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Article

Influence of Weights of Geographical Factors on the Results of Multicriteria Analysis in Solving Spatial Analyses

Šárka Hošková-Mayerová [1,*], Václav Talhofer [2], Pavel Otřísal [3] and Marian Rybanský [2]

[1] Department of Mathematics and Physics, University of Defence in Brno, Kounicova 65, 662-10 Brno, Czech Republic
[2] Department of Military Geography and Meteorology, University of Defence in Brno, Kounicova 65, 662-10 Brno, Czech Republic; vaclav.talhofer@unob.cz (V.T.); marian.rybansky@unob.cz (M.R.)
[3] Faculty of Physical Culture, Palacký University Olomouc, Třída Míru 117, 771-11 Olomouc, Czech Republic; pavel.otrisal@upol.cz
* Correspondence: sarka.mayerova@unob.cz; Tel.: +420-973-442-225

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Abstract: The main topic of the article is the use of multicriteria analysis in assessing the impact of the geographical environment on rescue and military activities. The evaluation is based on digital geographical data, and the influences of individual geographical factors are determined by spatial analyses. The essence of the article lies in the design of a methodical procedure for determining the weights of individual criteria and in the construction of a suitable resulting user function (utility value function) in a geographic information system environment with regard to the solved problem and in the verification of the proposed procedure. Using sensitivity analysis, the dominance of individual factors is determined, and the influence of the changes in the weights of the criteria on the overall results of the analysis is assessed. Detailed studies of the differences in the results of solving the same analytical problem with changed weights of individual criteria are performed, and these studies are documented on a model example. Based on verification tests performed both in office conditions and directly at selected locations, "optimized procedures" are recommended for assessing the potential of the geographical environment for the operation of rescue or military units in field conditions. Finally, the possibilities of further development of the model solution and its implementation into control systems are presented.

Keywords: multicriteria analysis; geographic information system; decision-making processes; geographical support; command and control systems

1. Introduction

A frequent task in dealing with operations in the landscape is to assess the impact of the geographical environment on the activities of the intervening forces. The geographical environment can accelerate or delay the start time of the intervention (rescue or combat activities) and its total time and thus affect the overall operational efficiency. In the extreme case, geographical conditions can also cause a professional task not to be fulfilled, which in many cases can be associated with a threat to both the intervening forces and the civilian population.

In [1], the authors addressed the basic approach to the geographical support of command and control systems based on the example of the analysis of suitable areas for the location of a mobile workplace. Its main objective was to point to the issue of the use of digital geographic data (DGD) in solving analytical tasks with the application of multicriteria analysis, especially when intervention in a large, previously unknown and unexplored area is necessary. Such an intervention may be, for example, the decontamination of the civilian population after the use of weapons of mass destruction or as a result of industrial hazardous substance release following an industrial infrastructure facility accident [2–6]. One of the important documents that the commander must receive is the evaluation of the influence of the geographical environment on the specific activity that must be performed as part of the decontamination intervention. The method of multicriteria analysis was used in the analysis of the influence of the geographical environment. The complete evaluation process corresponded to the Standing Operating Procedures (SOPs) used in the interventions of chemical units of the Army of the Czech Republic (ACR) and the Fire Rescue Service [7,8]. The results of the solution were verified mainly using orthogonalized aerial photographs, but their verification in the field did not take place.

In accordance with the conclusions of the mentioned article, the authors further specified and elaborated a previously proposed way of solving a spatial task. In particular, several more methods were used to determine the weights of individual criteria that affect the final analysis. Furthermore, a sensitivity analysis was performed, as well as a detailed assessment of changes in the results of spatial analysis in relation to the method used to determine the weights of individual factors, and, finally, a thorough verification of the results obtained in the field was performed. The main goal was to analyze the geographical factors that affect the location and operation of the decontamination site (DS). The secondary goal of the task was to assess the influence of the method of determining the weights of individual criteria on the results of the whole analysis.

The specific goal of the spatial analysis solution remained the same, i.e., to design and verify a method of selecting suitable locations for the development of workplaces for the decontamination of inhabitants and equipment after its impact with weapons of mass destruction or after a large-scale chemical accident, i.e., to select suitable places and areas for the decontamination of people, equipment and material. At the request of the experts who participated in the evaluation of the results of the previous analysis, the location in which the follow-up work took place was also changed. The location was changed mainly due to greater fragmentation of the terrain and to include a greater diversity of geographical objects.

The guaranteed geographical data of the Army of the Czech Republic (ACR) and the Czech State Administration of Land Surveying and Cadastre (CSALSC) were again used for the analysis. The method of multicriteria analysis (MCA) was used as a basic mathematical apparatus. Within the MCA application, multiple variants of determining the weights of criteria and compiling a user aggregation function were tested. The results of spatial analysis variants were verified in the field on areas that were selected as suitable for the location of the workplace.

The MCA methodology for certainty was used for the whole solution [9–11]. The reason for using this approach was the relative invariability of the DGD due to the duration of the decision-making process on the construction of the DS and due to the fact that meteorological conditions have not yet been considered in the solved task.

2. Model Situation

The model situation describes a case when a chemical substance leaked into the environment in a given location [12,13]. A toxic substance that requires the use of individual protective equipment before initiating the decontamination process has been considered. The aim of the analysis was to find suitable places for building a DS according to the following conditions:

- slope inclination up to 5°,
- long-term soil resistance for the movement of special chemical vehicles,
- as close as possible to paved roads and with suitable access and departure roads,
- should be outside the woods,
- as close as possible to water sources and abundant water source,
- due to the possible contamination of unaffected population, the DS should be outside of populated areas,

- continuous area of approximately 2.5 km^2.

The model area of interest (AOI) with a size of 20 × 20 km in the area northeast of Brno was chosen for the model situation (Figure 1).

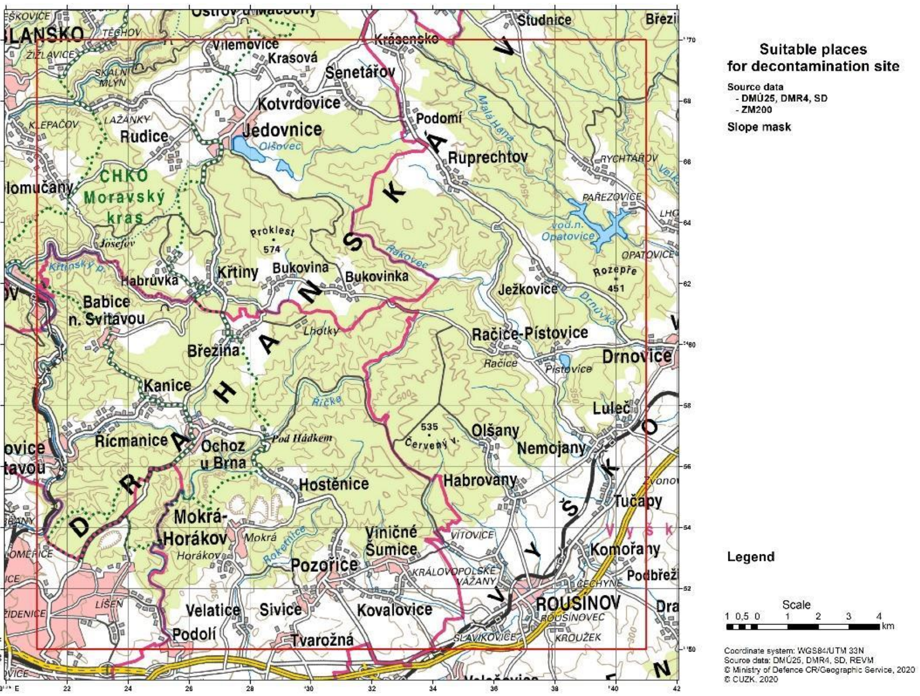


Figure 1. Area of responsibility for the analysis of the possibility of decontamination site (DS) deployment.

The geographical problem was to select suitable locations in the given area, where it would be possible to place the decontamination site so that this site was functional in the given area and the terrain configuration did not limit it or only limited it to a reasonable extent [8,14–18].

The deployment of a large DS for the solution of large-scale accidents is regularly practiced in the Czech Republic in cooperation with the Fire and Rescue Service and chemical units of the ACR. Due to the space requirements, two sufficiently large localities were selected in the Czech Republic, which were used for these exercises. These locations were in military training areas. From the experience of experts with these exercises, the mentioned SOPs were elaborated, which we used.

The aim of our work was to propose a procedure by which to use geographic data to identify other localities that would be suitable but where it is impossible to perform exercises of such a large scale due to the use of the landscape.

3. Methodology

3.1. Determination of Weights of Factors

As already mentioned in the general introduction, examining the sensitivity of the preferential order of variants to determine the importance of individual criteria falls within the field of experimentation on models where multicriteria evaluation of variants is performed with changing criteria weights. In order to demonstrate the sensitivity of the solution to the choice of priorities of individual factors, the weights of individual criteria were determined by several different methods on the basis of consultations with specialists dealing with the theory of decontamination. The first method was a direct determination of the weights of the criteria on the basis of an expert estimate of the addressed specialists, in two independent groups. The first group was composed exclusively of professionals dealing with the issue of decontamination in practice—i.e., they actually addressed this issue at the scene of the intervention (hereinafter referred to as Experts). The second group was composed of academic staff dealing with this issue from a scientific point of view (hereinafter referred to as Theorists). Due to deepening drought in the last decade and the lack of natural water in the landscape, another variant was developed by the Theorists group, in which this water deficit was taken into account by assigning a higher weight to abundant water resources (Var. 3).

Both groups then completed a questionnaire, which was not divided into groups, processed by the pairwise comparison method (Pairs), Metfessel allocation method (MES) and Saaty method (Saaty) [19,20].

Due to the narrowly specialized problematics and the therefore limited number of specialists working in this area in the Czech Republic, it was not possible to use large groups for the research. The "Experts" group had 11 members, the "Theorists" group 9 members. The lower number of completed questionnaires is thus a disadvantage of this study; however, on the other hand, the composition of both groups was such that it provided a guarantee of honest and true completion of the questionnaire, thus obtaining relevant values from all respondents.

3.2. Mathematical Methods Used for Determining the Weights of Factors

Method of pairwise comparison of criteria—criteria weights were derived from a preferential relation expertly defined for a given set of criteria. If we do not assume the possibility of equally evaluated criteria, we start from the incidence matrix of the relation of sharp preference P defined on the set of criteria K, for the elements of which the following applies:

$p_{j,k} = 1 \ldots$ if the j-th criterion is more significant than the k-th criterion.
$p_{j,k} = 0 \ldots$ if that is not the case.

