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Urban area exposure to landslides under landuse changes scenarios: application in a discontinuous data environment.

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INTRODUCTION

Romanian Curvature Subcarpathians are a well-known European mountain chain affected by multiple geomorphological hazards. The highly dynamic litho-structural units of the area, belonging to the Vrancea seismic region, determine a high mobility in terms of slope processes. Due to its structural, lithological and physiographic configuration, landslides are one of the most widespread geomorphic processes in the area. In particular, the most widespread landslide typological classes are represented by shallow and medium seated slides, intrinsically linked with the land cover distribution. Different land use practices (like forest clear-cutting or intense cultivation) play an important role in terms of landslide preparing (less triggering) factors, and it is widely accepted that changes in land use/cover can significantly affect the shallow landsliding. An increase in the rate of landslide occurrence as a result of forest logging or land clearance has been described in many studies (Reichenbach et al., 2014).

The study area belongs to the Romanian Curvature Subcarpathians (Buzau County). As the entire Romania country, the area has experienced important changes after the fall of the communism (1989) in terms of urban expansion, forest cover and land administration adaptations that have influenced the land use pattern.

In the region, the documented landslide events that have caused damages to infrastructures or houses are numerous. Despite that, unfortunately the information required for hazard analysis in terms of temporal probability of landslide occurrence, landslide type information and their magnitude, as well as the information concerning the vulnerability of the elements at risk, are scarcely available with high accuracy.

Due to the above-mentioned restrictions, in this paper we present an exposure analysis that can be considered an intermediate step towards the risk analysis. Special interest is focused to the analysis of the extent of the urban areas exposed to landslides and how much it will change in the future according to possible scenarios.

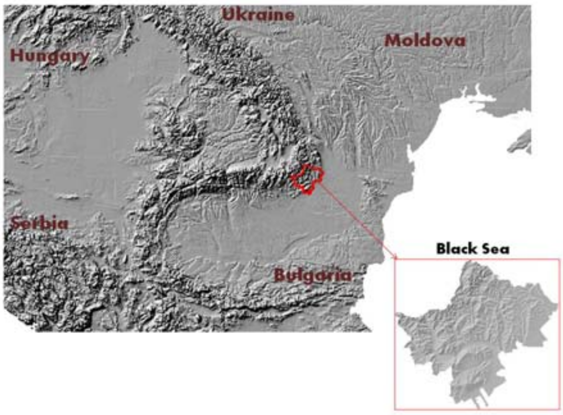


Figure1. Location and outline (red polygon) of the study area

Based on the observations of past changes and considering local experts' opinions, two possible driving forces have been identified for future scenarios: deforestation and urban expansion. In particular we have considered two types of urban expansions and two deforestation scenarios which have been used as input for a landslide susceptibility assessment in order to evaluate the possible urban areas exposed to landslide. The results were compared with the urban areas currently exposed to landslide and the observed changes were addressed.

We consider this approach as a possibility to show a rough estimation of future trends in terms of landslide exposure, suitable especially where a complete risk analysis is not possible due to data availability.

CASE STUDY AREA

The study area (2,421 km^2) belongs to the Buzau Subcarpathians (Figure 1), situated in the South-Eastern sector of the Romanian Carpathians. The Subcarpathian hills and depressions, built on Neogene molasse deposits, containing mainly marls and clays, present a mean altitude of 420m that can reach a maximum of 900 m, with a relative relief ranging between 300–500 m, and a slope angle barely exceeding 20 degree. The area, due to its geological and geomorphological setting, together with the precipitation regime with heavy spring and summer rainfall, make the terrain predisposed to landslide, and in particular to shallow and medium seated slides (Micu & Balteanu 2009; Micu & Bălteanu 2013; Bălteanu et al. 2010; Zumpano et al. 2014).

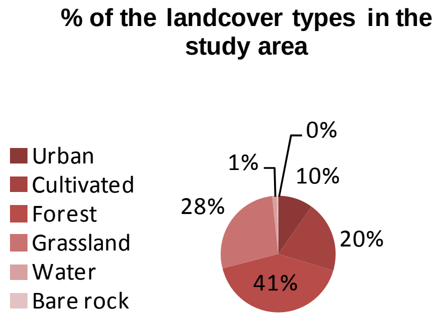


Figure 2. Percentage of land-cover types in the study area

Forests and grassland are the main land-use types respectively covering 41% and 28% of the total area (Figure 2). In the area live around 160,000 inhabitants and the urban area represents 10% of the entire surface (Figure 2). Data from INSSE (National Institute of Statistics) reports a decrease of 11% in the number of population since 1989, and a high increasing activity of forest harvesting and wood processing (Malek et al. 2014).

