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Natural Risk Management to Protect Critical Infrastructures: A Model for Active Learning

Catalin Cioaca, Vasile Prisacariu and
Mircea Boscoianu

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<http://dx.doi.org/10.5772/intechopen.70606>

Abstract

This scientific approach has been initiated in the context of the rapid and unpredictable developments of climatic factors that generate a major challenge for military critical infrastructure protection systems. The proposed methodology integrates on a specially designed decision-making platform the two approaches specific to risk management: adaptive-preventive (risk assessments at the local area based on the connection between climate change vectors—the asset of infrastructure—the potential impact on medium and long term) and adaptive-reactive (real-time event monitoring using emerging technologies: integration of sensors on a robotic aerial platform). The architecture of the research model was designed to meet both user requirements (modular, flexible, scalable) and the needs to overlap the stages of the risk management process. Model testing on simulated scenarios under laboratory conditions demonstrated the functionality and highlighted the expected performance.

Keywords: risk management methodology, climate vector, military critical infrastructure, aerial monitoring, decision support platform

1. Introduction

Regarding regulatory framework, the *National Strategy on Critical Infrastructure Protection*, developed in 2011, is the framework document for the adoption and implementation of specific measures and actions to reduce the negative impacts of specific risk factors on critical infrastructure at a national and regional level [1]. The strategy has been completed in order to identify national critical infrastructures [2]. In order to achieve the directions of action proposed in the strategy, the following coordinates are considered: prevention, mitigation,

and limitation of effects; response/intervention efficiency; and sustainability (risk analysis, correlation of resources with needs).

Romania's National Climate Change Strategy 2013–2020 addresses the issue of natural risks in two distinct areas: the process of reducing greenhouse gas emissions in order to achieve the assumed national targets and the adaptation to the effects of climate change. The Ministry of Environment and Climate Change is monitoring the process of adaptation to the effects of climate change. There is no defense sector among the 13 sectors vulnerable to the negative impacts of climate change [3].

The unitary risk assessment methodology and the integration of the sectorial risk assessments aim to provide a common framework for analysis for the sectorial risk assessments. It provides information on the types of risks present on the territory of Romania. The methodology defines the stages for the identification of scenarios, the construction of risk scenarios as well as the criteria for their prioritization and selection in order to establish the representative scenarios to be subjected to the evaluation process [4].

At a community level, the European Commission has initiated starting with 2010 a process of creating a unitary methodological framework for risk assessment to improve the capacity of member states to respond by means of prevention, preparedness, and intervention measures to identified risks. This approach also aims to better manage and distribute resources for the effective and efficient management of disastrous events in the European Union (EU).

The guidelines formulated at the level of the European Commission are mainly [5]:

- Using best practices of international standards in the EU and developing a common risk assessment approach.
- Creating a risk assessment tool for institutions/organizations with disaster management responsibilities.
- Developing knowledge on disaster prevention policies at different administrative levels.
- Providing resource information on how to prioritize and allocate investments to prevent, prepare, and establish rehabilitation measures.
- Increasing the awareness of the population about disaster prevention measures.
- Providing information to establish a European disaster-assistance capacity database.

These directions are embodied in the security plans in the form of structured procedures on the following stages: identification of important elements; performing a risk analysis based on major threat scenarios, on vulnerabilities and potential impact; and identifying, selecting, and implementing technical and organizational solutions. Critical military infrastructures can be assessed against the level of preparedness to the threats posed by climate change based on the following indicators:

- The way they perceive the threat.
- The adaptive-preventive capacity against threats.
- The adaptive-reactive capacity in case of threat manifestation.

Climate assessment at national and international levels indicates that the impact of weather on human activities is inevitable and growing. Climate change related to extreme weather events will increase infrastructure damage in the future [6]. However, the normative and procedural framework for assessing climate risks on critical infrastructures in general and military in particular is not developed in a way that will effectively address this particularly complex issue.

To build the database regarding extreme natural events in Romania, we have used the International Disaster Database, a product of the Disaster Epidemiology Research Centre (CRED). Thus, during the period 1915–2015, 90 natural events with disastrous consequences were identified: drought (2); earthquake (10); epidemic (3); extreme temperatures (19); floods (49); landslides (1); and storms (6).

The most significant of these (according to the number of victims) are shown in **Table 1**.

