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Multi-Criteria Land Evaluation of Suitability for the Sport of Foot Orienteering: A Case Study of Croatia and Slovenia

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Abstract: This paper describes a new multi-criteria land evaluation method, based on geomorphology and land cover, for the automated detection of suitable terrain for the sport of foot orienteering (footO). Reference data, in the form of areas already mapped and used for footO, was used to define criteria for geomorphology and land cover, and represents an expert knowledge component. The motivation for this research is that orienteering maps are often drawn for unfamiliar terrain that organizers of the event or mapmakers need to determine in advance, usually from base maps or by random reconnaissance. In a presented case study of Croatia and Slovenia, the geomorphology was derived from Digital Elevation Model over Europe (EU-DEM). The slope and aspect define components of the direction of the surface, and we tested the usability of these simple terrain parameters for the task. The CORINE dataset was used for the definition of the land cover. The results of the case study give potentially suitable areas for foot orienteering in Croatia and Slovenia, and in neighboring areas. Evaluation of the results, using reference areas as the control, proved that the proposed methodology gives a reliable indication of terrain suitability for orienteering. The method is simple, straightforward, and can be performed using standard GIS with common raster algorithms.

Keywords: orienteering terrains; slope; aspect; land cover; multi-criteria evaluation

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1. Introduction

Orienteering is a sport in which the orienteer completes a course of control points in the shortest possible time, aided only by a map and compass [1]. The sport of orienteering has been constantly developing since the mid-20th century, resulting in the revision and expansion of existing orienteering maps and the production of maps in areas not previously used for orienteering. Orienteering map-making has grown rapidly in response to the explosive growth of orienteering as an outdoor activity [2]. The typical scale of an orienteering map is 1:15,000 or 1:10,000, with a contour interval of 5 m. The four main orienteering disciplines are foot orienteering (footO), ski orienteering (skiO), mountain-bike orienteering (mtbO), and trail orienteering (trailO). There are also some other variations and types which are often utilized in training, undertaken for fun, or engaged in as a part of other complex events such as adventure races [3]. The maps for each of these disciplines are slightly different and need to be created according to an international standard prescribing scale, content, and map design [4]. The orienteering map aims to present the surrounding terrain to the orienteer on the ground as detailed as he can practically interpret it, indicating those features which can assist him in navigation and his choice of route [5].

For course setters and organizers of orienteering competitions, the most important factor for selecting areas for orienteering is difficult and challenging terrain, ideally as unpopulated and as wild as possible [6]. This is important for elite runners and championships, but for beginners or recreational runners, who are also important for the promotion of the sport, easier terrain should also be used. Most of the foot-orienteering disciplines (middle distance, long distance, and relay) are organized in a forested area—often in the mountains—while the sprint discipline is mainly run in urban areas [7]. The best way to determine if the terrain is suitable for orienteering is through field control by an experienced orienteer, allowing an assessment of whether competitors will be provided with the challenge of navigation, and if the terrain possesses a threat in terms of dangerous animals, mines, cliffs, sinkholes, and so forth. Besides these main criteria for setting challenging courses, other factors such as access to the terrain, distance to the traffic network, steepness, density of vegetation, run-ability, the frequency of changes in the terrain, and more, may need to be considered [6].

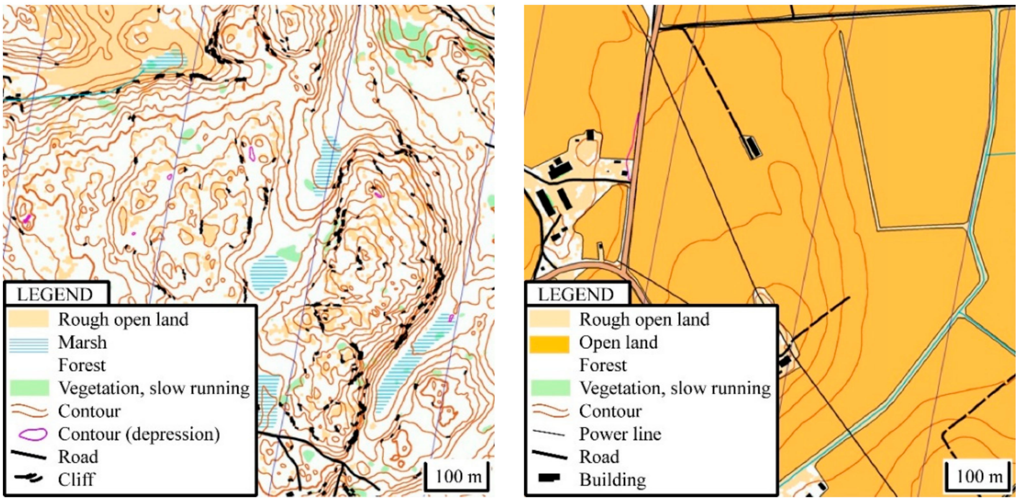
An orienteering map with a detailed representation of the terrain, containing rich landforms and land features, provides the competitor greater opportunities for testing navigation skills against the clock [8]. Looking at the map gives the orienteer a good indicator of the terrain quality for orienteering.

Organizers of orienteering events, or mapmakers looking for new terrain that is unfamiliar to orienteers, will typically use large scale topographic maps, local knowledge, or random reconnaissance of the terrain. The ability to have a good pre-selection of suitable terrains for orienteering can reduce the time and relatively high costs involved in making orienteering maps. Finding all the sections of land over some defined area that potentially meets orienteering criteria, such as in a country or region, reduces time and costs, and helps the ongoing development of this activity with its benefits for participants and society. Taking a systematic approach to a large area is the main aim of this research in evaluating land by terrain slope, aspect and land cover, and thereby finding potentially suitable terrain for foot orienteering. A multiple criteria decision-making approach applied to a GIS-based land suitability evaluation was selected to determine which areas meet the defined criteria of slope, aspect, and land cover. The new proposed methodology, based on value and priority assessment techniques for scaling the land suitability for footO, was tested for the territories of Croatia, Slovenia, and neighboring regions.

Until now, the only known attempt to determine suitable areas for orienteering that considered the whole country is MapAnt (http://www.mapant.fi). This automatically generated orienteering map of Finland is created from publicly available laser scanning and topographic data. The MapAnt.fi map can be accessed via Web Map Tile Service (WMTS) and Web Map Service (WMS). The quality of human-made maps is still a few levels higher than this automatically generated map (as the authors have stated on the web-page). Nevertheless, from MapAnt one can get insight into terrain type, run-ability, and other information important for orienteering terrain selection, which could be used for determining the suitability of the terrain (Figure 1).

Geographic Information Systems (GIS) provides enormous capabilities for both advanced and basic analysis of spatial data, as well enabling efficient visualization techniques. GIS, with its ability to combine the general with the specific, solves the problem of combining general scientific knowledge with specific information, and gives practical value to both. General knowledge used in GIS includes classification, rule sets, or in the case of multiple objectives in a stated problem, also employs a method known as multi-criteria decision making (MCDM) [9]. GIS is best suited for handling a wide range of criteria data at a multi-spatial, multi-temporal and multi-scale level, from different sources, for a time-efficient and cost-effective analysis [10]. Due to these capabilities, GIS is commonly used in research, administration, and industry worldwide. For the purposes of this paper, open source GRASS-GIS software was used. GRASS GIS has become a high-quality cutting-edge GIS with an almost unparalleled depth of offering directly within the main software package [11].