DATA AND METHODS

In order to overpass the relative scarcity of available data, the spatial overlay of the elements at risk (here represented by the urban area derived from the landuse maps) with the landslide susceptibility zones, was performed. This analysis can evaluate the portion of the element at risk susceptible to being impacted by landslides (Lee & Jones 2004). This evaluation can be performed analysing the assets located in each susceptible areas.

In the analysis we estimated the urban areas in each susceptibility class for the year 2035 considering changes in the forested in the urban areas distribution and extend. The year 2035 was defined as a medium term objective both from government development documents and involved stakeholders. The urban area was extracted using remote sensing imagery and accessible cartographic data (USGS 2013), and then overlapped with the susceptibility zonations obtained using the correspondent 2035 land use maps scenarious. The exposure was estimated as a percentage of the total urban area in the highest susceptible classes.

- **Land use scenario**

In the analysis, a land use map for the current situation (2014) and a set of land use scenarios for the year 2035 were exploited as input for the landslide susceptibility analysis.
Statistical relationships between the past changes and the driving forces were analysed in order to obtain potential future demands of urban and forest areas. For urban expansion, we analysed the influence of the increasing living standard on the spatial demand for built up areas, and also we took into account demographic trends available for the area (INSSE 2012). Scenarios of forest extent changes considered two processes: deforestation and forest expansion. For deforestation, we analysed the influence of the increased allowed forest harvesting on clear cutting, using projected trends for the development of Romanian forest resources (Schelhaas 2006). The amount of forest expansion was modelled by extrapolating observations on forest expansion in the last 30 years using remote sensing imagery (Malek et al. 2014). We developed two urban and two forest scenarios, and their combination. For the deforestation scenario we considered two possibilities - maximum and minimum forest extent changes; for the urban area we considered a maximum and a minimum possible extent changes respect to the present situation. In this way we have obtained four different scenarios:

I. Minimum urban and maximum forest changes
II. Minimum urban and minimum forest changes
III. Maximum urban and maximum forest changes
IV. Maximum urban and minimum forest changes

Both urban and forest changes were allocated using a raster based cellular automata model. We developed a spatially explicit model in Dinamica EGO, a software useful for modelling environmental changes on high spatial and temporal resolutions (Soares-Filho et al. 2002). The software has been already applied in several forested areas in socio-economic transition, also characterised by lack of detailed data (de Almeida et al. 2003; Maeda et al. 2011; Kamusoko et al. 2013). Spatial variables such as altitude, slopes, distance to roads and settlements, protected areas, were used to set up the model. The spatial patterns of future changes (the size and shape of future changes to either the urban or forest areas) were trained using past remote sensing observations on these processes.

- **Landslide susceptibility**

Landslide susceptibility analysis was performed using a statistical data-driven Bayesian probability model, the Weight of Evidence modelling technique (Bonham-Carter et al. 1989; Agterberg & Bonham-Carter 1990). It is based on the correlation between a training dataset representing the known occurrence of landslide events and a series of conditioning factors represented by evidential themes. The output is represented by post probability map. This approach has been widely used in our study area (Hussin et al. 2013; Zumpano et al. 2014) and in many scientific fields where it has been proved to give good performances in predicting spatial probability of landslide occurrence (Dai & Lee 2002; Lee & Choi 2004; Regmi et al. 2010; Ozdemir & Altural 2013) .
To run the analysis, eight explanatory variables were selected: DEM derivates (altitude, aspect, planar curvature, profile curvature, slope and internal relief), soil and land use maps.
For the actual susceptibility analysis we used the 2010 land use map, obtained from previous research (Malek et al. 2014), whether for the future susceptibility scenarios the 2035 land use projections were used.
The DEM derived maps were reclassified in 10 classes using quantiles; the slope aspect was reclassified in 9 classes according to the main compass directions plus one class showing

the flat areas; the soil and the land-use maps were reclassified based on expert judgment. The landslide inventory, derived from archive data (Institute of Geography, Romanian Academy, Buzău County Inspectorate for Emergency Situations) is composed by 1518 failures. Landslide were represented by the centroid points, then split using a random selection into two equal subsets and used as training and prediction set for the analysis. The final landslide susceptibility maps were reclassified into five classes, according to the percentage of landslide scarps that fall into particular susceptibility classes (Blahut et al. 2010). Breakpoints were identified at 50%, 70%, 90%, and 98% of the landslide scarps.