The significance of the j-th criterion, its non-standardized weight w_j, is then derived from the number of criteria over which the criterion is preferred and calculated from the following formula:

$$w_j = \sum_{k=1}^{m} p_{j,k} + 1 \tag{1}$$

Addition of 1 for each weight prevents the least significant criterion from being given a zero weight.

Determining the importance of criteria using the Metfessel allocation—each evaluator has 100 points; these points are assigned to individual criteria according to the importance of the criterion. The sum of values from one evaluator must be equal to 100. Zero numbers of points are also written. The importance of the criteria is determined based on the average value of the given evaluations from all evaluators.

Saaty's method is a method of quantitative pairwise comparison which takes place in two steps. In the first step, the preferential relationships of criterion pairs are determined and introduced into the so-called Saaty's matrix $S\left(s_{ij}\right)$ (i-th row, j-th column), which, in contrast to the pairwise comparison method, determines the size of this preference in addition to the direction of preference of criterion pairs, which is expressed by a certain number of points from the selected point scale [20]. The second step is to determine the scales themselves, which are based on the knowledge of the matrix S. The individual scales can be obtained under the conditions $\sum_i^n v_i = 1$ as follows:

$$v_i = \frac{\left[\prod_j^n s_{i,j}\right]^{\frac{1}{n}}}{\sum_i^n \left[\prod_j^n s_{i,j}\right]^{\frac{1}{n}}} \tag{2}$$

3.3. Input Data and Their Processing

For the model example, DMÚ25 [21], height model DMR4 [22] and Thematic Soil Database (TSD) [23] were used as a position model. All analyses were performed using the ArcGIS 10.4.1

software system [24], including extension modules. The geodetic reference system WGS84 and the UTM projection in the 33rd zone were chosen for all calculations. When working with raster files, a pixel size of 10 m was used [25].

The first step of the analysis was the selection of suitable tools for partial analyses of the effects of individual factors and for evaluating the overall influence of all factors [26]. Furthermore, the classification of the obtained information was solved so that it was possible to classify this information in a uniform assessment scale. The procedures for evaluating the influence of individual factors were the same as in [1], with the exception of the terrain relief factor, which had to be specified.

The chosen default height model for the evaluation of the relief factor was DMR4, which is a raster model with a pixel size of 5 × 5 m [22]. The Slope tool was used to calculate the inclinations of slopes. The raster file of slope inclinations, in which a slope inclination is expressed as the value of the given pixel, was obtained by the calculation. The obtained inclinations of slopes were classified on a continuous scale in values 0°; 72.23°. For use in MCA, it was necessary to reclassify them according to the selected ten-point scale, with the proviso that it was necessary to respect the limiting condition of the maximum possible slope inclination up to 5°. In contrast to the previous solution, the following scale was used for this reclassification by manual scaling (Table 1).

Table 1. Reclassification degrees of suitability for inclinations of slopes.

Slope Inclination (°)	Degree of Suitability
0–1.00	10
1.01–2.00	9
2.01–3.00	8
3.01–4.00	7
4.01–5.00	6
>5.00	0

Therefore, in places where the slope inclination exceeds the required maximum value of 5°, it is necessary to ensure that all the effects of the remaining assessed factors will have zero values. To ensure the aforementioned process, a slope inclination mask was created, in which the inclinations of slopes up to and including 5° are classified by the value 10 and other inclinations by the value 0. The mask and the result of reclassification are shown in the figure below (Figures 2 and 3).

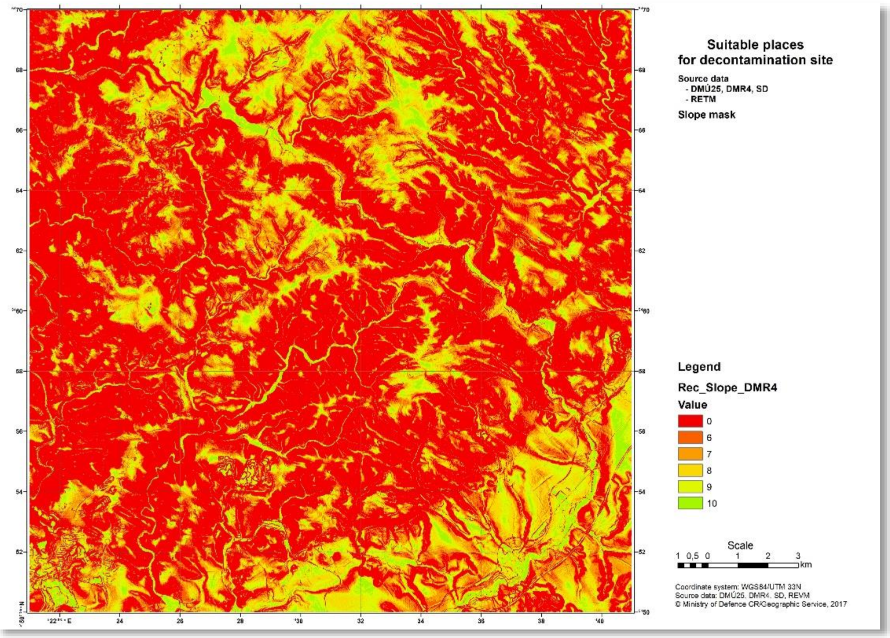


Figure 2. Raster file of reclassified slope inclinations.

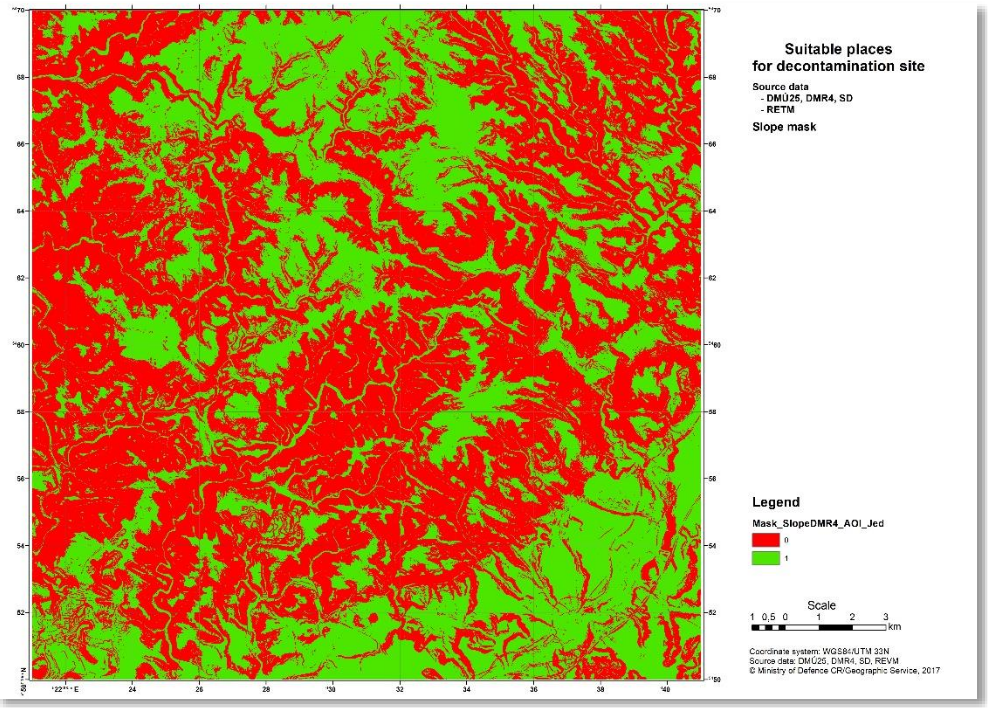


Figure 3. Raster file of slope inclination mask.

3.4. Analysis of Suitable Locations for the Deployment of the Decontamination Workplace

Reclassified files of the influence of individual factors express the degree of suitability for DS deployment. This rate was expressed in accordance with the principles of MCA in a uniform maximization assessment scale 1–10. The individual pixels then have the same effect on the result and differ only internally in their value.

According to the general theory of MCA, the individual evaluation criteria have different importance (weights) and are combined with each other according to different relationships expressed by the aggregation function. Two basic tools are used for the MCA application in the GIS environment—Weighted Overlay and Fuzzy Overlay. The result of both tools is a raster file, the so-called cost map, which is created by the required combination of reclassified input files. However, the MCA process itself is already predetermined by the specified input parameters of the calculation. If none of the tools meet the specified MCA conditions, it is possible to use the Map Algebra tool for calculating the cost map. This tool can be used to individually control the actual overlay of the individual layers.

The key point of the whole process in the proposed methodology was the calculation of the cost map with the pixel value PV, which is the degree of suitability for the deployment of DS in a given pixel. The cost map had to be calculated by a suitable aggregation function, the shape of which, due to the condition of the prohibition of places with a slope inclination greater than 5°, was determined as follows:

$$PV = \begin{cases} 0, & \propto > 5^\circ \\ \sum\limits_{i=1}^{6} w_i k_i, & \propto \leq 5^\circ \end{cases} \tag{3}$$

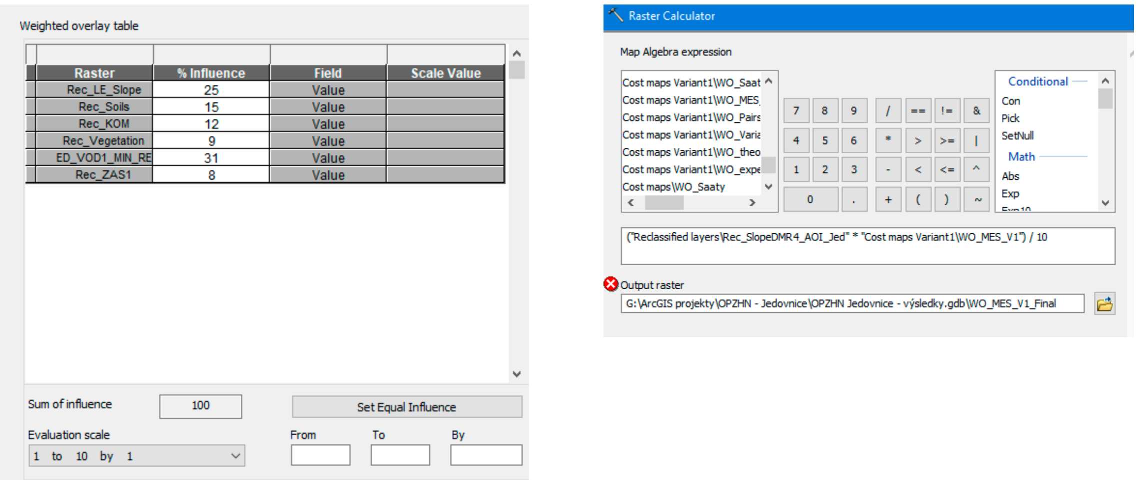
where

α is the slope inclination,
w_i is the weight of the i-th criterion,
k_i is the value of the i-th criterion.

