

Producing a landslide susceptibility map for the canton of Bern

Introduction

The goal was to produce a landslide susceptibility for a selected Swiss canton. To tackle this problem, different data is necessary. And after some research, I decided to focus on the canton of Bern, since all the relevant data is available for this area. In addition, Bern is a good representation of Switzerland, due to its diverse landscape, consisting of high, rocky mountains, steep hills and valleys with creeks and rivers, but also some agglomeration and a more even area.

Methods

Concept

After looking at different papers like the ones from Panchal et al. (2021) and Regmi et al. (2014), I decided to use a frequency ratio and calculate the landslide susceptibility index LSI. In short, it works by selecting different factors, that potentially contribute to the landslide susceptibility, defining classes for each factor and calculating a value, that tells how much they contribute to a set of reference landslides (Figure 1).

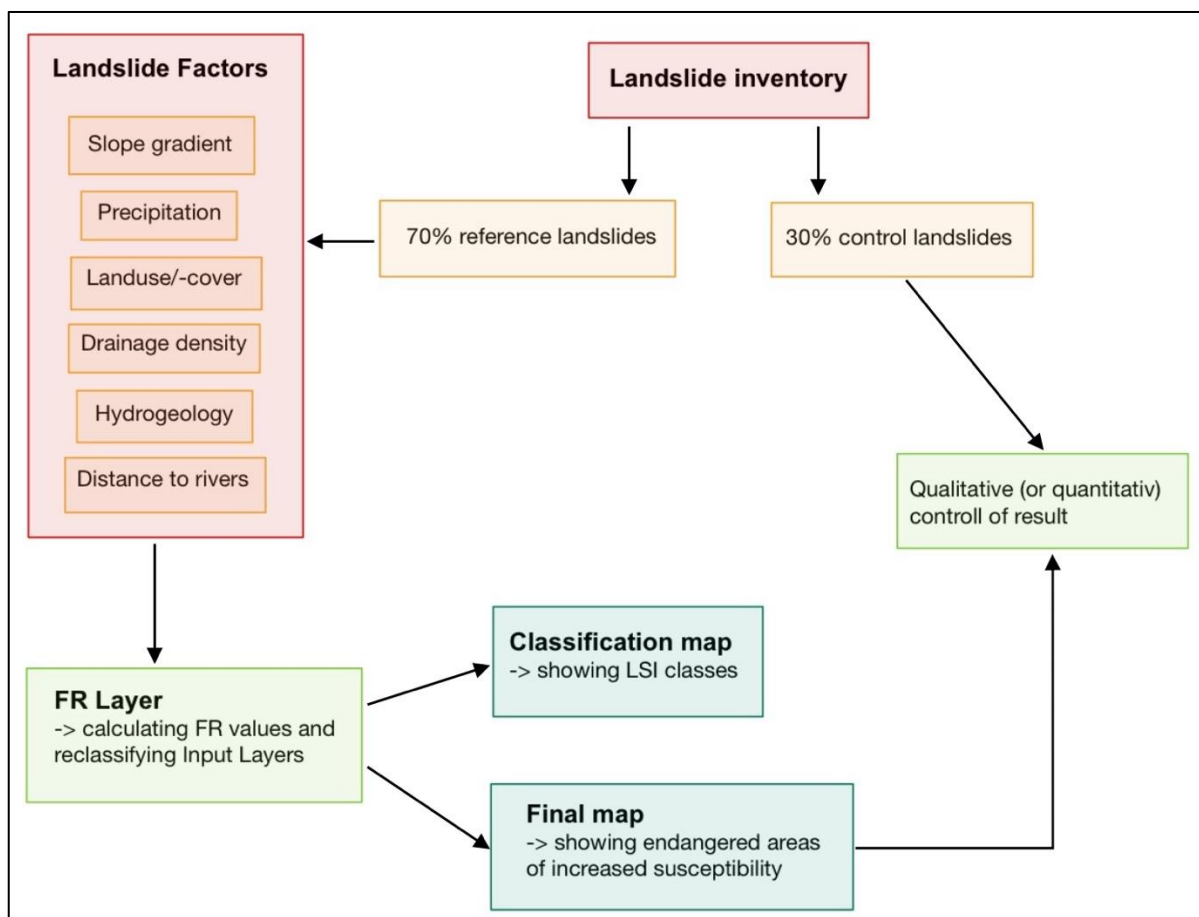


Figure 1. Flow diagram showing the general workflow and the concept.

