GAMS

Geografski atlas naravnih nesreč v Sloveniji

Geographical Atlas of Natural Disasters in Slovenia

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COLOPHON

GEOGRAPHICAL ATLAS OF NATURAL DISASTERS IN SLOVENIA

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GEOGRAPHICAL ATLAS OF NATURAL DISASTERS IN SLOVENIA

Rok Ciglič, Lenart Štaut, Blaž Komac (editors)

UDK:
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ABSTRACT

Geographical atlas of natural disasters in Slovenia

The Department of Natural Disasters at the Anton Melik Geographical Institute of the Slovenian Academy of Sciences and Arts has prepared the Geographical Atlas of Natural Hazards in Slovenia. The Atlas contains basic information on natural hazards and disasters that have occurred in Slovenia since the mid-18th century. In addition to data on historical events, the atlas also contains spatial data on avalanche, flood, earthquake, and fire hazards and historical events, as well as data on damage caused by natural disasters. The web application ganns.zrc-sazu.si enables spatial display and contextual retrieval of data. The atlas, which makes an important contribution to disaster prevention, is dedicated to the Slovenian geographer and academic Prof. Ivan Gams, who played a major role in shaping the field.

KEYWORDS

Geography, natural hazards, avalanche atlas, floods, earthquakes, forest fires, damage, prevention, geographic information systems, online application, Slovenia

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GEOGRAPHICAL ATLAS OF NATURAL DISASTERS IN SLOVENIA

Blaž Komac, Lenart Štaut, Rok Ciglič

1 INTRODUCTION

The Department of Natural Hazards at the Anton Melik Geographical Institute at the ZRC SAZU has developed an online Geographical Atlas of Natural Disasters in Slovenia with the acronym GANNS, which is aesthetically reminiscent of the name GAMS. The atlas is dedicated to the 100th anniversary of the birth of the Slovenian geographer Prof. Ivan Gams (1923–2014).

The atlas contains information on natural hazards due to avalanches, floods, landslides, earthquakes, forest fires and damage caused by natural hazards, and comprehensive data on historical natural disasters. The Geographical Atlas of Natural Disasters in Slovenia is one of the few collections of its kind. There are some important online atlases around the world that break down natural disasters by country, but to our knowledge there is no collection or representation that presents the situation for the territory of a country in such a complex way (26 categories) for the last hundred and fifty years.

The purpose of the atlas is to inform the interested public about the nature and frequency of natural disasters that have occurred on the territory of Slovenia since the 14th century. The collection is more complete from 1750 onwards, and covers the period of the last 150 years in detail – for this period newspaper sources are available. The total number of items is approximately 5,000 and comprises just over 100,000 data, of which the relevant data is displayed in an online geographical information system (GIS).

The atlas is important for improving knowledge about natural hazards in a particular landscape, both for permanent residents and occasional visitors such as tourists and hikers. It is also the basis for spatial management, which includes the construction of buildings and critical infrastructure in all Slovenian landscapes.

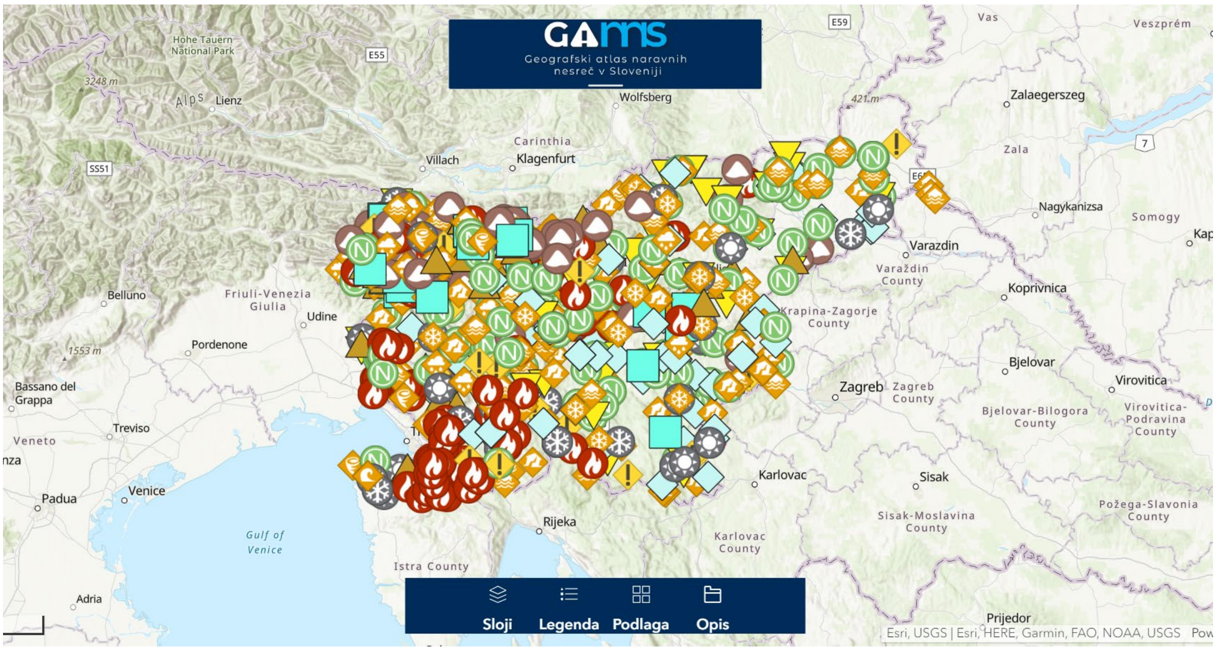

Figure 1: Screenshot of the Geographical Atlas of Natural Disasters in Slovenia webpage showing different types of historical natural disasters.

Geographers were among the first to study the most important natural hazards in Slovenia, thanks to their complex understanding of landscape processes. For example, after the floods in Celje on June 5 and 6, 1954, Anton Melik conducted the first complex geographical study

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of floods, Ivan Gams studied snow avalanches in 1955 and Drago Meze studied landslides in the 1960s. The first bases of the atlas were produced at the Anton Melik Geographical Institute of the Slovenian Academy of Sciences already in the 1980s, as evidenced by archival material. These data have been collected, updated, digitized and prepared for publication in an online atlas, which is searchable and browsable (Figure 1).
The Atlas is available as an online geographic information system at ganns.zrc-sazu.si.

