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Research Article

Reconsidering the basics of mountain trail categorisation: case study in Slovenia

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Abstract: Mountain trail categorisation remains an important piece of information for hikers when selecting a trail and preparing for a hike, despite new developments in trail difficulty assessment and trail recommendation systems and tools. National or regional trail categorisations should maintain a simple, mainly descriptive form to remain a useful guide for the majority of hikers. However, they are often still based on subjective expert assessments of trail difficulty. In this paper, we combine findings from our own empirical research and from the literature to support two arguments: available or obtainable geographical information and GIS -based methods can contribute to the objectivity of mountain trail categorisation, and improved categorisation contributes to increased hiking safety. An experimental GIS-based categorisation of mountain trails in two areas in Slovenia is conducted to support the above arguments. The comparison of the experimental categorisation with the existing official categorisation and the identification of potentially dangerous trail sections support perhaps the most important of the two arguments, namely the potential to improve hiking safety. However, it also stimulates further discussion on the establishment and implementation of an international standardisation of trail categorisation.

Keywords: GIS-based evaluation support; hiking; mountaineering; objective categorisation; mountain trails; international standardization; safety

Highlights:

- Unused potential of available geographic information and methods for trail categorisations.
- Experimental objective categorisation based on inclination and exposure of the trail.
- Systematic GIS-based detection of potentially dangerous trail sections.
- Objectifying categorisation can provide information that can potentially improve hiking safety.
- Transferable, upgradable method as a prerequisite for international standardization.

1. Introduction

Mountain hiking is an increasingly popular recreational activity. In some countries, more than a hundred times as many people participate in this activity as are recorded in the membership figures of mountaineering and similar associations (Apollo, 2017). For many hikers, it is essential to learn about a trail before and during a hike. Mountain trail categorisation has historically played a central role in providing this simple but important information in printed mountain trail guides and maps, on signposts along trails, and in some cases in the form of trail blazes reflecting the various trail categories. The assessments of the trail difficulty, and the categorisation of trails as one of their specific forms of information for hikers, are the result of long-term processes carried out mainly by national or regional mountaineering organisations. Only remotely inter-related discussions and decisions have led to different trail assessments or categorisations (explained in more detail in sections 1.2 and 1.3). We can assume that each was carried out as the best that was feasible and reasonable under the circumstances. Many features of trails or hikes have been considered conceptually but not actually measured or assessed only at a very general spatial level rather than at the spatial scale experienced by a hiker during the hike. One of the reasons for such indirect, inaccurate assessments is the enormous amount of work that has already been invested into producing such expert assessments, which deserves our respect and admiration. In recent decades, however, conditions for trail difficulty assessment and categorisation have improved. These include advances in technology, the availability of geographic information and tools, and knowledge about the characteristics of mountain hikes. To date, these new realities have had little impact on the mountain trail categorisations. In this paper, the logic described above is followed to stimulate and support the research and policy decisions needed to find and apply the best feasible and reasonable assessments and categorisations of trail difficulty, considering these new realities.

Nowadays, in addition to the printed form or signposting, categorisations of mountain trails are also conveyed in digital form, e.g., on online websites presenting mountain trails (e.g., Hribi.net, 2023; maPZS, 2023; Valrando, 2023). Among the outstanding examples that take advantage of the multiple opportunities offered by current advances in technology and geospatial information is the Syris platform (Calbimonte et al., 2020; 2021) for assessing and recommending trails. The authors' rationale for developing such a complex tool is that a given hiker requires more personalised, detailed, diverse, and situational information than a simple categorisation of mountain trails can provide. Given the ubiquity of digital technologies and their usability in recreational activities such as hiking, such views seem reasonable and have been empirically supported (Calbimonte et al., 2020). The intention to reduce the overwhelming amount of information about hiking trails through such complex tools is welcome. While they rely on a huge amount of data, they transform it into relevant information that a hiker can efficiently process and use. However, such an approach assumes that a hiker is constantly dependent on the provision of digital information about trails and hikes in real time, while he or she may embark on a hike precisely to escape this digital presence and dependence. The absence of a mobile signal or limited battery capacity may further complicate the frequent use of a smartphone while hiking. In a very likely situation, a hiker might see a hike as an opportunity for interesting exploration and simply want a reliable general assessment of the difficulty of a trail, including the effort or equipment required and the potential risks on a particular trail. This type of information is expected from a mountain trail categorisation.

This study reconsiders the relevance of mountain trail categorisation, assuming that a hiker needs both mountain trail categorisation and the more detailed and complex trail information as in Syris and other similar online services. The mainstream of research on mountain trail assessment is closely related to the discussion on trail categorisation, as they complement each other. The main questions that this study aims to answer are divided into two groups.

The first group deals with questions about the important features of mountain trails and the characteristics of mountain trail categorisation as a method:

- (Q1) Which features of mountain trails are essential for mountain trail categorisation?
- (Q2) Which are the expected characteristics of mountain trail categorisation?

The second group deals with questions about the objectivity of categorisation:

- (Q3) Which features of mountain trails are objectively measurable?
- (Q4) Can the introduction of objective criteria based on objectively measured data help to improve the expected characteristics of mountain trail categorisation?
- (Q5) Do the empirical results support expectations regarding the objectification potential of mountain trail categorisations?

The main activities in the search for answers to these questions include learning from methodological developments in research areas relevant to our research topic, observing existing mountain trail categorisations, and a case study in Slovenia. The latter consists of an empirical comparison between an attempt at an objective, experimental trail categorisation and the existing national trail categorisation based on subjective assessments by experts.

The remainder of the paper is organised as follows. First, we set the context for the discussion by providing an overview of a broader field of research focused on mountain trails and hiking (Section 1.1), identifying features and dimensions in mountain trail difficulty assessments, discussing potential for objectivity of such assessments (Section 1.2), and exploring selected mountain trail categorisations (Section 1.3). The empirical part of the paper begins with a presentation of the study areas (Section 2) and the empirical methods used in the case study (Section 3). Then, the results of an experimental categorisation of mountain trails in selected study areas are presented and compared with the official national Slovenian categorisation of mountain trails (Section 4). In the discussion, the answers to the main questions of this study are given and the results of the empirical part of the study are critically evaluated (Section 5). In the conclusions (Section 6), future development perspectives for the categorisation of mountain trails and the assessment of trail difficulty in general are identified.

1.1. Mountain trails and hiking in research: the context

A mountain trail (in the rest of the text also just trail) is not a uniformly defined term. For the purposes of this study, we follow Slovenian legislation (Mountain Paths Act, 2007) and define it as "a narrow strip of land," usually in hilly or mountainous terrain, "intended for walking, running, or climbing." It is usually "no wider than one metre and only where it is necessarily hardened with natural material." Despite some differences in meaning, the terms "path" and "trail" are often used as synonyms in practice, but the term "trail" seems to be more common.

In this paper, we consider mountain trails primarily from the perspective of their frequent users, mountain hikers. We define a mountain hiker (in further text also just hiker) as a person who undertakes a long hike in the mountains as a recreational activity, aims for some level of physical effort, and uses basic hiking or safety equipment where appropriate (e.g., on more difficult trails), such as walking sticks, helmet, harness, crampons, or the safety devices mounted on difficult sections along a trail. Some definitions of hiker differ by, for example, emphasizing the length or duration of hikes (e.g., several days) or indicating that no special equipment is required for hiking. On the other hand, the definition of mountaineer, which some could consider synonymous with the mountain hiker defined above, often includes sport as a motive for one's activities in the mountains and requires advanced skills (e.g., climbing) and equipment (e.g., ice axes, ropes). In our further text we limit the discussion to hiking, which only occasionally, in the highest trail difficulty rank, include elements of mountaineering (such as using hands, personal protective equipment like helmet, crampoons, harness).

Mountain trails and hiking are often the focus of current research, which in various ways creates the knowledge needed to better understand their characteristics and effects. Studies of the motives for hiking (or other trail activities) or selecting particular trails or landscapes (Snyder et al., 2008; Mohd Taher et al., 2015; Collins-Kreiner & Kliot, 2016; Li et al., 2017; Tomik et al., 2017; Upadhayaya, 2018; Korpilo et al., 2018; Sales et al., 2018; Wolek et al., 2021) contribute to understanding important aspects of hiker safety or satisfaction, or focus on collecting hikers' opinions to support management of the trails and risk prevention (Slabbert and Du Preez, 2017a; 2017b). Further studies assess hikers' experiences or satisfaction at the beginning, during, or after the activity (Gauvin et al., 2005; Deng et al., 2013; Mohd Taher et al., 2015; Apollo, 2017; Li et al., 2017; Korpilo et al., 2018; Peterson et al., 2018; Arts et al., 2021; Daniel et al., 2021; Sukumar & Ahmed, 2021; Wang et al., 2022), some of them emphasise the temporal aspect of hiking (Pitman et al., 2012; Magyari-Saska & Dombay, 2012).

Within a broader research context of mountain trail planning and management, trail alignment and similar GIS-based methods for searching potential or optimal connecting trails between known sites have a decades-long tradition (Xiang, 1996; Kliskey, 2000; Snyder et al, 2008; Chiou et al., 2010; Tomczyk & Ewertowski, 2013). Another vibrant area of research addresses the environmental impacts of hiking on trails, including trampling as one of the highlighted activities and soil/trail surface erosion as one of the common impacts. Various methods have been developed for assessing potential impacts and making recommendations to avoid environmental damage (Leung & Marion, 1999; Tomczyk, 2011; Tomczyk & Ewertowski, 2013; Ólafsdóttir & Runnström, 2013; Marion & Wimpey, 2017; Tomczyk et al., 2017; Vandanakis et al., 2019; Eagleston & Marion, 2020; Salesa & Cerdà, 2020; Sahani & Ghosh, 2021; Martin & Butler, 2021), including studies on sustainable management of mountain trails (Upadhayaya, 2018).

Studies more closely related to trail categorisation focus on assessing the suitability or difficulty of trails (Vías & Ocaña, 2014; Vías et al., 2018; Peterson et al., 2018; Campbell et al., 2019; Kanoulas et al., 2019; Zürcher et al., 2020). Some pay particular attention to assessing trail-related relief features such as inclination or other (Kliskey, 2000; Chiou et al., 2010; Clius et al., 2012; Tomczyk & Ewertowski, 2013; Tomczyk et al., 2017; Campbell et al., 2019; Kanoulas et al., 2019; Eagleston, Marion, 2020), or also consider external factors of hiking risks (Zürcher et al., 2020). Hikers' technical equipment and the importance of mountaineering education have been studied, mostly in relation to safety and preparation for hiking (Rochat et al., 2019; Zürcher et al., 2020; Arts et al., 2021; Daniel et al., 2021). An interesting study highlights the importance of knowing, correctly understanding, and following instructions such as warnings (Kortenkamp et al., 2021), which reminds us that even provided precise information is not necessarily followed by hikers. However, several studies emphasise the importance of local, precise measurements about the sections of the trails (Leung & Marion, 1999; Ólafsdóttir & Runnström, 2013; Tomczyk & Ewertowski, 2013; Kanoulas et al., 2019; Zürcher et al., 2020; Eagleston & Marion, 2020) to obtain reliable information and make relevant decisions about hiking. Examples of more applied research are seeking solutions for personalised, even real-time, delivery of relevant information to a hiker, such as already mentioned online platform for difficulty assessment and recommendation of hiking trails (Calbimonte et al., 2020 and 2021), or aiming at optimising trail or activity selection, studying walkability or ecometrics (Gauvin et al., 2005; Kanoulas et al., 2019; Frank et al., 2021; Wolek et al., 2021). Important findings from such studies include evidence of interpersonal differences among hikers and of various difficulties while hiking in different directions of a trail, e.g., uphill or downhill (Campbell et al., 2019).