The calculation itself then took place in two phases. In the first phase, the value of PV_{pom} pixels was calculated according to the following expression:

$$PV_{pom} = \sum_{i=1}^{6} w_i k_i \tag{4}$$

The Weighted Overlay tool was used for the calculation. The weights of individual factors were entered into the summary table (Figure 4 on the left) according to the results of individual MCA variants (Table 2).



(**a**)

Weighted overlay table

Raster	% Influence	Field	Scale Value
Rec_LE_Slope	25	Value	
Rec_Soils	15	Value	
Rec_KOM	12	Value	
Rec_Vegetation	9	Value	
ED_VOD1_MIN_RE	31	Value	
Rec_ZAS1	8	Value	

Sum of influence: 100

Evaluation scale: 1 to 10 by 1

(**b**)

Raster Calculator

Map Algebra expression

("Reclassified layers\Rec_SlopeDMR4_AOI_Jed" * "Cost maps Variant1\WO_MES_V1") / 10

Output raster: G:\ArcGIS projekty\OPZHN - Jedovnice\OPZHN Jedovnice - výsledky.gdb\WO_MES_V1_Final

Figure 4. Example of setting the weight values of individual input files for the Weighted Overlay tool (**a**) and the Raster Calculator for calculating the mask of slope inclinations over 5° (**b**).

The result was a cost map where, however, there were non-zero values of suitability even in places with a slope inclination greater than 5°. The second step, therefore, was to set the total suitability value for these places to zero. Although the Weighted Overlay tool with the Restricted Option can be used for this operation, there is no guarantee of correct calculation due to the possibility of the occurrence of pixels with a value of NoData. Therefore, the path of masking places with an inclination greater than 5° was chosen using a set of mask inclinations (Figure 3) and subsequent calculation using Map Algebra (Figure 4b).

The result of the whole process was the aforementioned cost map, which presents the potential of the landscape for the deployment of the decontamination workplace location (Figures 5 and 6). This analysis will give the intervention commander information about the possibilities of DS deployment. The commander therefore has the opportunity to choose the most suitable places with regard to the overall situation. However, the specification of a specific site always requires control at selected sites by chemical reconnaissance units.

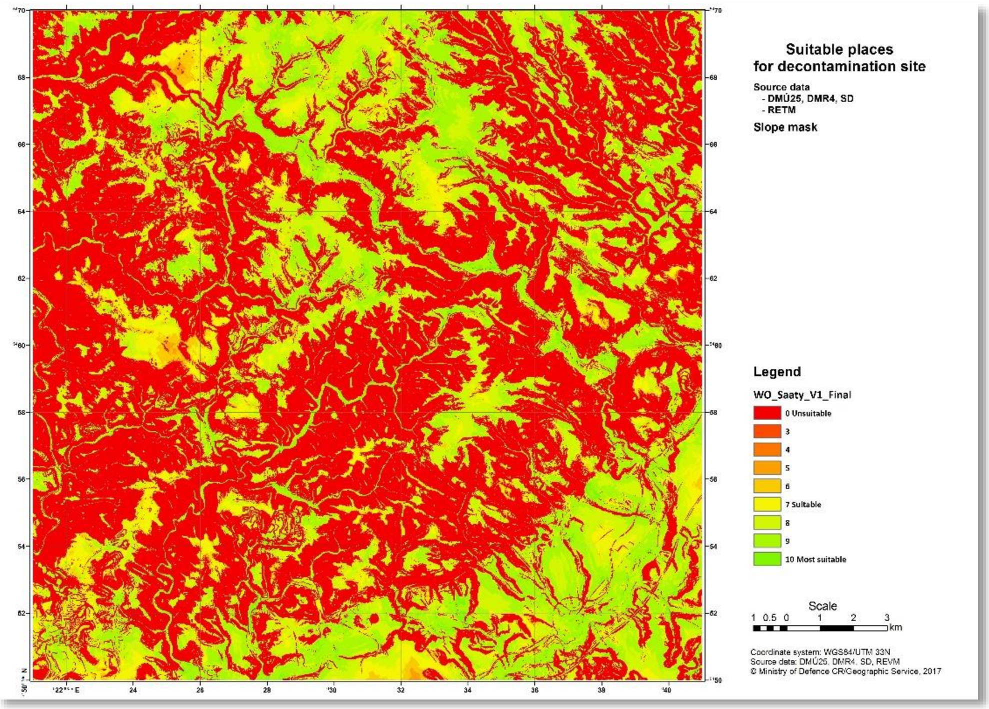


Figure 5. Final cost map of landscape potential for DS deployment.

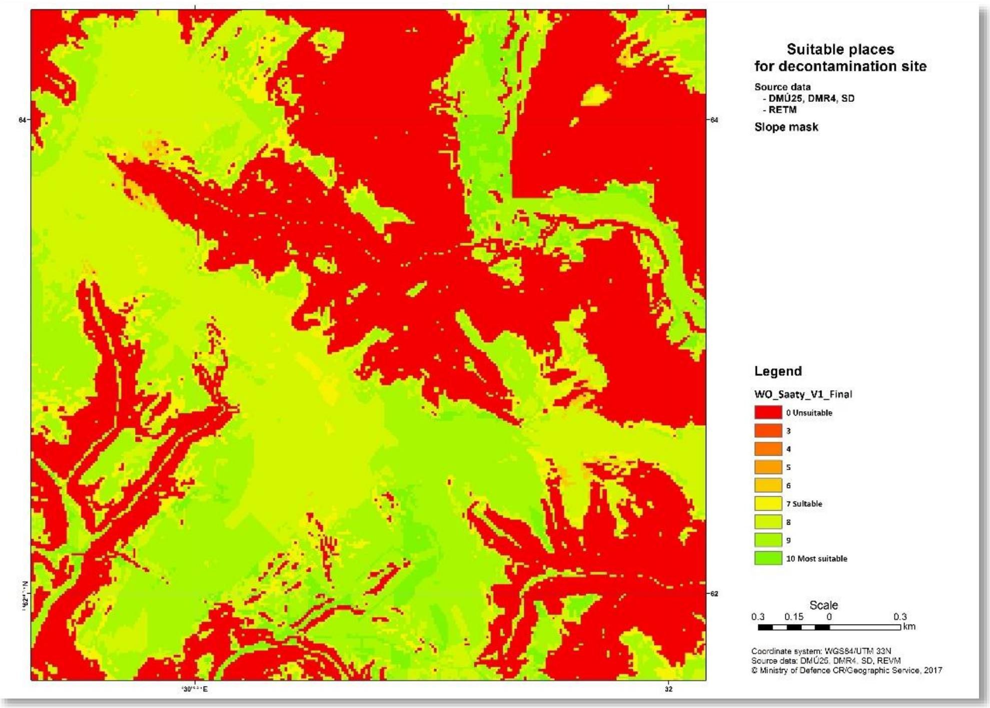


Figure 6. Final cost map of landscape potential for DS deployment in detail.

When looking at the final analysis in detail, it is clear that the selected areas do not fully meet all the initial requirements, which is due to both the properties of the MCA itself and the quality of the input geographic data and methods of their reclassification.

When using background data with the same quality, the method used by the MCA itself has a decisive influence on the result of the analysis. It is therefore necessary to assess how both the method of obtaining background data for determining the weights of individual factors and subsequently the method of determining the weights of the evaluation criteria affected the achieved results.

4. Obtained Results

As part of the solution of the model example, conformity tests were performed—or, rather, discrepancy tests in the MCA results—using different methods of determining the weights of the factors. In [1], the individual factors influencing the possibilities of DS deployment and the criteria by which the influence of the mentioned factors are evaluated are presented. The weights of individual factors were determined here only by expert estimation, and no sensitivity analysis was performed. However, the method of determining the weights of individual criteria can affect the entire analysis of the location.

The weights of individual criteria were determined according to the abovementioned methods for all 20 respondents, and the arithmetic mean of all methods was then calculated from them.

The results of all the methods used to determine the weights are given in the table (Table 2). Its structure is the same as Table 8 in [1]; however, it is supplemented by new weights and results of sensitivity analysis. For the Saaty method, the consistency of the individual matrices was checked by the eigenvalue method.

Table 2. Weights of individual factors and their differences.

Geographical Factor	Experts	Theorists	Var. 3 [2]	Pairs	MES	Saaty	Maximum Difference [1]
Hydrology	31	28	41	25	30	37	16
Terrain relief	25	20	15	21	21	17	10
Soil types	15	10	15	12	12	11	4
Roads	12	15	12	16	21	19	9
Vegetation	9	9	9	12	9	8	4
Built-up areas	8	18	8	14	7	8	**10** [3]
Maximum difference [1]	23	19	**33** [4]	11	21	29	

[1] Maximum difference of weights between individual methods; [2] Var. 3 note—Theorists also considered a variant of using machinery with better driving characteristics in the field, which, according to them, will cause a reduction in the weight of terrain relief and road factors and, conversely, will increase the weight of the soil types factor. Furthermore, according to them, it is also appropriate to consider climate change in Central Europe in the last decade, which causes a lack of surface water and, therefore, on the contrary, increased the importance of the hydrology factor; [3] The variance of the assigned values of the weights of individual factors did not differ by more than 10 percent; [4] For other methods, significantly higher weights were assigned to the dominant variants. Here, the maximum difference was up to 33 percent (Table 2).

To determine whether a factor is truly dominant, a sensitivity analysis, which compared the differences in the weights of the individual factors, was performed.

The sensitivity analysis showed that the clearly dominant factor in all the methods used is the "Hydrology" factor. The second most dominant factor was the "Terrain relief" factor, with the exception of Saaty's method, where it occupied third place but with a slight difference of two percentage points. For the other factors, the order differed depending on the respondents or the method used. However, the variance of the assigned values of the weights of individual factors did not differ by more than 10 percent.

On the contrary, the highest difference in weights was achieved with the clearly preferred factor, "Hydrology". This was due to the pairwise comparison method, in which the smallest differences between the individual factors were achieved. With this method, the respondents "smoothed out" the values of the scales the most. The difference in the weights determined by the pairwise comparison method was a maximum of 11 percent. For other methods, significantly higher weights were assigned to the dominant variants. Here, the maximum difference was up to 33 percent (Table 2).

