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Anti-Hail Protection—Assessment of Financial Effects on the Territory of Belgrade

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Abstract: The aim of this work is to assess damage to the City of Belgrade caused by the unfavorable weather condition of hail due to the absence of anti-hail defense of the city, and to argumentatively point out the necessity of introducing new technical-technological systems for preventing the effects of adverse weather conditions. The results are based on the direct correlation-analyses of two real unfavorable weather events and the estimated financial damage caused by these events. The overall calculation also takes into account financial investments (new financial model) necessary to establish two essentially different systems for anti-hail protection. The damage caused by the hail on the territory of the City of Belgrade and the financial investment in anti-hail protection to reduce it are empirically established for the first time. It is shown how the damage could be transformed to profit, as the financial investment in anti-hail protection is lower than the damage that hail can cause.

Keywords: agriculture; antihail suppression; Belgrade-Serbia; financial effects

1. Introduction

The discovery of some specific physicochemical properties of silver iodide (AgI) in the fifties and sixties of the previous century triggered an immediate widespread commercial application of AgI in suppressing hail in countries of the former Soviet Union [1,2], Switzerland [3] and northeastern Colorado [4]. A number of research, commercial, and mixed-character projects were carried out [5]. In all of these cases, AgI was used as a chemical agent. Different cloud-seeding concepts were applied in the projects: missiles, generators, and planes. They were conducted in independent territories, located far away one from another, and located on several continents (South America, Asia, North America, Europe). The effects were very different, even in the implementation of the same project, using the same technique, and using the same amount of AgI [4].

A serious disadvantage in the assessment of efficiency of these projects was the inclusion of subjective factors, since the assessment was based on the personal opinion of the creators, implementers, and evaluators of individual projects, leading to an unsuccessful set of evaluation criteria of the projects. Regardless of the observed shortcomings in evaluating the results of the project cycles, the recorded achievements are of paramount importance for further setting up and project management. Data collected by the Institute of Atmospheric Sciences following the implementation of eight projects between 1965 and 1970 represent a significant contribution to information on hail suppression, comparing the effect on seeded clouds with effects on unseeded clouds [6]. In all cases, as expected, cloud-seeding resulted in a decrease in hail precipitation. An especially significant achievement of these projects was the establishment of an objective set of criteria for assessing the efficiency of the operation. Intensity of hail precipitation was measured using hailpads.

Rocket anti-hail protection of the territory of the Republic of Serbia was established in the 1960s using a Soviet methodology (Northern Caucasus) [7,8]. In the last century, this kind of anti-hail protection was very much advanced but, over the time, this system has become obsolete in a technical-technological sense. Additionally, due to the proximity of the international airport "Nikola Tesla" and a large number of smaller airports in the vicinity (according to the data of the flight control agency, Belgrade had 476,156 flights in 2010), the rocket-based anti-hail protection cannot be utilized anymore [9].

The City of Belgrade and the rest of the territory of Serbia are not equipped with any instrumental means for the objective measurement of the effects of adverse weather conditions, although some other countries apply such measurements (Karlsruhe [10]). Furthermore, according to the annual reports of the Hydro-Meteorological Service of Serbia (RHMZ), in the city of Belgrade, there are 30–60 hail days per year when rocket-based anti-hail protection is applied [11]. Unfortunately, neither official authorities nor insurance companies have a more precise assessment of the induced damages. All previous assessments of the damage were based on an individual–subjective perception of the assessors. The assessments are summarized–synergetic effects of various adverse weather conditions. To establish a new technological system for protection from hail, fog, and other adverse weather conditions, it is necessary to establish a more precise assessment method of the damage that the territory of Belgrade suffers [12]. The current situation points to a need to assess the effects of financial investments in new efficient protection systems. In this study, we observe and analyze two key variables of the financial model: assessing the damage, and investing in an efficient profitable prevention system.

2. Materials and Methods

The City of Belgrade, as an administrative territory (44.1°–44.6° N latitude and 19.9°–20.8° E longitude), is situated at the confluence of two large rivers (length of the river bank is approximately 200 km): the Sava, and the Danube. The City is bordered by the Pannonian plain on three sides, and on the south by the two mountains: Kosmaj (628 m), and Avala (511 m) (Figure 1). It covers 3224 km^2—3.65%—of the territory of the Republic of Serbia, and it contributes around 23% of the total population of Serbia [13] and incorporates around 31.2% of employees in Serbia.