The values were calculated with this formula (inspired by Panchal et al. (2021) and Regmi et al. (2014), but slightly changed and adapted to this project):

$$FR_{value} = \frac{\frac{SX_{i,j}}{\sum_{j=1}^c SX_{i,j}}}{\frac{X_{i,j}}{\sum_{j=1}^c X_{i,j}}} = \frac{\frac{\text{landslides per class}_{i,j}}{\text{landslides per factor}_i}}{\frac{\text{pixels per class}_{i,j}}{\text{pixels per factor}_i}}$$

Where $SX_{i,j}$ is the number of landslide pixels per factor i and class j . And $X_{i,j}$ is the number of pixels per factor i and class j . And c is the number of classes per factor i .

If the value is over 1, the influence of this class is bigger than the average of the whole region, and vice versa. In general, the bigger the value, the bigger the influence.

To obtain the final layer, those values were used to calculate the landslide susceptibility index LSI. This is done by summing up all layers and dividing them by their count to get the average value for each cell:

$$LSI = \frac{\sum FR_{value}}{f}$$

Where f is the number of factors, which in our case is 6.

Data

I used a Layer of recorded landslide events in Bern, a layer for the boundaries of the cantons, a DEM to create a slope layer, a layer for mean annual precipitation, a layer of flowing waters to calculate drainage density and distance to rivers, a layer for land use/cover and a layer for hydrogeology. The layers and tables were searched and accessed through opendata.swiss. The resolution has been adjusted to 100m.

Layers

Reference landslides:

From a layer with different natural hazard events in the canton of Bern, the landslide events were selected and exported into a new layer. Then, a random number was assigned to each event, to split it into one layer with 70% of the points, used to estimate the values, and another layer with the remaining 30% of the points, used as a control for the result.

Canton boundary:

Since we are only interested in the canton of Bern, and most of the initial data is for the whole country, it was necessary to create a mask of the canton Bern to mask or clip the initial layers to the necessary extent.

Slope gradient:

A DEM of Switzerland with a resolution of 100m was used as an input. Then, a slope layer was calculated and masked with the boundary layer to fit the extent of the canton. This layer was then classified into the 5 classes (Figure 2. A).

Precipitation:

A data table was used as input, which contained the values for the mean annual precipitation of the measuring stations in Switzerland and their coordinates. This table was converted into a csv file and the coordinates of the stations have been converted from LV95 to WGS84. Then, it could be loaded into ArcGIS pro and converted into a point layer. In a last step, a raster was produced with IDW, masked with the boundary layer and classified into 3 classes (Figure 2. B).

Drainage density:

The line density of the flowing waters layer has been calculated, masked with the boundary layer and classified into 4 classes (Figure 2. C).

Distance to river:

The layer of flowing waters was used to calculate the distance accumulation, with the DEM as surface raster to include the terrain. Then it was masked with the boundary layer and the distance was classified into 3 classes (Figure 2. D).

Hydrogeology:

The hydrogeology layer has been masked with the boundary layer and was reclassified by merging the two aquifers with granite into one class (Figure 2. E).

Land use/cover:

The Arealstatistik layer was rasterized into a raster layer with a resolution of 100m. Afterwards it has been masked with the boundary layer and classified into 5 classes (Table 1., Figure 2. F).