The methodological and technological advances in trail assessment outlined above are contrasted by the lack of development in objectifying official (national, regional, or hopefully in perspective, international) trail categorisations. Almost all of the authors mentioned above used GIS as an essential tool for their research. Some used objective data to evaluate trail characteristics or activities conducted on trails. Many of these data and methods are similar or equivalent to those that can be used for trail categorisation, but as far as could be learned from the existing literature, they are rarely used for this purpose. Thus, objectifying categorisation of trails is not hindered by a lack of relevant data or methods or by not knowing that they exist.

1.2. Features, dimensions, and objectivity in trail difficulty assessments

For a hiker, information about a trail that is appropriate for his or her fitness level, experience with movement in difficult conditions, and availability of hiking equipment is critical to assessing his or her prospects for psychophysical performance during the hike, as well as for his or her safety and satisfaction with the hike. There are several approaches to providing such information to a hiker, but two are of particular interest in this study. Trail categorisation, discussed in more detail in the next section (Section 1.3), and the broader concept of trail difficulty assessment, discussed here.

Assessing the trail difficulty can range from simple data on the duration of the hike and the categorisation of the trail to an extremely complex personalised assessment of a hiking situation that matches the hiker's abilities, health status, and other relevant personal information with the difficulty of the trail and other information relevant to the hike. The increasing number of sources of information about mountain trails and other circumstances of a hike, such as weather or traffic, are a growing burden for hikers. One of the main problems to be solved in modern approaches to providing such information is the definition of the **relevant features (or characteristics) of trail difficulty** to be measured and efficiently provided to hikers. Calbimonte et al. (2020; 2021), building on the methodology used by French Hiking Federation (FFRandonnée, 2023), highlight three particularly important **dimensions** (also aspects or criteria, as named by Calbimonte et al., 2020) of such features which are also, directly, or indirectly, taken into consideration in majority of trail categorisations discussed in the section 1.3:

- effort: assessment of the effort, physical energy, required by a hiker on a particular trail,
- technique: assessment of the technical skills and equipment required to overcome obstacles/difficulties along the trail, and
- risk: assessment of the situations to which a hiker is exposed that could lead to possible accidents, injuries, or other hazards, related also to hiker's psychological condition.

Selected examples of various trail features or other circumstances during the hike (drawn primarily from eight different published assessments and categorisations of trail difficulty) are listed in Table 1 and grouped according to the dimensions of trail difficulty presented above. The listed features range from physical characteristics of a path or its adjacent slopes, technical equipment of a trail and hiker, personal abilities, and knowledge of a hiker, to external hiking circumstances such as weather or mobile network coverage. The list of features in the table is not considered to be complete. However, it also shows features that are rarely or never used in trail categorisations (the reasons for this are discussed in the next section).

Depending on how they are assessed, features are further divided into objective and subjective. In general, objective features can be assessed and verified objectively, while subjective features can be determined either by information from experts or by hikers' (subjective) assessment of the difficulty of a trail. Based on approaches known from the literature or from our own practice, Table 1 also attempts to determine the methodological **applicability of objective assessments** of the features listed above in the current situation, or in the near future. Some of the objective features were identified as objectively measurable using readily available relevant data and GIS -based tools (<u>underlined</u> in Table 1). Of the subjectively assessed indicators, only one was identified as objectively (indirectly) assessable: risk of vertigo. Developments in assessing trail difficulty are very rapid, so some of the features could potentially be assessed objectively (*italicised* in Table 1) under certain circumstances, such as availability of relevant data, development of appropriate methods, or extensive field measurements. Other features listed in the table are not automatically considered objectively measurable at the time this study was conducted and given current knowledge, data, and tools. In the appraisal of the features potentially suitable for trail difficulty assessment Calbimonte et al. (2020) point out that automatic or semi-automatic assessments of technique and risk are so far not yet feasible using the current technologies. Our assessments in Table 1 are more optimistic, which is demonstrated also by the methods used in the empirical part of this study (see section 3).

To avoid confusion, we add a brief remark about the concept of **objectivity of trail assessment**. Objective information is based on observable, measurable facts and is not influenced by personal (subjective) opinions or feelings. In practice, it can take two forms: as objectively potentially measurable characteristics of a trail or as its actual, objectively measured characteristics. In this paper, we focus on the latter form, i.e., the actual measured objective information. This is an important detail, because including objectively measurable information such as "steep trail section" in the description of a trail can give the impression that it was objectively measured, even though it was subjectively assessed by an expert or provided by a hiker as voluntary crowdsourced information. This is not a simple trust or accuracy issue, as both the expert and the hiker would likely make the assessment as accurate and honest as possible. It is primarily a **problem of semantics and the hiker's safety** (although other aspects such as the hiker's satisfaction or stress may also play a role). Semantically, the problem arises from the fact that the term assessed subjectively can actually lead to a homonym that has a different meaning for the expert than for a hiker. For example, an expert has the task of identifying steep sections of a trail and communicating them to the general public, such as less experienced hikers (in the form of a trail category or a warning in the description of a particular trail). He might not notice the steepness, which might already be problematic for some hikers. Subjective features in assessing the difficulty of a trail, such as the need to use hiking sticks, or to use hands to pass a particular section of a trail, are even more prone to misinterpretation. They are easy to understand, but there is an even greater risk of a discrepancy between the expert's perception of the trail (who assesses the difficulty of the trail) and the hiker's perception. Occasionally we come across reports of such negative experiences when reading, for example, mountain hiking forums on the Internet, but also some of the statistics on accidents in the mountains may be due to misperceptions of the actual situation based on difficulty ratings of mountain trails.

Table 1. Examples of trail or hike characteristics used in selected mountain trail difficulty assessments and categorisations grouped by the aspect and objectivity/subjectivity of the assessment (underlined and italicised characteristics at least potentially objectifiable, explanation in the text)[1]

Aspect of difficulty assessment	Objective measuring/assessment	Subjective assessment
Effort	• Average inclination of a trail, or its longer (e.g., 100 m) local section • Inclination of ascents or descents, whole trail or section • Trail length, vertical difference, ascents and descents, changes in trail inclination • Altitude • IBP Index	• Required hiker's (physical) fitness
Technique	• Short pitch (e.g., 5 m) inclination of a trail section • Maximum short pitch inclination of a trail • *Obstacles, steps, height of feet movement* • Crossing talus/scree, glacier,[2] water body • *Visibility, existence of a path* • *Markedness of the trail by blazes or other signposts* • *Existing trail safety devices*[2] • Path surface (solidity, roughness) • Path regularity (bends, branching, direction changes)	• Required hiker's abilities, knowledge and equipment; "surefootedness", "good balance", "good preparation", "normal behaviour", "care" • *Need to use hands to keep balance and advance* • Required safety equipment of a hiker and of the trail[2] • Required orientation skills
Risk	• Short pitch (e.g., 5 m) inclination of a trail • Maximum short pitch inclination of a trail • Inclination of the adjacent slope • Exposure of a trail section • Crossing talus/scree, glacier,[2] high or insecure bridge • *Existing or missing trail safety devices*[2] • *Path width* • Mobile phone network coverage • *Availability of drinking water* • *Availability of emergency assistance*	• Absent or damaged safety equipment of the trail • Required use of safety equipment of a hiker and of the trail[2] • Assumed hiker's abilities, knowledge and equipment • *Actual hiker's physiological, psychological conditions, mood* • *Perceived trail difficulty* • *Increased risk in particular weather* or other conditions (group dynamics, wild animals etc.) • Risk of getting lost • *Risk of slipping, falling (dangerousness)* • Risk of vertigo • Risk of mugging, attack

[1] Sources: Mountain Paths Act (2007), Schweizer Alpen-Club SAC (2022), Club Alpino Italiano (2021a, 2021b), Forrest Service (2008a, 2008b), Calbimonte et al. (2020, 2021), Amt der Tiroler Landesregierung (2018), Upadhayaya (2018), ibpindex.com (2023).

[2] Some of the features appear multiple times in the table if they are strongly associated with more than one dimension of difficulty assessment.

In our further discussion and in our case study, we claim that objectification of measurements and their analyses could reduce the problems arising from the subjectivity of expert assessments. By **objectification**, we primarily mean measurements that can be made automatically using available digital geographic data and transformation of these data into an assessment or categorisation of trail difficulty based on objective criteria/methods. Since this information is closely related to safety and the other aspects of hiking experience, we believe that even the slightest improvement in the objectivity of the information and the resulting unambiguity of its perception is worth further research and education. However, objective trail difficulty assessment or categorisation alone is no guarantee that the above problems will disappear. Hikers will need to do their part and learn what a particular measured feature of a trail means, preferably through practice on hikes. As we learn in this section, all the important aspects of a trail difficulty assessment might not be objectively measurable, which means that at least until relevant data exist and methods are developed, such assessments will remain a combination of objectively and subjectively assessed information.

1.3. Mountain trail categorisation

Categorisation (or classification, often used as a synonym) is the division of objects into categories (classes, types), i.e., groups of objects with similar characteristics, so that objects can be clearly assigned to one of the categories and members of a category can be clearly distinguished from non-members. In practice, categorisation is a tool to simplify the representation and perception of the observed phenomenon. From a basic statistical point of view, the categorical (or nominal) scale of measurement allows only a distinction between memberships of categories, i.e., membership in one category does not mean more or less than membership in another category. However, most categorisations of mountain trails involve ranking: trails are not only categorised, but the higher categories also mean more difficult trails, which is characteristic of an ordinal measurement scale. Because trail categorisation usually requires consideration of several circumstances, e.g., related to the trail, the hiker's equipment and fitness, assessed quantitatively or qualitatively, there is an increasing need to make the final categorisation as simple as possible. Consequently, the term "trail categorisation" seems as appropriate as "trail ranking", "trail scale" (as in Schweizer Alpen-Club SAC, 2022), or (as in Pogachnik, 2022) "trail grading".

A **mountain trail categorisation** (in further text also MTC) therefore refers to a robust division of mountain trails into categories, which are usually broad, static over time, simplified and ordered representation of trails' difficulty. A clear and simple trail difficulty categorisation is an important tool for the hikers to assess the expected requirements in relation to their abilities, essential for the hiker to choose a suitable trail (Gradič Oset, 2021), but contributes also to accident prevention and serves as an aid to trail keepers (Amt der Tiroler Landesregierung, 2018). A trail **category** usually presents only the overall, simplified level of its difficulty, and functions as its title. It is its descriptive part that provides more tangible information to a hiker. **Descriptions** of the trail categories include references to different aspects of the characteristics of trails or hiking. But only **further details** about the actual ways of assessing the selected aspects of the trail difficulty can help to understand whether data behind the categorisation are actually measured, objective, or they are assessed subjectively. Such details are usually found in the documents of alpine associations, or national legislation acts, which provide guidelines, rules, and responsibilities regarding the trail categorisation.