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2 CONTENTS OF THE ATLAS

2.1 Historical events 1750–2020 layer (Slv. *Zgodovinski dogodki*)

The data layer shows natural disasters with a known location for the period 1750–2020. The origins of the information system on natural disasters at ZRC SAZU date back to the time before the establishment of the Centre for Multidisciplinary Study of Natural Disasters in 1992. Already in 1983 the project "Threat of Natural Hazards to Slovenian land" (Orožen Adamič 1983; 1989; 1991; Orožen Adamič and Perko 1989) started to collect available material (books, magazines, newspapers, pictures) and literature and extracting reports on natural disasters from newspapers (Orožen Adamič and Perko 1989). Articles from *Delo*, *Dnevnik* and *Večer*, as well as *Slovenski narod* (1868-1943) and *Slovenec* (1873-1939) were examined. The data in the collection was digitized in the late 1990s, but only a short report on the "Information system on natural and other disasters" (Orožen Adamič 1989) has been preserved. The digital database was lost, while the central physical database, excerpts from the Slovenski narod and Slovenec newspapers, has been preserved and digitized in 2023 (Figure 2) and is accessible via the Atlas home page.

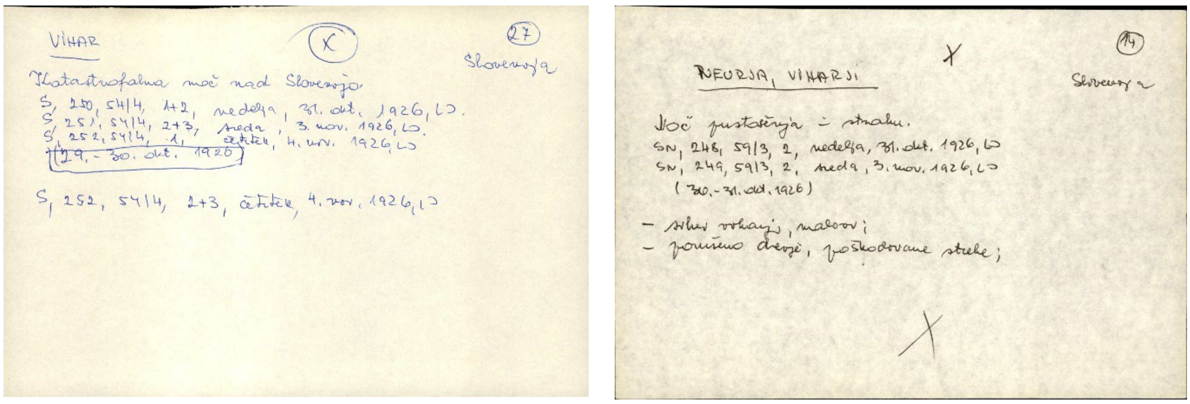

Figure 2: Scanned cards of handwritten printouts from the newspapers Slovenec (left) and Slovenski narod (right) with an account of the "catastrophic" floods at the end of October 1926 (Archive ZRC SAZU GIAM).

We have therefore redesigned the collection. The data was entered into a computer, computer-processed and supplemented for the period after the Second World War. This was done in the period between 2017 and 2023 with data obtained from the Digital Library of Slovenia (www.dlib.si), the *Delo* newspaper's journalistic Documentation Center and other sources. The database contains around 17,400 data on almost 2,350 historical natural disasters or events in Slovenia, and the associated extreme weather and environmental conditions (Figure 2).

Table 1: Overview of the attributes of the Historical Disaster Collection.

Name	Description
IDNN	Event identification number
X96	X coordinate in the D96 coordinate system
Y96	Y coordinate in the D96 coordinate system
X48	X coordinate in the D48 coordinate system
Y48	Y coordinate in the D48 coordinate system
Date	Date of the event
Location	Location of the event (descriptive)
Appearance	Category of natural disaster
Casualties	Number of victims
Source:	Source of information
Description:	Event description

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The historical natural disasters in the atlas are presented according to location, region and type of disaster. They are dividedinto the following categories: storm, cold, flood, heavy rain, warm weather, heavy snowfall, hail, forest fire, earthquake, drought, avalanche, high wind, heat wave, lightning, landslide, landslide, blast, sea flood, desert sand, frost, hail, tornado, locust attack, blizzard, windstorm, debris flow and storm blast. We have not collected data on earthquakes, which are processed by the Slovenian Environment Agency. The figure is based on the database in which the individual events or natural disasters are listed in rows with the associated attributes, as shown in Table 1.
Source: Orožen Adamič (work done from 1983 to 1989); Research Centre of the Slovenian Academy of Sciences and Arts, Anton Melik Geographical Institute, 1983–.

2.2. The Avalanche Atlas layer (Slv. *Lavinski atlas)*
The avalanche atlas is the name for the part of the Geographic Atlas of Natural Disasters in Slovenia that includes a map of avalanche events, a model map of triggering areas and a model of track and deposition areas for avalanches. These maps are supplemented by additional maps and some relevant data from the Slovenian Environment Agency (Slv. *Snežni podatki*).
The avalanche atlas provides an overview of where avalanches have occurred and where they are likely to occur, depending on geographical constants such as relief, variables such as vegetation and the corresponding now and weather conditions. It contains information on their spatial distribution and magnitude, including the expected thickness of avalanche deposit, and some descriptive information relevant for the management of mountain and highland landscapes. Avalanches are important for human settlements and especially for the construction of transportation, water and energy facilities, i.e. critical infrastructure. This also applies to data on the distance of avalanches to roads and buildings.
The avalanche atlas fills several gaps in the management of avalanche events and accidents that are perceived in Slovenia due to the lack of an avalanche service. Due to the relative rarity of avalanches compared to other processes such as flooding, their potential occurrence and spatial extent is often overlooked when planning major construction. In the long term, this can have significant consequences, as too many avalanches in the Slovenian Alps reach the valley floors.

2.2.1 Locations of avalanches *(Slv. Lokacije snežnih plazov)*
The avalanche atlas contains information on the locations of known and recorded avalanches, i.e. 2,670 avalanches and the more important of the 85,500 avalanche data, as well as information on the 85 avalanches recorded in written sources (Section 2.1). The first comprehensive study of avalanches in Slovenia was carried out by the then Geographical Institute of the SAZU, based on the collection of material after large avalanches in the years 1950-1954 (Gams 1955). Gams (1983) published an overview map of the avalanches registered in the winters of 1950-1954. The work was then taken over by the Hydrometeorological Institute of Slovenia. Finally, after 1983, under the direction of the Hydrometeorological Institute and later the Company for the Regulation of Torrents, an Avalanche Cadastre directly or indirectly endangering humans was started (Bernot et al. 1994) (initially 'preliminary'; Bernot and Šegula 1983). The original collection consisted of individual sheets of a topographic map at a scale of 1 : 25,000 with marked avalanche locations. 15 data were collected from the topographic map of the area of the avalanches. Later, the avalanches were identified through field work and written sources and marked on a map at a scale of 1 : 10,000 (Pavšek 2002).
At ZRC SAZU, GIAM,the original database from the early 1990s ws thoroughly revised, updated and supplemented with additional and new content and information, such as avalanche-to-population ratio, vegetation height data, influential relief factors, landslide

trigger zones and state-of-the-art landslide models, and its size was approximately doubled (Volk Bahun 2020). The new, updated database also covers areas that were previously not included in the cadastre or were less accessible, such as the Karawanks and the Kamnik-Savinja Alps. Since the database was created at different times and with different methods, the data is not validated, its accuracy is lower than the accuracy of the view provided by the online atlas, and the display of the avalanche atlas data at a larger scale is therefore limited (Pavšek 2002; Volk Bahun 2020).
Source: © Research Centre of the Slovenian Academy of Sciences and Arts, Anton Melik Geographical Institute, 2023. All rights reserved.
Content is freely accessible to users on the World Wide Web. According to the law, automatic retrieval of large amounts of data is only allowed with the consent of ZRC SAZU.