For the period 2000–2015, Romania recorded 55 extreme natural events, the consequences of which sums 697 deaths and over 3 billion USD of material damage.

At European level, the temperature has risen by almost 1°C in the last century, faster than the global average. Rainfall has grown considerably in Northern Europe, whereas in the southern continent, droughts have become increasingly frequent. Recent extreme temperatures, such as the 2003 summer heat wave in Central and Western Europe and the summer of 2007 in Southeast Europe, which have exceeded any record, are a direct consequence of human climate change. Although single meteorological phenomena cannot be attributed to a single cause, statistical analysis has shown that the risk of such phenomena has already increased considerably due to climate change [7].

The forecasting of changes in the climate regime at a national level was performed for the period 2001–2030 (compared to the period 1961–1990) for the parameters: air temperature and precipitation level [7].

The type of the event	Data	The number of victims
Earthquake	4 March 1977	1641
Floods	1926	1000
Earthquake	10 November 1940	980
Floods	11 May 1970	215
Floods	29 July 1991	108
Extreme temperatures	23 January 2012	86
Extreme temperatures	20 January 2006	68
Extreme temperatures	18 November 1998	60
Floods	1975	60
Extreme temperatures	22 January 2010	52

Table 1. Top 10 extreme natural events.

Air temperature:

- An increase in the average monthly air temperature is projected in November and December and in the hot period of the year (May–September), about 1°C, somewhat higher values (up to 1.4–1.5 1°C) in the mountains, in the south and west of the country; during the cold season, the heating does not exceed 1°C.
- The average annual heating in the country is between 0.7 and 1.1°C, with the highest values in the mountain range.

Rainfall:

- A decrease in monthly precipitation volumes is projected for the period 1961–1990, especially in the winter months (December, February), an increase in October, and in June a slight increase in the mountains and declines are projected in the hills and plains areas.
- 3.5% of Romania's surface area and 6% of the population would be affected by floods in a scenario with a probability of production once every 100 years; the 375 floodplains are located on 330 rivers and contain 16,000 km of flowing water, which represent about 20% of the length of the Romanian hydrographic network.

2. The natural risk assessment and analysis process

2.1. The risk of natural events

Natural hazards are extreme manifestations of natural phenomena with direct implications on each person's life, society, and the environment as a whole [8]. Between natural phenomena, climatic conditions are the subject of this analysis (e.g., storms, floods, tornadoes, extreme temperatures, drought, frost).

The natural risk, in terms of the possibility of occurrence of unwanted natural events, is defined as a function of assets, threats, and vulnerabilities. Asset, in the military organization, represents those values that the organization needs to fulfill its mission. If these values (e.g., people, information, facilities, activities, operations) have a significant weight in the accomplishment of the mission, and their total or partial loss would have serious consequences for the organization as a whole, then they are considered critical. Vulnerability is defined as an asset breach that can be exploited with negative effects on the organization's interests. Threat is the situation that can exploit a vulnerability [9].

Individual risks are related to the likelihood that a natural initiator event develops to a scenario with credible consequences. Thus, the notion of climatic vector is introduced to describe some aspects of the climate that are known to have significant destructive potential and disruptive potential over military infrastructure and operations.

Vectors, such as heavy snow, ice, strong winds, heavy rain, extreme temperatures, or electrical discharges, can cause material damage, military technique damage, and disruption of the

communications system. They can also quickly have a cascading effect on the military system as a whole, with an effect on the infrastructure of interest. Climatic vectors were identified based on the destructive potential of infrastructures and the disruptive potential of intervention actions (**Table 2**). These climatic vectors are described to provide an overview of climate change in the central area of Romania.

The value scales included in the description are in line with the specific climate regime of Romania, according to the National Meteorological Administration (NMA), and the uncertainty level was estimated based on the climate change risks included in the National Climate Change Strategy 2013–2020 [10].

Climate change, highlighted by both the effects of immediate catastrophic events as well as a part of a slower process, stimulates proactive decisions to reduce existing vulnerabilities and avoid future damage. Critical military infrastructures can be evaluated in relation to the level of preparedness to climate change threats based on the following indicators: how to perceive the threat; the ability to deal with the threat; and the ability to respond and adapt to threats.

