context of reforming and reducing the number of aviation. A well-grounded choice of a section of the region's territory for the deployment of UAC will increase the level of technogenic and environmental safety during work on the prevention, monitoring and elimination of emergencies of a natural and technogenic nature.

Output data: set of aerodromes of Ukraine $\overline{Z}=\{z_i\}, i=\overline{1,Z}$, where Z – is the number of aerodromes; z_i – is the number of aircraft at the *i*-th aerodrome; $(x,y)_i$ – coordinates of the i-th airfield; set of monitoring regions $\overline{R}=\{r_j\}, j=\overline{1,R}$, where R is the number of monitoring regions; r_j – is the area of the j-th monitoring area; $(x,y)_j$ – coordinates of the *j*-th monitoring area, from where the monitoring and rescue operations begin; monitoring characteristics of aircraft (speed *V*, maximum flight duration $T_{\max}$, monitoring performance *N*), which determine the maximum area of the *j*-th monitoring region that can be surveyed by one aircraft of the i-th aerodrome $S_{surv\ ji}$.

Problem statement (general view): find such a plan $\overline{X}=\{x_i\}, i=\overline{1,Z}$ for the use of the UAC of Ukraine monitoring facilities located at a set of specified aerodromes $\overline{Z}$ with a resource z_i, which minimizes the composition of aircraft for the operation and will allow the full scope of monitoring and rescue operations Ω to be performed $\overline{R}$), that is

$$\bar{X}=\min_{X\in\Omega}F=\min_{X\in\Omega}\sum_{i=1}^{Z}x_i, \tag{12}$$

when meeting the requirements for the total survey area and resources of aerodromes

$$\Omega:\left\{\begin{array}{c} S_{surv11}\cdot x_1+S_{surv12}\cdot x_2+\cdots+S_{surv1Z}\cdot x_Z\ge r_1 \\ S_{surv21}\cdot x_1+S_{surv22}\cdot x_2+\cdots+S_{surv2Z}\cdot x_Z\ge r_2 \\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ S_{survZ1}\cdot x_1+S_{survZ2}\cdot x_2+\cdots+S_{survRZ}\cdot x_Z\ge r_R \\ 0\le x_i\le z_i,\ i=\overline{1,Z} \end{array}\right\}. \tag{13}$$

Example. Let the Service have at its disposal five aerodromes with the following aircraft resource and location coordinates (Fig. 2): $z_1=5,(100,500)_1$; $z_2=4,(200,100)_2$; $z_3=6,(300,400)_3$; $z_4=5,(500,300)_4$; $z_5=4,(500,600)_5$.

It is necessary to survey three monitoring areas with the following coordinates of the starting point $(200,300)_1$; $(400,200)_2$; $(400,400)_3$ and areas of 100000 km^2 each. Find the minimum composition of UAC with the following monitoring characteristics: $T_{\max}=4,045$ hours (in case of full filling of all fuel tanks); $V=220\,{km}/{h}$; $N=4.95\,{10^3 km^2}/{h}$.

The order of the decision.

1. Determination of the distance between each aerodrome and the location of the monitoring area $L_{ji}, i=\overline{1,Z},\ j=\overline{1,R}$. Using the formula $L_{ij}=\sqrt{(x_i-x_j)^2+(y_i-y_j)^2}$, we obtain:

$$L_{ji}=\begin{Bmatrix} 223 & 200 & 141 & 424 & 300 \\ 424 & 223 & 223 & 141 & 412 \\ 316 & 360 & 100 & 141 & 223 \end{Bmatrix}. \tag{14}$$