To develop a more general characterisation of MTC, we first look closely at a few selected existing MTCs, and then re-evaluate their characteristics from the perspective of the new realities discussed in the section 1.2.

First, we consider the official, national trail categorisation in Slovenia (also referred to as OTC in the rest of the text), which is used in the empirical part of our study. OTC is qualitative, descriptive, and based on subjective assessments of trails by various experts. It is regulated by the Rules on the Categorisation of Mountain Paths (2008) and the Mountain Paths Act (2007). The marked trails are divided into 3 categories according to their level of difficulty: easy, difficult, and very difficult. The descriptive definitions of these categories, including the skills, fitness, or personal safety equipment required, are listed in Table 2. The most detailed information on how the actual trail assessments are done can be found in the Rules on the Categorisation of Mountain Paths (2008). The assessments depend solely on the opinions and skills of experts and are not supported by analysis of available geographic information. Numerous experts were involved in the preparation of OTC, e.g., the editor of the cartography of the Slovenian Mountaineering Association, hiking guides, mountain education instructors, the editor of the mountain trails cadastre, reviewers of mountain maps, and authors of mountain guides (Rotovnik, 2016). In addition, two ministers, responsible for sports and for spatial planning, are responsible for the legal design of this categorisation (Rules..., 2008). Given the diversity and number of experts involved, as well as the number and length of mountain trails they must categorise (see Section 2), the rigidity of the system and the need for stable categorisation are obvious.

Table 2. Slovenian mountain trail categorisation (OTC)[1]

Level	Description and requirements
Easy mountain trail	A hiker can move with normal mountaineering equipment, he does not need to use his hands for help, but he can make walking easier by using walking sticks. Where the easy mountain trail crosses a steep slope, it must be wide enough to allow safe walking even for less skilled users. All that is required is care, fitness, and suitable footwear.
Difficult mountain trail	A hiker must use his hands to help himself in some difficult places. It is equipped with safety devices (such as steel cables) that help the hiker to keep his balance. Caution, physical fitness, and appropriate equipment are required of users of a difficult mountain trail.
Very difficult mountain trail	The use of hands is essential, and has built-in metal cables, pitons, steps, or similar safety devices that allow the hiker to walk safely in areas that would be impassable to less experienced or fit mountaineers. It is recommended that self-protection kit, a helmet, or a climbing harness be used for additional protection.

[1] Rules on the Categorisation of Mountain Paths, 2008.

In selected categorisations from other Alpine countries, i.e., Switzerland, Austria and Italy, similar idea is followed, with some differences in criteria and number of categories (or levels). The Swiss categorisation of mountain trails (Schweizer Alpen-Club SAC, 2022) descriptively defines six categories based on difficulty of orientation, marking of the trail with blazes, inclination of the trail, whether it is protected by cables, need for using hands, type of surface (e.g., grassy areas, snowfields, glacier sections are considered more difficult), and exposure, i.e., sections with a risk of falling (Schweizer Alpen-Club SAC, 2022). It is shown in Table 3 as an example of a more detailed MTC. In the categorisation of trails in Tyrol, Austria, trails are divided into three categories: hiking, mountain and alpine. The second category mainly corresponds to the term mountain trails used in this paper. Mountain trails are further categorised according to the steepness and exposure of the trail as well as the required orientation skills and equipment of the hiker (Tyrol Info, 2022). According to the Tyrolean approach (Amt der Tiroler Landesregierung, 2018), the difficulty of a trail generally depends on its width, inclination, ground conditions, and exposure, and is essentially determined by its most difficult passage. The difficulty of a trail does not necessarily correlate with the dangerousness of hiking, so they suggest complementing the assessment of the technical difficulty of a trail with an assessment of its dangerousness. The Italian Alpine Club defines a four-level descriptive scale for the categorisation of mountain trails which is based on the criteria of the solidity of the trail tread/walking surface, altitude, markedness, orientation skills required and safety equipment (Club Alpino Italiano, 2021a).

An example of a complex trail categorisation that addresses a range of users (including hikers) but also considers trail management and planning is a five-level categorisation used by the U.S. Forest Service (2008a, 2008b). It can serve as an example of a primarily quantitative categorisation that can be used as a verified practice in our further discussion of objectifying categorisation of mountain trails. The criteria defined in "Trail Design Parameters for Hiker/Pedestrian" (Forrest Service, 2008a) focus primarily on the physical characteristics of trails and their adjacent areas, such as the width of a trail, inclination along the trail (a general measure for the entire trail and specific measures for short sections) and across the trail, the size of obstacles on the trail, and the like. Although the criteria used in this trail categorisation are not directly comparable to those used in the alpine examples above (e.g., the steepness of trails is generally less and no mountaineering equipment is required in the Forrest Service categorisation), the systematic and thorough approach to defining trail characteristics and categories may well serve as a guide.

Table 3. Swiss (SAC) Mountain and Alpine Hiking Scale hiking scale[1]

Level	Trail/terrain	Requirements
T1 Hiking	Well-constructed footpath. Where possible, all exposed areas are made secure with fixed cables, railings, etc. The risk of falling can largely be ruled out with normal behaviour.	None; also possible in trainers. Orientation without any problems, usually also possible without a map.
T2 Mountain Hiking	Continuous established footpath. Exposed areas made more secure. Partially steep terrain. Risk of falling not ruled out.	Surefootedness. Proper hiking boots are recommended. Basic orientation skills.
T3 Difficult Mountain Hiking	Path not always obvious/visible. The more exposed areas can be secured. You may need your hands for balance. Some exposed areas remain, where there is a risk of falling. Pathless sections over scree or talus.	Good balance and surefootedness. Mid/high top hiking boots are recommended. Average orientation skills. Basic alpine experience.
T4 Alpine Hiking	Occasionally pathless. In certain places you'll need to use your hands. Some quite exposed terrain, e.g. steep grass slopes, rock ledges, simple firn fields and minor glacier passages (with little crevasse risk).	Experience in exposed terrain. Appropriate, sturdy footwear. Good orientation skills. Alpine experience. Good preparation: time and weather considerations, ground conditions & group dynamics need to be considered.
T5 Difficult Alpine Hiking	Often pathless. Individual easy climbing sections. Exposed, challenging terrain, steep cliffs. Bare glaciers and firn slopes which posed some risk of falling.	Mountaineering boots. Very good terrain assessment- and orientation skills. Breadth of alpine experience, also in high alpine terrain. Basic skills with ice axe, rope, and crampons.
T6 Very Difficult Alpine Hiking	Mostly pathless. Grade II scrambling. Often very exposed. Terrain examples: Dangerous talus slopes, rock gullies, steeper sections of snow-free glaciers = increased risk of falling.	Excellent orientation skills. Extensive alpine experience and strong familiarity with all technical alpine aids (ice axe, rope, crampons, security devices, etc.)

[1] Schweizer Alpen-Club SAC (2022).

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The characteristics of the mountain trail categorisations studied can be summarised as follows:[1]

- the criteria for defining trail categories are primarily related to two dimensions of trail difficulty assessment, namely technique (including equipment) and risk, while effort is assessed only indirectly or not at all,
- trail category descriptions are primarily qualitative,
- trail category descriptions are mainly based on subjectively assessed characteristics of trail difficulty; the assessment is done by experts,
- trail categories are ordered according to the level of difficulty of the trails,
- a trail category refers to an entire trail, and
- trail characteristics used to define a trail category may refer to the entire trail or only a part of it, the latter usually pointing out a section with exceptional risk.

Maybe the most surprising finding about the studied trail categorisations is almost complete ignorance of the trail features related to hiker's effort. For example, none of the mentioned categorisations involve any relation to the length or vertical dimensions of the trail (e.g., height difference), duration of the hiking, or different requirements for a hiker taking the trail in one or another direction. Such information is obviously expected to be provided as external to the categorisation, e.g., in a detailed description of a particular trail, or in an online crowdsourced comments or recommendations (such as forum, blog posts). An exception to this general approach is a specific trail categorisation for disabled hikers by Club Alpino Italiano (2021b), which includes the above parameters such as length, height difference of a trail and duration of a hike into the criteria defining the categories. In contrast, assessing trail difficulty based on hiker effort is an important area of development in trail difficulty assessment methods such as the IBP index (ibpindex.com, 2023), which is also used in the aforementioned Syris trail difficulty assessment and recommendation system (Calbimonte et al., 2020).

Another surprising finding is the absence or lack of objectively measured data and objective criteria used in categorising mountain trails. Even for objectively measurable characteristics such as "steep slope" or "sufficiently wide path" in the Slovenian categorisation, or "steep terrain", "partially steep terrain", "more exposed areas" in the Swiss categorisation, no quantitative definition could be found. And even when such quantitative criteria exist, as in the Forest Service's categorisation of hiking trails (2008a, 2008b), it is not clear whether and how the quantitative characteristics of trails are measured, calculated, or assessed - e.g., as a field measurement or subjective assessment by an expert, using GIS, or by other means. It is also not clear how thresholds used in categorisation were defined, as no theoretical or empirical references are provided. In addition, many qualitative descriptions used in trail difficulty categorisations can be potentially ambiguous due to differences between expert and hiker perceptions, such as required "caution", "fitness", "normal mountaineering equipment" in the Slovenian categorisation, or "the more exposed areas can be secured" in the Swiss categorisation. Hikers often encounter categorisations that differ from actual conditions along the trail. Subjective assessments by experts, as in the case of Slovenian categorisation (Rotovnik, 2016), can potentially lead to differences in category perceptions between experts and hikers. Therefore, such discrepancies between the information provided, its perception and the actual situation on the trail are to be expected, at least occasionally (Gradič Oset, 2020). Possible errors in communicating information about a trail may contribute to incorrect conclusions and behaviours during the hike, which may also affect the hiker's safety. Objectification leading to a reduction of hiking risk is therefore an important goal of further work on the categorisation of mountain hiking trails, which is also pursued in the empirical part of this study.

In search for essential characteristics of categorising mountain trails, existing categorisations were re-evaluated in light of new realities resulting from previously discussed advances in technology, the availability of geographic data and GIS, as well as recent developments in real-time trail difficulty assessment tools. To make the MTC a stand-alone piece of information that is also a good complement to more detailed trail difficulty assessment, we try to highlight some of its specific characteristics as follows.

- Essential: it should contain the basic information about a trail category that a hiker needs: in particular, information about safety hazards should be clearly highlighted in the description of a category.
- Simple: multiple data and criteria (as many and as varied as deemed appropriate) may be used, but only a carefully selected and interpreted piece of information is then made available to a hiker.
- Stable: a category should be defined basis on infrequent and slowly changing characteristics to make it stable, robust, even rigid/static in a long term; it should be changeable only if the trail or its section changes enough to require a change in the category.
- Focused: should be primarily focused on the trail and adjacent slopes.
- Semantically clear: the meaning of a category description should be clear to provide unambiguous, understandable information about a trail and to help hikers make well-informed and correct decisions before or during the hike.
- Reliable and verifiable: this aspect is primarily about the hiker's confidence that the information is true to reality, and safety when this could be compromised by unreliable or misleading information.