Table 1. Classification of the Arealstatistik into 5 classes

Number	Class	Description
1,2,3,4,5	1	Agglomeration
6,7	2	Agriculture
8,9	3	No vegetation/pastures
10,11,12,15	4	Vegetation/Forest
13,14,16,17	5	Water, ice

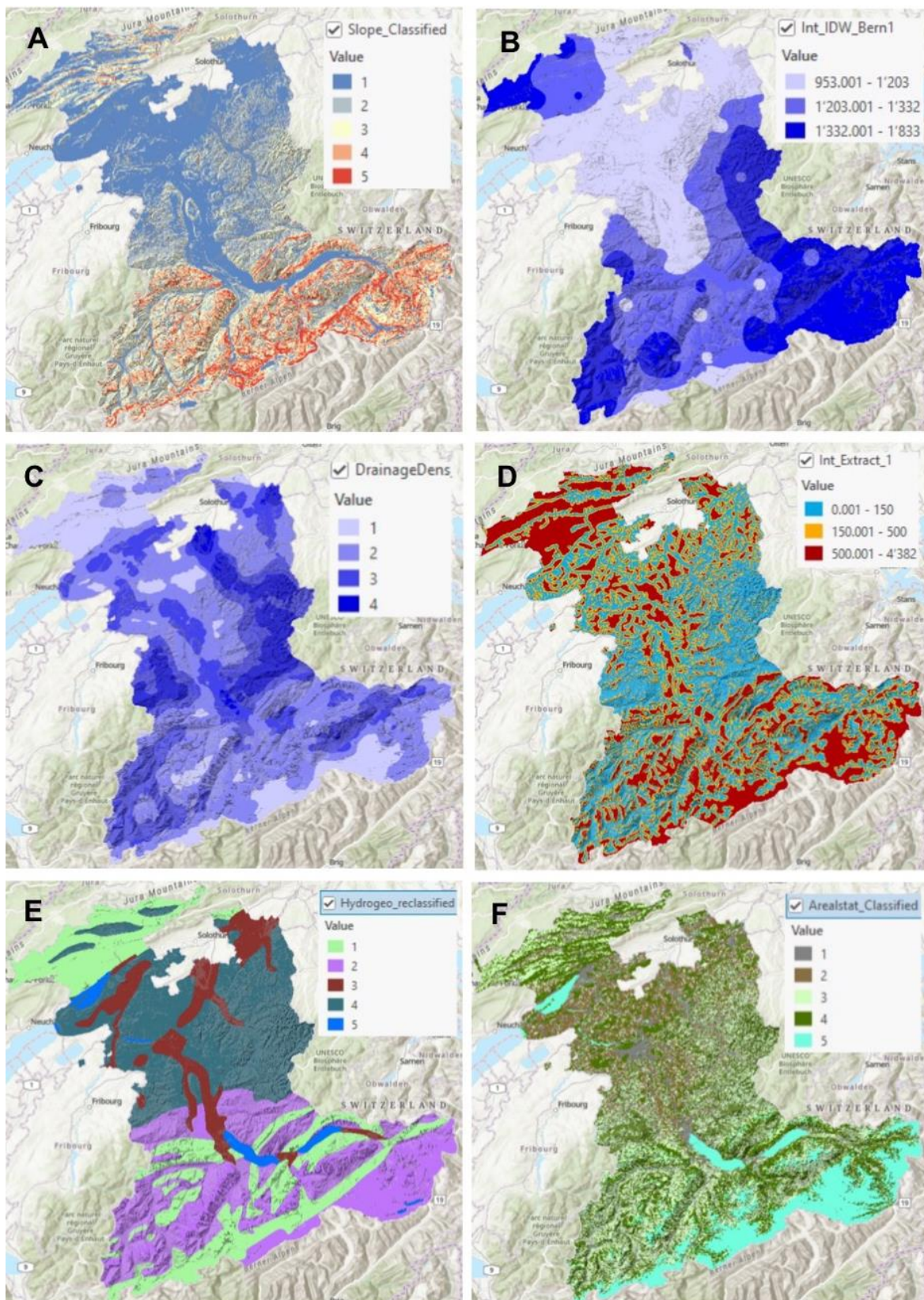


Figure 2. (A) Slope layer classified: 1 = 0-7°, 2 = 7-16°, 3 = 16-27°, 4 = 27-39°, 5 = 39-75° (B) IDW of mean annual precipitation[mm] classified into 3 classes (C) Drainage density classified into 4 classes (D) Distance[m] to rivers classified into 3 classes. (E) Hydrogeology classified into 5 classes: 1 = karst aquifer, 2 = fissure (partly pore) aquifer, 3 = unconsolidated rocks aquifer, 4 = pore (partly fissure) aquifer, 5 = lake (F) Rasterized Arealstatistik layer classified into 5 classes described in table 1.