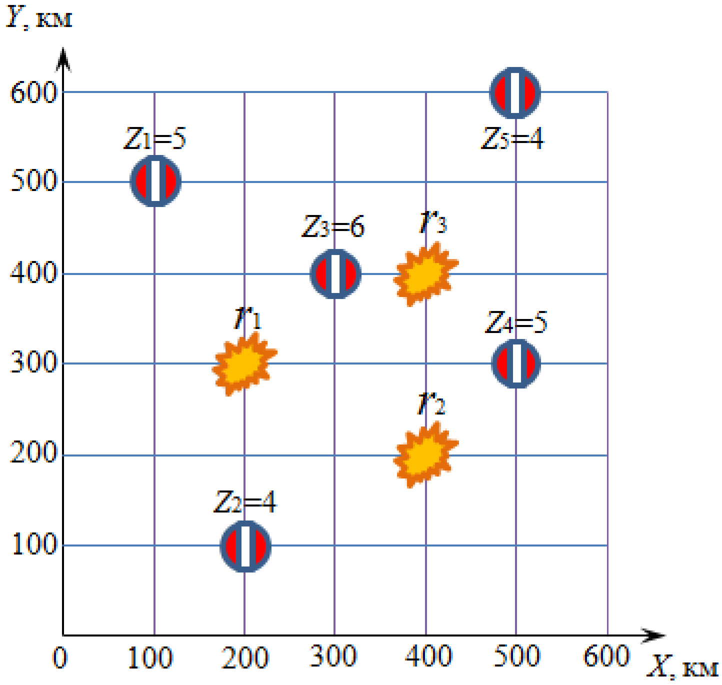

Figure 2. **Location of airfields of the Armed Forces of Ukraine for areas of hostilities**

2. Determination of the maximum area of the *j*-th monitoring area, which can be surveyed by one aircraft of the *i*-th aerodrome $S_{surv\ ji}$. Using the formula $S_{surv\ ji} = N\left(T_{\max} - \frac{2L_{ji}}{V}\right)$, we obtain:

$$S_{surv\ ji} = \begin{Bmatrix} 9990 & 11025 & 13680 & 945 & 6525 \\ 945 & 9990 & 9990 & 13680 & 1485 \\ 5805 & 3825 & 15525 & 13680 & 9990 \end{Bmatrix}. \quad (15)$$

3. Mathematical problem statement:

$$\bar{X} = \min_{X \in \Omega} F = \min_{X \in \Omega} \sum_{i=1}^{5} x_i. \quad (16)$$

if the requirements for the total survey area and airfield resources are met

$$\Omega: \left\{ \begin{array}{c} 9990x_1 + 11025x_2 + 13680x_3 + 945x_4 + 6525x_5 \geq 100000 \\ 945x_1 + 9990x_2 + 9990x_3 + 13680x_4 + 1485x_5 \geq 100000 \\ 5805x_1 + 3825x_2 + 15525x_3 + 13680x_4 + 9990x_5 \geq 100000 \\ 0 \leq x_1 \leq 5 \\ 0 \leq x_2 \leq 4 \\ 0 \leq x_3 \leq 6 \\ 0 \leq x_4 \leq 5 \\ 0 \leq x_5 \leq 4 \end{array} \right\}. \quad (17)$$

Calculation results:

– at the 13th iteration of the monitoring: $F = 11$, $x_1 = 0$; $x_2 = 1$; $x_3 = 6$; $x_4 = 2$; $x_5 = 2$;
– at the 103rd monitoring iteration: $F = 10$, $x_1 = 0$; $x_2 = 4$; $x_3 = 4$; $x_4 = 2$; $x_5 = 0$.

Thus, data were obtained on the number of aircraft at each aerodrome, which must be brought into readiness for flight.

Entering data into the computer program "TORA" (Fig. 3) and calculating the results (Fig. 4).