No.	Climatic vector	Description	Symbol
1.	Summer days	$t_{\max} \geq 25^{\circ}\text{C}$	
2.	Tropical days	$t_{\max} \geq 30^{\circ}\text{C}$	
3.	Frosty days	$t_{\max} \leq 0^{\circ}\text{C}$	
4.	Cold days	$t_{\max} \leq -10^{\circ}\text{C}$	
5.	Days with high humidity	Medium temperature of dew point $\geq 18\text{ C}$	
6.	Snowy days	Snow accumulation $\geq 10\text{ cm}$	
7.	Stormy days	Precipitation with electrical discharge $\geq 4\text{ mm}$	
8.	Torrential rains (1 day)	Daily precipitation $\geq 20\text{ mm}$	
9.	Torrential rains (5 days)	Total of precipitation $\geq 100\text{ mm}$	

Table 2. Identification of climatic vectors.

2.2. Natural risk assessment model

Risk assessment is the process of evaluating: what can happen, caused by what, and which can be the maximum impact. The outcome of the process may take the form of a qualitative measure of the potential of losses resulting from the occurrence of uncertain events in a specific period of time [11].

Standard or nonstandardized methods or techniques may be used to assess the level of risk, but these must include: name/type of method; initial assumptions; and approximations. The natural risk assessment process includes a preliminary step (quantitative analysis) and a detailed step (qualitative analysis). For the developed natural risk assessment model, we used the risk matrix method (in order to make possible the hierarchy of events based on the level of risk) and the checklist (to identify the vulnerabilities of the infrastructure) at the preliminary stage. In the detailed step, we used analysis of barriers protection (in terms of occurrence frequency of initiator event and multiplication factor of consequences).

The proposed model is based on the assumption that the risk has two characteristics: the uncertainty (the probability of occurrence of the event) and the negative effect (the seriousness of the consequences) [12]. Thus, the level of risk can be interpreted in terms of deviation from the desired final state, and the maximum deviation is the most unfavorable possible condition.

In order to increase the level of protection against the climate change of critical infrastructure in general and critical military infrastructures in particular, we have designed the following milestones: the definition of zonal climatic conditions; the identification of the infrastructure assets and critical activities; and the assessment of the natural risks (based on the coefficient of the asset's importance, the vulnerability level and the multiplier factors, risk prioritization, identification of adaptation strategies, monitoring, and reassessing risks).

At this step, the list of infrastructure assets and specific critical activities/operations is drawn up. Thus, a specific list of military aviation units has been pre-defined, with the possibility to be customized for any other type of objective (**Table 3**).

The risk assessment model is based on the assignment of relative risk scores (R_s) for each infrastructure asset or specific activity/operation that may be affected by the selected climatic vectors. The level of importance (Li), vulnerability (Vu), and multiplier factor (Mf) are estimated to be between 1 and 3. The risk estimation formula is a simple multiplication, and it is expressed in Eq. (1).

$$R_s = Li \times Vu \times Mf \quad (1)$$

The importance factor of the specific infrastructure/operation asset is defined according to the role within the system, based on the following indicators: interconnectivity with other subsystems, recovery costs, security and safety, legislative requirements. Thus, three levels of importance are defined in **Table 4**.

Vulnerability is defined in terms of the sensitivity of an infrastructure asset specific to a climatic vector. Thus, vulnerability is dependent on the strength of the infrastructure, the

Category	Name	Code
General aviation facilities	Access roads	I.1
	Underground access ways	I.2
	Hangars	I.3
	Motion group (loading/unloading)	I.4
	Flight command point	I.5
Aircraft	Aircraft	II.1
	Ground-handling equipment	II.2
	Take-off/ landing/backup runway	II.3
	Waiting areas	II.4
	Air navigation systems	II.5
	Flight attendance machines	II.6
Safety	Defrost	III.1
	Signaling/marketing boards	III.2
	Ornithological flight insurance	III.3

Table 3. List of critical infrastructure assets and activities.