Spatial multi-criteria problems involve a set of spatially referenced alternatives that are evaluated based on conflicting criteria according to the decision maker's preferences and consist of six key concepts: decision maker(s), alternatives, criteria, value scaling, criterion weighting, and combination (decision) rule [12]. The main task of GIS-based multi-criteria decision making/analysis (GIS-MCDM/A) is transforming and combining geographical data and value judgments (the decision-maker's preferences) to obtain information for decision making [13]. Spatial MCDM has also become one of the most useful methods for land use and environmental planning, as well as for water and agricultural management [14–18].



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

Figure 1. Automatically created orienteering map as an indicator of the quality of the orienteering terrain: (**a**) Rich terrain features suitable for orienteering; (**b**) inadequate terrain for orienteering (source MapAnt, http://www.mapant.fi).

Finding a suitable area for foot orienteering involves multiple criteria, some of which have already been discussed in the research by Petrovič [6]. In this paper, we use only two basic criteria—geomorphology and land cover—however, as GIS-MCDM/A has a variety of approaches and a developed theoretical basis, this is a valid method for the stated problem (especially in the absence of comparative studies). For that reason, after the problem statement (Section 2), selected methodology (Section 3), and case study for Croatia and Slovenia (Section 4), we also give the initial evaluation of the results (Section 5). GIS-MCDM/A, as the selected method, also gives us the opportunity to expand the model with additional criteria, which can be attempted in some future work.

2. Problem Statement

The motivation for and need to solve the problem of finding potentially suitable areas for foot orienteering can be stated as:

- Who has the problem? Course setters and organizers of orienteering competitions.
- Why is this a problem? Expansion of the sport of orienteering and prolonged use of existing orienteering terrain demands new orienteering maps of areas never used for orienteering before.
- Who decides this is a problem? Usually, these are national orienteering associations or orienteering clubs.
- Who can benefit from a problem solution? Orienteering organizations and orienteers.

We hypothesize that there exist suitable orienteering terrains that have not been used for this purpose before, and that they can be found using multi-criteria evaluation and assessment of existing orienteering terrains.

3. Methodology

Multi-criteria evaluation in GIS is concerned with the allocation of land to suit a specific objective, according to a variety of attributes that the selected areas should possess [19].

From among the many criteria suitable for multi-criteria evaluation of orienteering terrains, in this work, we selected terrain geomorphology and land cover. These are basic criteria, and areas that satisfy them should be narrowed by additional criteria such as ease of access (transport links, proximity to population centers), telecommunications (mobile coverage), and existing land use and land ownership/governance [6].

The selected specific criteria for this research are terrain slope, aspect, and land cover, as they have a straightforward relationship with and relevance to the quality of the orienteering terrain (Table 1).

Table 1. Relationship and relevance of selected criteria to foot orienteering (footO).

Criteria	Statistics	Relevance
Slope	Value	Too flat terrains tend to be less physically and technically challenging. Too steep terrains can be dangerous and physically too demanding, even for fit runners.
Slope	Variation	Variation in terrain slope means that the terrain probably has more features that are important for setting a challenging course. It is relevant because, even if the slope value is in the acceptable range, that does not mean that there are a variety of landforms for challenging courses (e.g., big hill slopes with no valleys, ridges, and pits).
Aspect	Value	The orientation of the terrain to certain directions is less important for the selection of orienteering terrains (it can be considered in some special cases).
Aspect	Variation	Variation in the terrain aspect means that the terrain probably has more landforms that are important for setting challenging courses.
Land cover	Value	Land cover is one of the most important criteria, since foot orienteering is a sport organized in forests or natural areas. Sprint orienteering, which is usually organized in urban areas, is not the topic of this paper.

In our application of multi-criteria evaluation, we define the criteria as a set of deterministic rules which are used to create a set of required maps. Then, the model is evaluated by applying Boolean operators to these maps. Therefore, a primary output map is a binary map. Deterministic rules are defined statistically from the reference data set; that is, areas of existing orienteering terrain, reducing subjectivity in the binary model as much as possible. Moreover, in the presented case study we also applied weighted criteria to get output maps with suitability scaling. Weights for suitability scaling are defined by expert opinion and involve a certain degree of subjectivity.

This method can be considered prescriptive, empirical, and knowledge-driven. Prescriptive means the application of the criteria is good practice, which blends the identified factors (these are set out in Table 1). Empirical means that the determination of the criteria is based on statistical or heuristic relationships. The proposed new methodology in this paper is based on statistical relationships. In knowledge-driven models, weights are estimated by expert opinion, as opposed to a data-driven model where weights are assigned using statistical criteria [20].

Spatial neighborhood (focal) operations are utilized in favor of cell-based (local) operations on slope and aspect maps. This approach is common in raster-based geostatistics, helping to better characterize and derive information on local properties [20]. The size of the spatial neighborhood is to be defined, and it depends on the intended application. For the purpose of finding foot orienteering terrains, this can be selected to cover typical leg length in foot orienteering, which is between 200 and 400 m.

The workflow for preparing the required maps for multi-criteria evaluation from input maps is given in Figure 2. Input maps (data) are digital terrain or surface models, land cover, and areas of existing orienteering maps in the region. The slope value is defined as the median value of the spatial neighborhood. The slope variation is defined as the interquartile range (IQR) of slope values in the spatial neighborhood. The aspect variation is defined as the diversity index (number of distinct values) in a spatial neighborhood of aspect values rounded to an integer. The GRASS GIS module *r.neighbors* was used to calculate maps using the spatial neighborhood [21].

Once the required maps are calculated, the next step is to define the criteria values from existing orienteering terrains empirically and statistically. Then, these criteria values are applied to the whole area, giving filtered required maps for multi-criteria evaluation. In this way we aim to filter terrains that have similar statistics to the reference terrains. For the slope and aspect criteria, this is accomplished by filtering only those pixels with values of the spatial neighborhood between the 5th and 95th percentile of the distribution of this value in the reference terrains. For land cover, only those land cover classes that are represented on >3% area of the reference terrains are kept (Figure 3). This value of the percentage of the area can be modified depending on the classification used for land cover, after inspection and identification of land cover classes expected for orienteering terrain—primarily forests and run-able vegetation.

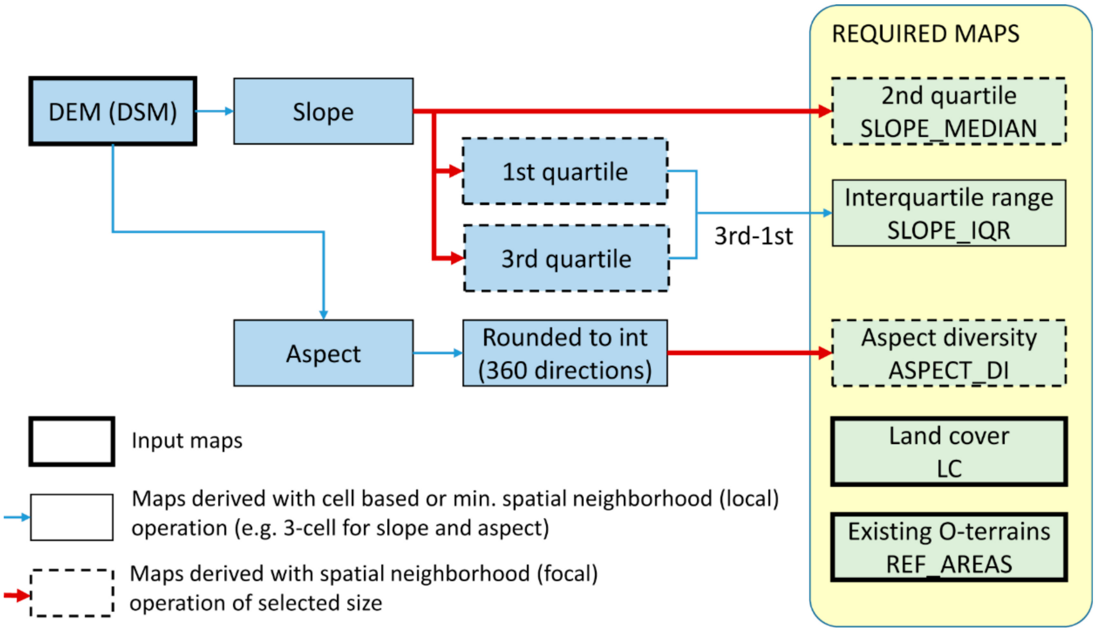


Figure 2. Workflow for preparing required maps for multi-criteria evaluation from input maps.