The financial model applied is based on two hail weather events objectively registered by Hydro-Meteorological Service of Serbia (RHMZ), on 24 May and 11 June 2012. Special attention is given to an objective determination of the area of the City of Belgrade affected by these unfavorable weather conditions, and a specific method of calculation that refers only to agricultural areas is applied. The calculations are based on an objectively determined amount of funds invested in the production and the estimated profit which is overall 1000.00 EUR per hectare of agricultural land. Such an assessment is the only possible objective assessment of the loss.

The financial model is complex, imposed by the field of the research. It includes calculations in real and standard costs using multiple costing methods for the same type of cost. Consistency of calculations is achieved by analyzing all involved inputs in processes and production. Revenues are determined using average selling prices for all types of outputs. These prices exclude income variability and show an objective financial result. The calculation is based on real conditions for obtaining results by eliminating the occurrence of an ex-profit or loss in the calculation.

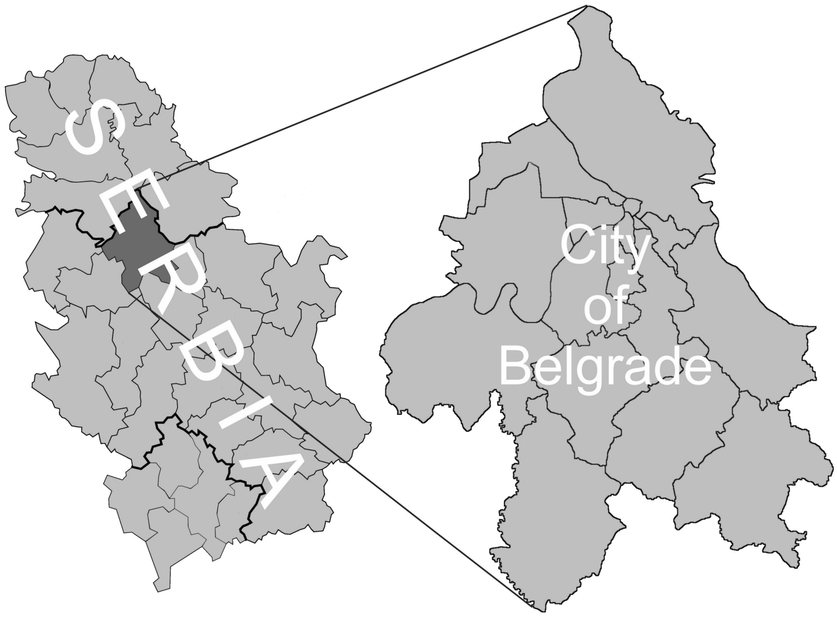

Figure 1. Geographical position of the City of Belgrade in the Republic of Serbia.

The established financial model involves a total investment, with all the elements necessary to establish essentially two different technical-technological anti-hail protection systems. The model is entirely in accordance with positive practice in the world [14,15].

The four proposed defense systems are as follows: (1) Ground–based ice nuclei aggregates [16,17]; (2) Turbojet ground aggregates (CCN—cloud condensation nuclei, IN—ice nuclei) (this is a modification of protection system (1) proposed in [12]); (3) Turbojet aviation (G-2, G-4, J-22) (IN) based on available military turbojet airplanes in Serbia [1,2,4]; and (4) Piston aviation (Dromader), same as (3), but based on agricultural aviation activity.

To define the structure of optimal elements for each of the proposed protection systems (Table 1), positive global experience was taken into account: applied technology, operational organization, and procedures for protection implementation. The elements mentioned above are subject to testing in order to determine the choice of an efficient and useful system of protection against weather disasters. The testing procedure was carried out firstly on the basis of efficiency and already accepted research results applicable to the same or similar technical and technological models under similar operational conditions [18–25]. The established financial models have been tested, taking into account the correction of the achieved results by the estimated degree of model efficiency [14]. The efficiency of the model and the economic benefit were obtained by simulation of recorded real events.

The economic benefit was calculated by a comparison of the financial means necessary for the establishment of a new protection system, and by considering the amounts of water that would be produced if hail was transformed into rainfall (Table 1).