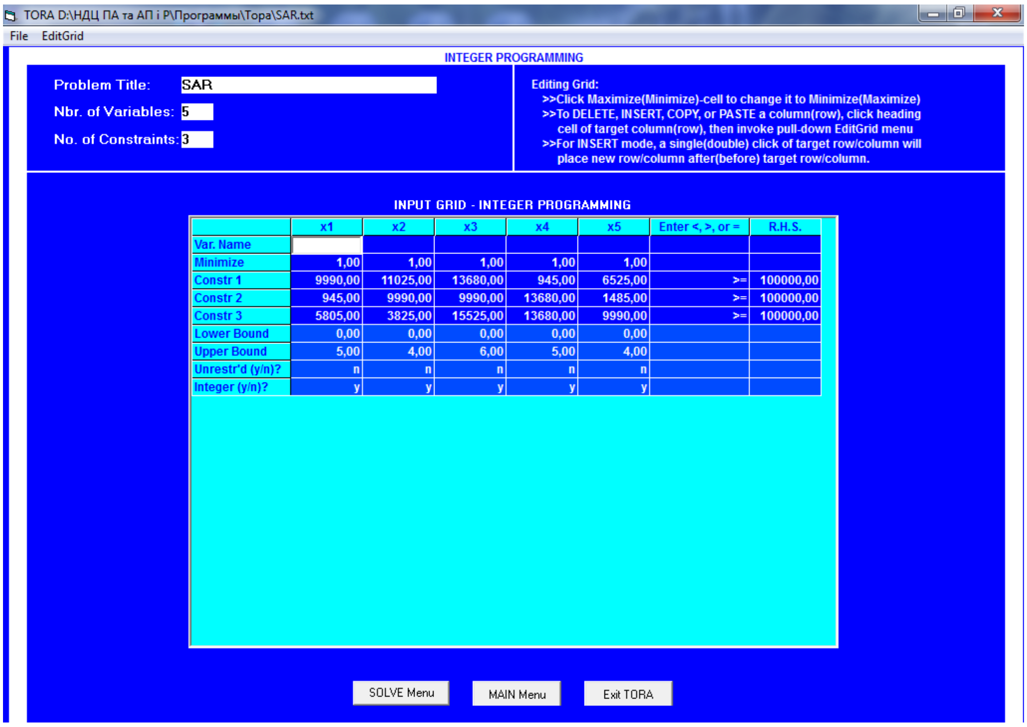

Figure 3. **Data entry into the computer program “TORA”**

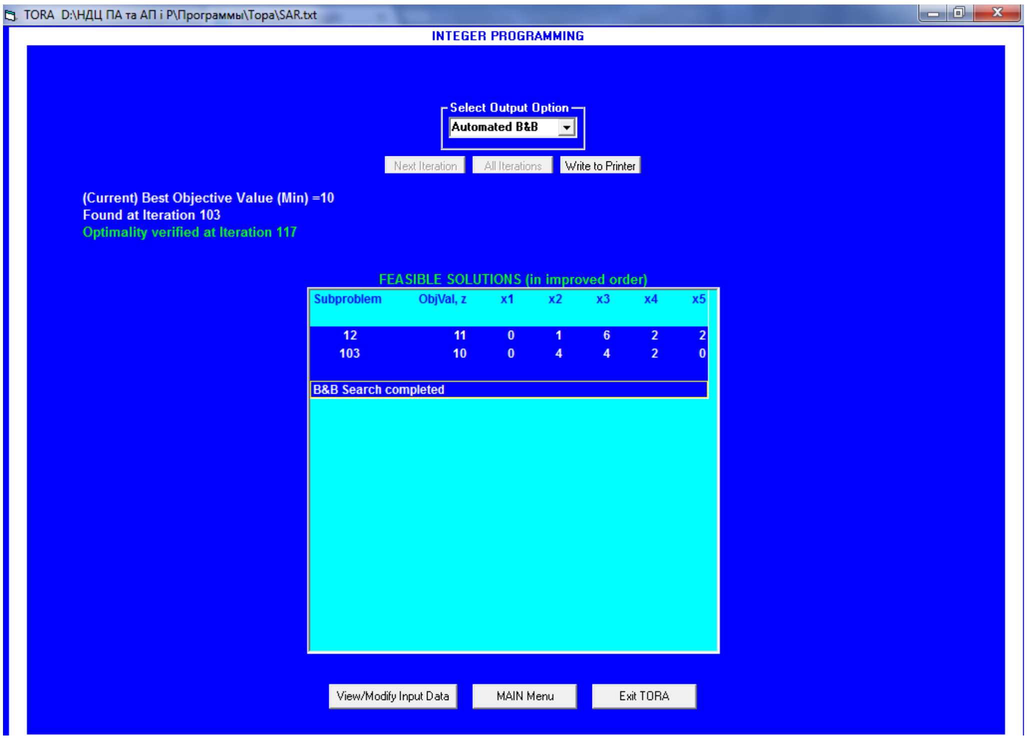

Figure 4. **Calculation of results in the computer program "TORA"**

Thus, the example of the practical application of the method of substantiating the required number of forces and means of environmental monitoring of operational zones and areas of hostilities is carried out according to the criterion of the minimum number of forces and means used, provided that the full scope of monitoring works is performed. The disadvantage of the solution is that the resulting decision provides information only about the number of deployed assets from each airfield of the Armed Forces of Ukraine, but does not provide an answer as to what proportion they will be used to survey this or that area of DB management. However, the obtained data can provide information on the number of aerial monitoring devices (aircraft, helicopter or multicopter type UAVs) at each airfield that need to be made ready for flight.

