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Topographic Maps as Risk Interfaces: Visualising Geomorphological Hazards for Outdoor Decision-Making

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Abstract:

High-altitude mountain environments are undergoing rapid transformations driven by climate and environmental change, often manifesting through natural hazards such as avalanches, floods, and geomorphological processes including rockfall, landslides, and slope instability. With the rise in popularity of outdoor recreation such as hiking and climbing, not only high-altitude settlements and populations, but also mobile individuals such as excursionists, are exposed to these hazards. Maps, as tools for planning and navigation, play a central role in how users assess terrain and make decisions, and therefore have the potential to support safer and more informed behaviour in mountain environments.

Traditional topographic maps used for recreation primarily represent the landscape as static and certain, while recent technological advances enable digital maps to integrate dynamic processes, uncertainty, and hazard-related information. This creates opportunities for new cartographic standards, but also raises challenges of graphical complexity, cognitive load, usability, and user acceptance. While previous cartographic research has investigated hazard communication, uncertainty visualisation, and spatial decision-making in contexts, for example floods (Meyer et al., 2012), wildfires (Cheong et al., 2016) and avalanches (Fisher et al., 2021), geomorphological hazards remain comparatively underrepresented within recreational topographic maps.

This research investigates how representations of geomorphological hazards can be integrated into digital topographic maps for outdoor users, and how this information influences decision-making, choice behaviour and cognitive load in hiking route selection tasks. It approaches topographic maps as behavioural interfaces that shape perception and action, addressing the question of whether hazards can be communicated without compromising usability. The research is rooted in Disaster Risk Reduction theory and a user- centred cartographic design approach is adopted and combined with a three-phase process of defining, designing, and refining (testing), inspired by Twomlow et al. (2022).

A within-subject experimental design is used in which participants evaluate multiple digital topographic map prototypes. The test is based on four maps that present hazard information through four different visual variables (hue, shape, value and texture). The selected visual variables and map designs are informed by literature on cartographic cognition, uncertainty communication, and decision-making under risk. Two visualisations (shape and hue) are binary (hazard present or not), whereas the visualisations with value and texture are probability-based.

Participants complete route selection tasks using topographic maps displaying different hazard visualisation prototypes. Each route scenario is presented both with and without hazard information in a randomised order, allowing the influence of hazard visualisation on route choice to be isolated from route geometry and effort-related characteristics. The study evaluates map usability by examining changes in route selection behaviour between control and hazard conditions and by assessing cognitive load through decision time and the subjective perception of task difficulty. In addition, post-task questions and a pilot think-aloud expert study are used to validate the experimental design, identify potential confounding factors, and examine which map elements participants rely on during decision-making.

The research employs a hybrid data strategy, integrating empirical datasets from Tyrol, Austria, with derived and synthetic hazard information to enable controlled experimental conditions. The aim is not to improve hazard prediction, but to enhance the communicative effectiveness of hazard information within digital maps. By bridging scientific knowledge and recreational use, this work contributes to hazard cartography by treating topographic maps as user-centred, behaviour-shaping interfaces.

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