FR Layers:

With the classified layers for the 6 factors and the 70% reference slides, the FR values were calculated by counting the slides in each class of the 6 factors and estimating the values in excel. Then, all the classes of the 6 factors have been reclassified with the according FR values shown in table 2.

Table 2. Classes with the calculated FR values for the 6 factors.

Class	Slope gradient	Drainage Density	Distance to River	IDW Precipitation	Landuse/Landcover	Hydrogeology
1	0.3721	0.1767	1.7332	0.7182	1.3532	0.5185
2	1.6471	0.791	0.6529	1.2816	0.2651	1.3632
3	1.8389	1.3333	0.1557	1.0006	1.5238	0.4356
4	0.6046	2.4981	-	-	1.1125	1.2363
5	0.0494	-	-	-	0.1883	0.3896

Result Layer:

In the end, all raster layers with assigned FR values have been summed up and split by their count to get the average value of each cell. The resulting layer was then classified into 4 classes shown in table 3. To make the classes, the histogram was used, and the fact that the value of 1 represents the average of the whole region. Therefore, values below were classified as areas of decreased susceptibility and values above as areas of increased susceptibility. Those were further split into classes of normal and strong difference.

Table 3. Susceptibility classes for different LSI values.

LSI Value	Susceptibility description
≤ 0.7	Strongly decreased
$\leq 1 > 0.7$	Decreased
$\leq 1.3 > 1$	Increased
> 1.3	Strongly increased

For the final map, the two increased classes were polygonised, mainly to have more option for the design. The area of strongly increased susceptibility was selected as a core zone. The area with a normal/moderate increase was selected as an extended zone of the core zone, representing also the uncertainty.

