Project vulnerability map of forest fires

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Abstract

Forest fires are a major problem in many regions of the world. Though there have not been any devastating forest fires in Germany for decades. However, there are also a few forest fires every year. Almost without exception, these can be traced back to humans as the cause of the fire. Therefore a model had to be provided, which includes humans as large factor. Nevertheless, the most important factor is that the risk areas are flammable. In the investigated test region Baden-Württemberg, almost 40% of the land area consists of forest. Thus, the task was to identify the most endangered regions. The result showed that especially forest areas in three regions are endangered. Especially the Black Forest. However, the new planning of fire watch towers turned out to be difficult due to the mountainous topography in these regions.

1. Introduction

There have not been devastating fires in Germany for decades, but there are still small forest fires in Germany. All in all, this means that there were 424 fires in 2017 and destroyed 395hectar. The area which is examined in this work is the federal state Baden-Württemberg which is located in the southwest of Germany. This federal state consists of 1,371,886ha of forest area, which at the same time represents 38.4% of the federal state area [1]. Thus, the state theoretically offers a large area of flammable forest. In 2016 19 forest fires were documented [2]. 11 of these 19 fire causes can be traced back to campers and other visitors to the forest. Another 7 fire causes were arson. According to the Federal Environment Agency, only 5% of the fires can be attributed to natural causes [3]. Lightning is the natural cause of fires.

1.1 - Topography

Figure 1 shows the topography of Baden-Württemberg. It can be seen that it is a very hilly landscape with many mountains and winding valleys. A flat area exists all the way to the west. In Figure 1 the 4 most striking regions were marked with regard to this work. Number 1 is the Black Forest. By far the largest forest area in the state. Number 2 are the Swabian Alps. Number 3 is another large forest of the country, the Swabian-Franconian forest. Number 4 is the Forest of Odes.

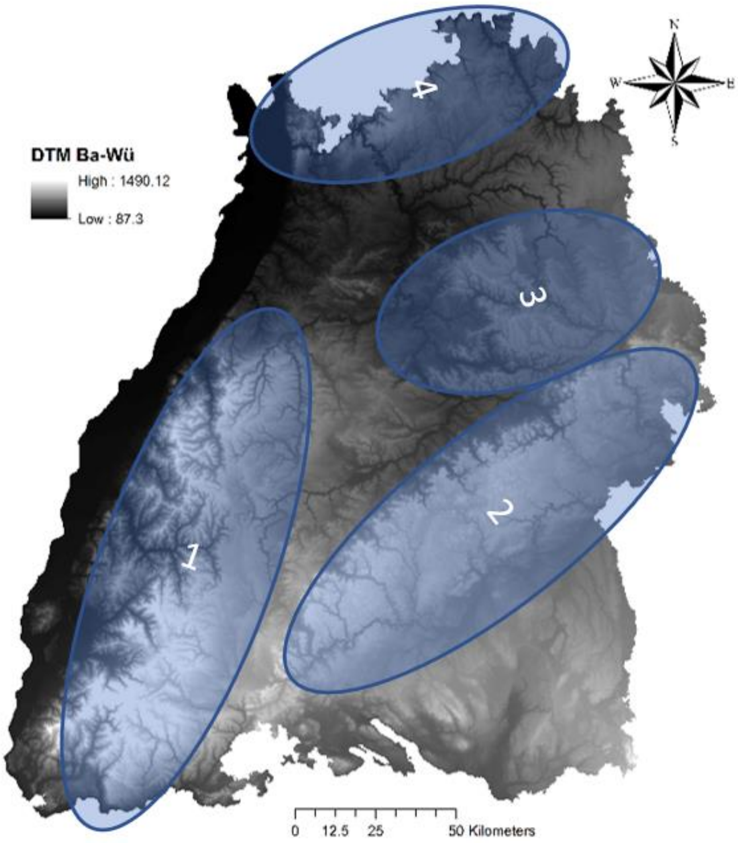

Figure 1 - Topography Baden-Württemberg

1.2 – Data

Factors must be used to calculate a risk for forest fires. The data used in this paper are described below.

1.2.1 – Land Cover

The Land Cover is the most important factor, because the flammability can be calculated by knowing what is at this point.