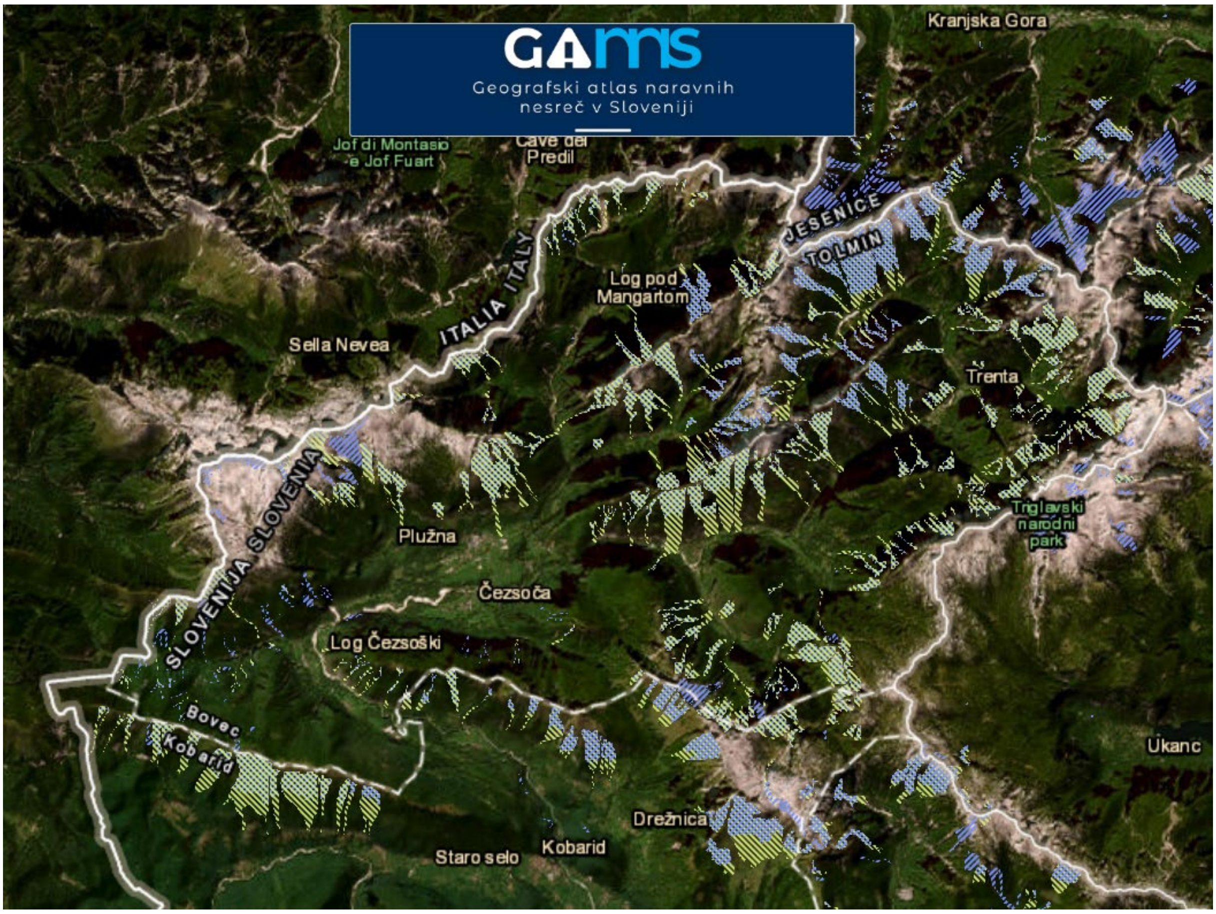

Figure 3: Screenshot of the Geographic Atlas of Natural Disasters in Slovenia showing the locations of avalanches.

2.2.2 Model of avalanche trigger areas *(Slv. Verjetnost proženja snežnih plazov)*
The second part of the database are avalanche models. We have developed a model of avalanche trigger areas. Three data sets were used for the creation, namely the avalanche cadastre (Volk Bahun 2020), the digital Lidar terrain model with a resolution of 0.5 m (DMR Slovenia ... 2021) and the digital canopy model with a resolution of 1 m (Kobler 2016). For processing and calculations, the data were resampled to 2 m resolution, and *ArcGIS Desktop* (version 10.8.1) and *SAGA* (version 8.2.0) were used. First, we determined the trigger zones of the avalanches and used the upper third of the avalanches for the calculations. Then we selected morphometric indicators by adding surface slope, a vector measure of roughness, a wind exposure index and a multiscale topographic position index as a fifth indicator, vegetation height. Based on the arithmetic mean and standard deviation, each indicator was divided into five classes, and each class was assigned an avalanche hazard rating (Figure

4). The results show areas that, under certain meteorological conditions, are occasionally and, depending on the relief characteristics, permanently potentially dangerous for the formation or triggering of avalanches. The results show the importance of relief as a geographical constant in the triggering of avalanches.
Source: Volk Bahun, Hrvatin and Komac (2022).