- **exposure scenario**

Future landslide susceptibility scenarios were prepared using conditioning factors and future land use maps.

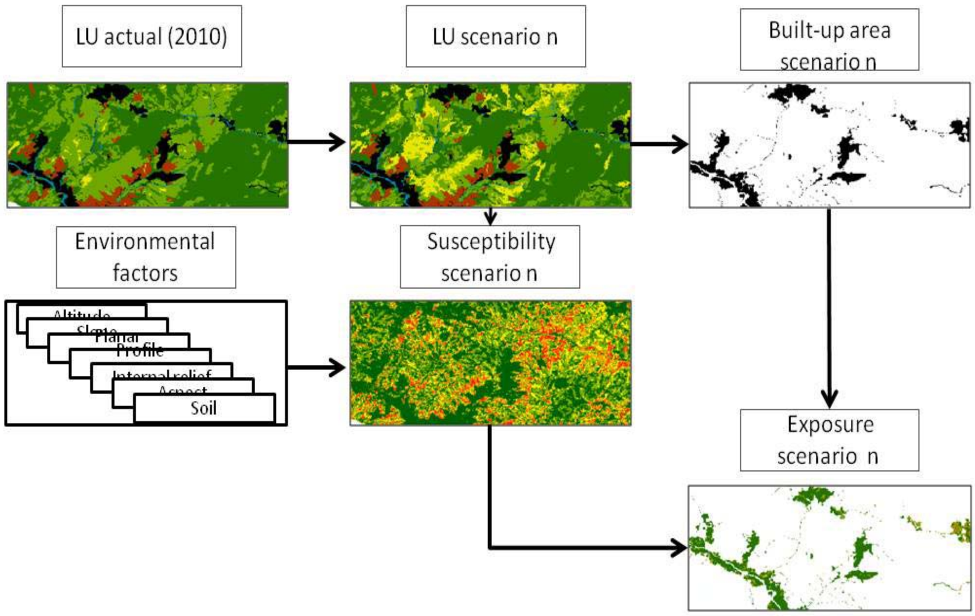


Figure 3. Flowchart of the methodology used for the exposure scenarios

The obtained susceptibility zonations were overlapped with the urban area footprint to estimate the area falling in each susceptible class. These data were then compared with the exposure obtained using the actual susceptibility map. A flowchart explaining this procedure is shown in figure 3.

RESULTS

In order to evaluate the future exposure, we first evaluated the land use scenarios, then the new land use maps were used as input for the susceptibility analysis and then the susceptibility was overlapped with the urban area setting to quantify the percentage of urban areas in each susceptible class.

- **landuse scenario**

Following the methodology reported we considered four future land use scenarios. Considering changes in the forest cover and in the urban development it is possible to notice that the variations will not be impressive. Infact comparing the actual land use with the 2035 projections, in all the scenarios there is a general increase in the forest extent, with some patches of reforestation located in the Northern part of the study area, where most of the grasslands were present in 2010. This is due to the fact, that most of the forest expansion is

on the account of grassland loss, a predominant trend of changes to the forest cover in mountain areas, such as the Carpathians (Kozak et al. 2007). The results show also an increase in the existent urban area. These results confirm previous analysis carried out for the same area and for the entire County of Buzau (Malek et al. 2014b).
Whereas the changes to the forest cover are present at a large spatial extent, changes to urban areas might seem insignificant in spatial terms. However, it is important to underline that the changes in the forest cover and in the urban area are located in the proximity of the landslides (Figure 4), which prompted the necessity to investigate the consequences for landslide susceptibility and the exposure of the urban areas.