1.2.2 – Soil Exposure

Soil exposure describes the degree of visibility of soil, because the more soil is visible, the drier the surface and vegetation becomes and the easier it is to ignite.

1.2.3 – Soil Exposure

The slope has two different influencing factors on the flammability. On the one hand, fire can spread more quickly if there is a slope. According to Cimolino, fire can spread twice as fast if the slope is 10 percent steeper [4]. In addition, slopes with an inclination dry out faster because the water drains off.

1.2.4 – Aspect

Regions facing south are more exposed to the sun and therefore drier. That is why these regions are more endangered.

1.2.5 – Water areas

Water areas have two major advantages. On the one hand, areas with water are more humid and therefore less flammable and, on the other hand, they represent a natural barrier to the spread of fire.

1.2.6 – Precipitation

Precipitation has a direct influence on the flammability of an area, as regions with more precipitation are more wet and therefore less flammable.

1.2.7 – Temperature

The temperature also has a direct influence, as hotter regions are drier and forests and grasslands are therefore more flammable.

1.2.8 – Residential areas

According to the Federal Environment Agency's report, humans are responsible for almost every fire, so it is crucial that humans can reach these regions. Regions close to residential areas are easily accessible and are therefore particularly at risk.

1.2.9 – Road network outside of residential areas

Any region that is close to a road network outside towns is therefore a further increased threat, as people can easily reach these regions.

1.2.10 – Hiking paths

Since human negligence is the uncertainty factor number one, regions close to hiking trails are also particularly at risk. When hiking, the dangers are particularly great, as you are already in nature. Careless negligence can therefore easily cause fires. For example by throwing away a cigarette.

1.2.11 – Camping and picnic sites

According to the fire statistics of the Federal Forest Agency, 11 out of 19 fire causes in Baden-Württemberg were caused by campers [2]. Thus this is one of the decisive factors for forest fires in Baden-Württemberg. This means that areas around camping and picnic areas are particularly at risk.

1.3. Data acquisition

Table 1 - Data sources

Daten	Quelle
Land Cover	CORINE CLC 2018 https://land.copernicus.eu/pan-european/corine-land-cover/clc2018?tab=download
Soil	CORINE CLC 2018 https://land.copernicus.eu/pan-european/corine-land-cover/clc2018?tab=download
Road network without residential areas	OpenStreetMap – Roads – Lines https://download.geofabrik.de/europe/germany/baden-wuerttemberg.html
Residential areas	Openstreetmap – Landuse – Areas https://download.geofabrik.de/europe/germany/baden-wuerttemberg.html
Hiking paths	Openstreetmap – Roads – Lines https://download.geofabrik.de/europe/germany/baden-wuerttemberg.html
Hydro elements	OpenStreetMap – Land use – Areas https://download.geofabrik.de/europe/germany/baden-wuerttemberg.html

Precipitation	World Clim http://www.worldclim.org/current
Temperature	World Clim http://www.worldclim.org/current
Camping & picnic sites	OpenStreetMap – POIs – Points https://download.geofabrik.de/europe/germany/baden-wuerttemberg.html
Dimension Shape Ba-Wü	Landesgrenze – Shape-File https://www.lgl-bw.de/lgl-internet/opencms/de/07_Produkte_und_Dienstleistungen/Open_Data_Initiative/

1.4 – Coordinate system

The coordinate system used in Baden-Württemberg is the ETRS 89 UTM Zone 32N with the EPSG code 25832. Since some data are not given in this coordinate system, they must first be transformed into this system. The following table shows all data with their corresponding coordinate system.

Table 2 - Coordinate systems of data

	Data	EPSG	Coordinate System
	CORINE 2018	3035	ETRS_1989_LAEA
	Openstreetmap	4326	GCS_WGS_1984
	World Clim	4326	GCS_WGS_1984
	Dimension Ba-Wü		ETRS 89 UTM Zone 32N (customized)

1.5. Point evaluating system

Table 3 - Point evaluating system

Variable	Classes	Risk class	Percentage
Land Cover	Rest 222, 333 14%, 221, 223, 322 211, 24%, 311 313, 321, 323, 324 23%, 312	0 20 40 60 80 100	75 of 440 ≈ 17%
Soil Exposure	Rest	0	40 of 440