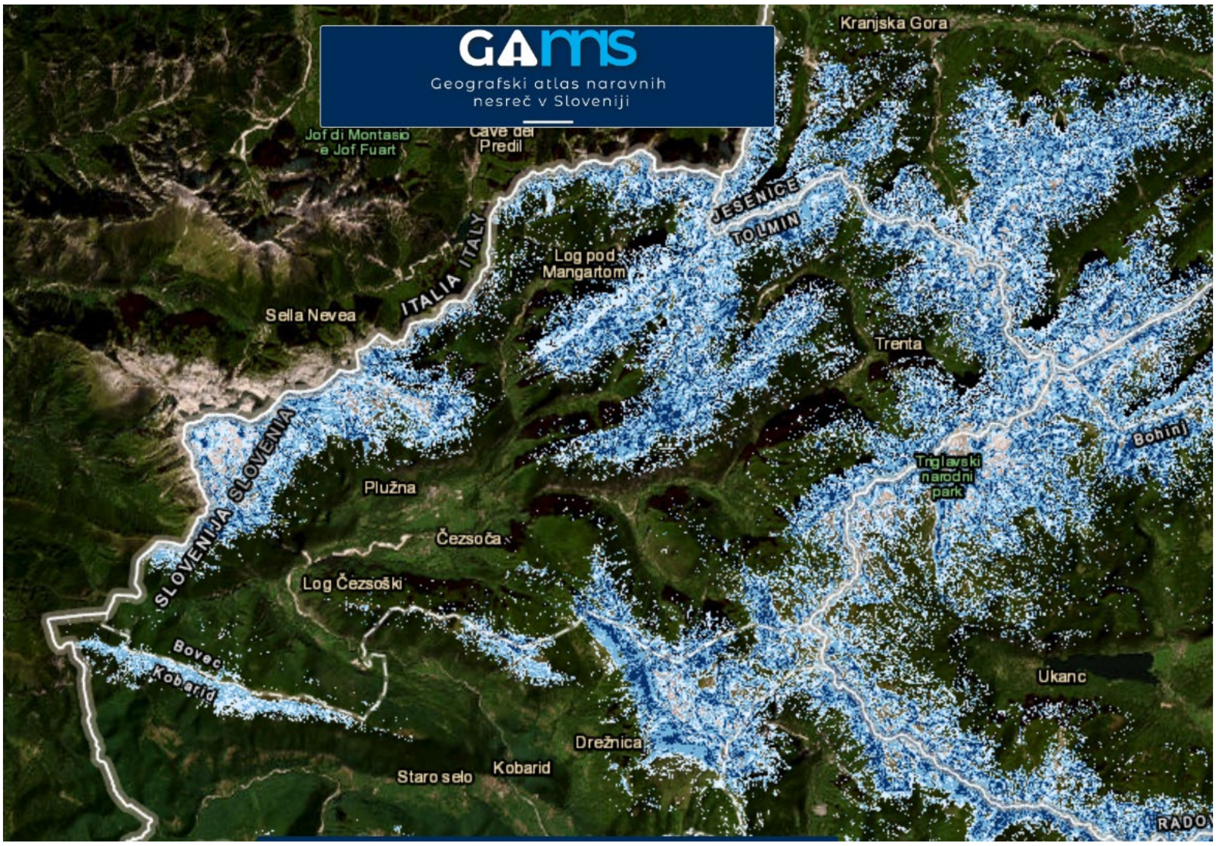

Figure 4: Screenshot page of the Geographic Atlas of Natural Disasters in Slovenia with a model of avalanche trigger areas.

2.2.3 Avalanche avalanche thickness model *(Slv. Debelina plazovine)*
The third layer, contained in the avalanche section of the atlas, shows modeled values of avalanche deposit thickness. The results were determined using model calculations in *RAMMS* (*Rapid Mass Movement Simulation;* Christen, Kowalski and Bartelt 2010). As we wanted to make the model calculations as uniform as possible for the entire country, the avalanches were modeled on the basis of previously defined ridges. The ridges were digitized in the areas where avalanches were assumed to occur based on the avalanche cadastre and the avalanche trigger zone model. The digitized ridge lines were then plotted on a 20 m wide strip on both sides of the ridge to obtain an indicative avalanche prone area. We then used *RAMMS* to determine that 0.5 m of medium density snow (300 kg/m^3) would be triggered in these areas. The program calculated the avalanche movement and deposition area as well as the avalanche thickness based on a digital elevation model with an accuracy of 5 m and the land use/forest layer. Data were selected for a return period of 100 years and the results were plotted on cells with an accuracy of 10 x 10 m.

Table 2: Avalanche thickness classes in cm.

class	**from ...**	**to ...**
1	0	5

2	5	10
3	10	25
4	25	50
5	50	100
6	100	500
7	500	1000
8	1000	2016

For comparison with the existing cadastre, we used the results of the maximum *flow-height*, expressed in centimeters (Table 2). The model results show not only the thickness of the overburden, but also the reach of the modelled avalanches, and the results agree quite well with the actual recorded landslide situation (Figure 5). The method has one limitation: as the trigger zones were only defined for ridges, landslides starting on slopes are not shown, and the method does not allow calculations for landslides starting in the forest.
Source: Research Centre of the Slovenian Academy of Sciences and Arts Anton Melik Geographical Institute, 2023.

Figure 5: Screenshot of the page Geographic Atlas of Natural Hazards in Slovenia with the model of avalanche range and thickness of avalanche material.

2.2.4 Snowpack data from the Slovenian Environment Agency *(Slv. Snežni podatki)*

The fourth part of the avalanche atlas is a display of snowpack data from the Slovenian Environment Agency. The maps were created using the spatial interpolation method, taking into account the dependence on geographical variables. As there are very few measuring stations at altitudes above 1000 m, the map is less accurate at these altitudes. Larger deviations from the map are also likely on very steep rocky mountain slopes, and on peaks and ridges exposed to strong winds. The maps are regional in nature and have been calculated on the basis of the relief with a resolution of 100 x 100 m. The final resolution is therefore between 1 and 2 km, depending on the density and representativeness of the stations.

The atlas shows the following data:

- Maximum snow load with a return period of 50 years (kN/m^2), which forms the basis of the national addendum to the European Building Construction Standards (EVROKOD) - Effects on structures. The map is based on measurements from meteorological stations using the optimal spatial interpolation method and the values for the 50-year return period are estimated for each station using the Gumbel method.
- The maximum snowpack depth with a return period of 50 years, based on measurements from meteorological stations and the optimal spatial interpolation method, and the values for the 50-year return period are estimated for each station using the Gumbel method.
- Average annual number of days with snow cover 1971-2000 and
- The average total new snowfall for the 1971/1972-2000/2001 period is a map based on 30-year averages for the reference period from winter 1971/1972 to winter 2000/2001. A year is a season that begins on July 1 and ends on June 30 of the following year. The map was created using the method of optimal spatial interpolation, which takes into account the dependence on geographical variables.

