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Modelling vulnerability by road accessibility analysis

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BACKGROUND

Natural hazard events such as landslides, avalanches or floods can block roads and hamper the disaster management on the land route significantly. Villages are threatened indirectly by blocked access roads, especially in mountainous areas. Several studies (cf. Bubeck and Kreibich (2011)) describe the direct costs and losses due to the disruption of processes in context of economic consequences for tourism, also caused by alpine hazards. The approach presented in this abstract of accessibility analysis is focused neither on an economic sector nor on a specific hazard. The aim is rather to identify isolated places in street networks in areas of complex terrain. The challenge of identifying critical locations in a network in the context of vulnerability is in discussion: Numerous studies about network reliability are concerned with connectivity and probability, the concept of vulnerability of Tayler et al. (2006) is more related to weakness and consequences of link failure within a network (Tayler et al. 2006: 270). The approach presented here is based on the latter, considering link failure as blocked roads.

Figure 1: Exemplary road blocked by landslides. Source: André Assmann, geomer GmbH.

The local streets are essential for rescue, support or service goods, especially for smaller villages which are dependent on other regional centres because of a poor infrastructure. The question of trapped places is important for different contexts, e.g. for emergency support, or for business interruption if the transport of goods is mainly based on the land route or if people are not able to reach their workplace. The loss of road utility and the resulting economic and social effects are also described in Winter et al. (2013). Pascale et al. (2010) explain the systemic vulnerability: If a hospital is connected only by a single road, and this road will be blocked, the hospital does not suffer direct damage or loses its intrinsic

functionality, but its functional integrity (Pascale et al. 2010: 1582). These assumptions have to be considered also in the context of the presented approach that focuses on the question: Which villages are trapped if a road will be blocked, e.g. by a landslide?

In the FP7-project IncREO (Increasing Resilience through Earth Observation) two areas of interest are defined, located in mountainous areas. In both the Alps and the Carpathians the local people are faced with landslide hazard. Therefore the approach is illustrated using the example of landslides. Especially the regional Civil Protection of Veneto, Italy, is interested in products that provide them with a better overview of local situations, the ability to prioritise correctly and to set up reliable emergency scenarios. The accessibility depends on the streets and on potential landslides that may occur and block the roads, so that the villages are not reachable any more. If a landslide occurs and affects a road, it is regarded as blocked – independent of the kind of road as illustrated in Figure 1.

APPROACH

A GIS based approach has been developed to identify potentially trapped places and to calculate the maximum detour if a road segment will be blocked by a landslide. The analysis is based on road network and settlement data. It is assumed that villages with e.g. more than 1 000 inhabitants (as a variable parameter) have a certain importance for the provision of medical care, education and food for surrounding places. This parameter depends mainly on the individual scale which directly depends on the area of interest. On national scale with urban areas or large cities with critical infrastructures, the definition of importance can be adapted depending on the surrounding area, the local critical infrastructure and the requested context.

The effects of a blockage for every single street segment on the accessibility of all villages to villages of higher importance are simulated and analysed in a predefined area. In this context the complete villages – and therefore also the population and local economy – are considered as the vulnerable elements at risk.

Within IncREO, the analysis is conducted for the community of Alpago (170 km²), Italy, and for Buzau County (3 200 km²), Romania. On the local scale of Alpago all roads were considered, apart from dead ends. For Buzau County only those road segments are regarded as blocked which are located outside of urban areas. It is assumed that there are sufficient alternative routes within urban areas. The focus is set to roads and tracks which area trafficable by normal vehicles. Traffic rules, e.g. one-way-roads or roundabouts, are ignored as a negligible issue in disaster cases.

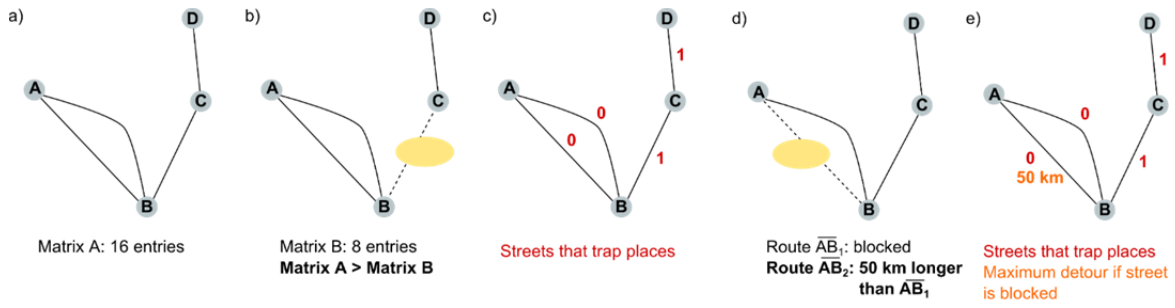

Figure 2: Schematic representation of the methodology of the network analysis, Leonardo Burckhardt, geomer 2014.