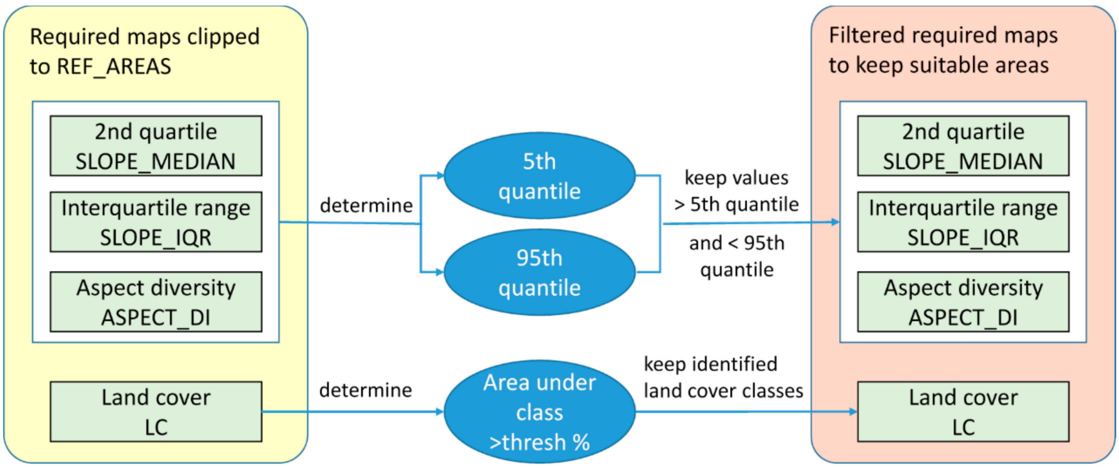


Figure 3. Workflow for determination of each criterion for multi-criteria evaluation.

Finally, the multi-criteria evaluation can be performed using the Boolean operator AND on all four maps, each representing a selected criterion and its values (Figure 4). For a better visual representation, a final binary map of potentially suitable orienteering terrains can be modified with the filling of small holes, and the removal of speckles and too small contiguous areas for setting orienteering courses.

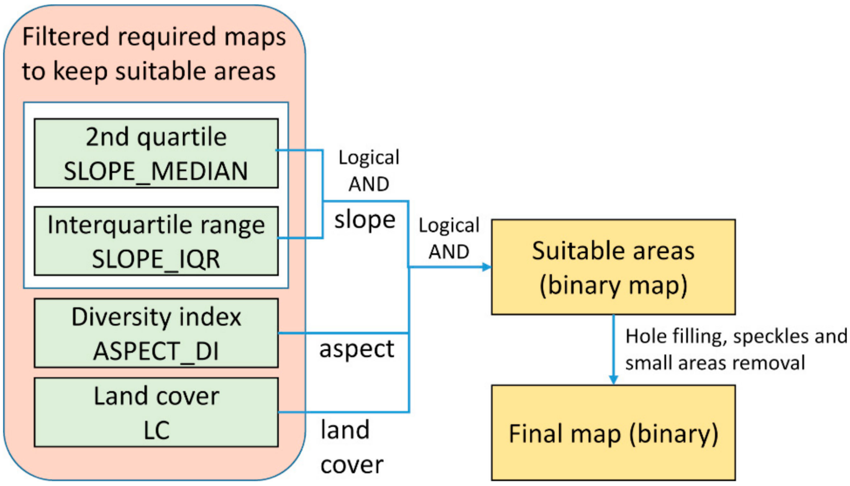


Figure 4. Multi-criteria evaluation model involving only the Boolean AND operation.

4. A Case Study of Croatia and Slovenia

For our case study, the best publicly available datasets were EU-DEM for the terrain model, and CORINE Land Cover.

The Digital Elevation Model of Europe from the GMES RDA project (EU-DEM) is a Digital Surface Model (DSM) representing the first surface as illuminated by the sensors. The term Digital Surface Model represents the earth's surface and shows all objects, including forests and buildings. The EU-DEM dataset is a realization of the Copernicus program, managed by the European Commission, DG Enterprise and Industry. The EU-DEM is a hybrid product based on SRTM and ASTER GDEM data, fused by a weighted averaging approach at 25 m resolution [22]. The first version (v.1) of EU-DEM was released in October 2013. The latest version 1.1 of the EU-DEM was available from December 2017.

The CORINE Land Cover (CLC) inventory was initiated in 1985 (the reference year is 1990). Updates have been produced in 2000, 2006 and 2012. CORINE is a geographic land cover/land use database encompassing 39 of the countries of Europe. The CORINE nomenclature is a 3-level hierarchical classification system. The first level (five classes) corresponds to the main categories of land cover/land use (artificial areas, agricultural land, forests and semi-natural areas, wetlands, and water surfaces). The second level (15 classes) covers physical and physiognomic entities at a higher level of detail (urban zones, forests, lakes, etc.), and the third and most detailed level has 44 classes. The CORINE is a vector map with a scale of 1:100,000, and a minimum cartographic unit (MCU) corresponding to 25 hectares. On a scale of 1:100,000, 25 hectares is represented by a 5 $\times$ 5 mm square, or a circle with a 2.8 mm radius. Linear features less than 100 m in width are not considered. Thematic accuracy is more than 85%; that is, more than 85% of the pattern has the characteristics of a given class from the nomenclature [23].

First, the data was prepared for analysis. The selected coordinate system was EPSG:3035, Lambert equal area azimuthal projection for Europe. The resolution of the raster data in the model was set to 25 m. EU-DEM was downloaded and clipped to the area of interest. The CORINE dataset was re-projected and converted to raster (Figure 5). Areas of existing orienteering maps and terrains obtained as vector polygons were also re-projected and rasterized, creating a mask of reference areas (Figure 6). From EU-DEM, the slope and aspect rasters were calculated.

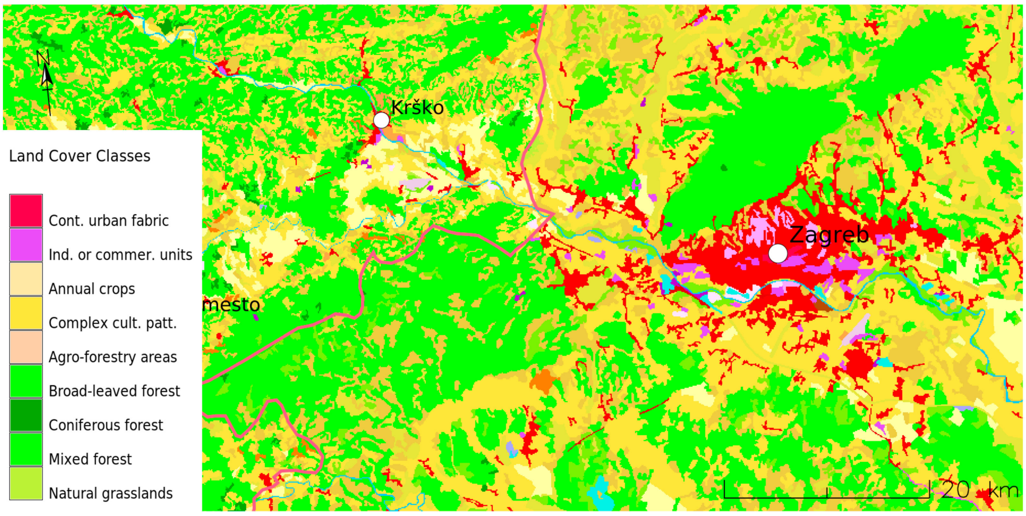


Figure 5. Part of the CORINE land cover dataset.