Source: Environment Agency of the Republic of Slovenia (Dolinar 2004); https://gis.arso.gov.si/atlasokolja/profile.aspx?id=Atlas_Okolja_AXL@Arso; https://geohub.gov.si/portal/home/item.html?id=e04e16b432a84b5391135fc6f806a127

2.3 Floods

This part of the atlas includes the flood hazard map (Komac, Natek and Zorn 2008) of the Water Directorate of the Republic of Slovenia, i.e. the maps of the Flood hazard classes and the Results validity area. The integral map of flood hazards classes shows flood hazard areas classified according to the magnitude of the flood discharge at the same probability of occurrence of the event (Figure 6). A low flood hazard exists if the water depth is less than 0.5 m or the product of depth and velocity of the water is less than 0.5 m^2/s at a discharge of Q100 or a head of G100. The map shows the areas at risk of flooding, which are classified according to the magnitude of the flood discharge with the same probability of occurrence (Figure 6). There is a medium flood hazard if, for a Q100 or G100 discharge, the water depth is equal to or greater than 0.5 m and less than 1.5 m or the product of water depth and velocity is equal to or greater than 0.5 m^2/s and less than 1.5 m^2/s or if the water depth is greater than 0.0 m for a Q10 or G10 flow. 0.5 m or less than 1.5 m/s or if the water depth is greater than 0.5 m/s or if the water depth is greater than 0.5 m/s. A high flood risk exists in areas where the water depth is equal to or greater than 1.5 m at a Q100 discharge or G100 level or where the product of water depth and velocity is equal to or greater than 1.5 m^2/s. The residual flood hazard class exists when the flood is caused by exceptional natural or man-made events (e.g. extreme meteorological events or damage to or failure of flood protection structures or other hydraulic structures), i.e. in most cases in flood hazard areas between Q100 and Q500 (a description of the methodology can be found at http://www.pisrs.si/Pis.web/pregledPredpisa?id=PRAV8318). In addition to the individual classes, the atlas also shows the area validity of the results, i.e. the areas in which the flood hazard classes shown are valid.

Source: Water Directorate of the Republic of Slovenia, 2023; https://podatki.gov.si/dataset/integralna-karta-razredov-poplavne-nevarnosti-ikrpn

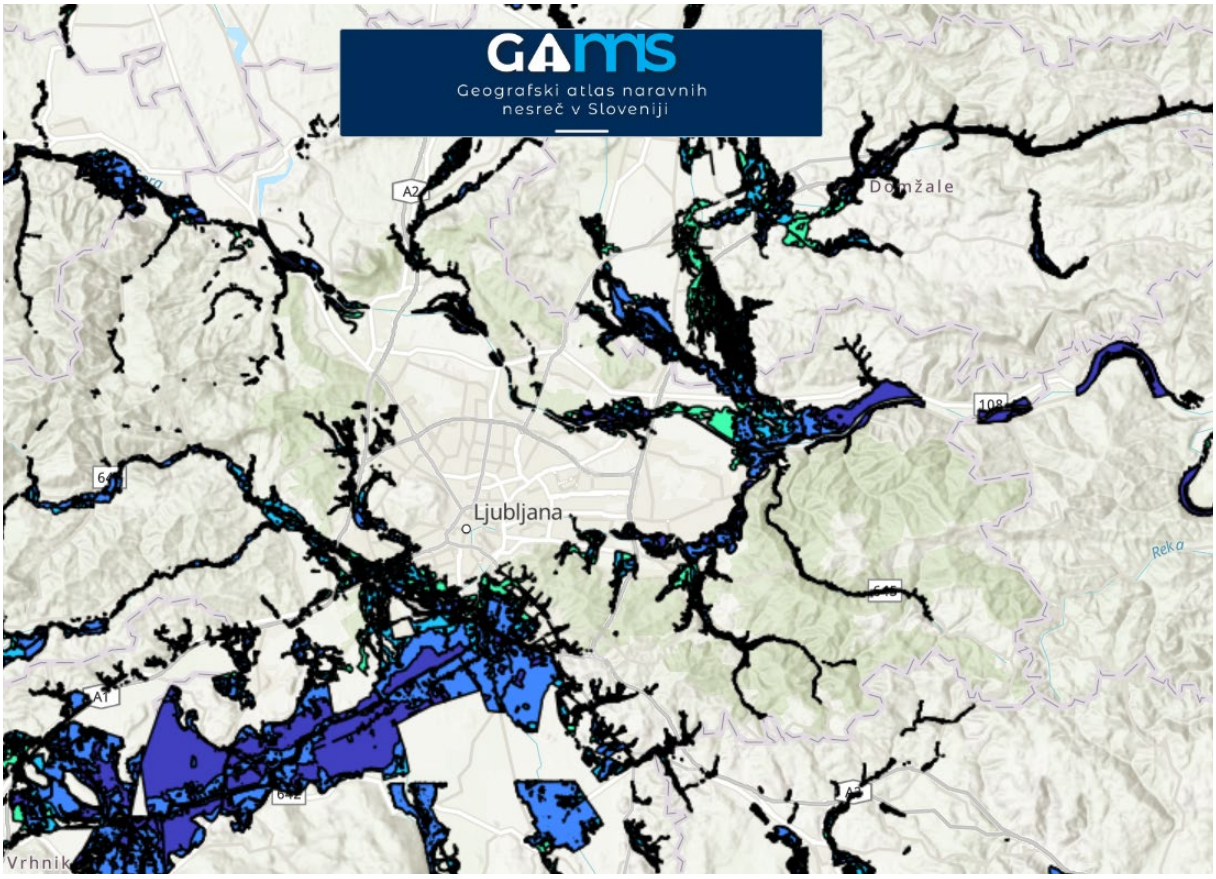

Figure 6: Screenshot of the page Geographic Atlas of Natural Hazards in Slovenia showing the flood risk.

2.4 Landslides *(Slv. Zemeljski plazovi)*
This part of the atlas consists of two maps, a map of landslide events and a map of landslide hazard.

2.4.1 Avalanche events (*Slv. Lokacije zemeljskih plazov)*
The first part conatins selected data on the locations of selected landslides. The aim is to show historical events from which we can deduce which areas are more prone to landslides and which are not.
Sources: National Landslide Database, 2006; Zorn and Komac 2008; Ažman Momirski et al. 2013 (municipality of Brda); Gabrovec and Brečko Grubar 1990 (municipality of Laško).

2.4.2 Risk of landslides *(Slv. Plazljiva območja)*
The second part is a map showing the risk of landslides. The landslide probability map for Slovenia is based on data on the location of about 3000 landslides and an analysis of the influencing factors (lithological composition – weight 0.30; land use – 0.25; slope gradient – 0.25; surface curvature – 0.10; and 24-hour maximum rainfall and exposure – 0.10 each). The analyzes were performed with raster data. Five hazard categories were created, of which the first covers 35% of the Slovenian territory, the second 40%, the third 10%, the fourth 1% and the fifth less than 1% of the territory. Avalanche susceptibility is highest in the alpine regions of Slovenia. The most landslide-prone alpine mountain ranges are Cerkljansko, Škofjeloško and Polhograjsko hills, the Posavsko hills, the Ložnica and Hudinja hills, and the Velenje and Konjice hills. Among the Alpine mountain ranges, the Western Karavanke, Eastern Karavanke and Kamnik-Savinja Alps stand out in terms of avalanches.