Results

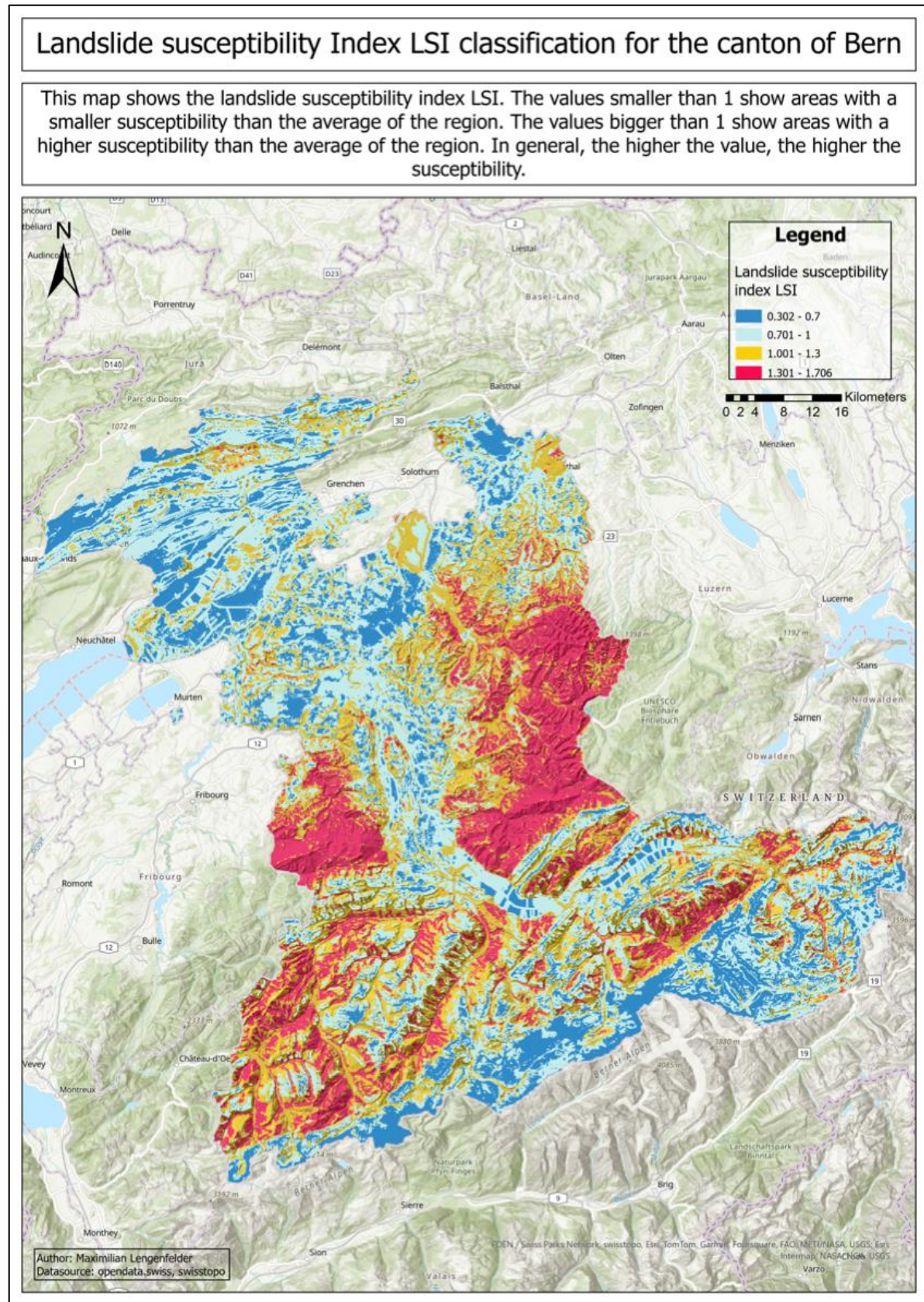


Figure 3. Classification map of the landslide susceptibility LSI for the canton of Bern. The higher the LSI value, the higher the susceptibility.