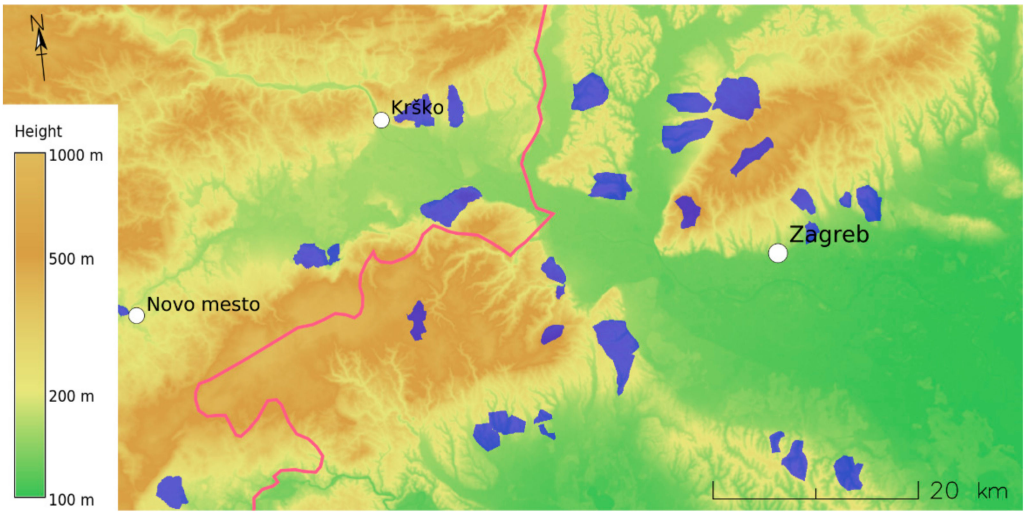


Figure 6. Part of the EU-DEM data overlaid with areas of existing orienteering terrain (blue).

This type of analysis depends on data resolution. One way to produce a more valuable result is to test different resolutions and discover their impact. If data with a higher resolution gives a better and more truthful representation of real world objects, and thus would yield better results, we used the highest available resolution (25 m). This assumption needs additional testing; for instance, for Slovenia, a high-resolution DEM obtained from LIDAR is available, and it is possible to compare results based on it with results in this study. For spatial neighborhood (focal) operations the diameter of the circular area is set to 15 pixels (375 m), and is selected to cover typical leg length in foot orienteering, which is between 200 and 400 m.

Using the neighborhood operator slope median, the 1st and 3rd quartile were calculated. The interquartile range (IQR) was calculated as the 3rd quartile minus the 1st quartile. Then, the histograms of the median (Figure 7) and interquartile range (Figure 8) were created, for the whole area and the area of existing orienteering terrains. Histograms and bar charts were created with custom Python scripts using the libraries *gdal*, *numpy*, and *matplotlib.pyplot*.

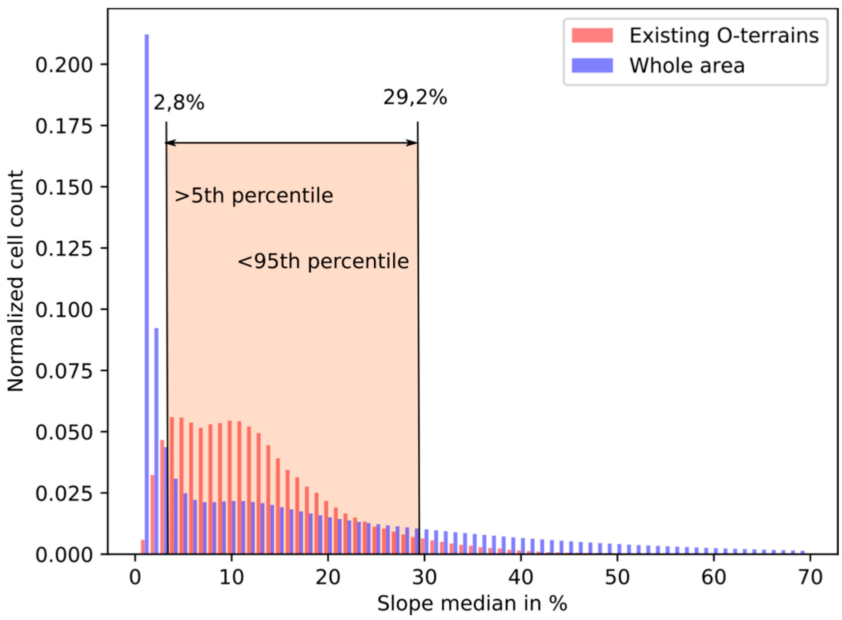


Figure 7. Histograms of the slope median determined for the spatial neighborhood, defined as a circular area with a diameter of 15 pixels, with cut off values determined from existing O-terrains then applied to the whole area.

The histograms reveal that orienteering terrains have a distinct slope value and variation distribution compared to all terrains. They tend to avoid flat and very steep areas (Figure 7), as well areas with small and high slope variation (Figure 8). These findings are consistent with the assumed relationship and relevance of the slope for selecting orienteering terrains (Table 1). For orienteering terrains, the 5th and 95th percentiles of the slope median distribution are 2.8% and 29.2%. For slope variation, these percentiles are 2–18.5%. These values are used for filtering areas with acceptable slope properties (Figure 9). For simplicity and repeatability, we have used only the 5th and 95th percentiles for determination of the cut-off values.

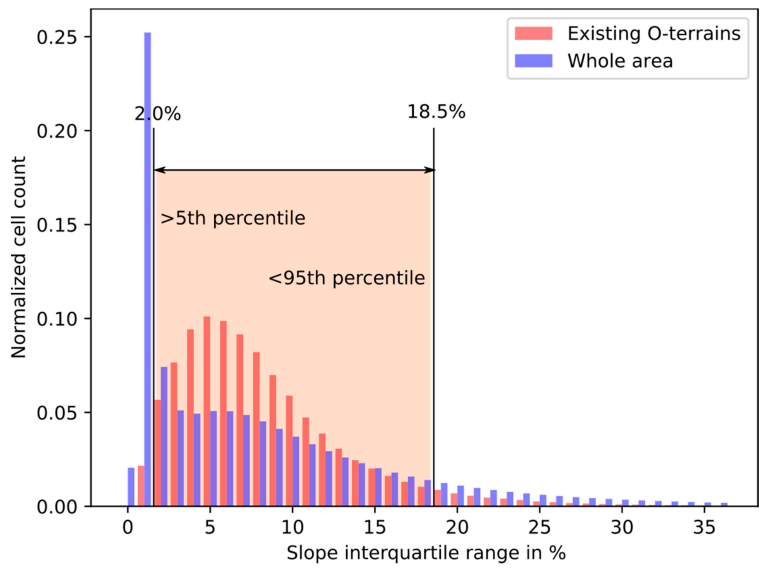


Figure 8. Histograms of the slope interquartile range determined for the spatial neighborhood, defined as a circular area with a diameter of 15 pixels, with cut off values determined from existing O-terrains then applied to the whole area.