4.1. Influence of Changes in Weights of Factors on the Location Analysis

Using the determined weights, an MCA was performed according to the same process model as in [1]. The result of the MCA was six variants of the cost map with the potential of the landscape for the deployment of DS. From a global perspective, the individual variants did not differ in principle, and all made it possible to identify the basic suitable areas for the deployment of DS. However, in the detailed analysis, partial differences appeared. It was therefore necessary to assess where these differences occurred, what the differences were and what the sources of the identified differences were.

The influence of the method used for determining the weights was manifested both in the size of the total area corresponding to the given value of suitability and in the position of the areas thus analyzed. Therefore, it is necessary to assess the analyzed areas from both points of view. The following table (Table 3) shows the share of the analyzed areas sorted according to the degree of their suitability for the deployment of DS in the total area of AOI Jedovnice, i.e., 400 km^2.

Table 3. Percentage share of the sizes of selected areas of the same suitability value in individual variants on the total size of the area of responsibility.

Degree of Suitability	The Share of the Total Analyzed Area in the Total Area of AOI Jedovnice (%)					
	Experts	**Theorists**	**Var. 3**	**Pairs**	**MES**	**Saaty**
0	56.7297	56.7297	56.7297	56.7297	56.7297	56.7297
1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000
4	0.0312	0.0027	0.0159	0.0012	0.0063	0.0122
5	0.7060	0.1739	0.3618	0.2463	0.2705	0.1986
6	4.6197	2.2792	2.0725	3.6697	2.9353	1.9998
7	7.4910	8.5267	8.9049	7.0306	8.1132	8.7993
8	14.3981	14.6016	16.6356	16.5854	14.7434	14.7788
9	14.6718	15.4171	13.7583	14.0686	15.9364	15.7341
10	1.3525	2.2692	1.5213	1.6685	1.2654	1.7475
Total	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000

From the results of the sensitivity analysis, it could be concluded that the most advantageous methods for determining weights are the expert estimates of experts and theorists. However, if the MCA is used to assess the impact of the landscape as a geographical environment in solving a particular problem, it is necessary to realize that the result of the analysis depends not only on the MCA method used but also on the quality of spatial data and ultimately on changing geographical conditions in the secured area [27,28]. Assuming that the same geographical data are used for this analysis, i.e., that their quality does not change in different variants of the MCA, the result of the analysis is affected by changes in the geographical conditions of the secured area. For example, the effect of soils will depend in part on the slope inclination or whether the selected area is in the valley and how this particular valley is irradiated by the sun during the day, i.e., the daily value of solar radiation and associated drying of the topsoil [29].

Therefore, if it is not certain which variant dominates, the authors propose to determine the intersection of variants and consider it an optimum solution (i.e., certainty).

For the abovementioned reasons, a spatial analysis of the conformity of individual suitability values in the entire security area was performed. However, only values higher than 4 were taken into account, which, according to the table (Table 3), are relevant to assess. The following table shows the results of this analysis, both in the number of matching pixels and in the percent match in the whole secured area, with a total number of 4 million pixels (Table 4).

Table 4. The number of identical pixels in the intersection of all MCA methods used and their percentage.

Degree of Suitability	Number of Identical Pixels	% of Identical Pixels in the Whole AOI
4	4	0.00
5	1849	0.04
6	30,232	0.76
7	91,660	2.29
8	315,031	7.88
9	376,195	9.40
10	47,614	1.19

However, the numbers themselves must be considered together with the spatial distribution of identical areas. For suitability grade 10, the intersection distribution is illustrated in the following figure (Figure 7).

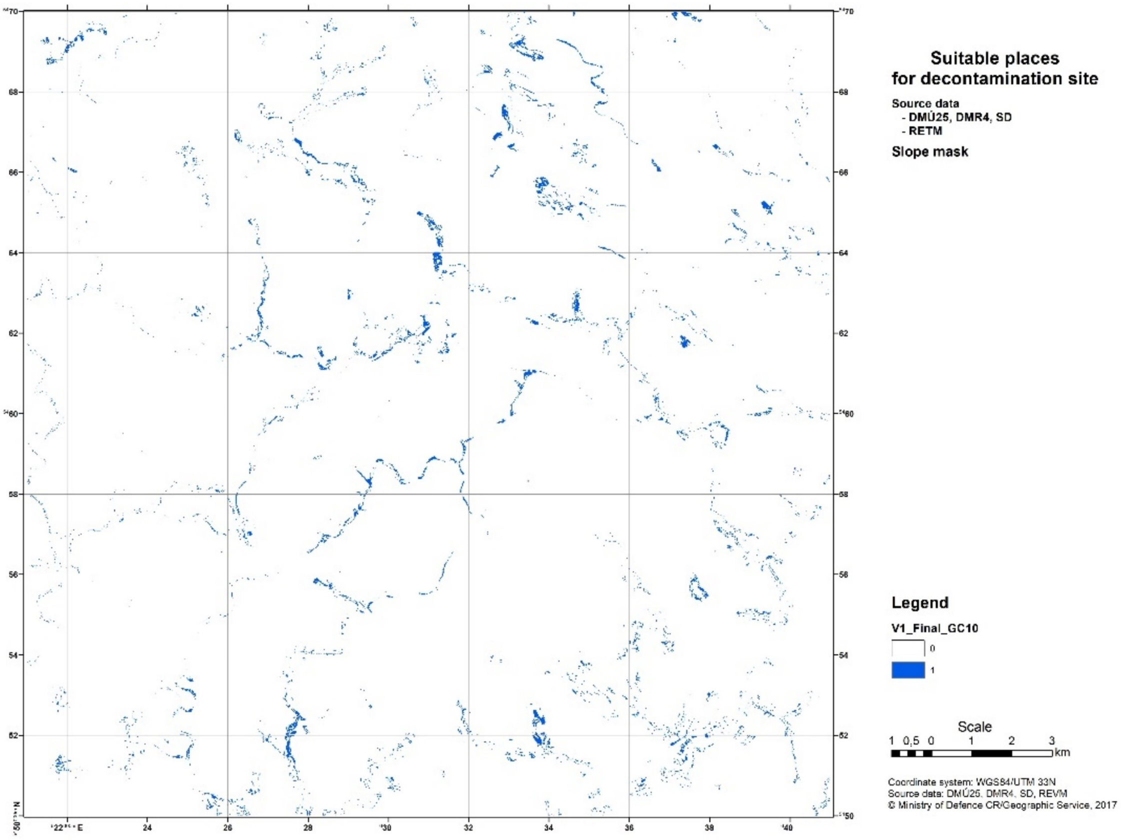


Figure 7. Intersection distribution of the same suitability values for the value 10 in the Jedovnice AOI area.

From the map in the figure (Figure 7), it is clear that not only does a small number of pixels meet the specified condition of conformity in all variants of the MCA for suitability level 10 but also the evaluated areas are small in terms of size, and they are completely inappropriately distributed in the whole space. In such a case, it would be appropriate to use the procedure of unification of suitable areas for several degrees of suitability. This unification can be expressed mathematically by an expression that, for the unification of all input cost maps for the individual MCA variants with a degree of suitability ≥6, will be the following:

$$GC = \begin{cases} 1, (\text{CM WO\_Saaty\_V1\_Final} \geq 6) \cap \\ (\text{CM WO\_MES\_V1\_Final} \geq 6) \cap \\ (\text{CM WO\_Pairs\_V1\_Final} \geq 6) \cap \\ (\text{CM WO\_Variant3\_V1\_Final} \geq 6) \cap \\ (\text{CM WO\_Theoreticians\_V1\_Final} \geq 6) \cap \\ (\text{CM WO\_Experts\_V1\_Final} \geq 6) \\ 0, \qquad \textit{otherwise} \end{cases} \tag{5}$$

where *GC* is the output value of the merged pixel (Grid code).

Using the Map Algebra tool (Raster Calculator), the intersections of individual MCA variants were determined for a given combination of degrees of suitability. The following table (Table 5) shows the results of intersections and the percentage of suitable areas out of the total area of the AOI. Since the percentage of suitable pixels in the intersection of all MCA methods used for suitability grades 4 and 5 is insignificant, these variants are not listed in the table (Table 5).

Table 5. Intersection results and percentage of suitable areas from the total area of the AOI.

Intersection of Suitability Values—Number of Pixels					
Intersection Value—GC	**GC = 10**	**GC ≥ 9**	**GC ≥ 8**	**GC ≥ 7**	**GC ≥ 6**
0	3,952,385	3,519,215	2,882,454	2,516,449	2,30,919
1	47,614	480,784	1,117,545	1,483,550	1,694,080
Area Percentage	1.19%	12.02%	27.94%	37.09%	42.35%

It is clear from the table that, as the requirements for the geographical quality of a potential site for DS deployment decrease, the percentage of areas found increases. However, it is necessary to attach the layout of selected areas in the specified space to the table. The following four pictures show in which locations the selected areas are concentrated as well as how their location and area change (Figure 8).