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In the Pannonian regions, the hills most prone to landslide are Boč and Macelj, Haloze, and the Voglajna and Zgornjesotelsko hills. In the Mediterranean landscapes, Goriška Brda, Brkini, the edge of the Vipava Valley and Koprska Brda are themost prone to landslides. The Dinaric landscapes are the least threatened by landslides (7.2%), with the Idrija Hills being the most threatened by landslides.
Source: Zorn and Komac (2008).

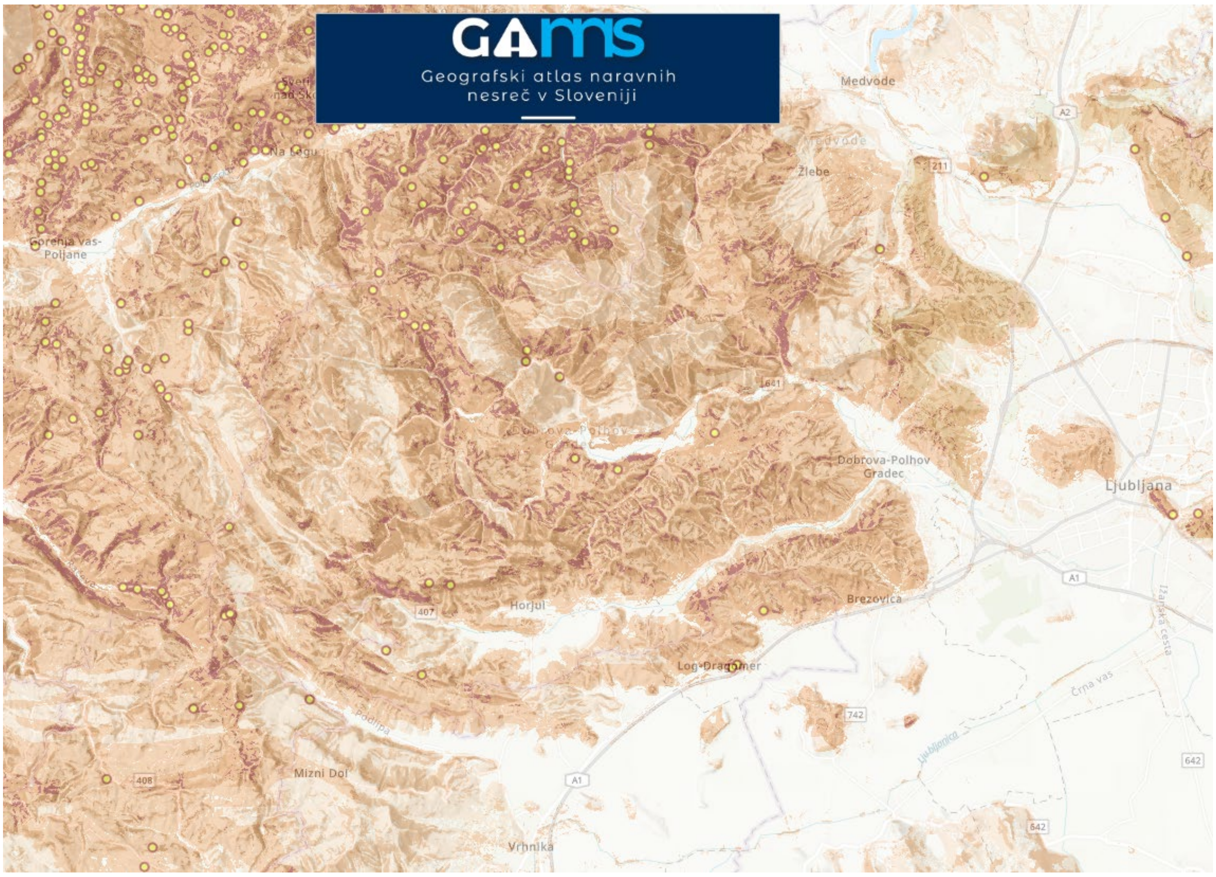

Figure 7: Screenshot of the Geographic Atlas of Natural Hazards in Slovenia page showing landslides and landslide hazards.

2.5 Earthquakes (Slv. Potresi)
This part of the atlas consists of two maps, the map of earthquake events and the map of earthquake hazard.

2.5.1 Earthquake locations *(Slv. Lokacije potresov)*
The map of earthquake events shows the most important historical earthquakes for the Slovenian territory. The database contains 601 earthquakes and is based on the catalog of earthquakes in Slovenia and neighboring countries of the Slovenian Environment Agency, Office of Seismology, which covers the period since 456 (Živčić et al. 2018).

2.5.2 Seismic hazard *(Slv. Potresna nevarnost)*
The second part shows the map of design ground acceleration for a return period of 475 years of the Slovenian Environment Agency, Office of Seismology, which is an annex to the national supplement to the Eurocode 8 (EC8) standard for earthquake-resistant construction.

The seismic hazard was calculated according to the probabilistic procedure of Cornell (1968) for a return period of 475 years. The map shows the calculated mean acceleration values, which were divided into ten classes of width 0.025 g (from 0.1 to 0.325 g) and rounded to the upper limit of the class (Šket Motnikar et al. 2023; Figure 8).
Source: © Ministry of Environment and Spatial Planning, Slovenian Environment Agency, 2021
https://gis.arso.gov.si/portal/apps/opsdashboard/index.html#/48ad6a51977c4ee886722a3c09c4f470?locale=sl and https://podatki.gov.si/dataset/karta-potresne-nevarnosti