What information is essential for categorising mountain trails and how to keep categorisation focused and simple requires further (interdisciplinary) research and negotiation. The focus of trail categorisations will likely be redefined to better complement other information a hiker needs, including real-time information about trails and hikes. To maintain the focus of a MTC, such information should remain external and complement the categorisation. It is expected that reliability, verifiability, and semantic clarity will be considerably improved by objectifying/quantifying the MTC, as this paper attempts to emphasise.

Perhaps the most specific characteristic of an MTC compared to more detailed and real-time trail difficulty assessments is its stability over time. Trail categorisation is used in ways that require stability, such as depiction on trail maps and billboards, locating and managing safety equipment along trails, or depicting a trail's category on signsposts and markers (blazes). The stability of MTC is closely related to the selection of trail or hiking features that are assessed through categorisation. To keep a categorisation stable, it is necessary to assess those characteristics of a trail

1. Exceptions are explained in the text: the Forrest Service trail classification (2008a) and the trail categorization for disabled hikers by Club Alpino Italiano (2021b).

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or hike that do not change significantly over time. Another important source of MTC stability is assumptions about the hiking conditions under which the categorisation is valid. For example, the Swiss categorisation advises experts to assess the trails "assuming favourable conditions, i.e., good weather and visibility, dry terrain, suitable snow and firn cover, etc." (Schweizer Alpen- Club SAC, 2022). Similar assessment conditions are also assumed in the Tyrolean (Amt der Tiroler Landesregierung, 2018) and Slovenian (Rules on the Categorisation of Mountain Paths, 2008) guidelines for trail categorisations. Assumptions may also count on the ability of hikers to assess increased hiking risks due to "residual snow fields, debris and other weather influences" or "damage to trail facilities after storms," which also implies an increased difficulty assessment (Amt der Tiroler Landesregierung, 2018).

Some details on the mountain trail categorisations are further discussed in the presentation and argumentation of the experimental categorisation in Section 3.

2. Study Areas

Hiking is one of the most popular recreational activities in Slovenia, a country with 2.1 million inhabitants and an area of just over 20000 square kilometres. The Alpine Association of Slovenia manages 2000 mountain trails marked by blazes with a total length of 10045 km, has more than 55000 members[2], and estimates 1.4 million hikers using these trails yearly[3]. Only 1.3 % of the mountain trails are categorised as difficult or very difficult [4], easy trails prevail with more than 98 % of all the managed mountain trails.

To test the experimental categorisation of mountain trails in this study, two areas were selected in the southern and central parts of the Kamnik-Savinja Alps (Figure 1). They differ in terms of relief, altitude and land cover, and include a range of terrains, from foothills to high mountains. To present the characteristics of the study areas, a GIS-based analysis of the digital elevation model (DEM) with 1 m resolution, created from a lidar point cloud (ARSO, 2015) and data on actual land cover/land use (MKGP, 2022), was performed. The area of the studied mountain trails located in the southern part of the Kamnik-Savinja Alps[5], consisting of foothills and lower mountains, is characterised by average altitude 1116 m, with the highest point at 1569 m above sea level and the lowest at 593 m. The average slope inclination of the area is about 26°. Most of the area is covered by forest, 21 % is grassland and only 1 % is open land with little or no vegetation. The other, high-mountain study area in the central part of the Kamnik-Savinja Alps[6] is characterised by the average altitude 1927 m, with the lowest point at 740 m and the highest point at 2557 m above sea level. The average slope inclination of the area is about 42°. Almost 80 % of the area is open land or open land with some vegetation, followed by forest with 15 % and grassland with about 5 %.

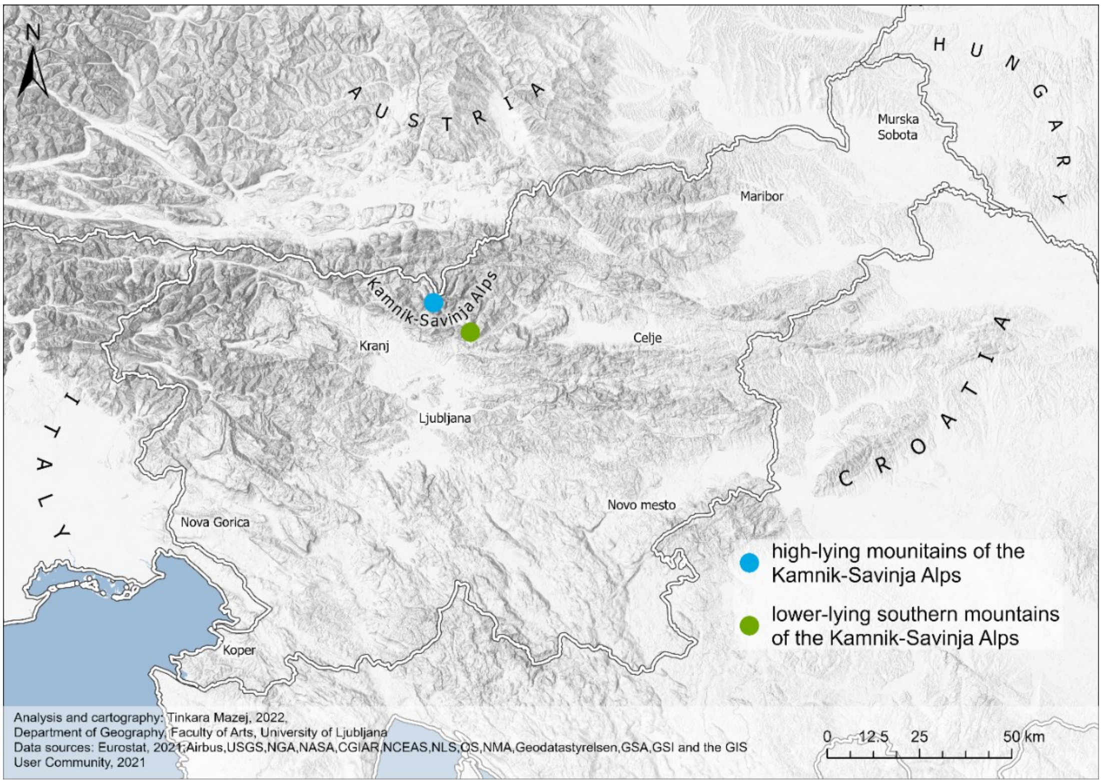

Figure 1. Location of the two areas studied within the Kamnik-Savinja Alps in Slovenia

2. https://stanje-poti.pzs.si/, cited 3 August 2022.
3. https://www.pzs.si/javno/pzs-letopis-2021-splet_3.pdf, cited 3 August 2022.
4. https://www.pzs.si/javno/javno/PZS_planinske%20poti_NK.pdf, cited 3 August 2022.
5. The studied trails in the southern part of the Kamnik-Savinja Alps are: Kranjski Rak - Sončna griča - Gojška planina, Krivčevo - Podkrajnik - Gojška planina - Domžalski dom na Mala planini, Planina Kisovec - Mala Planina.
6. The studied trails in the central part of the Kamnik-Savinja Alps are: Frischauf Trail, Kokrska Kočna - Jezerska Kočna, Kokrsko sedlo - Mala vratca - Veliki podi - Skuta, Kokrško sedlo - Dolci - Dolška škrbina, Kokrško sedlo - Kalški greben, Kremžarjeva pot, Mlinarsko sedlo - Skuta, Slovenska pot, Šrempova Trail, Suhadolnikova planina - Kokrska Kočna, Turska gora - top of Turski žleb - Skuta, Veliki podi - Mlinarsko sedlo, Veliki podi - Sleme - Mali podi - Turska gora, top of Turski žleb – Rinke.

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3. Methods

Answering the first three and, to some extent, the fourth question from the introduction required a thorough study of the relevant literature and other sources of information (mainly available online) on the assessment and categorisation of mountain trails. The analysis of selected mountain trail assessments and categorisations and the comparison between them provided facts needed for the synthesis of general characteristics of the categorisations, as well as for the design of the experimental trail categorisation presented in this section. The benefits of objectifying methods for assessing or categorising mountain trails, addressed in the fourth question, were demonstrated by highlighting examples of good practises and showing positive effects of objectification, e.g., on semantics, reliability, and other aspects of the assessments or categorisations, but most importantly on the potential to reduce risks to hikers. The remaining argumentation to answer the fourth and fifth questions is provided in the empirical part of the study, which aims to develop, implement, and evaluate an experimental categorisation of mountain trails on selected routes in the Kamnik-Savinja Alps, taking the following methodological steps:

- the selection of objectively measurable trail features and criteria for categorisation,
- the design of a method for implementing the categorisation of mountain trails, that allows systematic, objective assessment of all trail sections in the study area,
- the implementation of a GIS-based objective categorisation of selected mountain trails,
- the assessment of the consistency of the results of the experimental categorisation (in further text also ETC) with the official categorisation of mountain trails, OTC (Mountain Paths Act, 2007; Rules on the Categorisation of Mountain Paths, 2008), and
- the identification of dangerous sections of the mountain trails and their comparison with the sections of the studied trails that are already equipped with safety devices (mostly metal cables, pitons, or steps) in order to provide suggestions where additional safety equipment could be installed.

3.1. Selecting relevant trail features and criteria for categorisation

To make the potential for objectifying categorisation of mountain trails as clear as possible, ETC is designed to use only objectively measurable trail characteristics that are measured and categorised using quantitative data and criteria. Systematic development of GIS-based models needed to calculate indicators for all trail difficulty characteristics relevant in our empirical study, or at least for those underlined in Table 1, is beyond the scope of this paper. ETC is not the best possible categorisation proposed to challenge OTC. We consider it to be a quantitative model of a trail categorisation used to present, observe, and evaluate its operation and results. Consequently, only objectively measurable trail characteristics were considered in the selection process. To keep the categorisation simple, we selected only a small number of relevant trail characteristics, at least one for each of the three essential dimensions of trail difficulty assessment: effort, technique, and risk. One of the difficulty assessment indicators measures effort, one measures technique-related difficulty, and a combination of three measures risk, which already exceeds the quantifiability expectations of Calbimonte et al. (2020) mentioned in Section 1.2. The selected trail characteristics representing three essential dimensions of the trail difficulty assessment are:

- inclination of longer sections of a trail indirectly assessing required hiker effort,
- steep short sections of a trail indicating required hiker's technical skills or equipment, and
- exposed short sections of a trail indicating potential risk for a hiker; exposed trail sections are considered particularly dangerous if they occur in combination with short steep trail sections.