	- 211, 212, 244, 31%, 322, 323, 324 22%, 241, 242 23%, 243, 321, 333	25 50 75 100	≈ 9%
Slope	0 – 10) [10 – 15) [15 – 20) [20 – 25) [25 -	20 40 60 80 100	40 of 440 ≈ 9%
Aspect	N NE, NW E, W SE, SW S	0 25 50 75 100	20 of 440 ≈ 4.5%
Roads outside residential areas (motorway, trunk, primary, secondary, tertiary, unclassified and corresponding link streets)	[1km – 0 - 1km)	0 100	20 of 440 ≈ 4.5%
Residential areas	[1.5km – 0 – 1.5km)	0 100	30 of 440 ≈ 7%
hiking	[1.5km – [1.0 – 1.5km) [0.5 – 1.0km) 0 – 0.5km)	0 33 66 100	40 of 440 ≈ 9%
water	0 - 1.5km) [1.5km -	0 100	45 of 440 ≈ 10%
Precipitation	[144 - [81 – 95) [72 – 81) [63 – 72) 0 – 63)	20 40 60 80 100	40 of 440 ≈ 9%
Temperature	0 – 155) [155 – 164) [164 – 177) [177 – 190) [190 -	20 40 60 80 100	40 of 440 ≈ 9%
Camping & picnic sites	[1.5km – 0 – 1.5)	0 100	50 of 440 ≈ 11%

2. Work

2.1 - Vulnerability

Through the previously defined scoring, the goal was to have each influencing factor present in a classified raster image in order to then be able to calculate all factors with each other. However, in order to have these factors in a classified model, a few steps had to be carried out beforehand.

All steps are shown in the working flow figure below and the decisive steps of how the vuln. areas were identified are discussed now. The CORINE was used for the Land Cover and Soil Exposure classes. This first had to be transformed into the German coordinate system. Then it was clipped. For the assignment of the corresponding risk value a new field was added and correctly filled with the Field Calculator. It was then converted into raster format.

For all OSM data the same principle was used. They were first transformed into the correct coordinate system, then filtered according to the desired values. With the now available shp-file a Euclidean Distance could be calculated. The risk classes were then defined on the basis of these distances.

The DTM was also transformed with Project Raster. The slope and aspect were then calculated and classified as described in the table above.

The temperature and precipitation were separated in files by month. Therefore, the average was calculated for the decisive months for forest fires March to October. These were clipped into the correct coordinate system and resampled to the pixel size of the DTM.

Now all values are classified as raster and can be calculated with a raster calculator. For this purpose, each risk class was multiplied by the corresponding factor. This total sum was now divided by the sum of all factors to have the risk in percent.