Table 1. The standard protection investment calculations for the municipalities Grocka, Mladenovac, and Palilula on 11 June 2012.

Technical-Technological Defense System	(1) Ground–Based Ice Nuclei Aggregates	(2) Turbojet Ground Aggregates (CCN, IN)	(3) Turbojet Aviation (G-2, G-4, J-22) (IN)	(4) Piston Aviation (Dromader)
Method	Anelfa	Anelfa	WMO	WMO
Necessary number of devices	17	6	4	6
Capacity	200 g/h	5–10 kg/s	10–1000 g/s	20–100 g/s
Total operating time (h)	6	2	1-2	4
The total quantity of the agents (kg)	20	7000	320	15
Price per agent unit	1200 EUR/kg	300 EUR/t	100 EUR/kg	100 EUR/kom
Activity cost per day (EUR)	24,000.00	12,600.00	32,000.00	18,000.00
Fuel and other costs	-	8 t × 0.8 EUR/kg	2000 EUR/h per aircraft	500 EUR/h per aircraft
Total reagents, fuel, etc. per day in EUR	24,000.00	6400.00	8000.00	30,000.00
Overall material costs per day in EUR	24,000.00	19,000.00	40,000.00	30,000.00
Gross earnings of employees in EUR	42,299.00	125,893.00	139,979.00	139,979.00
Gross earnings per day in EUR	115.88	347.65	383.50	383.50
Average number of engagement days	23	23	23	23
Total variable costs per day in EUR	24,115.88	19,347.65	40,383.50	30,383.50
Maintenance costs and depreciation per day in EUR	140.00	493.00	-	-
The cost of the satellite data in EUR	685.00	685.00	685.00	685.00
Cost of insurance in EUR	13.69	15.07	-	-
The overall cost of operation in EUR per day	178.10	219.17	178.10	191.78
Total cost of activity per day in EUR	25,006.67	20,759.89	41,246.60	31,260.28
The disaster reduction effect in%	30-40	80-90	50-60	40-50
Daily prevented economic losses on the total activity area	350,000.00	850,000.00	550,000.00	450,000.00

3. Results and Discussion

The financial model simulates the effect registered by radar center Bukulja on 24 May 2012 (which covers city municipalities Grocka, Mladenovac and Palilula with total area of 168,000 ha) and on 11 June 2012 (which covers city municipalities Surčin, Obrenovac and Lazarevac with total area of 760,000 ha).

Research implies observation of the effects with the same criteria and units in both of the mentioned cases. The task required that each protection model be utilized only once per day, and that all costs incurred at the annual level be adjusted to cost per day. Variable costs are the concrete costs of used raw materials and deployed personnel and property (equipment, means of transportation, aircrafts; Tables 1–3).

The applied systems (1–4, Tables 1–3) show the possibility of effectiveness as a scale from 30 to 90%, and therefore give potential damage risk reduction on the same scale. Protection system 2 (turbo jet ground aggregates [18]), also ensures transformation of potential hail to rainfall (expected water production of 170 t/ha which, reduced by 10%, amounts to 487,210.00 EUR). The produced water offers multiple benefits: avoiding damage to property and crops by preventing hail, increasing humidity of soil, and causing extended useful effects for production of many types of agricultural plants due to an increase of hydrological capacity of the area. The financial effect of all prevented losses is much higher than the amounts of projected funds for the anti-hail protection system per day. Analysis of the prevented daily losses (Table 1) shows by how much a protection system can reduce losses. The degree of efficiency is calculated as an average of the interval and amounts to 35% for all protection systems.

Table 2. Shorter form of standard calculations of investment in protection from natural disasters on agricultural area of municipalities of Grocka, Mladenovac, and Palilula on 24 May 2012.

Technical-Technological Defense System	(1) Ground–Based Ice Nuclei Aggregates	(2) Turbojet Ground Aggregates (CCN, IN)	(3) Turbojet Aviation (G-2, G-4, J-22) (IN)	(4) Piston Aviation (Dromader)
Total variable costs per day in EUR	24,828.57	20,540.72	41,068.50	31,068.50
Overhead functioning costs in EUR per day	178.10	219.17	178.10	191.78
Total activity costs per day in EUR	25,006.67	20,759.89	41,246.60	31,260.28
The disaster reduction effect in %	30–40	80–90	50–60	40–50
Disaster reduction effect for average number of days in EUR	54,775.00	252,756.00	132,189.00	181,195.00

Table 3. Standard calculations of investment in the protection against natural disasters in the agricultural areas of municipalities of Surčin, Obrenovac, and Lazarevac on 11 June 2012.