- | | |
|---|--|
| 1 | Loss of assets/disruption would have a negligible impact on the fulfillment of the mission |
| 2 | Loss of assets/discontinuation of operations would significantly impede the fulfillment of the mission |
| 3 | Loss of assets/discontinuation of operations would hinder the fulfillment of the mission |

Table 4. Defining levels of importance.

adaptability to a specific vector, and the expected changes. Prospects from which vulnerability can be addressed include: age, physical condition, location of repairs and maintenance (for infrastructure assets), personnel training, the existence and updating of procedures, and the time elapsed since the last update (for specific activities/operations). Vulnerability is calculated by multiplying the consequences of a climatic vector with the probability of producing consequences on an infrastructure asset or specific activity/operation. Vulnerability levels are detailed in **Table 5**.

The multiplication factor is defined in terms of the negative weather evolution of climatic conditions, being expressed by the time variation of the climatic vectors. To define the variation of the selected climatic vector, the historical data provided by the National Meteorological Institute for the Brasov station were used. On this data, the FORECAST.ETS function (version AAA of the Exponential Smoothing algorithm with a 95% preselected confidence interval) was applied to Excel 2016 in order to estimate the evolution of the medium-term climatic vector (10 and 25 years) (**Figure 1**).

-
- 1 The specific asset/operation is unlikely to be affected by the climatic vector
 - 2 The specific asset/operation is likely to be affected by the climatic vector
 - 3 The specific asset/operation is likely to be significantly affected by the climate vector
-

Table 5. Defining the levels of vulnerability.

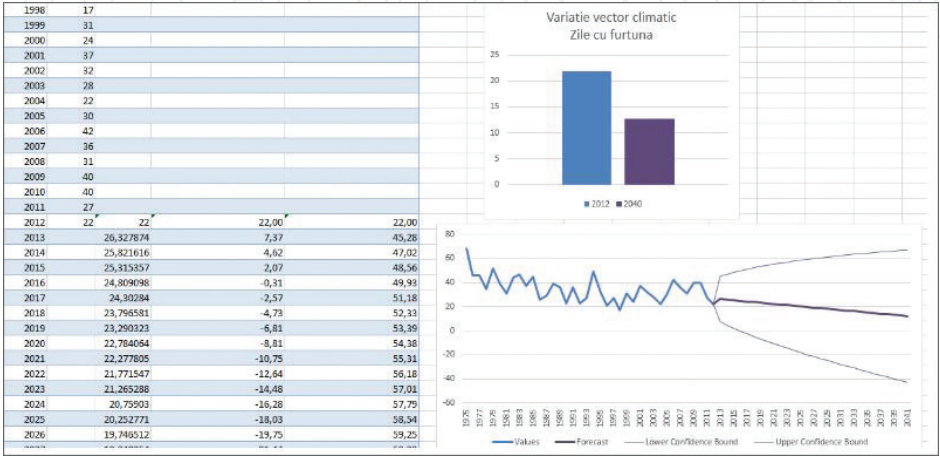


Figure 1. Capture from Forecast sheet excel 2016 for “Stormy days”.

The multiplication factor is determined by the estimated number of days of variation of the climatic vector toward unfavorable conditions (**Table 6**).

In order to represent the risk matrix associated with each selected infrastructure asset and selected specific activity/operation, the risk matrix with three regions is used (**Table 7**). These regions are acceptable (1, 2, and 3), tolerable (4, 6, 8, and 9), and unacceptable (12, 18, and 27).

This is the interpretation of the three risk areas: the red region (the risk is considered unacceptable, regardless of the benefits it could bring, the treatment of risk is imperative regardless of costs); the yellow region (the risk is tolerable only if the decrease is impossible or if the reduction costs exceed the value of the damage); and the green area (the level of risk is considered negligible and monitoring is required).

-
- 1 Vector variation less than 1 day per year
 - 2 Vector variation ranging from 1 to 3 days per year
 - 3 Vector variation greater than 3 days per year
-

Table 6. Defining the multiplier factor.

		<i>Vulnerability</i>			
		Low	Medium	High	
<i>Importance</i>		1	2	3	<i>Multiplier factor</i>
3	Very important		1, 2, 3		3 Considerable
2	Important		4, 6, 8, 9		2 Significant
1	Little important		12, 18, 27		1 Insignificant

Table 7. Risk matrix.

2.3. Natural risk analysis

A risk analysis is a proactive approach that consists of identification of possible negative events or situations, determination of cause-and-effect relationships, and evaluation of various outcomes under different assumptions. Risk analysis becomes important not only from the perspective of increasing risk assessment utility for decision-making, but also from the perspective of improved techniques used in risk assessment [13].