Potentially quantitatively measurable trail characteristics (using accessible geographic data and GIS-based methodology) that are not considered in ETC include, for example, crossing talus/scree, glaciers, bodies of water, branching of a trail, length, and elevation change of the trail, which could either be included in the criteria for distinguishing between categories or add detail to the category descriptions. The simplicity of ETC is not only a matter of principle (as stated in Section 1.3), but also owes to the simplicity of OTC, with which it will be compared later in the study. As mentioned above, OTC does not explicitly consider effort, nor does it mention the inclination or exposure of a trail, although these can be inferred from descriptions of difficulty along a trail.

Inclination (steepness, slope, gradient) of the trail is perhaps the most commonly used criterion in assessing the difficulty of a trail or the effort of a hiker. Early studies of the relationship between the inclination and the effort of a hiker walking up or down a slope were conducted by Margaria (1938), in a search for an ideal match of walking speed to a given inclination of the trail, which then turned into a search for an ideal inclination for the most economical expenditure of energy by a hiker. Several authors continued to explore these relationships (e.g., Hugo, 1999; McNeill, 2002; Giovaneli et al., 2015; Peyré-Tartaruga et al., 2021), the results of which can be used in the assessment of the difficulty of a trail, either in the development of complex applications for difficulty assessment and recommendations (as in Calbimonte et al., 2020) or in a study of basic trail categorisation as presented in this paper.

In general, humans adjust walking speed in such a way as to use as little energy as possible per unit distance. As the inclination increases, the energy expenditure of walking or running increases (Hugo, 1999; McNeill, 2002; Giovaneli et al., 2015; Calbimonte et al., 2020). Theoretically, one will be able to climb a given inclination faster at a higher inclination, but it will take more energy to do so. The key is therefore to determine the inclination at which energy consumption will be most economical, but which will still allow the goal to be reached in a reasonable time. On steeper trails, balance is also more difficult, and walking often requires assistance with the hands (Giovanelli et al., 2015).

To find a more specific inclination threshold which could be used in criteria for trail categorisation, we wish to look a bit further. Margaria discovered the minimal energy expenditure at the inclination around -10°, in other words, when a hiker descends on a slightly inclined path. The function of "metabolic cost" (Llobera & Sluckin, 2007) increases in both directions, toward greater inclination when a path goes up, and even faster as the inclination rises when a path goes down. Relating energy expenditure to another wish of a hiker, to reach the destination as fast as possible, resulted in a search for an ideal (also called optimal or critical) hiking inclination. This search is aiming at an optimal compromise between the required effort and the speed of the hiking, or as expressed above, to determine the inclination at which energy consumption will be most economical, but which will still allow the goal to be reached in a reasonable time. We can learn a lot about this idea from historical practices, looking at the existing paths. Some studies provide evidence for this claim, like Minetti (1995) and McNeill (2002) who found certain coherence between the modelled optimal inclinations and the existing paths in the Alps and Himalayas. When the inclination is low, the path leads as straight toward the final destination as possible. When the path becomes very steep, a direct (the steepest) walk across a slope could demand too much effort from a hiker. A common mountain hiking strategy of zigzagging (Llobera & Sluckin, 2007) results in a reduced inclination of the path at the expense of a longer hiking distance, keeping the energy expenditure as optimal as possible. The inclinations of such zigzagging paths however depend on the decisions taken by historical path designers, based on their knowledge and intuition, very much also on previously existing paths made by animals, hunters or other locals. Consequently, these inclinations differ considerably. In our study we follow empirical and theoretical estimations from selected studies, mainly those by McNeill (2002), Giovaneli et al. (2015) and Llobera and Sluckin (2007), presented in Table 4.

Table 4. Selected examples of critical inclinations related to walking or running uphill or downhill

Authors	Inclination (degrees)	Impact of inclination
Giovanelli et al. (2015)	45	very critical inclination for uphill walking or running on threadmill, using hands to maintain balance, discomfort in calves and feet
Giovanelli et al. (2015)	40	critical inclination for uphill walking or running on threadmill
Giovanelli et al. (2015)	20.4 – 35	most economical uphill inclination for walking or running (athletes)
Langmuir (1995)	25	zig-zag walking is desirable
Langmuir (1995)	20	care is required while walking
Llobera and Sluckin (2007)	16	critical uphill inclination to divert from the fastest walking direction
Minetti et al. (2002)	16	critical uphill or downhill walking inclination to start zigzagging to keep most economical energy expenditure
Langmuir (1995)	15	limit of roadways
Minetti et al. (2002)	14 – 16	optimal uphill or downhill walking inclination to keep most economical energy expenditure
Llobera and Sluckin (2007)	12.4	critical downhill inclination to divert from the fastest walking direction
Upadhayaya (2018)	<6	Optimal/ideal inclination of a safe hiking path

As stated above, two lengths of trail sections were used in the study. Longer sections (100 m) were used to calculate the generalised local steepness of a trail, based on which the overall difficulty of a trail was assessed. The threshold used to interpret the **general level of difficulty of a trail** in our study is 16° on a longer (100 m) trail section, which corresponds to the empirically estimated limit of the "ideal" inclination for mountain trails. Up to this inclination, the energy expenditure is still so low that walking does not require a great deal of fitness, while exceeding this steepness results in trails diverting from the fastest walking direction, often in the form of zigzagging. This threshold is derived from the results of the study by Giovaneli et al. (2015), who measured the relationship between inclination and energy expenditure of mountain walkers and runners. Other studies on the "optimal trail inclination" (see Table 4) also provide some logical support for this choice. In experimental categorisation, this threshold is used to distinguish between easy and difficult mountain trails. Inclinations of easy and moderate mountain trails in the observed trail categorisations that explicitly use this criterion (e.g., Forrest Service, 2008a; 2008b) are much lower, but those thresholds have no clear relationship to hiker's effort.

Short trail sections (5 m) were defined like in the method used by the Forrest Service (2008a; 2008b) to determine the "short pitch gradient" of a trail. Calculating the inclination of short sections of a trail allowed us to identify **potentially very difficult and dangerous sections** (also named difficulty points, DP in Calbimonte et al., 2020) that would be overlooked if only longer sections were considered. The threshold used to define steep short section of a trail is 45°. Trail sections with inclination exceeding this threshold are considered those where walking is already very difficult and often requires the use of hands to maintain balance. This makes walking more difficult and strenuous and increases the likelihood that the hiker will fall (Minetti et al., 2002). Threshold is estimated based on the results of an experiment performed by Giovanelli et al. (2015), where walking and running with the treadmill inclined at extreme angles was observed. At about 40° the effort needed to perform the activity was already very high (even for athletes), but with the treadmill inclined to 45° energy expenditure increased dramatically, hands were used to maintain the balance, and discomfort in participants' calves and feet was reported.

The inclination of a trail section was calculated as the angle between the line connecting the two nodes of a single 100 m or 5 m section and the horizontal line passing through the lower of the two nodes.

The definition of **exposure of a trail** is based on the steepness of the slopes adjacent to the trail and the land cover that increases the harmful effects of a potential fall from the trail. A trail is exposed if it crosses **exposed area**, which is defined as open land with little or no vegetation (e.g., barren ground, grass, low vegetation), where at the same time the inclination of the surrounding terrain (and not necessarily the trail) exceeds 35°. It also corresponds to a typical inclination of a talus (Rapp & Fairbridge, 1968), which is often crossed by mountain trails. Talus is usually without high vegetation cover and therefore a good example of an exposed area. The exposure of such areas, particularly in combination with a high inclination of the trail, is considered potentially dangerous because there is a higher probability of losing balance, falling off the path and having difficulties to stop after the fall (e.g. on a slippery grass that prevents stopping, or crossing a talus/scree as a very unstable and steep walking surface), and being seriously injured (e.g., impact of head on rocks).

The use of thresholds is a methodological simplification that could be replaced by a more detailed (e.g., fuzzy) or complex transformation of the measured phenomena into trail difficulty levels (e.g., IBP index), or categories. Although these values are not considered or suggested to be the best, they provide the objectivity needed for further research and discussion.

3.2. Experimental mountain trail categorisation

The ETC is intended to provide categorisation in line with the logic of OTC. The experimental criteria were composed to mimic the increasing difficulty of the OTC in Table 2, although they were defined focusing on other trail characteristics, objectively measured thresholds, and data. Rather than calibrating the criteria so that the experimental categorisation results are as coherent as possible with OTC, or simply using criteria from one of the existing trail categorisations, we took a risk and applied carefully selected quantitative criteria based on research from the literature (presented in Section 3.1). The criteria used in the implementation of the ETC are listed in Table 5.

Easy mountain trail was defined as trail where the inclination calculated on 100 m trail sections did not exceed 16° and no 5 m section of the trail had inclination above 45°. **Difficult mountain trail** was defined as trail with at least one 100 m trail section's inclination exceeding 16° or a 5 m trail section with inclination above 45°, but only if the latter occurred in non-exposed areas. **Very difficult mountain trail** was defined as trail where inclinations of more than 45° occur on 5 m sections in exposed areas.

The most stringent criterion determined the category into which the trail is classified (approach used also in other categorisations, e.g., in Calbimonte et al., 2020). For example, if there is a single 5 m section of the trail with the inclination exceeding 45° and passing through an exposed area, the trail was classified as very difficult.

Three easily accessible data sources were used in the implementation of the ETC: a vector layer of mountain trails from the maPZS portal (2020), inclinations of trails and surfaces from a digital elevation model (DEM) rasterised at 1 m resolution from a lidar point cloud (ARSO, 2015) and relevant land cover areas, extracted from the vector layer of current agricultural and forest land cover/land use (MKGP, 2022).

To prepare data needed for categorisation 5 vector layers were created: 100 m trail sections with inclinations less than 16° on 100 m sections, 100 m trail sections with inclinations greater than 16° on 100 m sections, 5 m trail sections with inclinations greater than 45° on 5 m sections, 5 m trail sections with inclinations greater than 45° in exposed areas on 5 m sections in exposed areas, and 5 m trail sections with inclinations greater than 45° on 5 m sections in unexposed areas. An additional raster layer of exposed areas, needed to prepare some of the above layers, was obtained by overlaying the layer of selected land cover (MKGP, 2022) and areas with relief inclinations greater than 35° (ARSO, 2015). Most of the GIS based tasks were performed using ArcGIS; QGIS and GRASS were used only to cut the trails into equal length sections, and MS Excel to calculate relief inclinations for the trail sections. The procedures used in the categorisation performed with ArcGIS Model Builder are shown in Figure 2, illustrating the simplicity and transferability of the method.