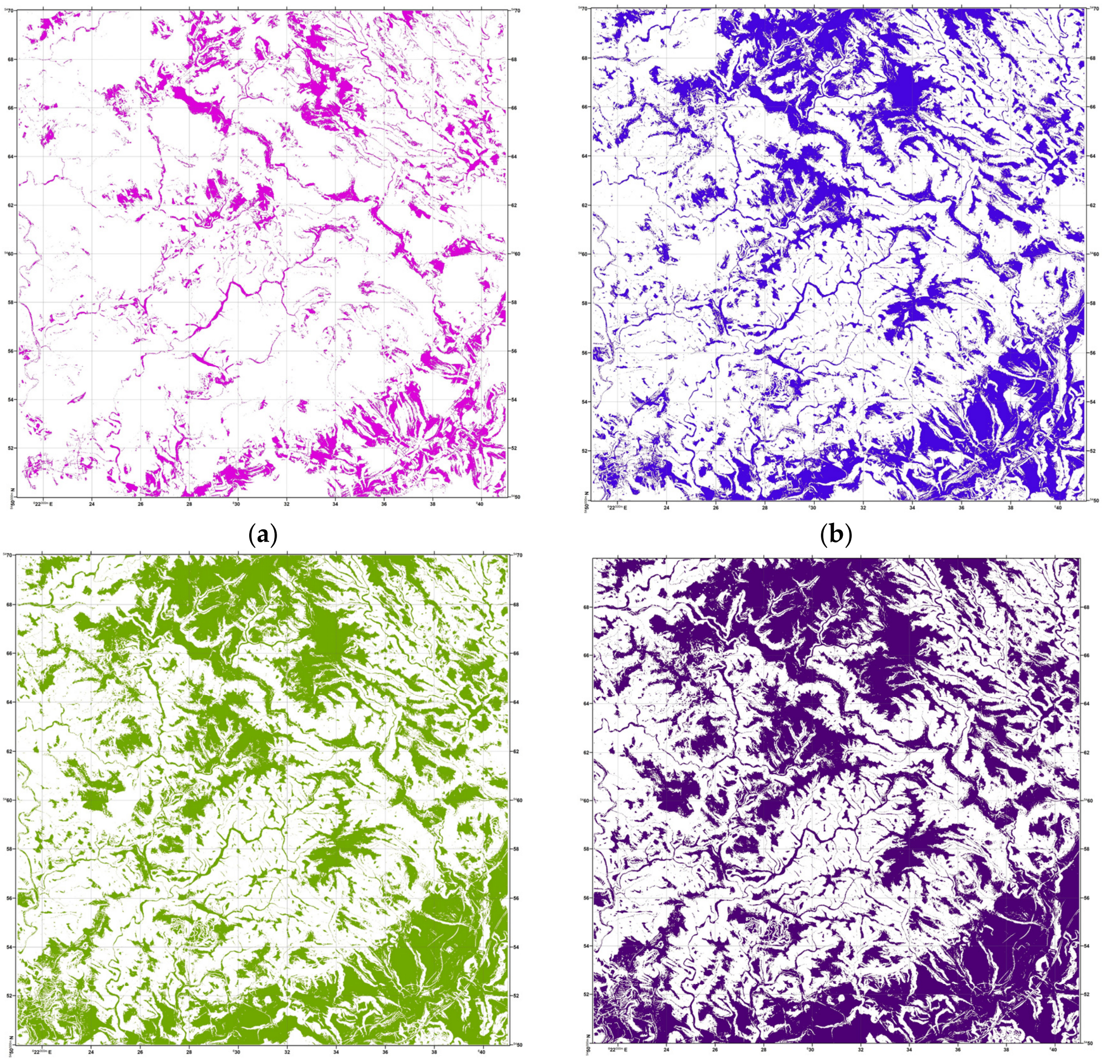

(**a**) (**b**)
(**c**) (**d**)

Figure 8. Distribution of the intersection of the same values of suitability for DS deployment in the AOI area for values (**a**) ≥ 9, (**b**) ≥ 8, (**c**) ≥ 7, (**d**) ≥ 6.

These outputs are in a raster format and therefore do not allow us to analyze the size of the total areas of suitable locations for DS deployment. In order to be able to select suitable areas according to the "minimum area" criterion, it is necessary to transform these outputs into a vector format and then select areas that meet the requirements for their minimum size.

The results of such an "optimized" procedure again only make it possible to assess the potential of the landscape in the area of responsibility for the possibility of deploying DS in it. A specific assessment of suitability must again be made by chemical survey units as part of a local survey.

4.2. Verification of Results

All results of the analyses were verified in order to find out the following:

- whether the tools used were able to identify suitable potential locations for DS deployment;
- whether these tools were able to find completely inappropriate locations.

4.2.1. Verification in the Field

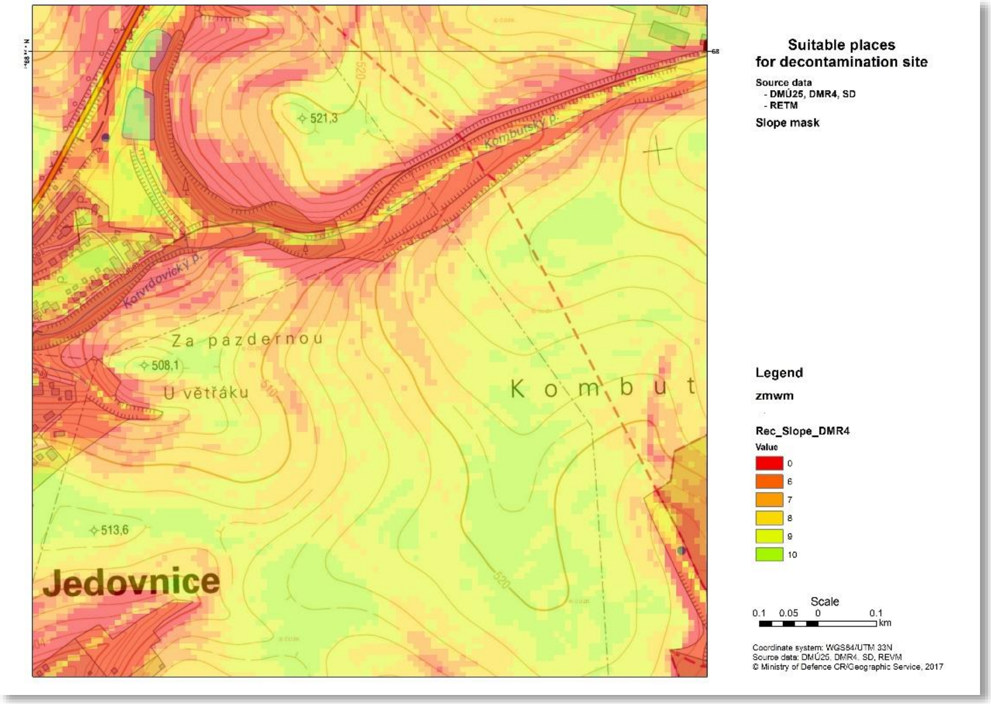
The basic verification was performed using orthogonalized aerial photographs from 2017 and 2018, available as a web service of the CSALSC Geoportal [22]. This basic verification was supplemented by an inspection of the security area directly in the field in June 2019. Due to the extent of the area, it was not possible to carry out a detailed examination of the entire model area of responsibility in the field. Therefore, the places that were analyzed as unsuitable were verified by a brief inspection while driving a vehicle. Subsequently, 10 selected sites were analyzed in detail, where the effectiveness of the MCA used was determined, differences were identified, and the degree of effectiveness of the analysis for the fulfillment of tasks within chemical security was assessed.

A brief inspection of the entire area was performed at each of the 10 selected locations. Furthermore, the actual inclinations of slopes were determined by simple methods using a mobile phone (iPhone SE), and the quality of the underlying DGDs was assessed in relation to reality. The ArcGIS 10.4 program was used to determine the actual dimensions of the selected areas at a given location. During the verification, the causes of differences in the results of individual variants of the MCA were determined and finally the effectiveness of the choice of the "optimized" procedure. The selected locations usually had an area of around 1 km^2.

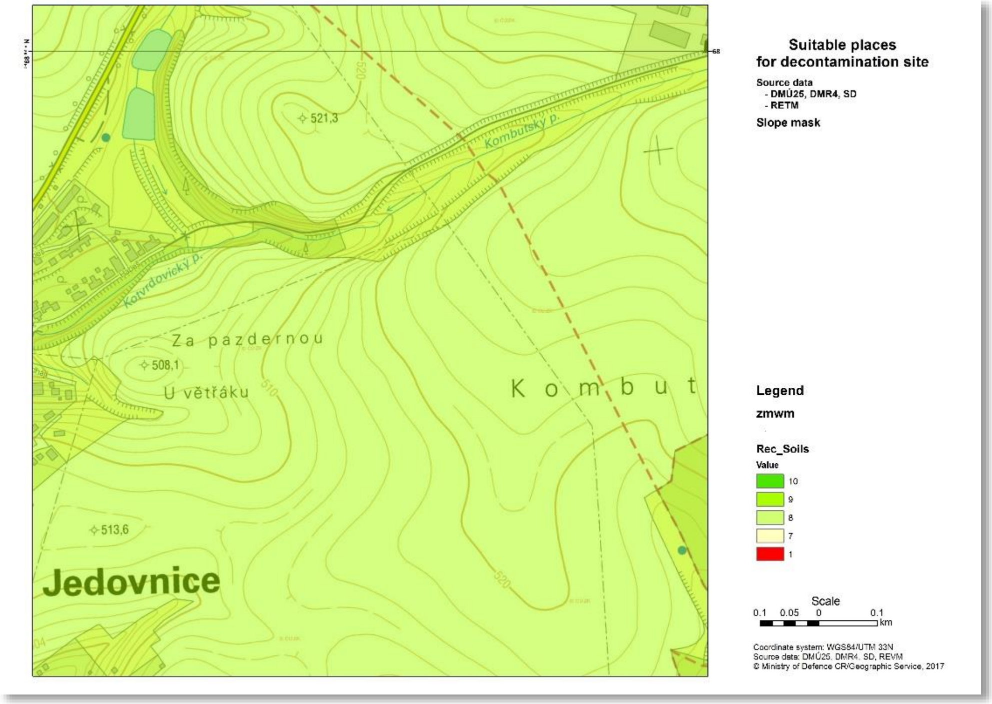
The Jedovnice area was chosen as an example of a detailed assessment of the results—specifically, the area "U Větřáku". At the time of the local survey, a large part of the surveyed areas was sown with grass grown for seed. The following pictures show an example of the landscape from the Jedovnice area and a section of a topographic map of this area (Figure 9).

Figure 9. Landscape in Jedovnice area and a topographical situation [22].

For the MCA, reclassified layers of analyses of the influence of individual factors on the deployment of DS were used. The detailed visualizations of these analyses for the assessed location are in shown Figure 10a–f.