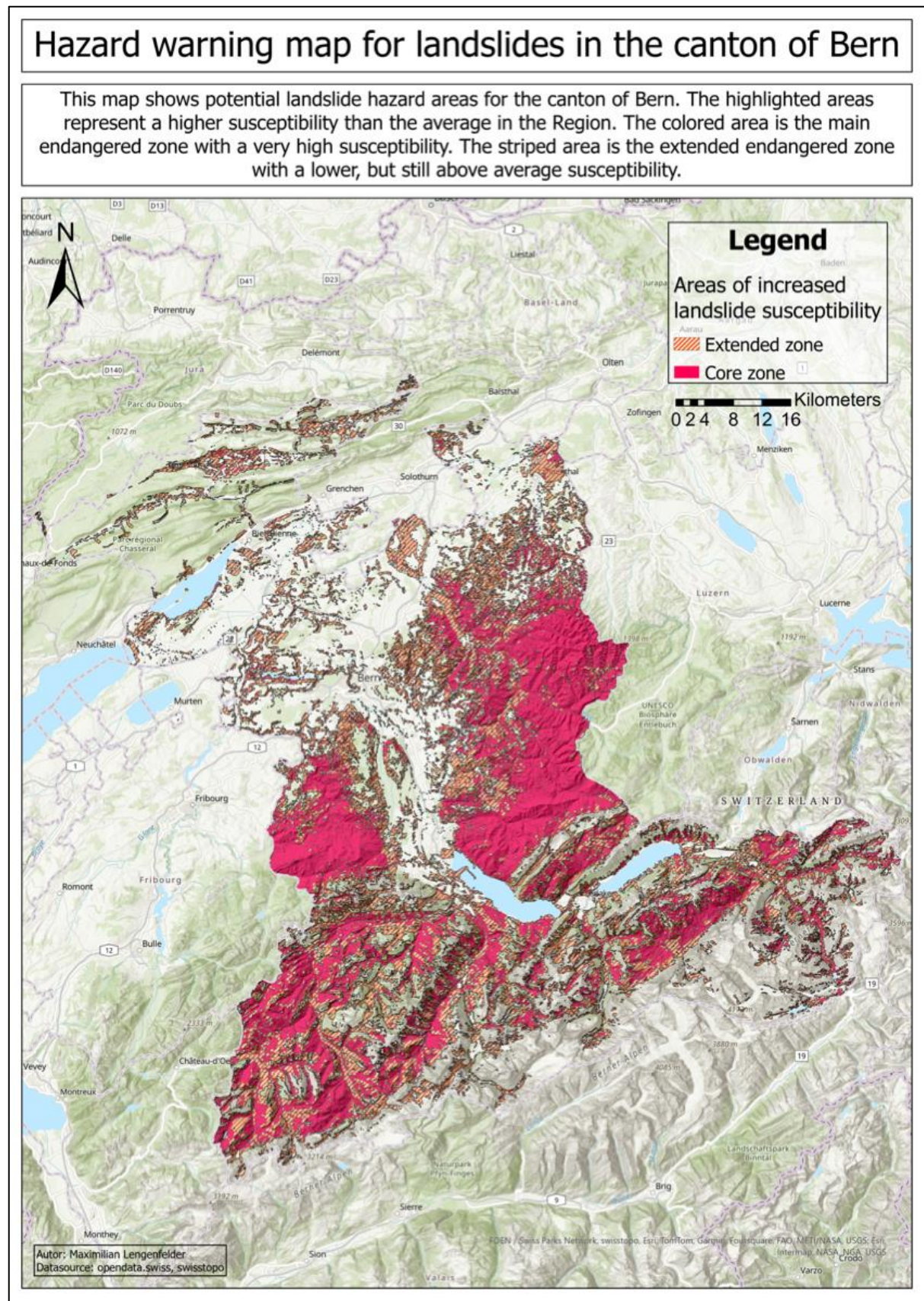


Figure 4. Final hazard warning map showing areas of increased landslide susceptibility. The colored area is the core zone with a strongly increased susceptibility. The striped area is the extended zone with lower, but still increased susceptibility.

Discussion

The final maps look very plausible and 86.8% of the control landslides fall within the whole endangered area and 50.4% into the core zone (Figure 5). Nonetheless, there are some limitations. The first concern is the simplification due to the limited extend of the project. Then, we must look at the quality of the input data, which for all 6 factor layers should be more than sufficient. The biggest concern comes from the reference landslides. Although they are controlled, the question is, what counts as a landslide and if there are some blind spots of unrecognized events. This could lead to either an under or overestimation in certain areas. This could be handled for example with additional sources of information like remote sensing data. Another issue is the classification and the choice of the resolution. It is not always intuitive to choose the barriers and number of classes or the classification method. While minor differences might not have a great influence, an unsuitable classification could cause big errors. And the resolution must also be suitable. It should not be too big, to avoid funky patterns and loss of information. But if it is smaller than necessary, it can cause an unnecessary overload of data leading to potential problems with the program and the calculations performed on the layers. Then, if we zoom in on the map, there are some very small spots classified differently. It is questionable if those very small-scale differences make sense and therefore would be beneficial to smoothen the boundaries. A further variable is the method used to weight the layers and/or estimate values for the classes. Despite that there is a lot of literature comparing many methods, some might be more suitable for certain landscapes than others. You would have to use several methods and compare the results to decide which one is the most accurate. But it can also be unclear, if the factors are independent. If several of them are not, this could cause an over or underestimation. And in the end, since the values for the classes have been estimated with data from the past, we can argue to what extent this result is able to represent the future situation.