For designing adaptation strategies, it is taken into account the impact of the climatic vector on the operational requirements of the specific infrastructure/activity asset and the level of risk (which determines the priority of the action—immediate, medium, and low). Effective management of adaptation strategies is done by drawing up a risk sheet (**Table 8**).

Immediate priority risks are those where the infrastructure asset or specific activity/operation is essential for the entire military system, the climate impact is present, and the evolution toward more dangerous conditions is high and imminent. In these situations, it is imperative to immediately adopt the identified adaptation strategies.

Also, if some unidentified weaknesses become apparent during specific activities/operations, updating information, risk prioritization, and adjustments to the adaptation strategies for the major threats are made.

Asset	Climatic vector	Risk score	Impact	Adaptation strategy/priority
Communication antenna	Torrential rain – 1 day	1/2/1 2	Interruption of power supply	Installing a generator/ <i>low</i>
Aircraft	Frosty days	2/1/3 6	Changing the features of the on-board instrumentation	Installing the thermal protection/ <i>medium</i>
Surface fuel storage/supply	Tropical days	2/3/3 12	Increasing the pressure in the tank Content loss	Installation of double wall storage system Absorbent material/ <i>immediate</i>

Table 8. Risk sheet model.

Checklists may be drawn up in order to facilitate the selection of adaptation strategies by keeping the following records: the infrastructure assets or the specific activities/operations that will be affected, the priority with which the strategy is to be implemented, who is responsible for that risk.

This qualitative approach provides an initial picture of the risk exposure of military objectives, which of the risks require action, training, or monitoring. The action lines for risk management include: reduction of risk exposure (structural protection); reducing vulnerability (prevention); improving resistance to change (forms of training and education); reorganization of the military objective; and training, response, and recovery (emergency services).

In order to have a complete picture of the issue, risk analysis should also include a justification of the cost of the solutions identified in relation to the reduction of the level of risk. Thus, the cost-benefit analysis is carried out for each adaptation strategy, after being evaluated from the point of view of effectiveness, feasibility, and action priority [14].

The challenge is not only to determine the cost of solutions but also to determine the cost needed to achieve the system's resilience to natural disaster events. First of all, it is a question of effectively allocating existing resources to bring the risk to an acceptable level. In most cases, the cost of adaptation strategies is more tangible than the cost of benefits.

In this respect, a model for calculating the potential benefits for an identified solution was proposed by Cioacă et al. [15]. This model, initially applied to assess security investments to mitigate terrorist risk, can be easily adapted and applied in risk analyses of natural disaster events [15].

Thus, the estimate of the benefit (B) corresponding to the introduction of a package of measures A at the level of an infrastructure element i is based on the effect/impact on the level of risk (the difference between the initially assessed risk level— Rs_0 and the assessed level of risk after the implementation of the adaptation solution— Rs_A) and the cost of avoided consequences (CCA) (Eq. (2)).

$$B_i^A = P_i^A \cdot \frac{Rs_0 - Rs_A}{Rs_0} \cdot CCA^A \quad (2)$$

where P_i^A represents the priority of adopting package A on infrastructure i , based on the following scale of values: 1, low; 2, medium; and 3, immediate. The CCA has a human component (cost of life saved by application A) and a material component (material damage saved according to the percentage of saved infrastructure and accounting value attributed).

3. Natural event monitoring

This section, which integrates the adaptive-reactive approach to risk management, is an active learning tool by testing the natural risk assessment model on simulated scenarios

under laboratory conditions. The scenario considered is the post-storm assessment of the explosion hazard in the fuel storage area of a military base.

The section for monitoring ongoing natural events is based on the technical possibilities offered by:

- The aerial vector (it provides real-time data on temperature, humidity, presence/absence of smoke, and flammable gases), as well as real-time video information about the area/infrastructure in the field of view (**Figure 2**).
- Ground weather station (provides real-time data on rainfall, wind speed and direction, temperature, humidity).