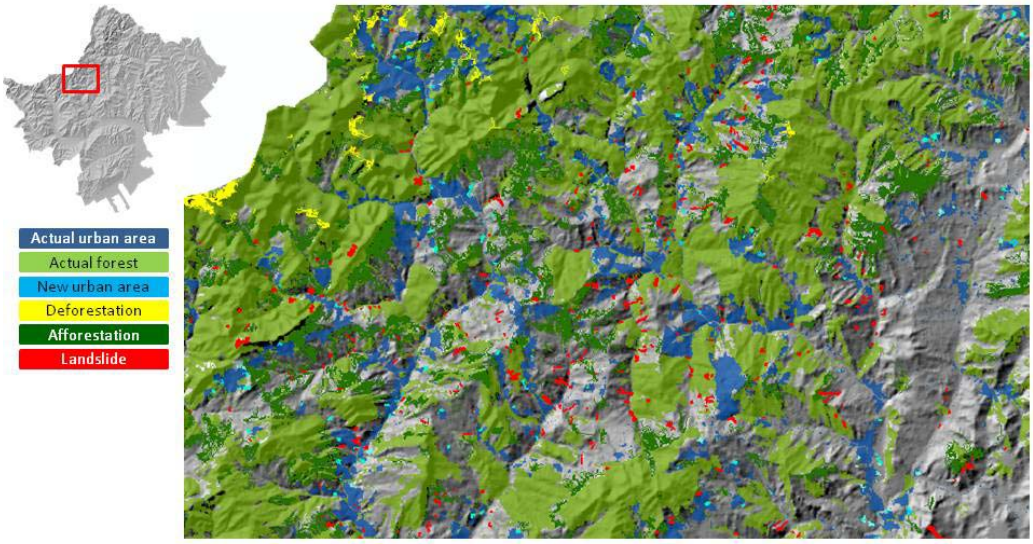


Figure 2. Changes in the land cover extent considering the minimum urban and the minimum forest changes scenario.

Table 1. Extent of the urban and of the forest classes in the actual map and in the four future scenarios

	high urban area changes, minimum forest change scenario	high urban area changes, high forest change scenario	minimum urban area changes, minimum forest change scenario	minimum urban area changes, high forest change scenario	**actual landuse (2010)**
Urban Km^2	180.34	180.34	175.23	175.23	**163.81**
Forest Km^2	751.65	745.74	752.46	746.53	**694.38**

- **landslide susceptibility**

The landuse scenarios were used to obtain different landslide susceptibility maps for 2035. Comparing the actual susceptibility map with the maps obtained using different land use scenarios, it's possible to highlight that, despite minor changes in the land use setting, it is possible to appreciate modifications in the susceptibility zonations. In all the scenarios it is possible to notice a redistribution of the susceptibility classes, given by either change towards lower and higher values. The first one is located in areas where the presence of large reforestation patches is larger. In the scenarios analysed, around 400 sq km the area changed to higher susceptible classes, whether around 520 sq km showed a decrease in the susceptibility values (Figure 5).