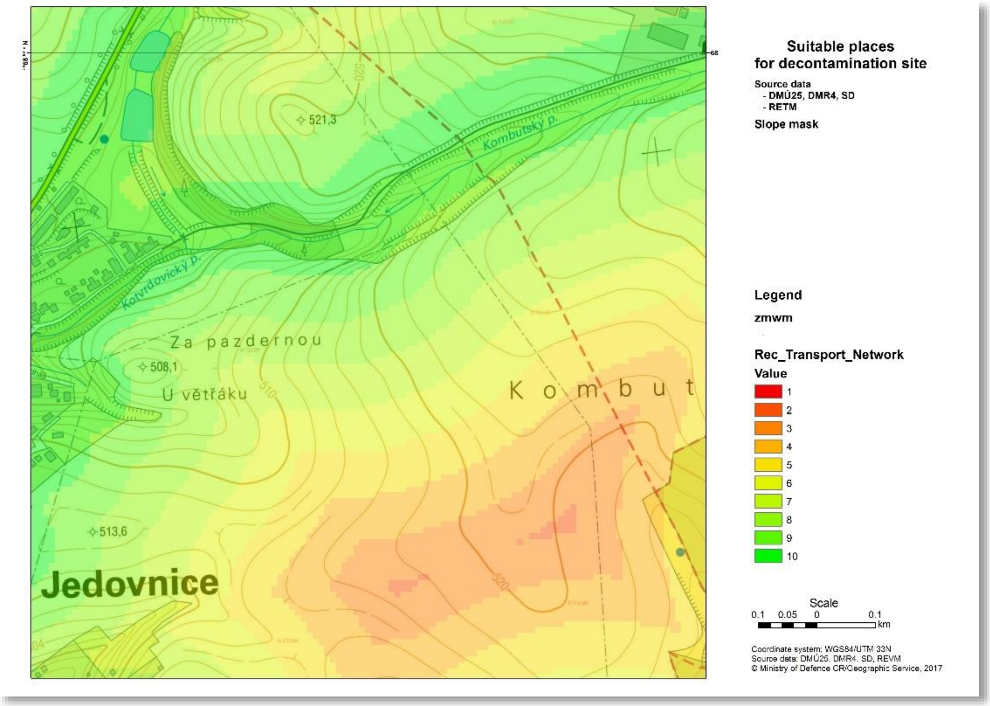


(**a**)

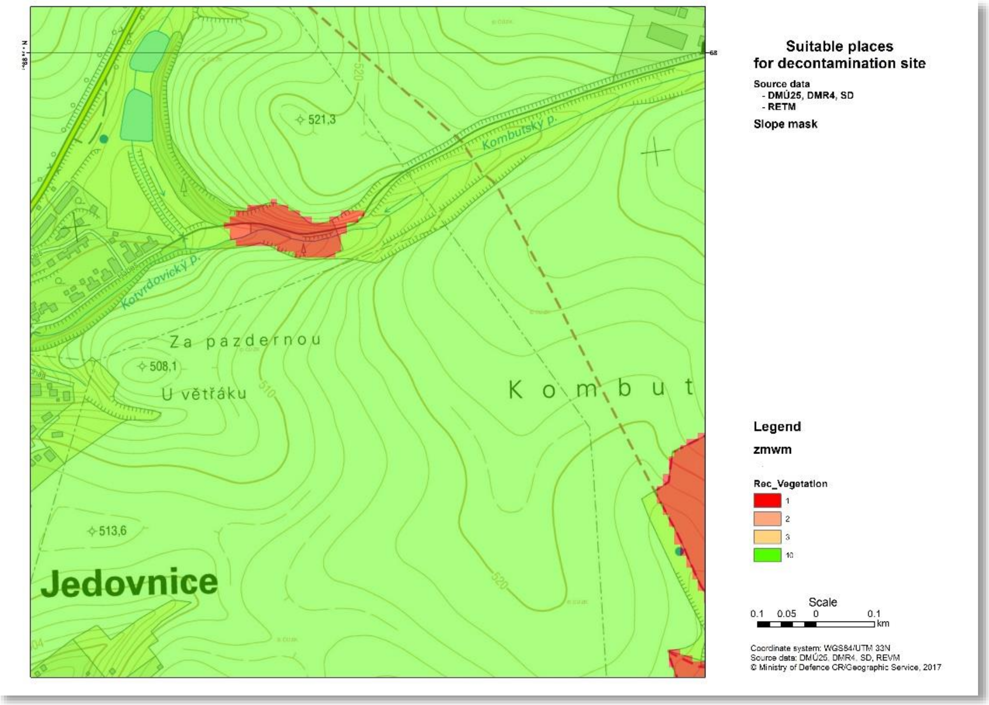


(**b**)

Figure 10. *Cont*.

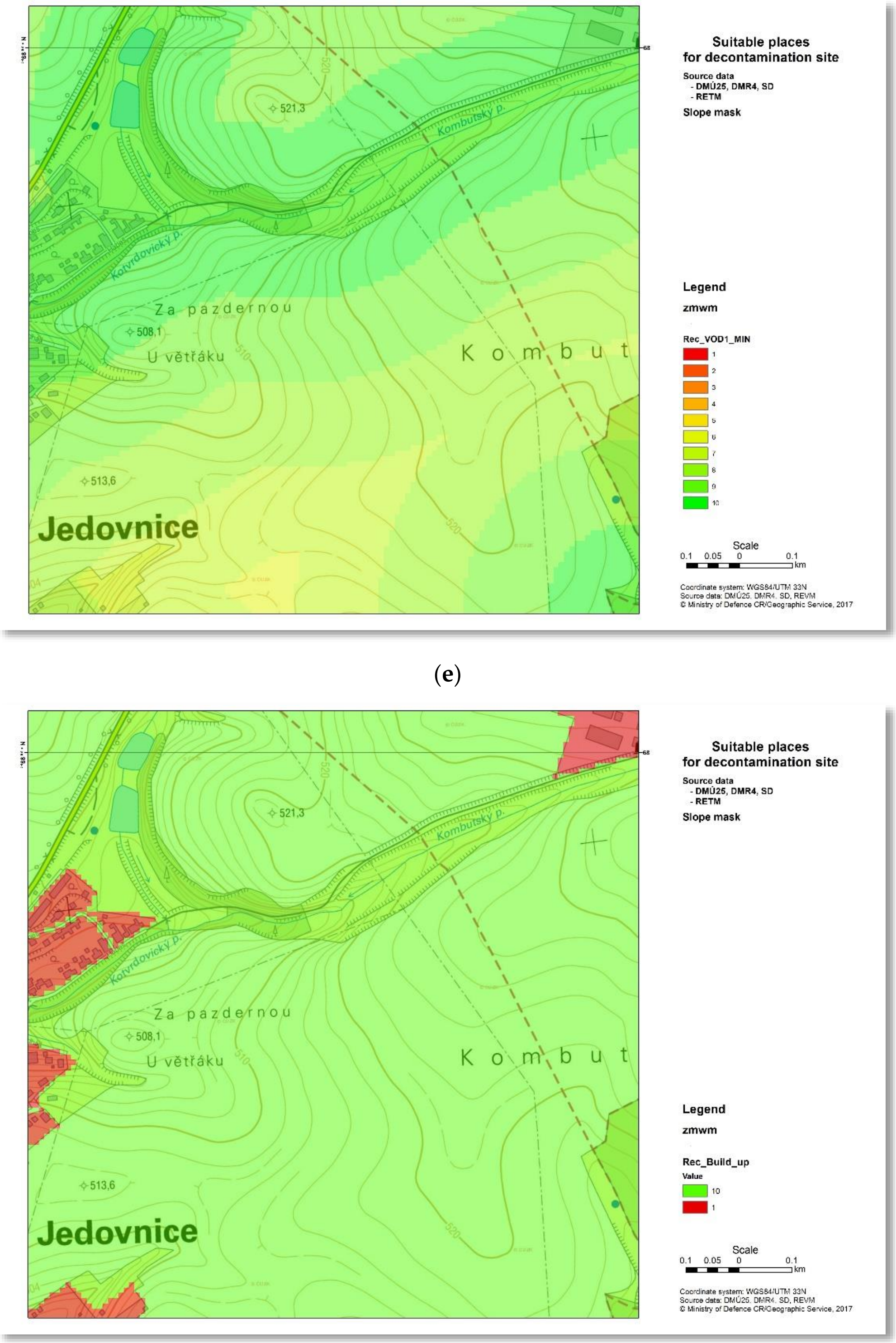


(**c**)



(**d**)

Figure 10. *Cont.*

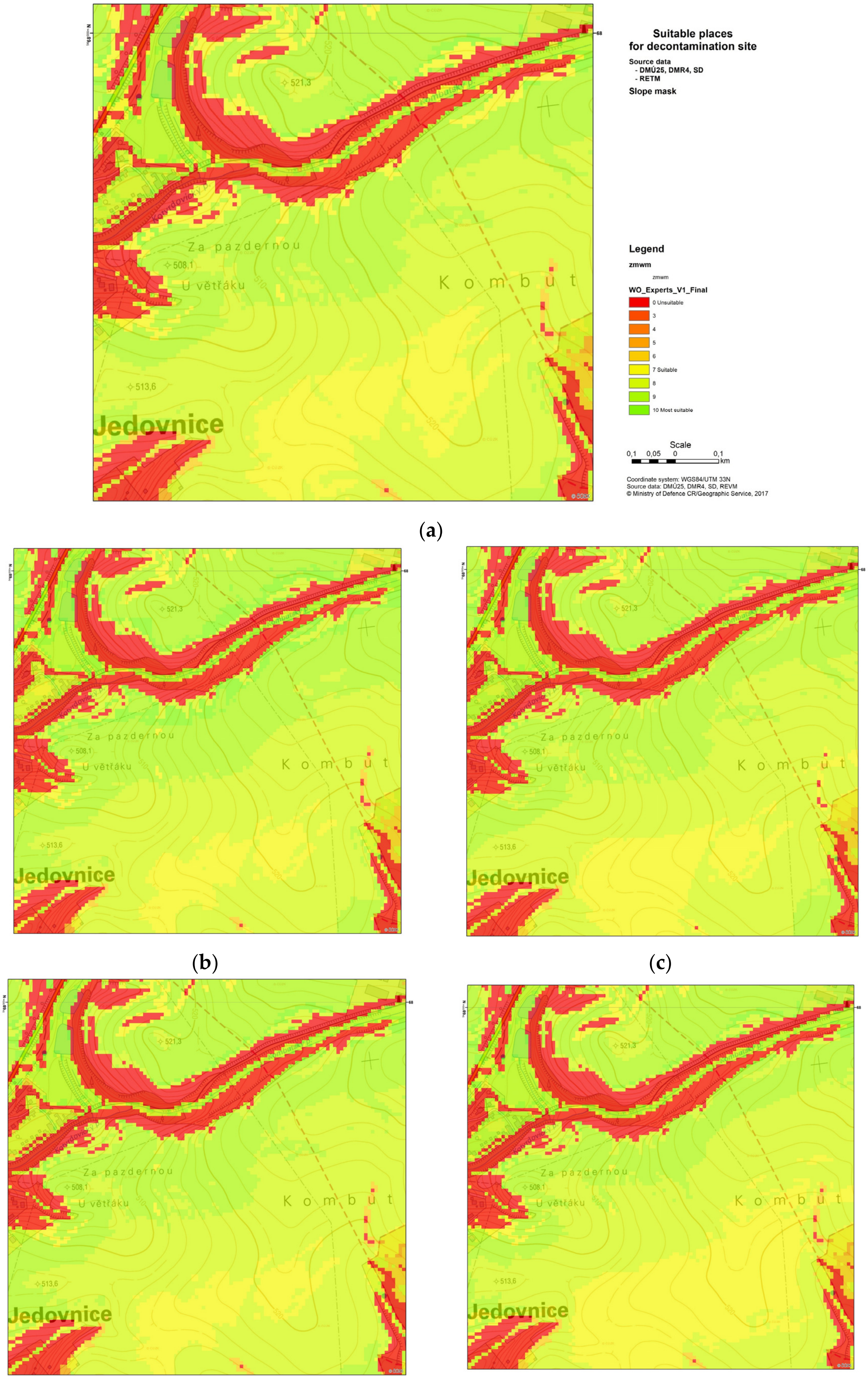


(**e**)

(**f**)

Figure 10. Input reclassified layers for MCA in Jedovnice area: (**a**) slope inclinations, (**b**) soil types, (**c**) roads, (**d**) vegetation, (**e**) hydrology, (**f**) built-up areas.