Arduino UNO is an open-source processing platform based on flexible and simple software and hardware. It consists of a small-scale platform built around a signal processor and is capable of retrieving data from the environment through a series of sensors. The processor is able to run written code in a programming language that is very similar to C++:

```
#include <idDHT11.h>.

int. idDHT11pin = 2; //Digital pin for communications.

int. idDHT11intNumber = 0; //interrupt number (must be the one that use the previous
defined pin (see table above).

//declaration.

void dht11_wrapper(); //must be declared before the lib initialization.

//Lib instantiate.

idDHT11 DHT11(idDHT11pin,idDHT11intNumber,dht11_wrapper);

float sensor = A0;

float gas_value;

void setup().
{
pinMode(sensor,INPUT);

Serial.begin(9600);

Serial.println("Academia Fortelor Aeriene GAZTEMP MONITORING");

Serial.print("LIB version: ");

Serial.println(IDDHT11LIB_VERSION);

Serial.println("-----").
```

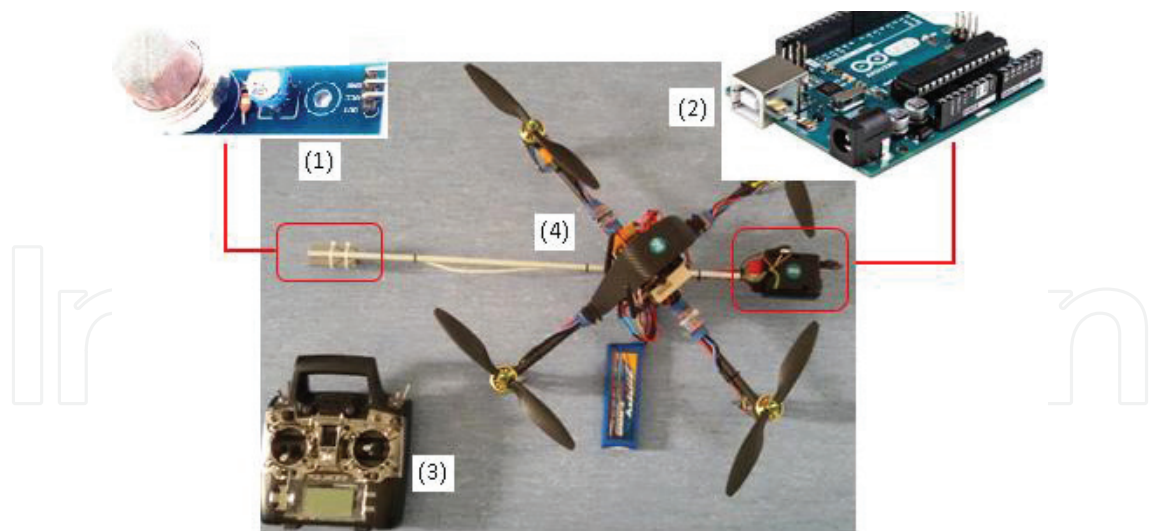


Figure 2. Integrated architecture aerial vector sensors. (1) Smoke sensor and flammable gases; (2) Arduino UNO; (3) radio transmitter; and (4) quadcopter.

The smoke and flammable gas sensor has the ability to detect the following flammable gases: butane, propane, hydrogen, and methane. The presence of these gases in the air is measured in parts per million (ppm). In **Table 9**, the lower explosion limit (LEL) and the upper explosion limit (UEL) and the immediate danger to life or health (IDLH) are presented.

Depending on the explosion limits specific to each type of gas detected, the hazard grid was developed on four levels: Green, Yellow, Orange, Red (**Table 10**).

Quadcopter is a customized solution developed in the Autonomous Aerial Systems Laboratory. Testing of air vector functionality and integrated sensors was performed within the “Henri Coanda” Air Force Academy on a source of heat and smoke (**Figure 3a**), based on a flight planner (**Figure 3b**).

Some of the measurement results are represented in **Table 11**. A variation in the concentration of flammable gases can be observed, with a peak of 983 ppm at melting point 10.

Gas	LEL (ppm)	UEL (ppm)	IDLH (ppm)
Butane	16,000	84,000	–
Propane	21,000	95,000	2100
Hydrogen	40,000	750,000	Asphyxiant
Methane	50,000	150,000	Asphyxiant

Table 9. Lower and upper explosion limits.

Risk score	Concentration measured (ppm)			
	<900	900–2099	2100–16,000	>16,000
Insignificant				
Low				
Medium				
High				

Table 10. Interpretation of monitoring data.



Figure 3. Testing weather sensors: (a) photo and (b) capture from mission planner.