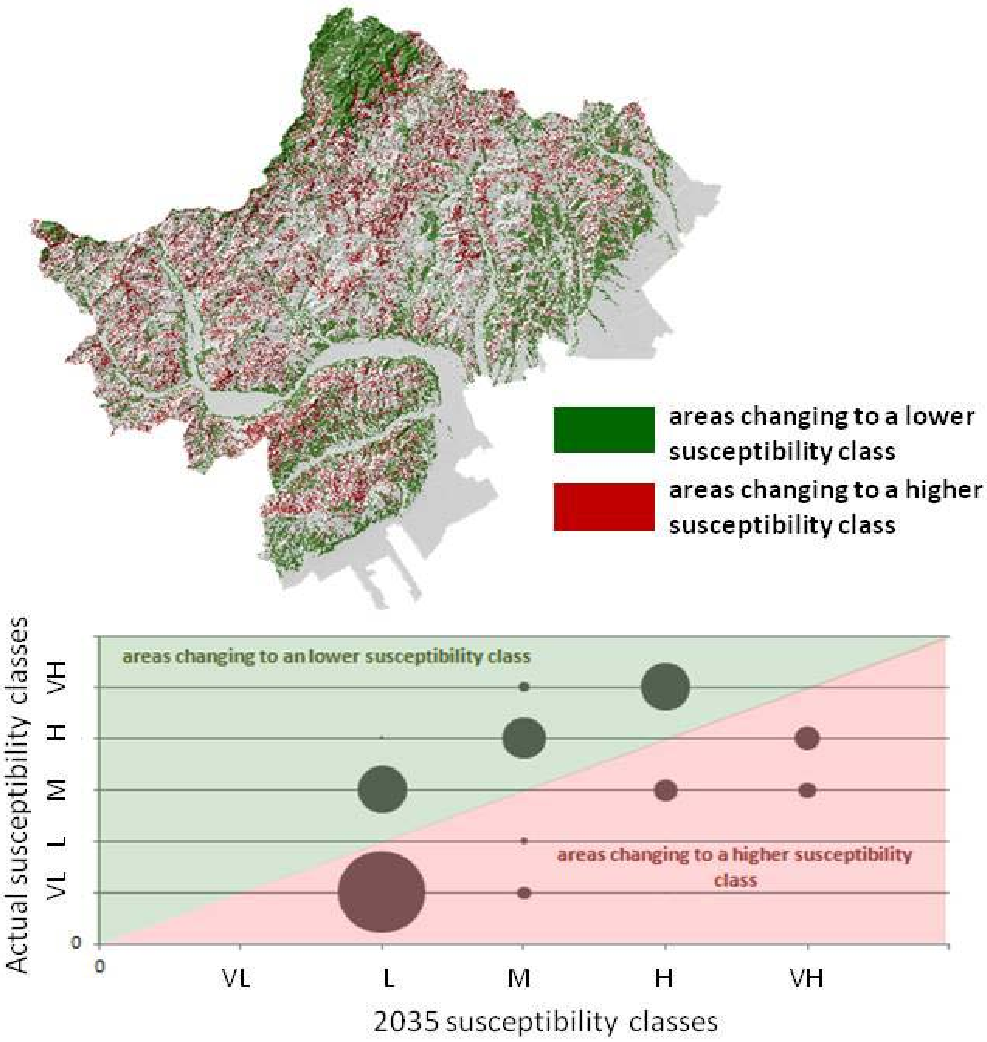


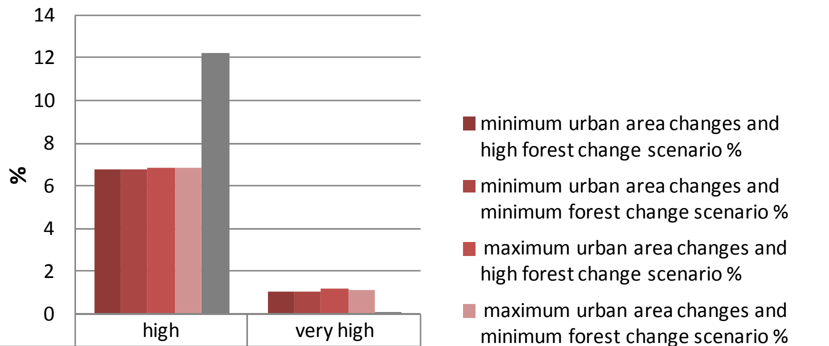
Figure 5. In the figure are shown the changes between the actual susceptibility and the maximum urban changes/minimum forest change scenario. The map represents areas changing to higher (red colour) and to lower (green colour) susceptible classes. In the graph the same data are shown. The width of the circles corresponds to the extent of the area of that particular change. The circles in the green corner identify areas changed to lower classes; in the red corner areas changed to higher classes.

It is important to underline that the differences among the scenarios (both to higher or lower susceptibility) are quite small, ranging around 1 or 2 sq km. Hence, especially for decision making purposes, we can assume a general trend for the future indicated by all the four scenarios leaving out any differentiation among them.

- **exposure scenario**

At this point the urban area exposed to landslide susceptibility was calculated. Therefore the susceptibility maps obtained using land use scenarios have been overlapped with the urban area footprints representing the asset exposed to landslide, and the asset's portions falling in the highest susceptible classes were estimated as percentage of the total area. All the scenarios proved that there is a general decrease of the exposed urban area, in the "high" susceptible class with respect to the present, but there is an increase of the area in the class "very high" (Figures 6 and 7). In addition, analyzing the maps it is possible to notice that in the scenarios with maximum changes in urban area extent, the new patches of urban area are located in the higher susceptibility classes in respect to the actual situation.