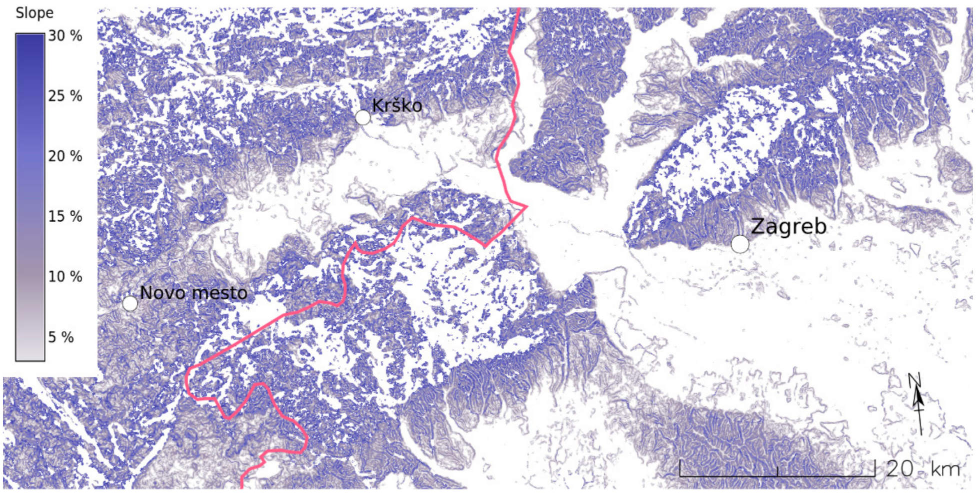


Figure 9. Areas filtered by slope criteria. Flat and too steep areas, as well as areas with very low and very high variation of the slope, are excluded (white).

Comparisons of the slope median and interquartile range (Figure 10) distribution of Croatian and Slovenian orienteering terrains show a similar distribution. This confirms that the application of unique values to regions of both countries is justified. Croatian terrains are a little bit steeper than Slovenian terrains, and the variation of slope represented with the interquartile range shows almost the same distribution.

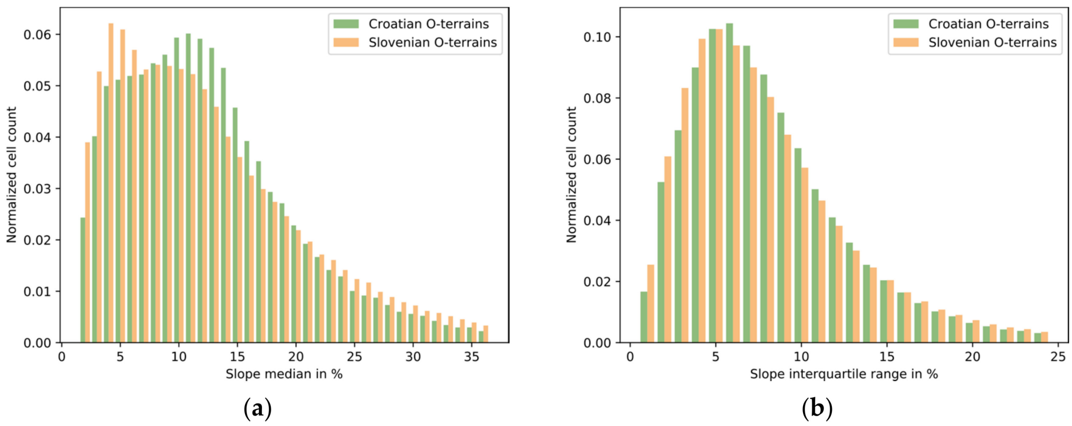


Figure 10. Histograms of slope median (**a**) and interquartile range (**b**) on existing Croatian and Slovenian orienteering terrains.

The second criterion is aspect. Since aspect has different relationship and relevance to orienteering than the slope, we have used only its diversity indication. The absolute terrain aspect does not influence the quality of the terrain, but the diversity of aspect is important as challenging courses should be set on terrains with rich terrain features that are reflected through aspect diversity. For that reason, using aspect values as floating numbers which are in the range of 0–360 is not useful. To obtain a value that will reflect the diversity of aspect over an area of the neighborhood operator, first it was rounded to an integer, and the diversity (i.e., number of different values) was calculated using the neighborhood operator with a circular area with a diameter of 15 pixels. Rounding to integer values is a simple way to classify aspect into a limited number of classes suitable for counting. A smaller number of classes can also be used. Using only a few classes (e.g., eight cardinal and primary inter-cardinal aspect directions) should be avoided, as it leads to over-simplification and the possibility of hiding aspect variation in small landforms.

Histograms for aspect diversity were created for the whole area and the area of existing orienteering terrains (Figure 11).

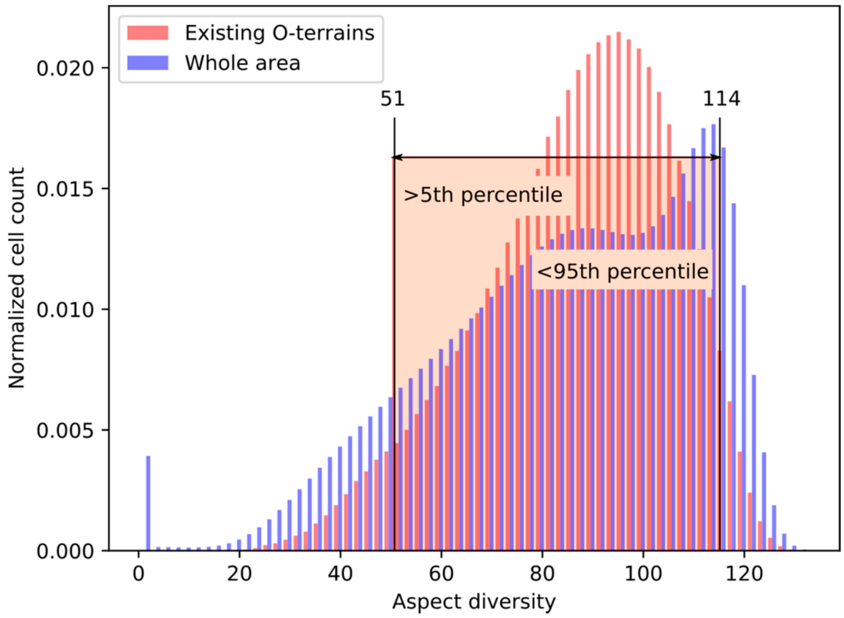


Figure 11. Histograms of aspect (rounded to an integer) diversity determined for the spatial neighborhood, defined as a circular area with a diameter of 15 pixels.

Histograms of aspect diversity reveal that orienteering terrains have distinct aspect diversity when compared to all terrains. They tend to avoid areas of small aspect diversity, as well areas with very high aspect diversity. Very high aspect diversity usually appears in flat areas where even very small height differences cause the calculation of different aspect values. For existing orienteering terrains, the 5th and 95th percentiles of aspect diversity distribution are 51 and 114 (the number of different integer aspect values). These values are used for filtering areas of acceptable aspect diversity (Figure 12).

The question arising here is whether it is necessary to limit aspect diversity to the upper bound. The slope parameter already filters flat areas, and a very high aspect diversity should not be an obstacle for orienteering terrain. This question is to be answered in future work.