Humidity (%)	Temperature (°C)	Flammable gases (ppm)
41	19	366
41	19	331
41	19	322
41	19	298
41	19	296
41	19	291
41	19	299
41	19	305
41	19	315
41	19	983
41	19	797
41	19	640

Table 11. Test results.

4. Decision support platform

The information provided in the risk analysis and event monitoring (if the option is activated) are integrated into a decision support platform using the Delphi 7 program. The decisional architecture was designed to meet both user requirements (modular, flexible, scalable) as well as the need for overlapping with the stages of the risk management process.

The platform is designed to: easily identify the infrastructure asset of the climate vector in real-time and to identify the medium-term evolution; to update the risk indicators (**Figure 4**); to visualize the level of risk; to be able to save a risk report (data about the climatic vector, the infrastructure asset, the level of risk, the severity of the impact, and the adaptation strategies).

User input values are essential to delimit the risk classes according to the scales from **Tables 4–6**. For situations of inapplicability, the value 1 is entered. To facilitate the accurate determination of the vulnerability level, scenario analysis is performed.

For the correct interpretation of the results provided by the support decision-making platform, it is very important to understand the following: the growth or decrease trend of the climatic vector in the next 10 or 25 years, respectively; the projected climate change for the next 10 and 25 years; the level of uncertainty reported for each climatic vector; communicating best practices identified at regional level from other critical infrastructures. For the event monitoring section, data are available to the user after executing the mission/monitoring in .txt or.avi format. Once downloaded, they are automatically retrieved and displayed in the Monitoring Report (**Figure 5**).

This section provides the possibility to save a risk report by creating a text version (.txt). For the correct interpretation of the results provided by the support decision-making platform, it is very important to understand the following: the growth or decrease trend of the climatic

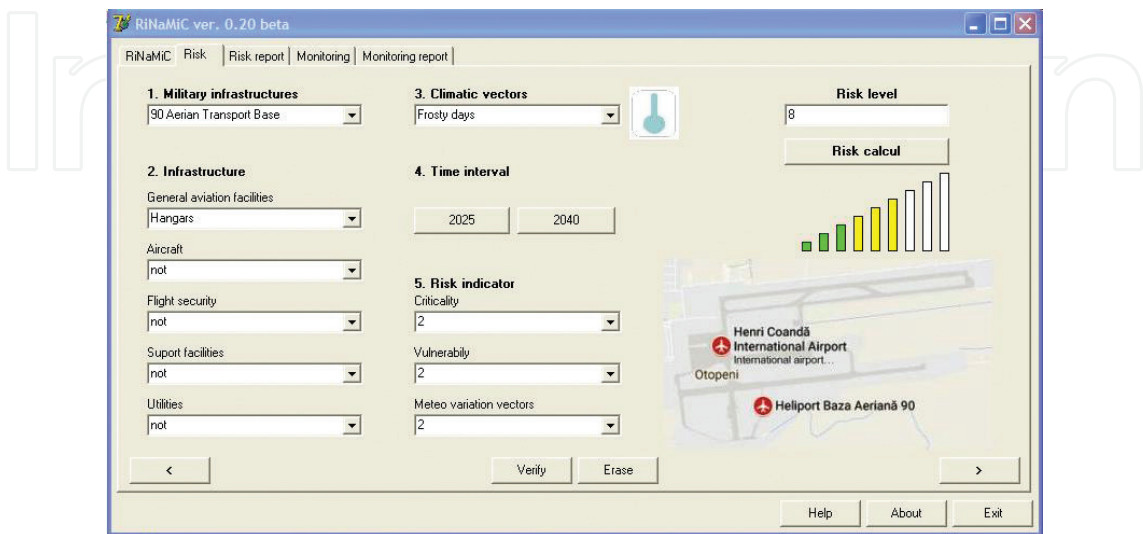


Figure 4. Definition of risk indices.