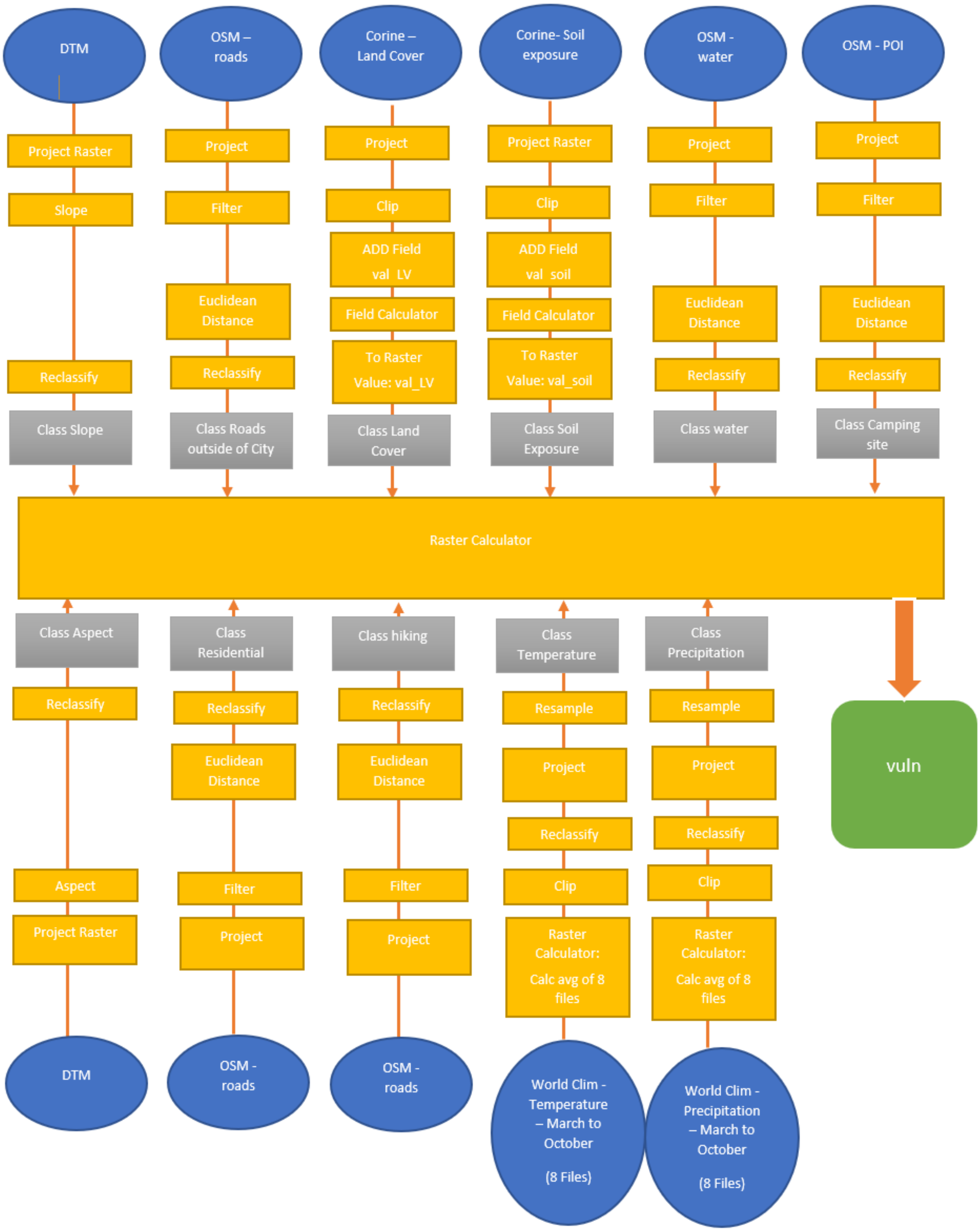

Figure 2 - work flow vulnerabilty

2.2 – Spatial optimization of forest observation structures

The task is to find areas that are not guarded by observation towers for forest fires. But there are also areas to be identified that are already well observed. In Portugal, these fire observation towers are used to monitor forests. Something comparable does not exist in Germany and especially in Baden-Württemberg. In the OpenStreetMap data of the POIs the attribute observation towers exist. These points are used in this work as fire observation towers. These towers serve a similar purpose in reality, as they are used by tourists and they also inform the fire brigade in case of a fire.

For the viewshed only a dtm with the resolution 200x200m could be used, because this is the highest resolution provided by the German authorities for free. The results are presented and discussed in the next chapter.