Technical-Technological Defense System	(1) Ground–Based Ice Nuclei Aggregates	(2) Turbojet Ground Aggregates (CCN, IN)	(3) Turbojet Aviation (G-2, G-4, J-22) (IN)	(4) Piston Aviation (Dromader)
Total variable costs per day in EUR	24,828.57	20,540.72	41,068.50	31,068.50
Overhead functioning costs in EUR per day	178.10	219.17	178.10	191.78
Total activity costs per day in EUR	25,006.67	20,759.89	41,246.60	31,260.28
The disaster reduction effect in%	30–40	80–90	50–60	40–50
Disaster reduction effect for average number of days in EUR	54,775.00	252,756.00	132,189.00	181,195.00

Protection system efficiency testing also includes the ratio between costs of application and prevented financial losses for every established financial model. The ratio of prevented losses and invested funds greater than 40:1 (850,000.00:20,759.89 = 40.94; Table 1) emphasizes the second proposed protection system as the optimal one. Furthermore, produced rainfall increases the financial benefit by 487,210.00 EUR (Table 1, column three), which additionally increases the initially calculated ratio mentioned above. Loss prevention by implementation of the first, third, and fourth protection system is significant, but it is not as efficient as the second system; an additional benefit of the second proposed system is significant rainfall production.

The shorter version of the new financial model from Table 1, applied only to agricultural area of 78,995 ha, is shown in Table 2.

Analysis of the obtained results (Table 2) leads to the conclusion that there is a significant difference between the studied systems with respect to natural disaster impact reduction effects. The second proposed system achieves the highest level of preservation of investments, even though it does not include produced rainfall in the calculation (which is significant for this system). The amount of saving is the value of decreased or avoided financial losses that are converted to economic benefit by single application of any of proposed technical-technological protection systems per day. For the second system, it amounts to 252,756.00 EUR. The value derived from rainfall production, which amounts to 226,483.00 EUR (expected rainfall production of 170 t/ha, which, reduced by 10%, amounts to 226,483.00 EUR), has to be added. The total value of the prevented damages and achieved benefits after this correction is 479,230.00 EUR. The order of efficiency for the other systems is the same as in the previous simulation and decreases in sequence: turbojet aviation (G-2, G-4, J-22); piston engine aviation (Dromader); ground aggregates (acetone solution, IN).

The same financial model and same research and damage evaluation criteria are applied for an event that occurred on 11 June 2012. The results related only to the agricultural area are shown in Table 3. The same requirement of material–formal continuity of methods and comparability of anticipated results, as in previous event (24 May 2012), was followed.

The previous simulation analysis results show that the second technical-technological system again shows the best effects (Table 3). An estimated rainfall output with application of this system amounts to around 210,711.00 EUR per day. The remaining three systems show weaker effects, but among them, the third system is the most effective.

Results obtained by application of the new financial model confirm that the second and third anti-hail technical-technological defense systems—turbojet ground aggregates (CCN, IN) and turbojet aviation (G-2, G-4, J-22)—provide the most effective protection and the greatest economic benefits.

4. Conclusions

Potential application of four different technical-technological systems of protection from damage caused by unfavorable weather conditions was economically tested through a new original financial model. The model offers the possibility of comparing financial effects of different protection systems, pointing to the possible profit and unfavorable weather conditions (primarily hail) damage reduction. A direct correlation is performed using the data registered by RHMZ on the occasion of two selected events during which the territory of the City of Belgrade was hit by hail, with special emphasis on agricultural areas affected by hail.

The financial model presented in this paper arguably suggests that the application of either any one of the proposed technical-technological systems or their combination could result in significant economic profit. Technical-technological systems 2 and 3 give the best results, and system 2 (turbojet ground aggregates) is the most effective, since, in addition to protection, it simultaneously improves the overall hydrological situation of the protected area.

In order to establish a more precise efficiency assessment of the proposed models of protection, it is necessary to introduce objective instrumental damage recording.

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Conflicts of Interest: The authors declare no conflict of interest.

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