Table 5. Criteria used in the experimental categorisation of the mountain trails (ETC)

Category/Level	Criteria
Easy mountain trail	none of the 100 m trail section has inclination exceeding 16° and there are no 5 m sections of the trail with inclination exceeding 45°
Difficult mountain trail	at least one of the 100 m trail sections has inclination exceeding 16° or a 5 m trail section has inclination exceeding 45°, but only if the latter occurred in unexposed areas
Very difficult mountain trail	5 m sections with inclination exceeding 45° occur in exposed areas

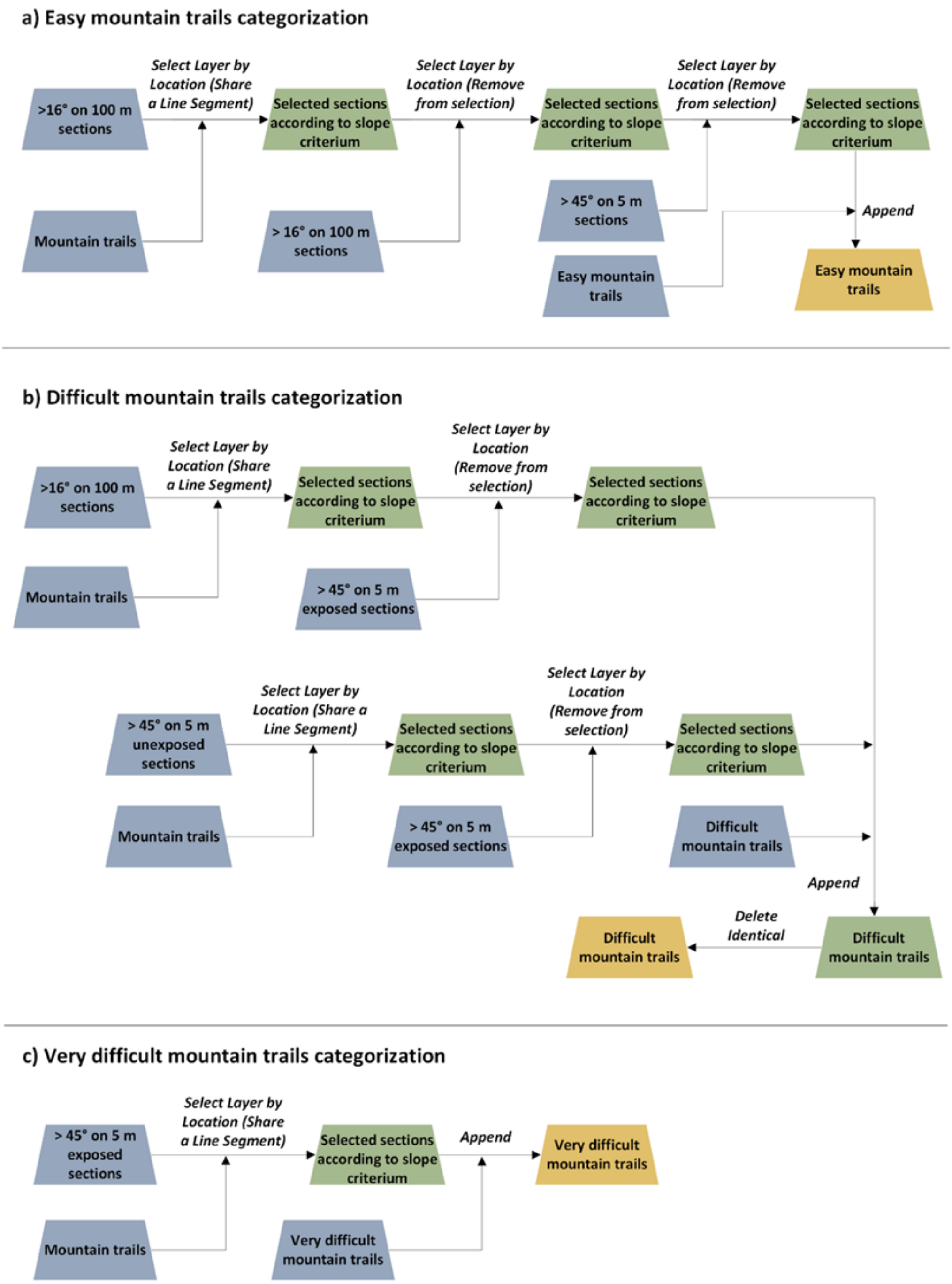
The criteria listed as category descriptions in Table 5 are not user-friendly, especially when compared to the OTP category descriptions in Table 2. However, such quantitative information can be included in the description of the categories, as in the Forrest Service (2008a) categorisation, together with careful descriptions of other aspects of trail difficulty assessments, required equipment and skills. The quantitative presentation of criteria may not be easy for hikers to understand at first, but only because they must learn through experience what a trail inclination of 16° or 45° means in reality, or how an exposed area (a combination of inclination of adjacent slopes exceeding 35° and the absence of forest) is perceived on a particular trail. Therefore, a hiker improves the semantic clarity of the categorisation through 'training'. In the final description of the categorisation, the exact values can be replaced by terms such as "steep path" or "exposed section". In the long run, the reliability and stability of the criteria used in a categorisation could lead to a common understanding of the terms among hikers.

3.3. Dangerous mountain trail sections

If only one steep and exposed short section is detected on a trail, the entire trail is categorised as very difficult according to the criteria used in ETC. The same criterion, a short (5 m) section in an exposed area with inclination exceeding 45°, has also been used to identify difficulty points (DP). They indicate sections of a trail where the provision of safety equipment (e.g., metal steps, anchored steel cables) might be recommended.

In addition to the presence of such dangerous sections along a trail, information about their exact location is very useful to a hiker (see Calbimonte et al., 2021). The locations of DPs were overlaid with the sections of mountain trails equipped with safety devices obtained from a vector layer of the Utility and Public Infrastructure Cadastre - GJI (GURS, 2022). DPs without such safety equipment can be considered as **potentially dangerous trail sections** that require special skills, equipment, and fitness of a hiker. As mentioned above, the identification of such sections can serve as a suggestion where new safety devices could be installed, but it can also be taken into account when planning or maintaining trails.

Figure 2. Schematic representation of the experimental categorisation of mountain trails (ETC) defining a) easy, b) difficult and c) very difficult trails



4. Results

The results of the experimental categorisation for the southern part of the Kamnik-Savinja Alps are presented in Table 6 and Figure 3. All four studied trails were categorised as easy in the official categorisation by the Slovenian Mountaineering Association (OTC). In the experimental categorisation (ETC), only one of the trails remains assessed as easy, while the other three are assessed as difficult. The reason for categorising these three mountain trails as difficult is that they all have 100 m sections with inclination exceeding 16°. Short (5 m) trail sections with inclination exceeding 45° are not present in this area.

Table 6. Comparison of the official (OTC) and experimental categorisation of mountain trails (ETC) in the lower part of the Kamnik-Savinja Alps

Mountain trail	OTC	ETC
Kranjski Rak – Sončna grča – Gojška planina	easy	difficult
Krivčevo – Podkrajnik – Gojška planina – Domžalski dom	easy	difficult
Planina Kisovec – Mala Planina	easy	difficult
Podkrajnik – Kisovec	easy	easy

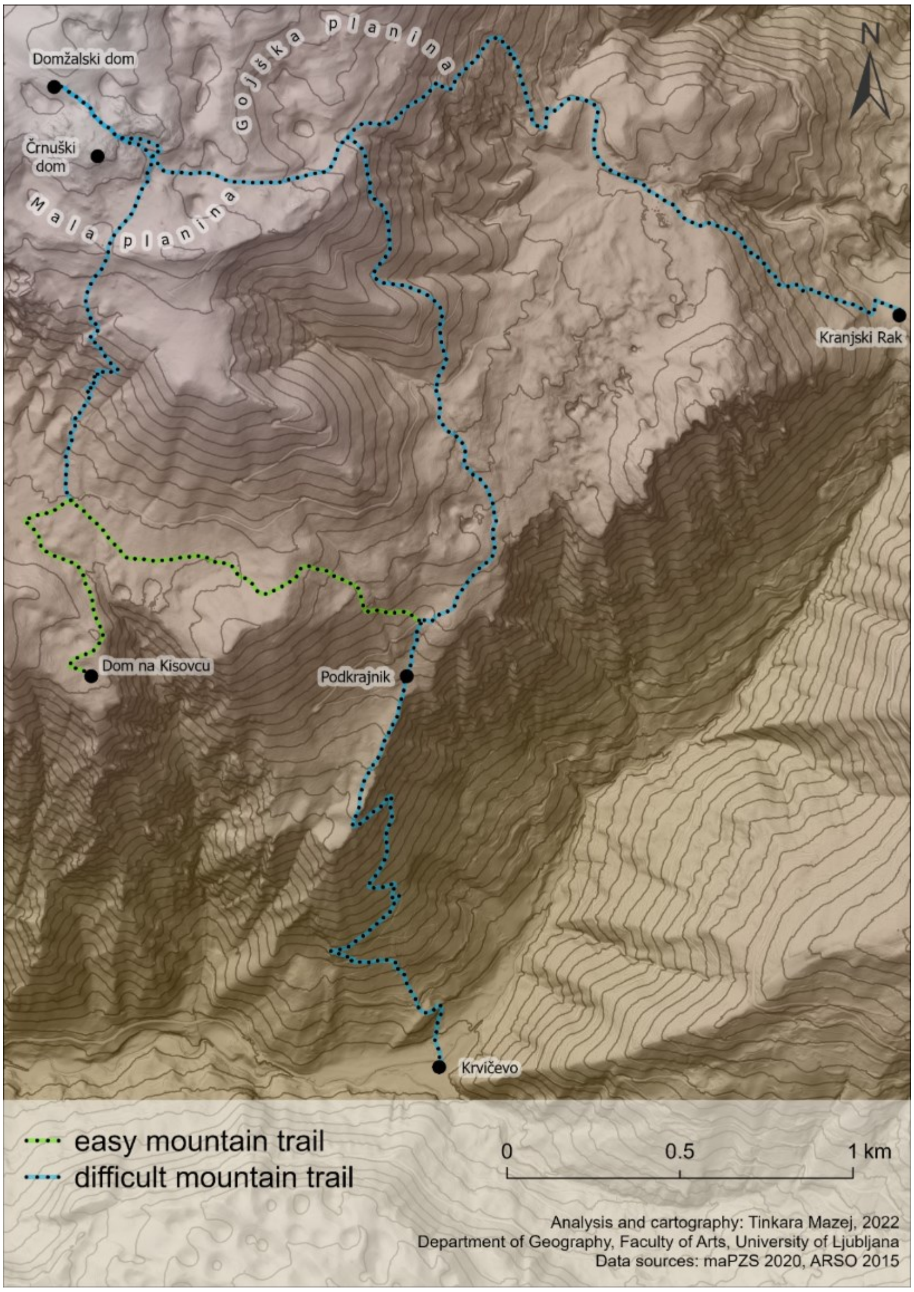


Figure 3. Experimental categorisation (ETC) of mountain trails in the lower-lying southern part of the Kamnik-Savinja Alps

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The results of the ETC for the central part of the Kamnik-Savinja Alps are presented in Table 7 and Figure 4. As this study area is more mountainous than the first, only two of the trails are defined as easy, six as difficult, and six as very difficult by the Slovenian Mountaineering Association. Again, the experimental categorisation often assesses the trails as more difficult than the "official" categorisation: two trails were categorised as difficult, 12 trails as very difficult, and none as easy. In one case (trail Vrh turskega žleba-Rinke) the assessment was more difficult by even two categories, due to exposed and steep (>45°) 5 m sections.