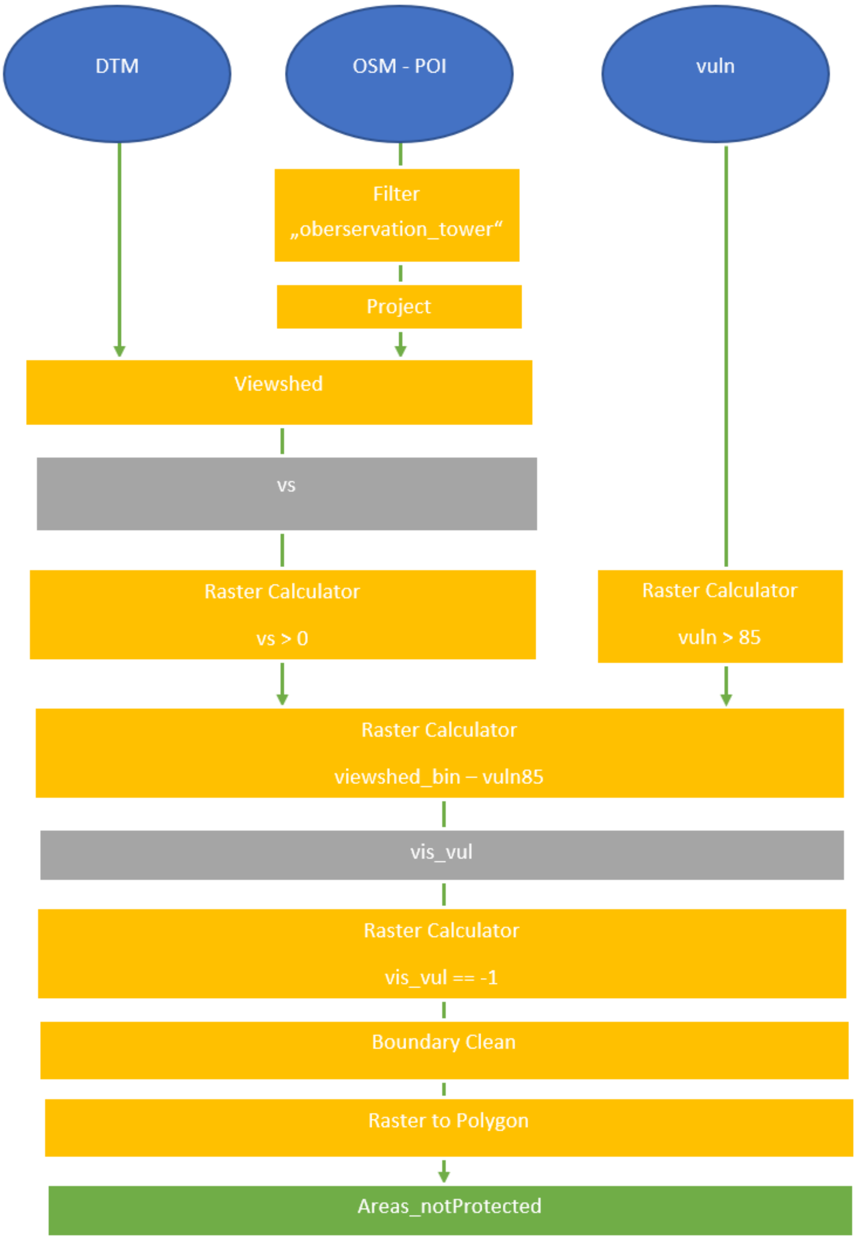

Figure 3 - work flow of "not protected areas from fire observation towers"

The workflow presented in Figure 3 can be used to identify risk areas that cannot be covered by any viewpoint. The diagram is self-explanatory, therefore only the decisive points are addressed here. First a viewshed is made from DTM and the observation towers to identify the visible regions. This output is then binarized to subtract it from the binary grid of the vulnerability. Thus, the pixels that are not visible in the viewshed and are a risk area in the vuln raster are obtained by subtraction -1. Those areas are converted to a polygon and result in areas that are not protected.

When looking at the result, it can now be decided where new viewpoints would be suitable. These can be added to a shape file with existing points. Then the workflow of Figure 3 is repeated. Now the new results can be compared with the old results and it can be decided whether the new points bring a significant added value. This step is repeated until the result of the new points is satisfactory.

2.3 – Optimizing accessibility of forest fire fighting brigades

With the previously defined risk areas, optimal routes from the existing fire stations to the areas should be defined. The dtm was also needed as a basis for this. Since it is possible to drive at different speeds on different roads, this must be taken into account when optimizing the routes. Therefore, the different roads have cost factors, depending upon possible speed. These are illustrated in table 4.

Table 4 - costs by type of street

Type	Speed	Cost
motorway, trunk	100	6
primary	80	8
secondary	60	10
tertiary, residential, service, unclassified and all link streets	50	12

Figure 4 illustrates the workflow. Also, here only the decisive steps are discussed. First a classified model of the slopes with the corresponding cost factors is created. In addition, cost factors are also given to the roads depending on the type of road. These are classified with this cost factor. With a raster calculator a raster file is then created, which fills in the cost values of the roads for the corresponding pixel and where no road exists the cost factor of the slope is used. With this grid and the points of the fire brigades the cost distance is calculated. This grid can then be used using the shapes with vuln areas to calculate the cost path. The paths that are now available in raster format must be converted to polylines so that the final optimized routes are available in shp format.