These layers then entered their own variants of the MCA, the outputs of which in the Jedovnice area are shown in the following figure (Figure 11).

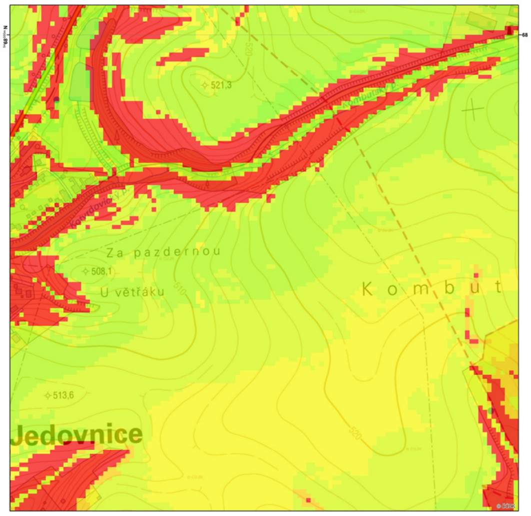


(**a**)

(**b**) (**c**)

(**d**) (**e**)

Figure 11. *Cont.*



(**f**)

Figure 11. Entry cost maps of landscape potential for DS deployment for MCA variants from the Jedovnice area: (**a**) Experts, (**b**) Theorists, (**c**) Var. 3, (**d**) Pairs, (**e**) MES, (**f**) Saaty.

4.2.2. Analysis of Differences of Individual Variants

The individual variants of the MCA in the Jedovnice area do not differ, and all variants evaluate the given area as being mostly suitable for the deployment of DS. In the assessed area, the differences in pixel values in all variants ranged from −1 to 0 to 1. Nevertheless, it is important to evaluate the differences between the individual cost maps.

To explain the principles of the methodology for evaluating differences, only the differences in individual variants in relation to the Expert variant as a standard are given below. The remaining analyses are listed in the Supplementary File.

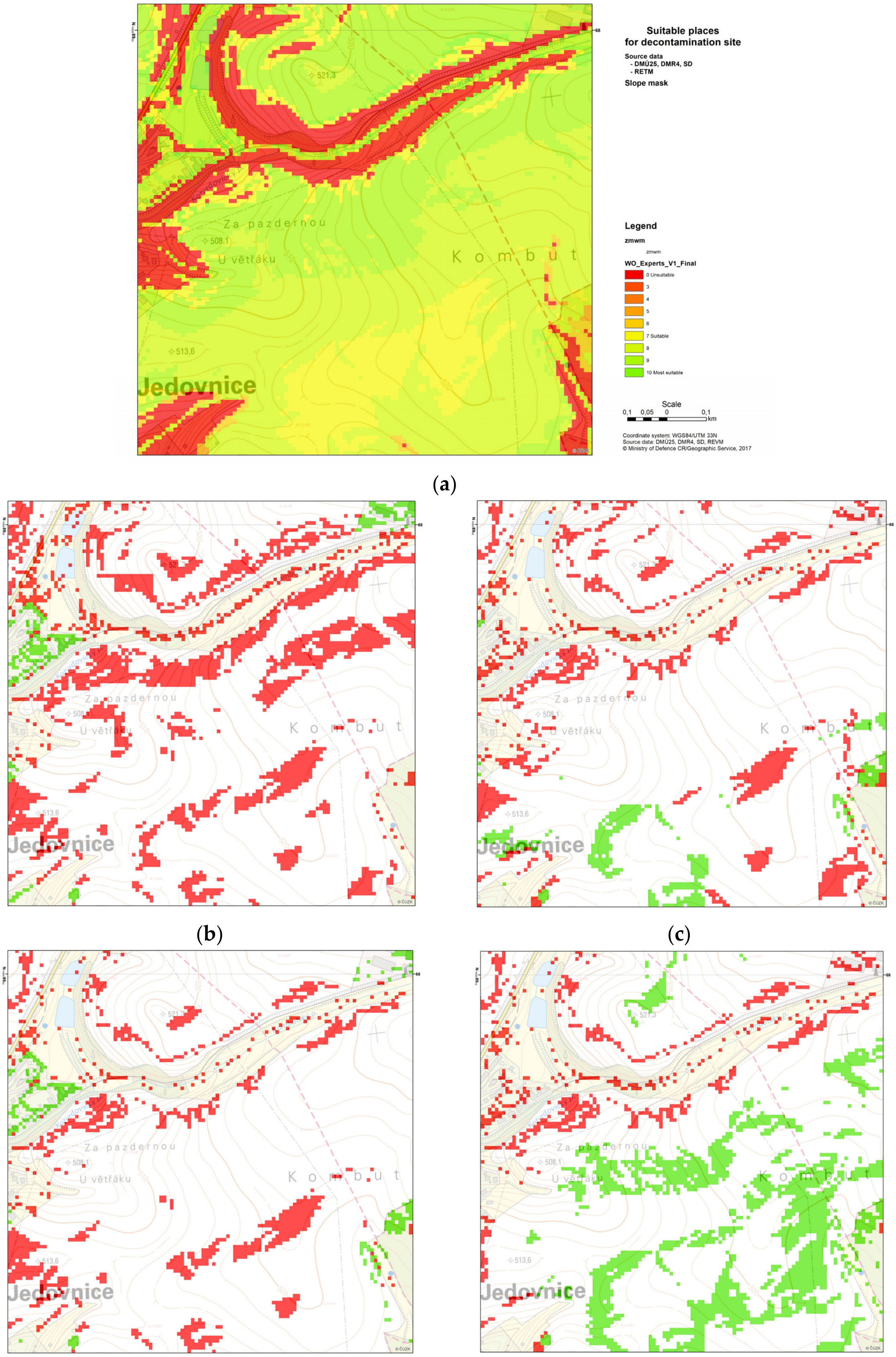
4.2.3. Differences between the Experts Variant and Other Variants

The cost map of the "Experts" variant was used as the first standard for the evaluation of differences, and both the absolute numbers of differences in the suitability values in individual pixels and the spatial distribution of these differences were identified. The following table shows their absolute numbers of different and identical pixels and their percentage relative to all pixels (Table 6).

Table 6. Absolute numbers and percentage share of differences from all pixels in the Jedovnice area for individual MCA variants related to the Experts variant.

Difference	Experts—Theorists		Experts—Var. 3		Experts—Pairs		Experts—MES		Experts—Saaty	
	Cells nr.	% of All Cells	Cells nr.	% of All Cells	Cells nr.	% of All Cells	Cells nr.	% of All Cells	Cells nr.	% of All Cells
−1	2506	17.85	1301	9.27	1180	8.41	753	5.36	1209	8.61
0	11,273	80.31	12,294	87.59	12,581	89.63	11,197	79.77	11,567	82.41
1	257	1.83	441	3.14	275	1.96	2086	14.86	1260	8.98
Cells total	14,036	100.00	14,036	100.00	14,036	100,00	14,036	100.00	14,036	100.00

It is clear from the table (Table 6) that if the expert estimates of practitioners (Experts) are taken as a standard of MCA weights, then there are the biggest differences between experts and theorists, where theorists underestimate the suitability of space in almost 18% of the areas, and also between experts and MES method, where this method, on the other hand, overestimates almost 15% of the areas. The greatest conformity assessment occurs in comparison with the Pairs variant. However, it is appropriate to supplement the absolute numbers with the spatial distribution of the identified differences, which are shown in the following figures (Figure 12).

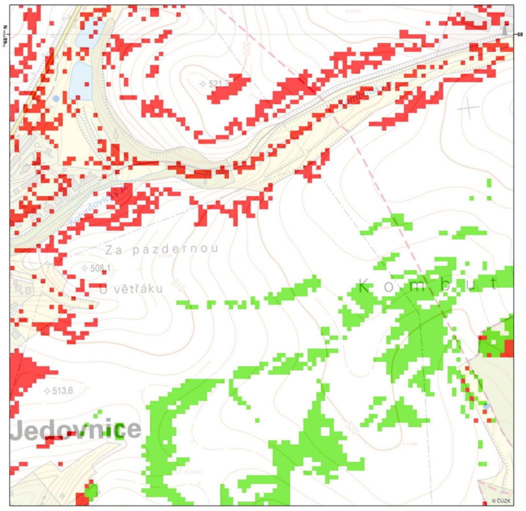


(**a**)

(**b**) (**c**)

(**d**) (**e**)

Figure 12. *Cont.*



(**f**)

Figure 12. Differences in cost maps of landscape potential for DS deployment for MCA variants from the Jedovnice area in relation to the Experts variant: (**a**) Experts cost map, (**b**) differences with the Theorists variant, (**c**) differences with the Var. 3 variant, (**d**) differences with the Pairs variant, (**e**) differences with the MES variant, (**f**) differences with the Saaty variant. Legend: red indicates the difference −1, green the difference +1, white identical areas.