The basic idea of the validation process is to analyse the influence of blocked roads on the accessibility of villages. Figure 2 illustrates the process: A matrix *A* will be created first that contains the shortest routes from all villages to the other villages within the network (a). In the next step, a blocked road is simulated by a hazardous event using the GIS tools. At this point the assumption is that only one road segment will be blocked at a time. A second matrix *B* will be generated whose entries will be compared with the values of the first matrix. If matrix B contains less entries than A, at least one place will be trapped from the surrounding road network if the respective road segment will be blocked (b). By repeating the analysis for every road segment in the network, an evaluated road network is generated. (c). In addition to these critical connections, a second evaluation criterion is added: For each road segment the maximum detour value is calculated that is caused by the blockade in comparison with the non-blocked road network (d). The final result is illustrated in (e).

INDICATOR OF IMPORTANCE

The value of maximum detour is used as an indicator of importance of a road segment. The longer a detour, the more important a road is considered for the accessibility of a village within an area. Hence, the more important a road is, the more vulnerable an isolated village is. The classification of detour values as illustrated in Figure 3 is adjustable and depends on the size of the area of interest.

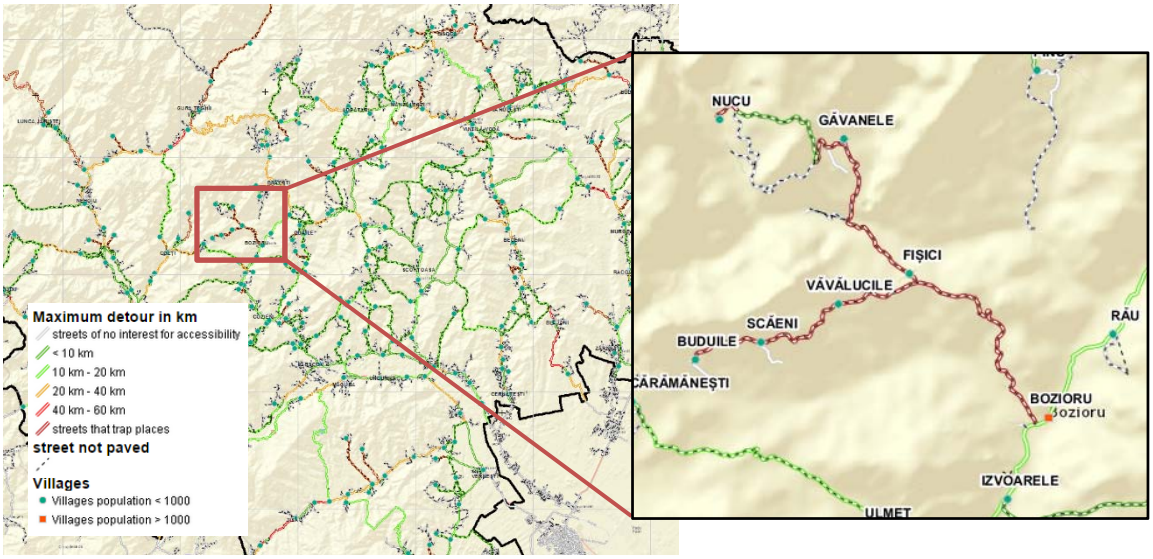

Figure 3: Example of potentially trapped places, Buzau County, Romania.

Figure 4: Example of maximum detour values, Alpago, Italy.

In Figure 4 two roads classified in yellow are highlighted by red circles. If one of these roads will be blocked, a maximum detour between 5 and 10 km will be the consequence to reach the next village of higher importance.

The map information can be extended by adding hazard information. If there is no probability information available, e.g. the landslide susceptibility information can be considered. By combining the vulnerability and hazard information, an indirect risk information can be derived. This concept of risk of inaccessibility is applied for Buzau County, Romania. The accessibility analysis provides information about the importance of a road for the accessibility within the road network.