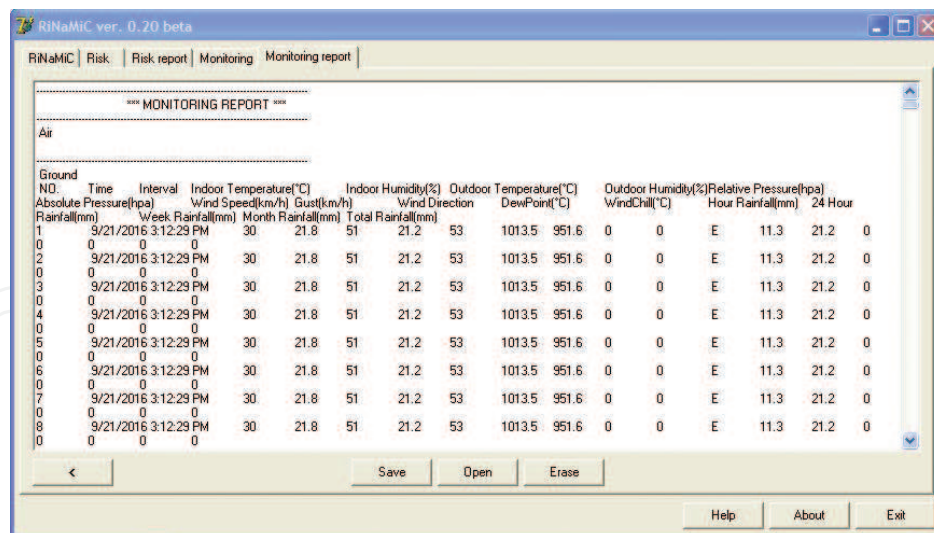


Figure 5. Display air monitoring report.

vector in the next 10 or 25 years; the projected climate change for the next 10 and 25 years; the level of uncertainty reported for each climatic vector; communicating best practices identified at regional level to and from other military objectives.

5. Conclusions

The impact created by such a scientific approach beyond the benefits of active innovation-based learning can also be assessed in potentially applicative terms: increasing the resilience of critical military infrastructures to natural events with catastrophic effects in the context of climate change. Future research directions include the removal of the current limitations of this innovative solution: it is necessary to improve the databases on infrastructure assets, the potential impact of the climatic vectors and the adaptation strategies; the application does not evaluate the cumulative effects of multiple vectors; data recorded by sensors integrated in aerial vectors are not available in real time.

The impact of this scientific approach is found in four main directions: increasing the capacity to understand the dynamics of natural risks from climate change and its impact on infrastructure assets/specific operations in the Romanian Air Force infrastructures; assessing the effectiveness of current plans in the context of future needs; optimizing the allocation of resources needed to initiate the climate change adaptation planning process; and increasing the resilience of critical military infrastructures in the Air Force to natural events with catastrophic effects in the context of climate change.

The solution can also significantly improve the planning process at the level of each military objective, which is currently taking place within an adaptive-reactive management. Existing planning documents do not provide opportunities to incorporate adaptation strategies to climate change in the short, medium, and long term. These documents are drawn up in the form of action orders whose triggering factor is the occurrence of an event or alerts issued by the NMA.

From the point of view of adaptive-preventive management, it is necessary to develop Climate Change Adaptation Plans (PASCs) at the level of each critical military infrastructure. The military objectives that have been endowed or are in the process of endowment with modern military technique represent an emergency. This process involves the initiation of some infrastructure projects.

This risk management approach in critical military infrastructures also has a number of limitations that constitute future research directions: for transformation into a functional model, it is necessary to improve the built databases on infrastructure assets, the potential impact of climatic vectors and adaptation strategies; information is not exhaustive, for special situations (e.g., hangars design) further studies and analysis are required; the model does not assess the cumulative effects of several vectors on the same infrastructure or specific operation; data recorded by weather sensors integrated into the air vector (temperature, humidity, flammable gas) should be available in real time also to the institutions with responsibilities in emergency management.

Acknowledgements

This research was supported by the Romanian National Authority for Scientific Research CNCSUEFISCDI in MAPIAM project “Modular Aircraft Platform for Intelligent Atmospheric Monitoring,” Program 2—Increasing the Competitiveness of the Romanian Economy through Research, Development and Innovation, Domain 3—Energy, Environment and Climate Change. We are thankful to our colleague Sebastian Pop who provided expertise that greatly assisted the research in the field of aerial vector operation.

Author details

Catalin Cioaca*, Vasile Prisacariu and Mircea Boscoianu

*Address all correspondence to: catalin.cioaca@afahc.ro

“Henri Coanda” Air Force Academy, Brasov, Romania

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