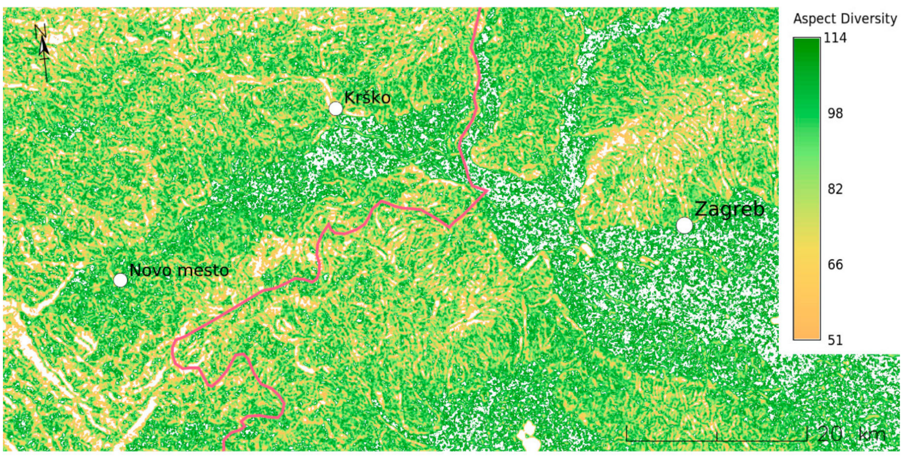


Figure 12. Areas filtered by the aspect diversity criteria. Big slopes with a uniform aspect and some flat areas are excluded (white).

Comparison of the distribution of aspect diversity on existing Croatian and Slovenian orienteering terrains shows a similar distribution. Slovenian terrains tend to offer more aspect diversity (terrain features) (Figure 13).

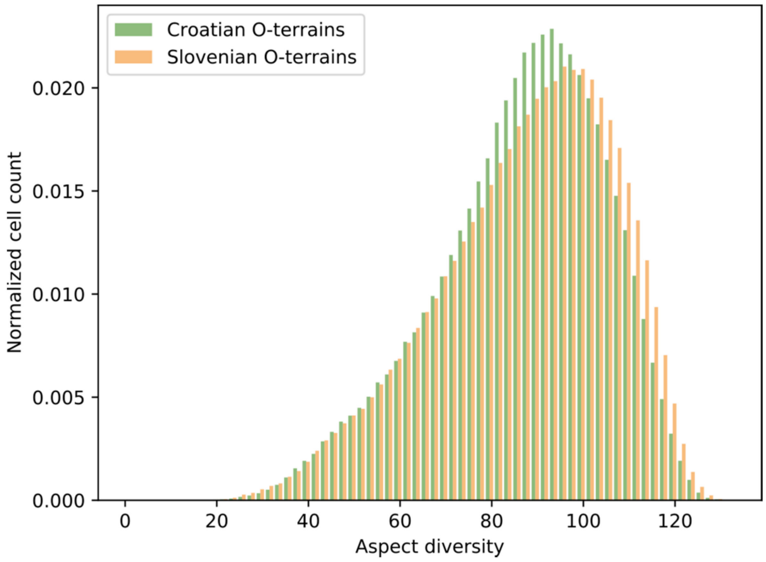


Figure 13. Histograms of the aspect diversity of existing Croatian and Slovenian orienteering terrains.

The land cover data in the CORINE data set is in a nominal scale (distinct land cover classes), and analysis was performed using cell-based (local) operators. Bar charts for the whole area and existing orienteering terrains revealed that forests are the most frequent choice for orienteering terrain (Classes 23: Broad-Leaved Forest, 24: Coniferous Forest, and 25: Mixed Forest), which confirms an unwritten rule that challenging orienteering courses are to be set in forests (Figure 14). The reasons for this arise from the fact that orienteering started in Scandinavia, where maps are mainly drawn in forested areas, and this type of land cover predominates for orienteering in Europe where the majority (estimated by authors) of all orienteering maps in the world are placed. Additionally, a forest setting reduces visibility, thus providing a navigational challenge while often also providing a soft running surface. It is also necessary to stress that in Europe, broad-leaved, coniferous and mixed forests usually provide good run-ability. In other regions, this may not be the case—for instance in Asia and South America, where tropical plants prevent any running in the forest. The predominant land cover classes determined for Slovenia and Croatia should not be used for other countries. Rather, it should be determined from a reference data set of existing orienteering terrains which, in the proposed methodology, represents an expert knowledge component (assuming that these are carefully selected).

Classes that cover up to 10% of the existing orienteering areas are Class 20: Complex Cultivation Patterns, and Class 21: Land Principally Occupied by Agriculture, with significant areas of natural vegetation. Since the run-ability may vary in cultivated land, such areas should be avoided when setting courses [24] but are often covered by orienteering maps because cultivated land is often located near forests or other interesting terrain for orienteering.

A smaller ratio of cover, up to 3% each, is found for Class 2: Discontinuous Urban Fabric, 18: Pastures, 26: Natural Grasslands, and 29: Transitional Woodland-Shrub. Class 2: Discontinuous Urban Fabric was omitted from further analysis since this paper is focused on foot orienteering and not sprint orienteering, that latter of which is usually organized in urban areas. Existing orienteering maps can include a small portion of urban areas that are close to main terrains, and that is the probable reason for its appearance.

Comparison of land cover classes in existing Croatian and Slovenian orienteering terrains shows that broad-leaved forest prevails in Croatia, while in Slovenia the most commonly occurring land covers are coniferous and mixed forests (Figure 14).

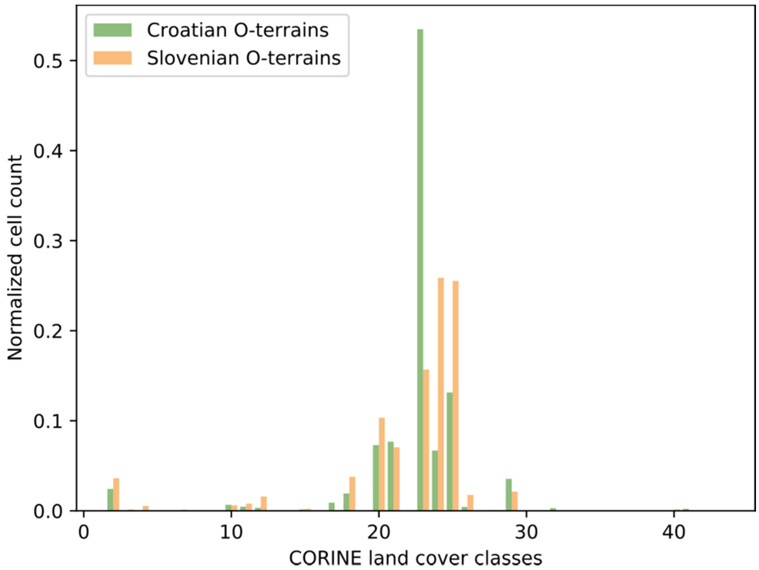


Figure 14. Bar chart of the ratio of land cover classes in existing orienteering terrains.

Filtering of suitable land cover areas was done with CORINE classes: 18 (Pastures), 20 (Complex Cultivation Patterns), 21 (Land Principally Occupied by Agriculture), 23 (Broad-Leaved Forest), 24 (Coniferous Forest), 25 (Mixed Forest), 26 (Natural Grasslands) and 29 (Transitional Woodland-Shrub) (Figure 15).