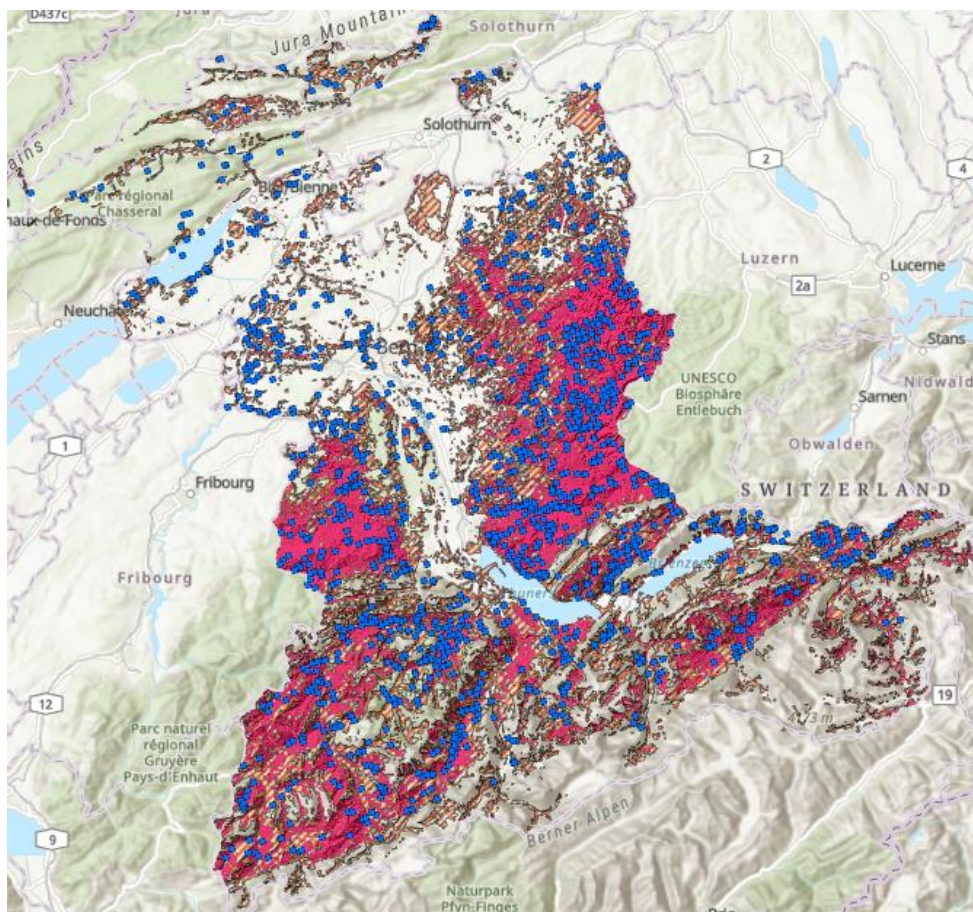


Figure 5. Comparison of the 30% control landslides with the endangered zones from the final map in figure 4.

References

Panchal S., Shrivastava A.K. (2021). *A Comparative Study of Frequency Ratio, Shannon's Entropy and Analytic Hierarchy Process (AHP) Models for Landslide Susceptibility Assessment*. ISPRS Int. J. Geo-Inf. 2021, 10, 603. <https://doi.org/10.3390/ijgi10090603>

Regmi AD, Yoshida K, Pourghasemi HR, et al. (2014). *Landslide susceptibility mapping along Bhalubang–Shiwapur area of mid-western Nepal using frequency ratio and conditional probability models*. Journal of Mountain Science 11(5). DOI: 10.1007/s11629-013-2847-6

Data source

opendata.swiss, geocat.ch, swisstopo.ch, (Olat)

Data ⇒ Layer:

- Source

Arealstatistik ⇒ Land use/cover:

- <https://data.geo.admin.ch/browser/index.html#/collections/ch.bfs.arealstatistik/items/arealstatistik?language=en>

dhm25_100m_elevation ⇒ Slope gradient:

- Olat (Swiss topo)

dhm25_025m_hillshade ⇒ Hill shade (only for map design):

- Olat (Swiss topo)

Flussordnungszahlen ⇒ Drainage density, Distance to rivers:

- <https://www.bafu.admin.ch/bafu/de/home/themen/wasser/zustand/karten/geodaten.html#-518983285>

Hydrogeologische Skizze ⇒ Hydrogeology:

- <https://www.bafu.admin.ch/bafu/de/home/themen/wasser/zustand/karten/geodaten.html#-518983285>

Klimanormwerte 1991-2020 ⇒ Precipitation:

- <https://data.geo.admin.ch/ch.meteoschweiz.klima/normwerte/normwerte.zip>

Naturereigniskataster ⇒ reference/control landslides:

- <https://geofiles.be.ch/geoportal/pub/download/NGKAT/NGKAT.zip>

Swissboundaries ⇒ Canton boundary:

- https://data.geo.admin.ch/ch.swisstopo.swissboundaries3d/swissboundaries3d_2024-01/swissboundaries3d_2024-01_2056_5728.gpkg.zip