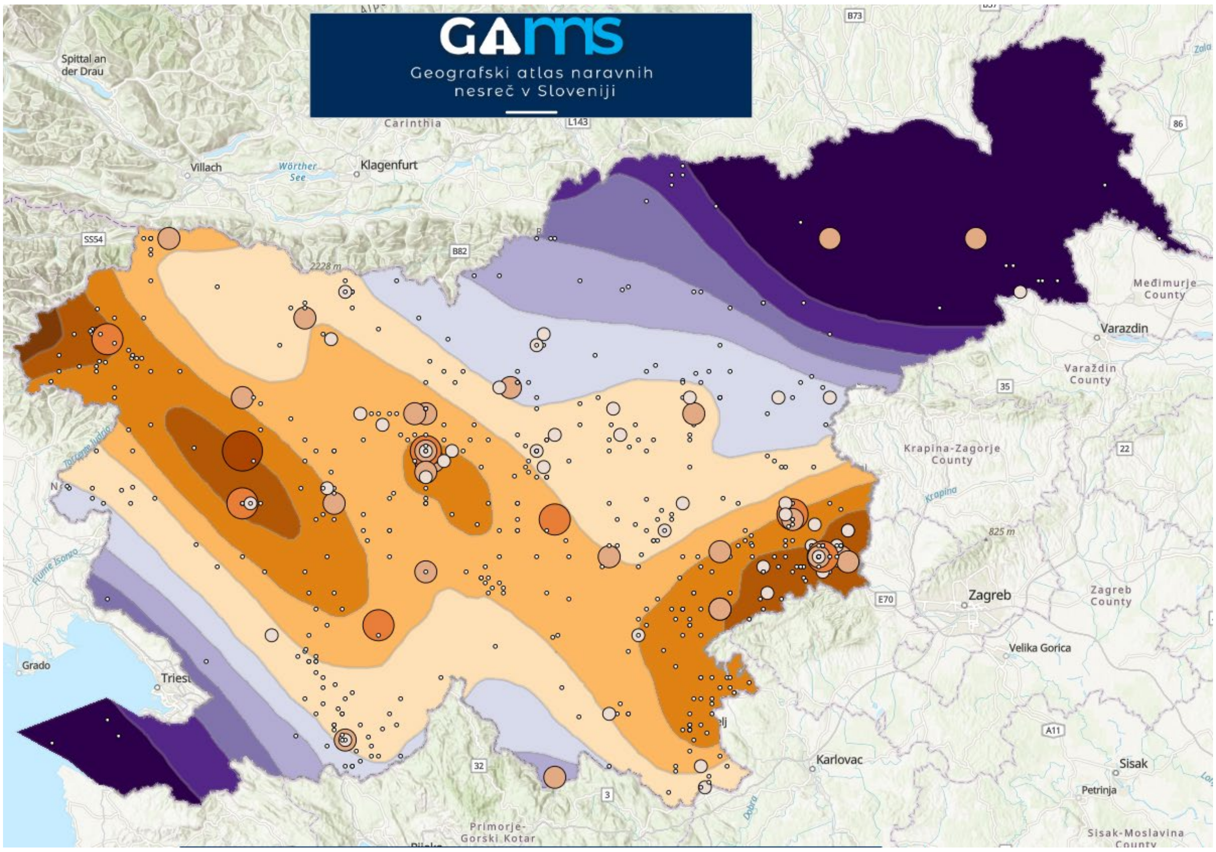

Figure 8: Screenshot of the Geographic Atlas of Natural Hazards in Slovenia page showing historical earthquakes and earthquake hazards.

2.6 Forest fires (Slv. Gozdni požari)
This part of the atlas contains two maps, the forest fire events and the forest fire risk according to the Slovenian Forest Service.

2.6.1 Fire locations (1995-2019) *(Slv. Lokacije požarov (1995–2019)*
The first data layer shows the location of the 100 largest forest fires in the period 1995-2019. Most of them are located in the south of the country, most of them occur in sunny weather, and drought and wind are also important factors for their occurrence. In addition to fuel availability and human factors, which may include activity- and policy-driven land-use changes, the most important influences on the occurrence of forest fires in Slovenia are atmospheric temperature, precipitation and cloud cover (Komac 2022).
Source: © Slovenian Forest Service, 2019.
http://www.zgs.si/gozdovi_slovenije/o_gozdovih_slovenije/pozarno_ogrozeni_gozdovi/index.html

2.6.2 Forest fire hazard *(Slv. Požarna ogroženost gozdov)*

The second data layer is a map showing the classification of forests according to fire risk levels, which are divided into four fire risk levels, ranging from very high risk to high risk, medium risk and low risk, in accordance with the method described in Annex 2 of the Regulation of Forest Protection (Official Gazette of the Republic of Slovenia 114/2009) (Figure 9).
Source: © Slovenian Forest Service, 2019.
http://www.zgs.si/gozdovi_slovenije/o_gozdovih_slovenije/pozarno_ogrozeni_gozdovi/index.html