Conclusions:

1. The practical use of the result of solving this problem will ensure the highest speed of response to possible emergencies of a military nature and acceptable costs for their monitoring, response and liquidation.
2. The methodology for optimizing the placement of UAVs for environmental monitoring on the territory of Ukraine is presented. Ecological and economic justification of the optimal location can be used in the development of normative documents and methods of choosing the location of the infrastructure of mobile ecological laboratories of Ukraine, provided that it is highly efficient.
3. This will ensure the maximum efficiency of the use of forces and means in the region for the performance of environmental monitoring works, provided that a sufficient level of environmental and man-made safety is ensured.
4. Reasonable selection of the area of the region for deployment of forces and means of ecological monitoring will allow to increase the level of man-made and ecological safety during the execution of works on the prevention, monitoring and liquidation of emergencies of a military-man-made nature.

Thus, the example of the practical application of the method of substantiating the required number of forces and means of environmental monitoring of operational zones and areas of hostilities is carried out according to the criterion of the minimum number of forces and means used, provided that the full scope of monitoring works is performed. The disadvantage of the solution is that the resulting decision provides information only about the number of deployed assets from each airfield of the Armed Forces of Ukraine, but does not provide an answer as to what proportion they will be used to survey this or that area of DB management. However, the obtained data can provide information on the number of aerial monitoring devices (aircraft, helicopter or multicopter type UAVs) at each airfield that need to be made ready for flight.

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МЕТОДИКА ОБҐРУНТУВАННЯ НЕОБХІДНОЇ КІЛЬКОСТІ ЗАСОБІВ МОНІТОРИНГУ ДОВКІЛЛЯ ТА ОПТИМІЗАЦІЇ МІСЦЬ ЇХ РОЗТАШУВАННЯ

Вступ. *У сучасних умовах актуальним питанням для України є розробка методики обґрунтування місць розташування пересувних екологічних лабораторних баз та їх складу, що дозволить проводити обмежений у часі моніторинг територій, що постраждали від бойових дій, потенційно небезпечних об'єктів (ПНО) та про об'єкти критичної інфраструктури (ОКІ).*

Мета*. Мобільні екологічні лабораторії в регіоні повинні бути розташовані, щоб мінімізувати витрати на моніторинг та реагування на обмежені за часом надзвичайні ситуації.*

Методологія*. Існуючі основи засобів екологічного моніторингу слід розглядати як вихідні умови для створення методології вирішення даної проблеми оптимізації розміщення мобільних екологічних лабораторій на територіях, що безпосередньо прилягають до районів бойових дій.*

Висновки*. Результати дослідження можуть бути використані при розробці рекомендацій щодо вибору оптимального розміщення УАК та їх інфраструктури на території України в контексті реформування та скорочення чисельності авіації. Обґрунтований вибір ділянки території області для розміщення ОАК підвищить рівень техногенно-екологічної безпеки під час проведення робіт із запобігання, моніторингу та ліквідації надзвичайних ситуацій природного та техногенного характеру.*

Оригінальність. *Результати дослідження можуть бути використані при розробці рекомендацій щодо вибору оптимального розміщення УАК та їх інфраструктури на території України в контексті реформування та скорочення чисельності авіації. Обґрунтований вибір ділянки території області для розміщення ОАК підвищить рівень техногенно-екологічної безпеки під час проведення робіт із запобігання, моніторингу та ліквідації надзвичайних ситуацій природного та техногенного характеру.*

Практична цінність. *Таким чином, приклад практичного застосування методики обґрунтування необхідної чисельності сил і засобів екологічного моніторингу оперативних зон і районів бойових дій здійснюється за критерієм мінімальної чисельності сил і засобів, що використовуються, за умови, що виконано повний обсяг моніторингових робіт. У статті подано математичну постановку задачі на розробку методики та приклад її розрахунку для визначення місця розміщення мобільних екологічних лабораторій з використанням безпілотних авіаційних комплексів.*

Ключові слова: *методологія; екологічний моніторинг; БПЛА; оптимізація; ПНО; ОКІ.*