Table 7. Comparison of the official (OTC) and experimental categorisation of mountain trails (ETC) in the high mountain central area of the Kamnik-Savinja Alps

Mountain trail	OTC	ETC
Frischaufova pot	difficult	very difficult
Kokrska kočna-Jezerska Kočna	very difficult	very difficult
Kokrško sedlo-Mala vratca-Veliki podi-Skuta	difficult	very difficult
Kokrško sedlo-Dolci-Dolska škrbina	difficult	difficult
Kokrško sedlo-Kalški Greben	very difficult	very difficult
Kremžarjeva pot	very difficult	very difficult
Mlinarsko sedlo-Skuta	difficult	very difficult
Slovenska pot	very difficult	very difficult
Šrempova pot	very difficult	very difficult
Suhadolnikova planina – Kokrska Kočna	difficult	very difficult
Turska gora-vrh Turskega žleba-Skuta	very difficult	very difficult
Veliki podi-Mlinarsko sedlo	easy	difficult
Veliki podi-Sleme-Mali podi-Turska gora	difficult	very difficult
Vrh turskega žleba-Rinke	easy	very difficult

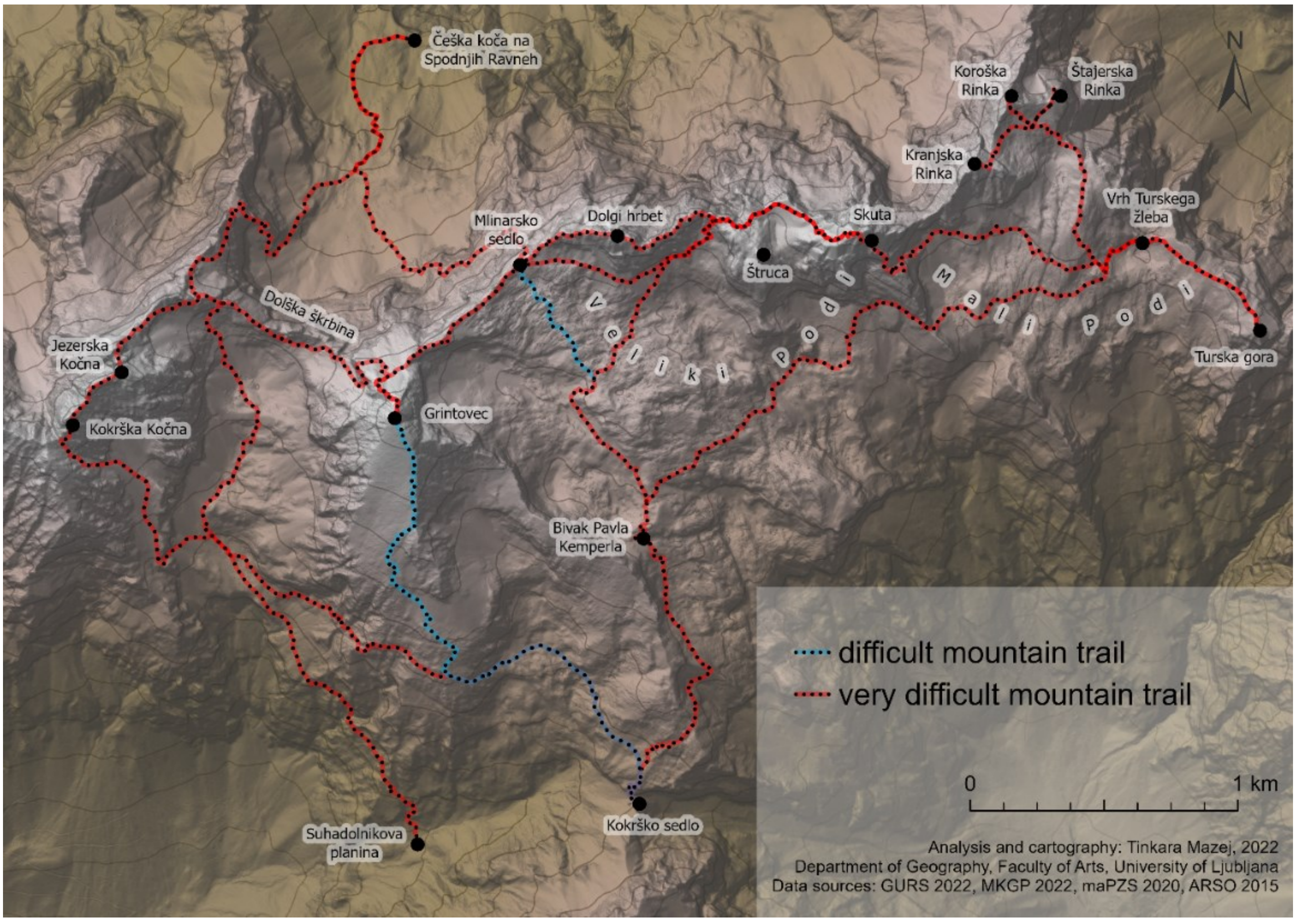

Figure 4. Experimental categorisation (ETC) of mountain trails in the high mountain central area of the Kamnik-Savinja Alps

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Comparison of 189 difficulty points (with exposed and steep 5 m trail sections) with trail sections which are already protected by safety equipment (registered in the GJI mountain trails layer by GURS, 2022) shows that only 44 (23 % of the 189) match. This means that 77 % of the exposed and steep sections which can be considered potentially dangerous, are not yet protected by safety devices (Figure 5).

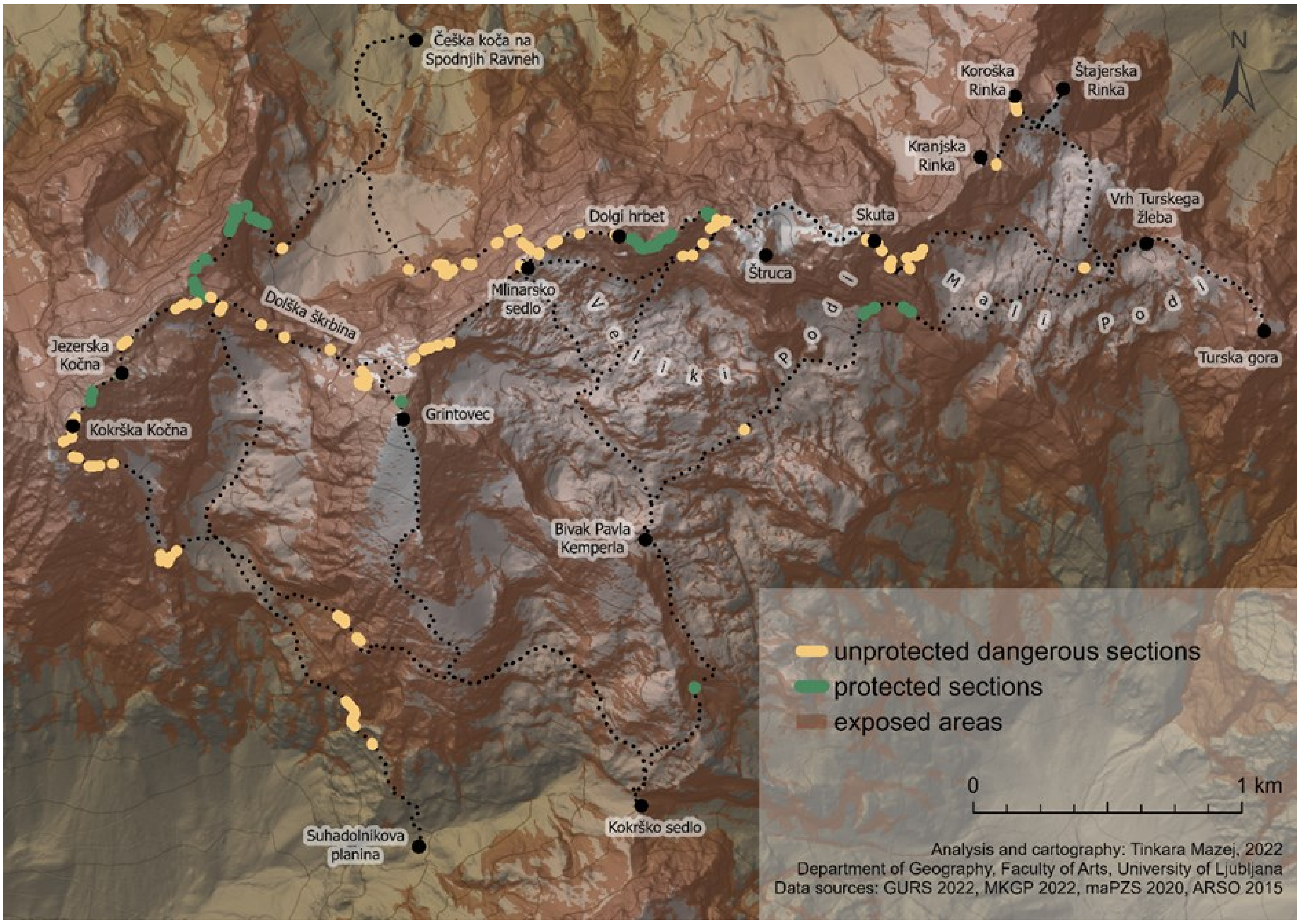

Figure 5. Identification of dangerous steep and exposed trail sections can help improve trail safety equipment

5. Discussion

The first set of questions posed in this study is related to **the composition and characteristics of the mountain trail categorisations**. Our answer to the first question (Q1), which features of mountain trails are essential for categorising mountain trails, is twofold. At a more general level, we followed the idea of the French Hiking Federation (FFRandonnée, 2023), used by Calbimonte et al. (2020), by considering the three main dimensions or groups of trail features, effort, technique, and risk, as essential to any difficulty assessment of trails, including their categorisation. At a more specific level, the answer is blurred by the diversity of current practices. Considering seven categorisations, and two recent approaches to assessing trail difficulty (see Table 1) allowed us to capture a broad range of trail and hiking characteristics and demands on hikers that were used for categorisations. Further research could reveal the relative importance of potentially essential features. But discussion among stakeholders, particularly those responsible for providing such categorisations, could also lead to a more robust list of essential features in an MTC or even some degree of standardization.

The answer to the second question (Q2), which are the expected characteristics of mountain trail categorisation, is an attempt to devise a descriptive list of rather obvious principles that are followed by MTCs. Based on existing and anticipated commonalities among the MTCs, that could be interpreted as expected features of an 'ideal' mountain trail categorisation, the following characteristics emerge on the list: MTCs contain essential information for the hiker, are simple and selective, are stable over time, focus on the trail and adjacent areas, and are semantically clear, reliable, and verifiable. In this study the list serves as a guideline in discussing various aspects of the existing MTCs, and the anticipated improvements the objectification might bring to them. If we take a closer look at the Slovenian OTC, which was used in the case study, we get the impression of a very simple, easy to understand and usable categorisation, which is unlikely to change over time. Lacking information on effort, the OTC only partially provides essential information needed by a hiker, and the trail and adjacent slopes seem almost not to be explicitly focused on. Semantically, most of the descriptions are clear, but some seem too general to be truly helpful, such as "caution is advised" or "areas impassable to less experienced climbers." Experienced hikers would likely find OTC reliable, but they are the ones least likely to need such information. Less experienced hikers and hikers who come from areas where other trail categorisations are used might have problems with the lack of specificity or the resulting poor comparability with a categorisation they know from another area. Reliability and verifiability of an MTC are especially related to the objectification of the MTCs, discussed in relation to the next questions.