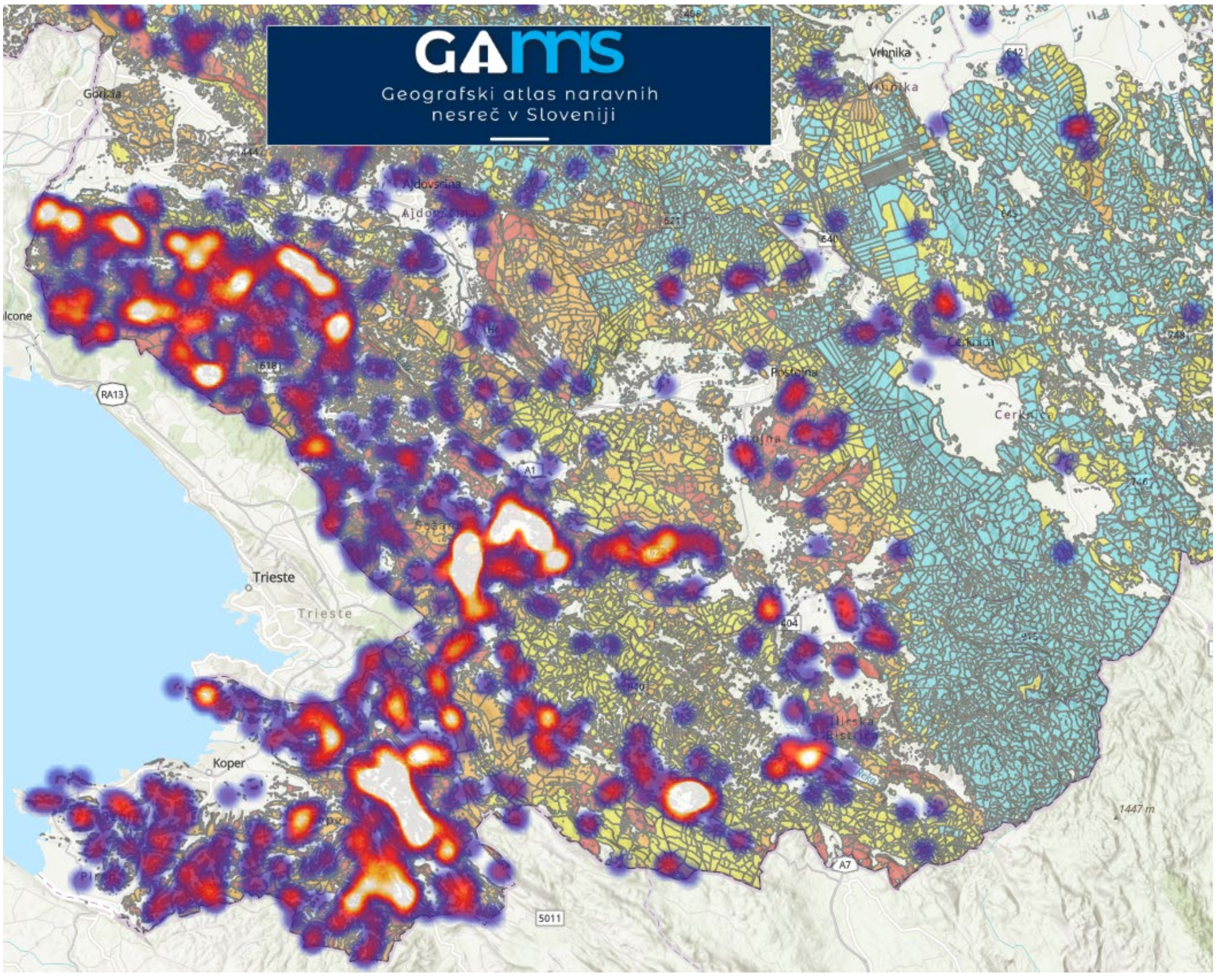

Figure 9: Screenshot of the Geographical Atlas of Natural Disasters in Slovenia page showing the density of forest fires in the period 1995-2019 and the forest fire risk.

2.7 Damage caused by natural disasters

The magnitude of the natural disasters can be deduced from the data on damage caused by natural disasters (2018). In 2018, damage was highest in southwestern Slovenia, as this part of the country is prone to forest fires, which are more likely to occur in the future. The annual damage in this area can amount up to EUR 50 per capita. Damage is also high in the central and northern regions, reflecting the more complex landscape conditions. This area is exposed to river flooding, flash floods and slope processes. These natural hazards affect large areas and the damage is greater than in other areas, exceeding EUR 60 per capita (Figure 9).
Sources: Zorn and Komac 2011; Komac 2021.

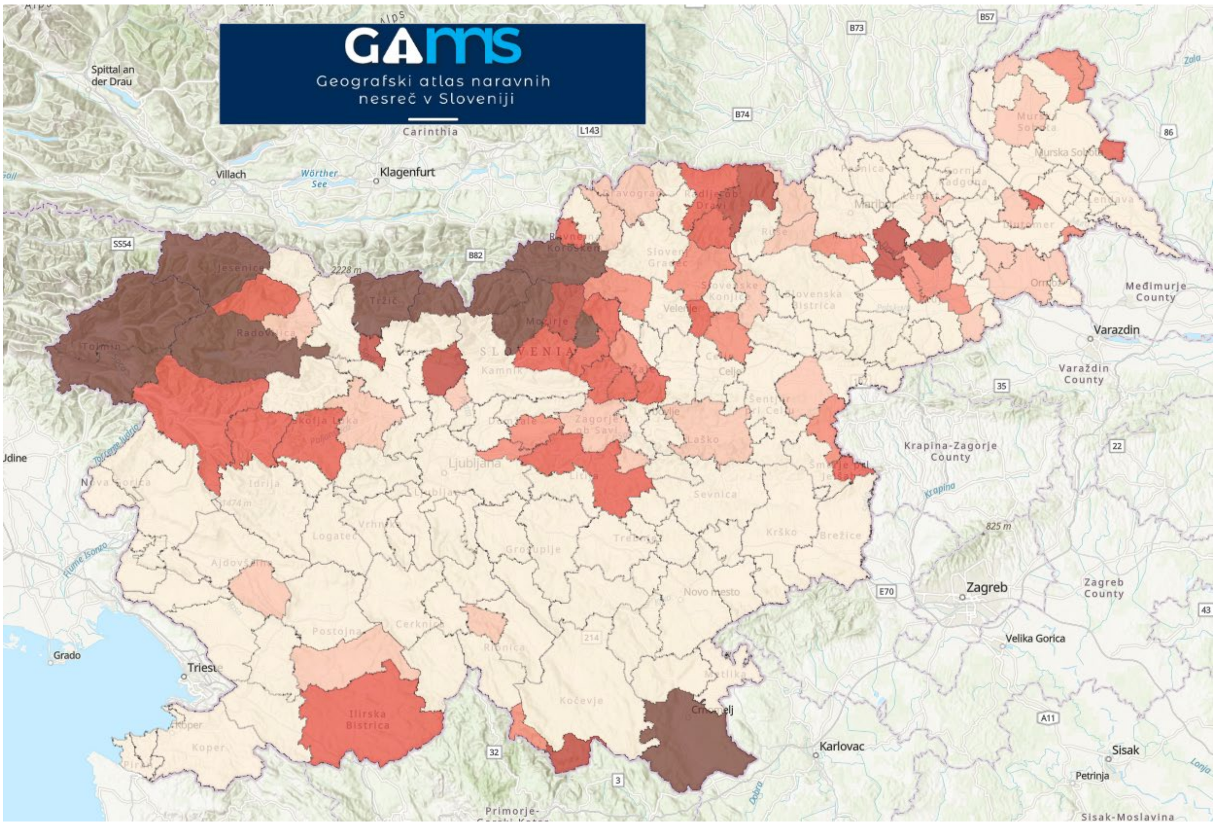

Figure 9: Screenshot of the Geographic Atlas of Natural Disasters in Slovenia page showing the damage caused by natural disasters in 2018.

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3 CONCLUSION

A database on the occurrence of natural hazards, which also includes some content from other sources, is important to improve knowledge about natural hazards in a given landscape, both for permanent residents and for occasional visitors such as tourists and hikers. At the same time, the database is also the basis for spatial management, which includes both the construction of buildings and, in particular, critical infrastructure in alpine landscapes, where the phenomenon of avalanches is a particular highlight. The database will also enable or facilitate further research that will hopefully lead to better risk assessments. The atlas will thus make an important contribution to the prevention of natural disasters, which Slovenia is called upon to do in a number of international documents. The importance of the database is all the greater as it is publicly accessible as an online geographical information system and can therefore be accessed by anyone at any time at ganns.zrc-sazu.si.

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In contrast to historical events, where locations and additional information are displayed, the hazard maps (floods, avalanches, landslides, forest fires and earthquakes) only show the source areas of processes, but not the transportation and deposit areas. The exceptions are the models of avalanche trigger zones and the deposition of avalanche material. Hazard maps and model results are limited by the spatial (extent) and temporal (time period) accuracy of the input data and the accuracy of the geographical bases and methods used, so some maps are presented at a smaller target scale.

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