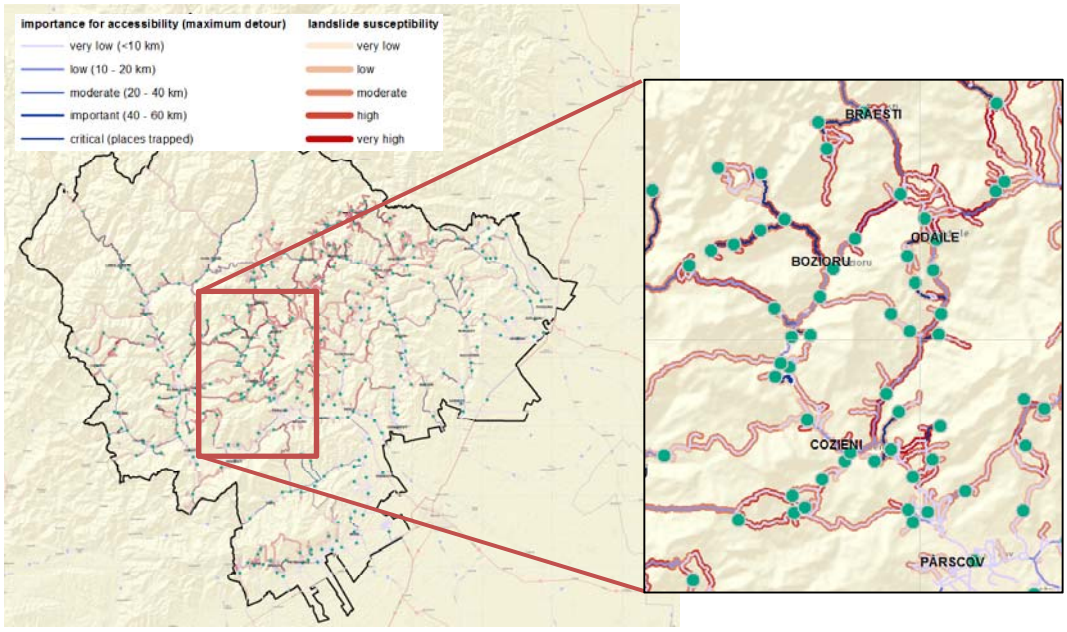

Figure 5: Combination of accessibility information and landslide susceptibility, Buzau County, Romania.

Adding the information of potential hazards at this location increases the value of information. The degree of exposure of a road segment to landslide-susceptible areas defines the

blockage risk of the respective segment. Figure 5 shows the combination of accessibility information and landslide susceptibility for Buzau County: Light red roads have a minor landslide susceptibility. The information of importance for the accessibility of places is overlaid in blue colours. Deep red to orange marked roads are running through highly prone areas and additionally have a relatively high importance for the accessibility. For prevention planning in the context of natural hazards and disaster management, potentially trapped places can be easily identified.

DATA SOURCES AND APPLICABILITY

The transferability of the approach to other areas of interest is essential and a key challenge of the approach. Therefore a pan-European and consistent data source has to be used. Within IncREO there was the choice of open source, local or administrative data sources or commercial products like HERE (http://here.com/).

The first run is based on OpenStreetMap (OSM) data. However, lots of errors are identified in the streets data by the Italian user. Although the data availability and coverage grows rapidly, there is no consistent quality assessment available regarding coverage and correctness of uploaded data in OSM.

The CNR-IRPI (Consiglio Nazionale delle Ricerche) provided detailed cadastral street data from the FP7-CHANGES project for the communities of Alpago. The data contains more road type information but there are also lots of feature errors that would have to be corrected manually. Furthermore the dataset was only available for the Alpago communities and ends at the administrative boundary. This can be a problem, because the accessibility analysis requires in most cases the street network of the surrounding area beyond the boundary of the actual area of interest. Data sources from local institutions may contain more detailed information but they would not meet the requirement of data consistency between different areas of interest. For smaller areas of interest the quality could be checked manually but that is not possible for larger areas such as Buzau County.

As alternative data source the commercial HERE street data is chosen that is prepared for routing purposes. The product is consistent for Europe and a quality assessment is assured by the manufacturer. The other data sources are considered not reliable and would require more manually efforts for quality assessment. The compromise of data is determined by the correctness of general roads. Missing road information, especially concerning the type of road, could be solved by adding other data sources. Within the context of an intended transferable service the combination of different data sources does not allow a consistent data source concept without an additional evaluation process – if viable for large areas at all.

CONCLUSION

The accessibility analysis in the context of vulnerability of villages provides new information to emergency institutions for prevention and planning on different map scales. Information about potentially trapped places is essential for preventive hazard and risk management. Isolated villages are threatened by economic interruptions and hampered disaster management if the roads are blocked by hazardous events. By taking into account the street network and settlement data, the accessibility of all places within a pre-defined area can be analysed. The value of maximum detour is calculated as an indicator. The longer a detour caused by a blocked road is, the more vulnerable and more important this road is for the accessibility of a village within an area.

Detailed and comprehensive road information is of importance for the evaluation of practicability, e.g. forest roads as alternative routes in disaster events. Both OSM and administrative data sources are restricted in either data quality, extent or detailed street type information as: Which roads are trafficable? How is the road surface and slope? Which vehicle type is able to pass a street? Currently HERE data, a commercially available road network data set, is assumed as the compromise between applicability for accessibility or routing analyses, data availability, -quality and consistency. Collecting data of high quality and the issue of regular and practicable updates, are still a challenge for a transferable product or service.

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