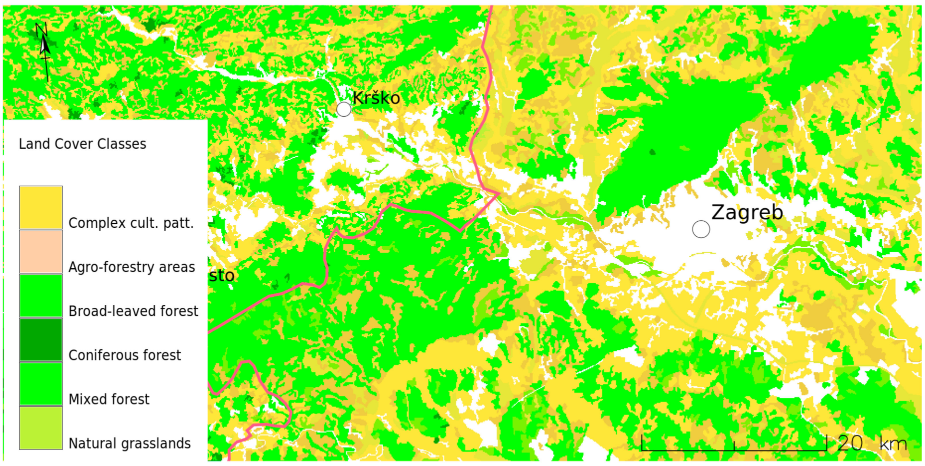


Figure 15. Areas filtered by land cover criteria.

Areas that are potentially suitable for orienteering are given as an overlay of three maps (filtered by slope, aspect, and land cover criteria) using the Boolean AND operator. The result contains small holes and speckles which affect the presentation quality. Hole filling was performed for holes of an area less than 62,500 m^2 (250 $\times$ 250 m) to improve the presentation quality of the result. Such small patches that appear as not suitable for orienteering can be avoided with careful course planning, if necessary. Finally, selected areas with an area of less than 0.5 km^2 were deleted, since very small areas do not allow for proper course lengths (Figure 16).

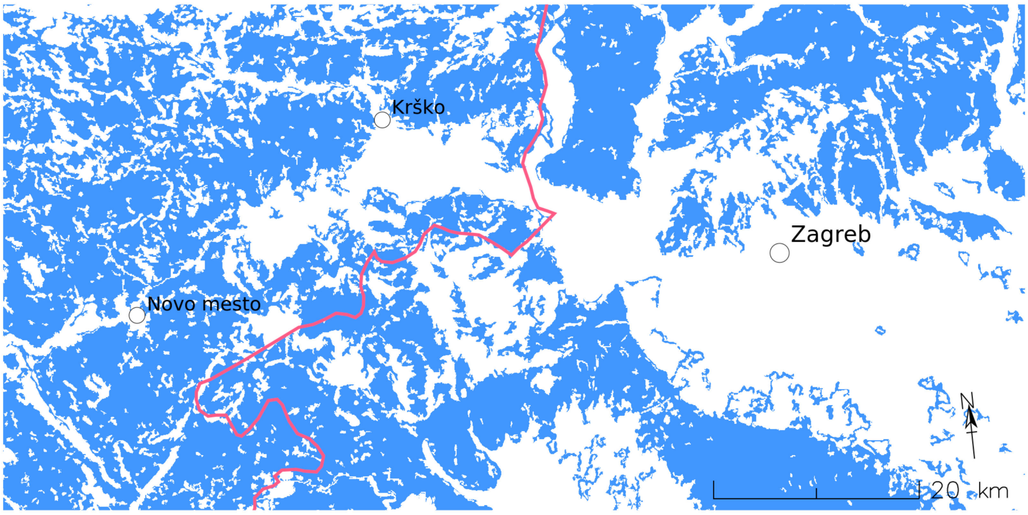


Figure 16. Final areas of potentially suitable terrain for foot orienteering.

The last step in this case study included the addition of quality information to the selected areas. This was achieved by setting rules based on data analysis and expert knowledge in orienteering (Figure 17).

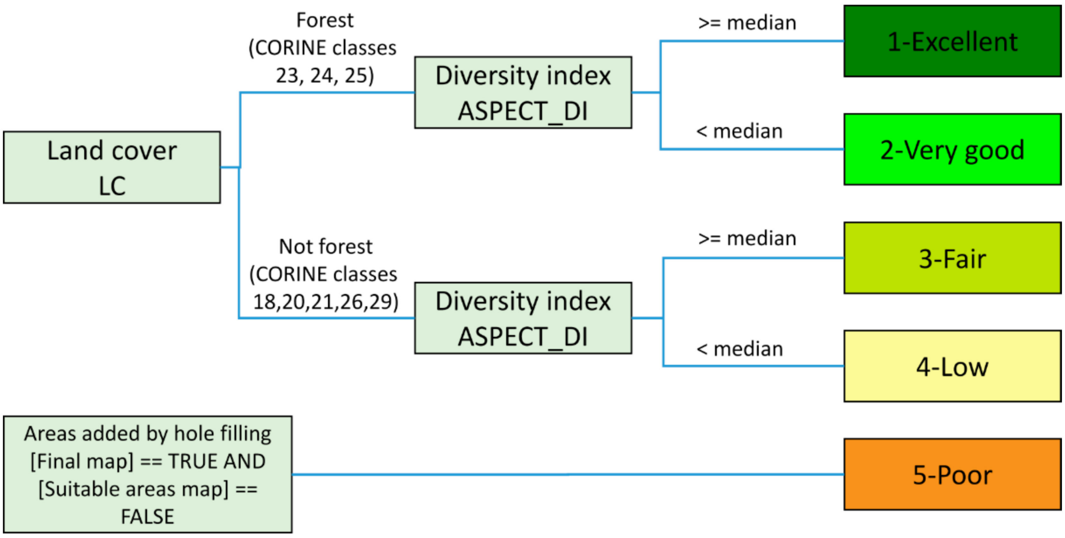


Figure 17. Rules set to indicate the quality of potentially suitable areas.

The predominant land cover classes and higher aspect diversity values (above and under the median value of the existing orienteering terrains) were selected as the most important properties for good orienteering terrain. Since the selected areas already have a slope that fits within the appropriate range, this was not used as a quality indicator. Small areas added in the hole filling operation were classified as of poor quality, but as already mentioned, these can be avoided with careful course planning. Even the best terrains will have patches that are not suitable for running. A map with an indication of the potential quality of terrain for orienteering is given in Figure 18.

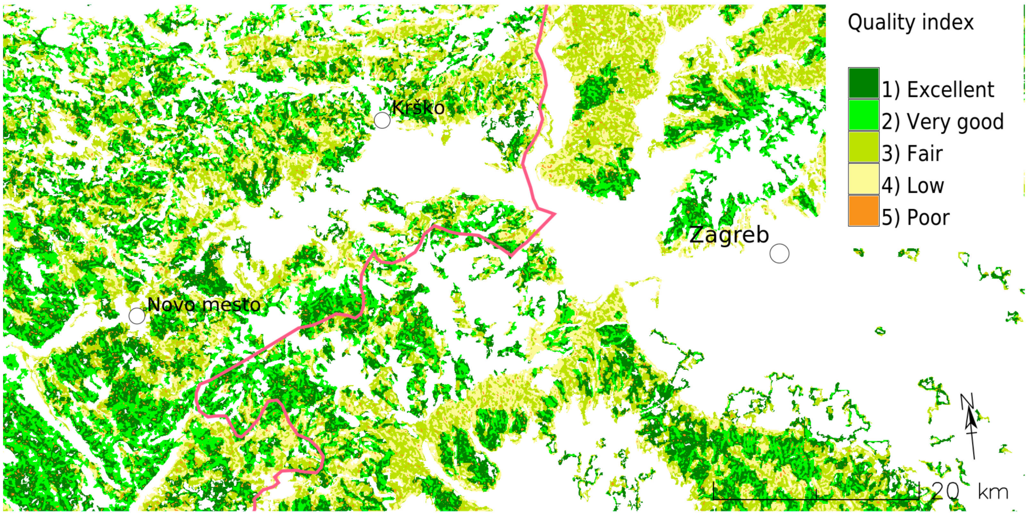


Figure 18. Potentially suitable orienteering terrains with an indication of quality.