The differences between the actual and the future exposures and particularly among the four scenarios are minor, similarly with what we observed in the susceptibility analysis. This can be justified by the fact that the difference were already little in the land use maps we used as input.



	high	very high
minimum urban area changes and high forest change scenario %	6.785	1.082
minimum urban area changes and minimum forest change scenario %	6.790	1.075
maximum urban area changes and high forest change scenario %	6.828	1.157
maximum urban area changes and minimum forest change scenario %	6.830	1.154
Actual (2010) %	12.205	0.006

Figure 6 The histogram and the table show values of the percentage of the urban area in the "high" and the "very high" susceptibility classes for the four scenarios and the actual situation.

CONCLUSION

In this contribution the asset exposed to landslide was analyzed under four possible scenarios for the year 2035 where changes in the forest extent and in the urban area were considered. Analyzing the results and comparing them with the actual situation it was possible to notice that the expected changes even if not substantial, show a general decrease in the susceptibility. Accordingly, similar trend was noticed for the exposure, even if the new urban areas are located in zones classified as highly susceptible.

Moreover, the differences between the four land use scenarios were minor and it was not possible to identify a worst and a best case (Figure 7). Instead, we can assume a general trend (confirmed by the four scenarios) that doesn't indicating a significant increase of the exposure for the existent urban area but the new urban patches will be located in higher susceptible classes in respect to the present.

These scenarios should however not be used to predict the potential development of future risk to landslides in the study area. Firstly, the uncertainties in data and the land use change model prevent the exact identification of locations subject to a possible risk increase. Secondly, the scenarios were based on assumptions on future development, and covered four potential futures – many more could have been considered as well. Finally, the susceptibility model applied had its uncertainties as well, related to the methodology and the landslide inventory. Nevertheless, such approaches can be exploited to analyse potential undesirable future events, or to make urban planning for a desired future. Moreover, this type of analysis can be useful for a better preparedness against potential negative consequences derived from land use change.

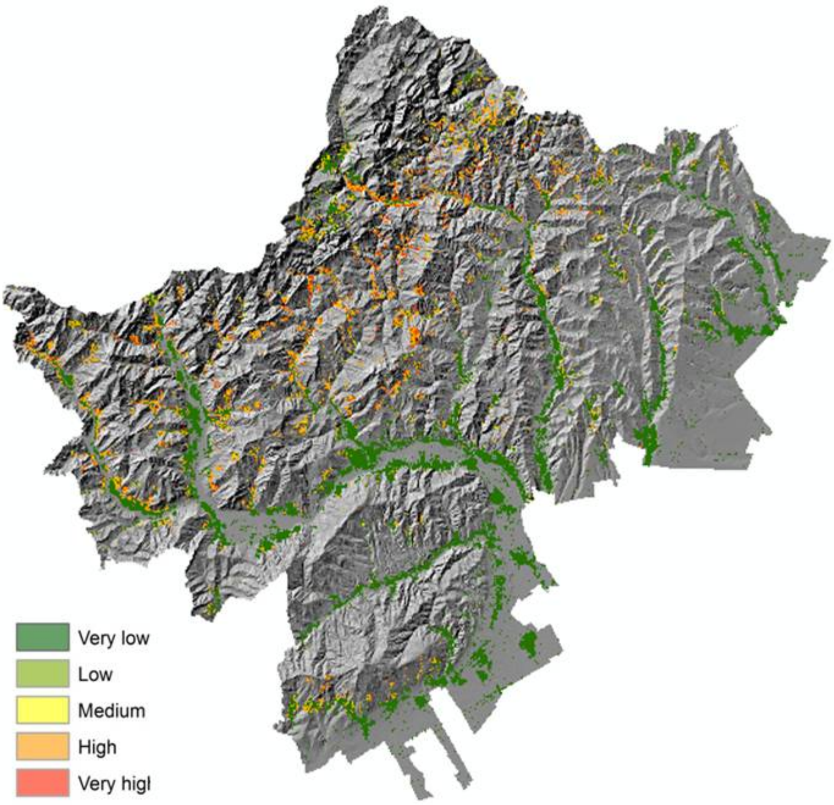


Figure 7.Maximum urban area and maximum forest change exposure scenario map.

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