The **objectification of mountain trail categorisations** addressed by the second group of questions in this study is probably the most promising research directions to move towards the goal of an 'ideal' categorisation. As Hugo (1999) put it, "The best way to foster participation in any one particular trail is to describe the trail as scientifically as possible and then allow hikers to decide for themselves whether they would like to undertake the trail." We follow this idea on the conceptual level, aiming at considering the objectivity in the whole process of defining a trail categorisation, from data collection to final categorisation. Objectification is therefore not limited to quantitative measurements of trail features such as inclination, or the use of results of another objectified categorisation, e.g. land cover, which is usually obtained by categorisation of remotely sensed quantitative data. In MTC we rely also on qualitative information, such as recognizing a difficult or dangerous section of a trail, or a section where the use of hands is required, or where a possible problem of vertigo should be considered. Our understanding of objectification implies any effort taken to 'objectify', or using Hugo's wording, do a part of categorisation "as scientifically as possible".

The third question (Q3), which features of mountain trails are objectively measurable, can be answered only temporarily and circumstantially. Availability of adequate data to measure particular aspects of an MTC is generally improving over time. The GIS-based methods such as those needed to extract relevant information from the available data are invented almost daily. The assessment of objective measurability in Section 1.2 was therefore performed mainly to illustrate which aspects of the MTC could be objectified already today, or in the near future. The majority of the existing MTCs is based on subjective assessments of the trail features. The presented possibilities of MTC objectification are substantial and are not entirely exploited even in advanced trail difficulty assessments such as in Syris. Due to the anticipated methodological and technological developments various aspects of trail and hiking difficulty assessment will become increasingly objectifiable. However, objectively measurable trail and hiking features are not necessarily the only ones that are relevant to categorisation and to the hiker. The assessment of trail difficulty and an MTC should therefore be based on a balanced selection of indicators, some of which are likely to remain subjectively assessed also in the future.

The answer to the fourth question (Q4), whether the introduction of objective criteria based on objectively measured data can help to improve the expected characteristics of mountain trail categorisation, bases on the interrelation between the answers to the previous two questions. The aspects of the MTCs that could benefit the most directly from the objectification, are reliability and verifiability. However, with the systematic, accurate processing of the relevant data about each trail section and its vicinity, objectification has a potential to considerably improve also the semantic clarity and the provision of essential details about the trail.

In addition to potential improvements in the characteristics of MTCs, objectifying categorisations may also lead to other opportunities for improvement. Existing differences between national or regional trail categorisations limit the ability of hikers to use the information for their own hikes, especially when visiting trails in unfamiliar areas abroad. The ubiquity of fairly precise data on relief, trails, land cover, and other factors that might be relevant to assessing trail difficulty already makes the idea of an objective assessment or categorisation of trail difficulty in the Alps and several other mountain regions realistic. The transferability of objective categorisation, at least in terms of methodological feasibility, is only one step away from its eventual international standardization.

The answer to the fifth question (Q5), whether the empirical results support the expectations regarding the objectification potential of mountain trail categorisations, is affirmative. The applied objective (quantitative) approach to ETC is simple, focused on trails and their vicinity, fully transparent, verifiable, accurate and reliable. Its methodological transferability is a characteristic required for international harmonization or standardization. It includes indicators for all three essential aspects of an MTC, effort, technique, and risk. However, many of the features of a trail or hike that might be potentially important to hikers are not included in the categorisation, which means that only parts of the methodology used for ETC may be of interest for such transfer or comparison. As mentioned earlier, semantic clarity is not automatically achieved through objectifying measurements or data modelling. It is very important how the categorisation, and individual categories are presented and documented, and that hikers do their part by learning to understand the information that an MTC provides – both aspects are set aside in this study. Among other characteristics of ETC requiring further consideration are the sizes (5 or 100 meters) of the analyzed trail sections. Although they have been defined following examples from the literature, other criteria might be needed to identify specific, empirically determined trail or hiking difficulties. Similar considerations might be appropriate for trail or surface inclination thresholds to distinguish easy from difficult or difficult from very difficult or dangerous trail sections. These and other deficiencies of the ETC are mainly due to its experimental, demonstrative purpose, rather than their prototyping for real-world application. Only further research, and especially collaboration between researchers and experts who designed the existing categorisation (OTC), could lead to a verified version of a new, objectified mountain trail categorisation and improved category descriptions.

The intention to build ETC 'as scientifically as possible' is reflected in many ways. The categorisation is based solely on objectively measurable characteristics related to effort, technique, and risk. The critical values in the criteria used to create ETC were drawn from physiological research (e.g., Giovaneli et al., 2015), theoretical and empirical studies of trails (e.g., Langmuir, 1995; Llobera and Sluckin, 2007), or the geomorphological literature (Rapp & Fairbridge, 1968). Categorisation was done systematically by assessing the difficulty of each trail section using the same combination of criteria applied to data from the same data sources.

All three thresholds used in the construction of the criteria for the ETC were set rather high, meaning that also the results were expected rather demanding for a hiker. For example, quite steep trails (with inclination up to 16°) are categorised as easy, and only extremely steep short sections are detected as difficult. Based on such expectations, the trail categories in the ETC should be lower (easier) than those in the OTC. Empirical results have proven the expectation wrong. ETC performed even more sensitively than OTC. None of the trails have been categorised by OTC as easier than by ETC. And many of the trails have been categorised as difficult, or more difficult, by ETC as by OTC. Considering the above expectations, differences in the applied criteria, and the fact that many of the ETC categorisations are one level higher as in OTC due to detection of local difficulties that might have been overlooked by the experts creating OTC, the two categorisations are surprisingly coherent.

These results are encouraging, since ETC was developed with the idea of complementing, not replacing, OTC. To see how such complementation could look like let us consider a merged description of the categories by combining the two categorisations (Table 8). The descriptions in the table are potentially applicable only in cases where both categorisations (OTC and ETC) match. Even in such cases, the table is for illustrative purposes only and should be used with caution. The 'objectified' part of the descriptions provides semantically clearer, more reliable, and verifiable information, although hikers would need to learn the meaning of these values in real situations.

Objective categorisation potentially helps to reduce discrepancies between hikers' perceptions of categorisation and the actual difficulty of mountain trails.

By contributing to a better understanding of the difficulty of mountain trails, objective categorisation also helps reduce the likelihood of problems and accidents and systematically and reliably contributes to hiker safety. The latter may be considered as the most promising aspects of

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objective trail assessment and categorisation. This is particularly evident in the identification of 'difficulty points,' dangerously steep and exposed 5 m sections of trails (Figure 5), which - once the criteria have been verified by experts - can serve as an indication of where safety equipment should be installed.

Table 8. The attempt at a possible combination of objective and subjective mountain trail category descriptions, created by merging the descriptions of OTC and ETC, is only potentially applicable if the categories of both categorisations match

Level	Description and requirements
Easy mountain trail	A hiker can move with normal mountaineering equipment, he does not need to use his hands to help him, but he can make walking easier by using walking sticks. Where the easy mountain trail crosses a steep slope, it must be wide enough to allow safe walking even for less skilled users. All that is required is caution, fitness, and suitable footwear. Most sections of the trail are not steep (inclination of the 100 m sections does not exceed 16°). There are no very steep (inclined 45° or more) or exposed short sections of the trail (the adjacent slopes are forested or inclined less than 35°).
Difficult mountain trail	In some difficult places, the hiker has to help himself with his hands. The trail is equipped with safety devices (e.g., steel cables) to help the hiker keep his balance. Caution, physical fitness, and appropriate equipment are required of users of a difficult mountain trail. At least one of the 100 m trail sections has inclination exceeding 16°, or at least one short (5 m) trail section has inclination exceeding 45°, but only if this very steep trail section is not also exposed (the adjacent slopes are forested or inclined less than 35°).
Very difficult mountain trail	The use of hands is essential. The trail has built-in metal cables, pitons, steps, or similar safety devices that allow the hiker to safely walk in areas that would be impassable for less experienced or fit mountaineers. It is recommended that self-protection kit, a helmet, or a climbing harness be used for additional protection. Difficulty points detected as short (5 m) sections with inclination exceeding 45° occur in exposed areas (with adjacent slopes inclined 35° or more, without forest).

Existing categorisations may still serve their purpose, but as shown in this study, they could be significantly improved – so much so that they could regain and strengthen their central role in informing hikers about trail difficulty. This line of argument is supported by the research trends identified in this paper and the empirical results of the case study presented in Slovenia.

6. Conclusions

We believe that the assumed future importance of the mountain trail categorisations in this paper is not exaggerated. The growing number of hikers depending on reliable and understandable information about the trails and the hiking is already a good argument to support this belief. But the study provides also other arguments, mainly related to the benefits brought by the objectification of the categorisations, and their contribution to hiker safety.

Looking ahead, improvements in the categorisation of mountain trails are expected in two broad areas. As just stated, the first area is **objectification** of the categorisation, based primarily on the opportunities afforded by complementing experts' subjective assessments with objectively measured and modelled data. The proposed brings the lively research field of trail difficulty assessment and its stagnant research subfield of mountain trail categorisation closer together. Both fields rely on digital geographic data, GIS-based methodology, and tools. Even though some of the data come from different sources, are modelled in different ways, or are at different spatial scales, the methodological and semantic overlaps between the two fields are evident. Close collaboration between them is not only feasible, but potentially fruitful. What aspects of difficulty assessment should be the focus of a categorisation, how we measure, model, and interpret them, and how the final categorisation and its description are presented should be further explored and discussed. Numerous authors from different disciplines cited in this paper and numerous experts from mountaineering or similar associations and clubs can be considered as nodes of a possible broad transdisciplinary network that could participate in this lively activity.

This line of reasoning brings us to the second important area of possible improvements, the **international standardization** of mountain trail categorisation. The benefits of such standardization, even if only partially implemented, seem very compelling, primarily because it has a great potential to reduce ambiguity in the interpretation of categorisation, facilitates international mountain hiking, and, most importantly, improves hiker safety and satisfaction. Its implementation is not likely to be straightforward, as it would require dedicated cooperation among several national and regional stakeholders and, at the concrete implementation level, numerous local experts, and mountain trail maintainers. Even hikers who are used to the existing categorisations, might need some time to get used to the new one. But learning a single categorisation that would be valid in all countries or regions joining the standardization effort would be a major step forward. Therefore, expectations in this area can be moderately optimistic. In Chamonix in 1997, the Club Arc Alpin (CAA), composed of the national and regional alpine clubs or mountaineering associations from Italy, France, Austria, Germany, Switzerland, Liechtenstein, and Slovenia, succeeded in manifesting the will necessary for such a step and adopted a decision on the uniform signposting of mountain trails (Amt der Tiroler Landesregierung, 2018). To follow such an example, with an even larger goal and hopefully a wider geographical arena, would trigger an exciting process.

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