Evaluation

To evaluate the filtered areas suitable for orienteering we first use a percentage of the existing orienteering terrains overlapped by the filtered area. A complete overlap is not expected because we only used the 5th to 95th percentile range of variables over the orienteering terrains. There is also the fact that existing mapped areas used for orienteering in Slovenia and Croatia cover neighboring areas (usually some urban or village areas) which are not used for setting orienteering courses, and in our analysis, these were excluded as non-suitable land cover classes. Table 2 gives the percentage of existing orienteering terrains in Croatia and Slovenia overlapped by the filtered area, by quality class.

Table 2. Percentage of existing orienteering terrains overlapped by filtered areas.

Selected Area	Percent of Overlap with Existing Orienteering Terrains	
	Croatia	Slovenia
All	79.3%	73.9%
Excellent	31.4%	28.3%
Very good	29.4%	24.2%
Fair	9.2%	10.1%
Low	7.3%	8.8%
Poor	2.3%	2.6%

The analysis shows that the filtered areas given by the proposed method have a high level of compatibility with existing orienteering terrains, reaching 80% for Croatia and 74% for Slovenia. This confirms that the choice of slope, aspect, and land cover as criteria was justified. Out of the total overlapping area with the existing orienteering terrains, almost 40% is categorized as excellent, and almost 90% as suitable (fair and better). Furthermore, we can see that the final operation—which was used to improve the presentation quality of the data (added areas that were not selected by initial criteria and classified as poor)—did not significantly affect the results (less than 3%).

Next, evaluation was achieved by visual inspection of areas familiar to the authors. According to our evaluation and experience in the selection of suitable areas for orienteering maps, we can conclude that from our point of view, the analysis provides satisfying results. Steep alpine slopes in Slovenia were excluded in the analysis, as well as the Croatian mountains Velebit and Dinara—all areas that are estimated to be too steep for orienteering (Figure 19). By using variations in slope, we have managed to detect reliefs with a diversity of details (such as valleys and ridges) that are very attractive for orienteering running. When comparing results with existing maps, the areas filtered as excellent in this analysis correspond with our evaluation of the terrain from orienteering maps.

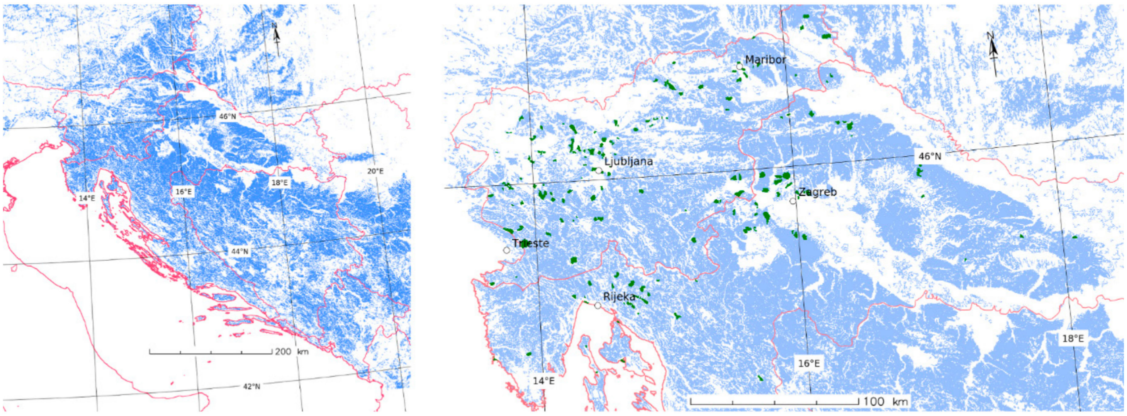


Figure 19. Potentially suitable areas for foot orienteering over the whole area (left) and areas with the most existing orienteering terrains used for the case study (the whole dataset can be downloaded from the GitHub, https://github.com/GEOF-OSGL/Orienteering-Maps/blob/master/Potential_O-terrains_HR_SI_50m_EPSG3035.tif).

On the other hand, the results in southern Croatia and the islands were heavily influenced by vegetation mask, excluding Classes 32 (Sparsely Vegetated Areas) and 33 (Burnt Areas), which may be used for orienteering. At the moment, there are no maps in such places due to a lack of orienteering clubs, resulting in a lack of input parameters for the land cover analysis. Therefore, these areas were not recognized as potentially interesting for orienteering running. Because this type of terrain can sometimes be dangerous for running due to sharp karst formations (škrape) and heavy ground, the best way to check this area in the future is through field control by experienced orienteers. These issues were the reason we chose to use existing orienteering maps as a reference data set in the proposed methodology.

By publishing the results to the orienteering communities in Croatia and Slovenia, orienteering experts will be able to give feedback and estimate the fitness of the results, thus improving the presented evaluation. One must keep in mind that if areas are excluded by the proposed method, due to its limitations, it does not necessarily mean that these are in fact unsuitable for setting foot orienteering courses. The presented results should be mainly used for finding new terrains that have suitable geomorphology and land cover. The final raster dataset with a resolution of 50 m is published under a CC-BY-SA license on GitHub (https://github.com/GEOF-OSGL/Orienteering-Maps/blob/master/Potential_O-terrains_HR_SI_50m_EPSG3035.tif), and over the Web Map Service with a resolution of 150 m on QGIS Cloud (https://wms.qgiscloud.com/dtutic/qgiscloud/).

5. Conclusions

For the first time, detection of suitable terrain for foot orienteering based on geomorphology and land cover, using multi-criteria land evaluation and a new methodology, was performed. The results of the case study give potentially suitable areas for foot orienteering in Croatia, Slovenia, and neighboring areas. Open spatial data sets, in this case the EU-DEM and CORINE land cover datasets maintained under the Copernicus program of the European Union, were successfully used for this task. The presented methodology and results may encourage orienteering development and help professionals find new orienteering terrains never used for that purpose before. The straightforward method proved to be simple and easily implemented using standard raster GIS operators. The initial evaluation in the presented case study showed that we were able to get reasonably reliable results.

The hypothesis that there exist suitable orienteering terrains not used for that purpose before, and that they can be found using multi-criteria evaluation and assessment of existing orienteering terrains, is proven by the application of the proposed methodology to the case study.

Further refinement of the selected areas should include additional criteria. There are some factors which can influence the final choice of new orienteering terrains. Forbidden areas (private access), mine suspected areas (very important for Croatia), land parcels and owners, access to the terrain by vehicles, distance to the traffic network, density of vegetation, run-ability, frequency of changes in the terrain, and possible dangers on the terrain are some examples of such factors. Some of these criteria can be applied at a regional level if such reliable data sources exist (e.g., traffic network or mine suspected areas), and some only to smaller areas (e.g., frequency of changes, dangers from wild animals).

Based on the results obtained by the proposed methodology, one additional conclusion is that Croatia and Slovenia each have around 45% of the total country territory potentially suitable for foot orienteering. That is a notable potential resource for the advancement of the sport, and for further refinement of the presented methodology based on additional data and criteria.

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