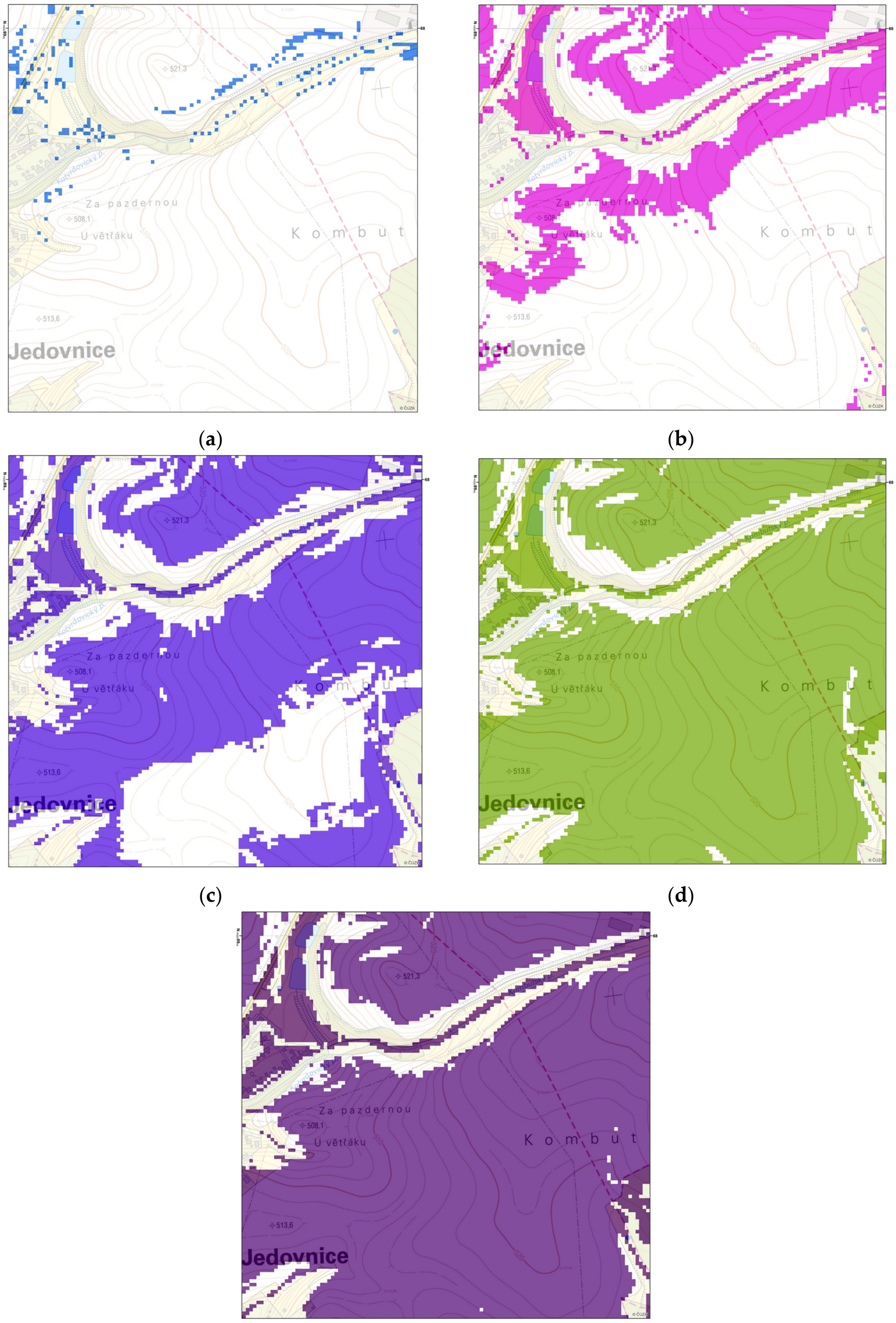
One of the highest concentrations of differences in variants is in the northern half of the area around the Kombutský and Kotvrdovický streams and in the places of the north-eastern edge of Jedovnice. In the vicinity of these streams, there is relatively dense vegetation, and both streams have steep banks, including their immediate surroundings. The aforementioned variants of the MCA responded to this fact according to the set weights for the evaluation of the influence of vegetation, hydrology and built-up area.

In the southern half of the evaluated area, in the place of an open landscape with a field, the differences in the setting of the weight of the terrain relief influence were particularly evident. Therefore, it is possible to find both positive and negative differences in suitability values in individual variants.

In a similar way, the differences between the variants during the gradual change of the standard were determined, a detailed description of which is given in the Supplementary File.

4.3. Method of Finding the "Optimal" Variant

From the performed analyses of the differences of individual variants, it is clear that none of the MCA variants can be reliably marked as the most suitable, not even on the basis of verification of their results in the field. Therefore, the path of the "optimal" variant was used in this area as well. The optimization consisted of gradually reducing the requirements for the geographical quality of the properties of the space of the potential location for the deployment of DS. The reduction of requirements was realized using the principle illustrated in Relation (3) and according to Table 5. The results of the individual intersections are shown in Figure 13a–e.



(**a**) (**b**)

(**c**) (**d**)

(**e**)

Figure 13. Intersection distribution of the same suitability values in the AOI area in the Jedovnice area: (**a**) for the value 10,(**b**) for the values 10 a 9, (**c**) for the values 10, 9 a 8, (**d**) for the values 10, 9, 8 a 7, (**e**) for the values 10, 9, 8, 7 a 6.

From the verification of the results of individual variants of the MCA and the "optimized" variant on the spot, it can be stated that all variants basically met expectations and relatively accurately selected suitable locations for the deployment of DS.

Nevertheless, the authors recommend the use of an "optimized" analysis procedure for practical application, as its result will provide a sufficiently large continuous area meeting all other criteria at the appropriate level, at the same time respecting a balanced view of the values of individual weights. At the same time, this procedure enables a continuous reduction of the requirements for the quality of the analyzed space up to the level when sufficiently large continuous areas have already been found.

5. Discussion of Results

The solution of the model example showed the possibilities provided by the DGD and spatial analyses in the implementation of geographical support of decision-making processes of commanders, staff and security elements, especially whether it is necessary to solve professional tasks in large areas [30–32]. The solution was based on the general theory of the MCA in solving spatial analyses and described in detail the approach to the methodology of determining the weights of individual geographical factors. Specifically, methodological procedures for determining weights using expert estimates and mathematical methods were presented and documented. Furthermore, the results of the MCA for different variants of weights of geographical factors and the causes of their differences were analyzed in detail. Finally, an "optimized" analysis procedure was proposed.

The solution of the model example confirmed the possibilities of using geographical analyses based on the MCA in the geographical support of decision-making processes. It is mainly about increasing the efficiency of the whole decision-making process and subsequently also increasing the efficiency in the deployment of forces and resources that are intended for a given intervention, in a model example for the construction and use of a decontamination workplace. The results of the study also showed that the basic points of increasing the efficiency of decision-making processes mentioned in [1] remain unchanged, i.e., that

- the intervention commander receives objective and up-to-date information on the potential of the landscape in the secured area in terms of fulfilling his professional task;
- objective information subsequently saves him time in decision-making, as he does not have to deal with areas that are unsuitable or less suitable for his task;
- objective information subsequently saves time for reconnaissance teams, which only have to go through selected suitable areas;
- the intervention commander can react more flexibly to changing conditions, which can be reflected, for example, by a change in the weights of the factors.

However, the solution again did not consider the current meteorological conditions and their effect on soil bearing capacity (for example, precipitation, air humidity, temperature, amount of cloud cover and length of sunshine). The solution also did not include conditions for the transport of material and especially water from water sources, so the solution did not address issues of terrain permeability, although this solution is already basically functional for various types of military equipment [27,32,33].

As part of the solution of the model example, the influence of the quality of source data on the result of spatial analysis was also not evaluated. The solution included data in the quality that is declared in the descriptions of the data models used [21,23]. For real use, it would be necessary to evaluate in detail the impact of the standard quality of the underlying data in terms of their use and define which data properties do not correspond to the task and in which ways it would be necessary to improve their parameters. At the same time, it would be necessary to assess how the effect of changes in data quality will affect the overall result of spatial analysis [34]. The whole solution was also not verified by stress tests with practitioners who solve similar situations in practice, as well as directly in the field. These problems need to be addressed in the further development of the solution so that a verified tool can be put into practical use.

As part of the study, the proposed procedures were also evaluated by the staff of the Nuclear, Biological and Chemical Defence Institute of the University of Defence in Brno (NBCI). Specifically, the possibilities of using DGD and MCA to support the fulfillment of the tasks of the chemical units in the chemical security of the troops were evaluated. According to the NBCI employees, the proposed solutions for the valuation of premises in relation to their potential usability in favor of complete decontamination are very beneficial, not only in the process of long-term planning of the operation but also in specifying potentially usable premises. This is also with regard to the development of automated command and control systems, which are implemented in the automated command and control systems of the ACR ground forces. Based on the information that would emerge from the analysis, the commander of the chemical protection unit would decide to reduce the selected decontamination sites and purposefully organize reconnaissance measures in order to definitively and comprehensively specify the current state of the terrain, water, roads and so on. This approach would allow the most efficient use of time, effort and resources in the assessment of situational factors.

6. Conclusions

The task solved could not, of course, cover all the problems that occur in solving analytical activities within the geographical support of command and control systems [35]. Its main goal was to show the use of DGD in solving analytical problems with the application of multicriteria analysis. At the same time, the way to continue solving the problem was indicated.

One of the key problems of all models that use multicriteria analysis is the determination of the weights of the criteria. The weights of individual criteria can significantly affect and do affect the outcome of the decision-making process. In this study, common methods based on pairwise comparison of individual criteria were used. In addition to these methods, it is also possible to use the AHP method (Analytic Hierarchy Process) [36], the DEMATEL method [37] or the BWM (Best Worst Method) [38]. However, all these methods, by their nature, contain the subjective influence of their reviewers.

The benefit that resulted from the processing of this task is the finding that, when applying the MCA over spatial data, it is possible to successfully use the intersection of the results of the space suitability analysis determined by individual variants as the most suitable variant.

However, in a published article [39], a completely new method of full consistency was proposed—the Full Consistency Method (FUCOM)—which significantly eliminates this effect. The model assumes the definition of two groups of constraints that must meet the optimal values of the weighting coefficients. This new method has been tested on several numerical examples from the literature, and the results obtained show that FUCOM provides better results than the BWM and AHP methods when taking into account the relationship between consistency and the required number of comparison criteria. Its use is therefore one of the possible directions of further study and development of the studied issues.

Supplementary Materials: The following are available online at http://www.mdpi.com/2220-9964/9/8/489/s1, Supplementary file—Differences between Individual MCA Variants.

Author Contributions: Conceptualization and Methodology, Šárka Hošková-Mayerová, Václav Talhofer, Pavel Otřísal, and Marian Rybanský; Software, Václav Talhofer; Validation, Formal Analysis, Investigation, Resources, Šárka Hošková-Mayerová, Václav Talhofer; Data Curation, Šárka Hošková-Mayerová; Writing—Original Draft, Šárka Hošková-Mayerová, Václav Talhofer; Writing—Review and Editing, Šárka Hošková-Mayerová, Václav Talhofer, Pavel Otřísal, and Marian Rybanský; Visualization, Václav Talhofer; Project Administration, Václav Talhofer; Funding Acquisition, Šárka Hošková-Mayerová, Václav Talhofer. All authors have read and agreed to the published version of the manuscript.

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