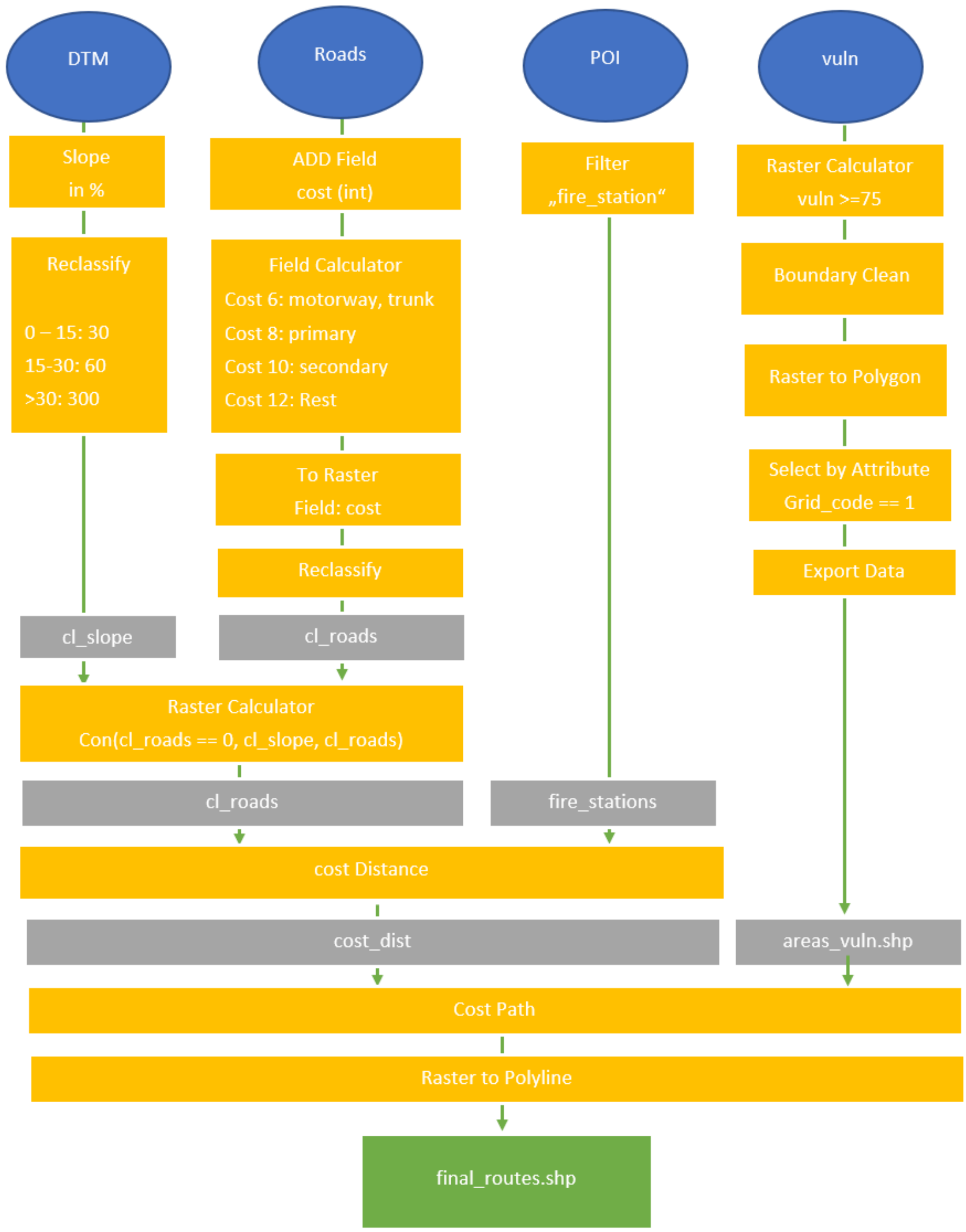

Figure 4 – final optimized route for fire brigades

3. Results

Vulnerability map of Federal State Baden-Württemberg

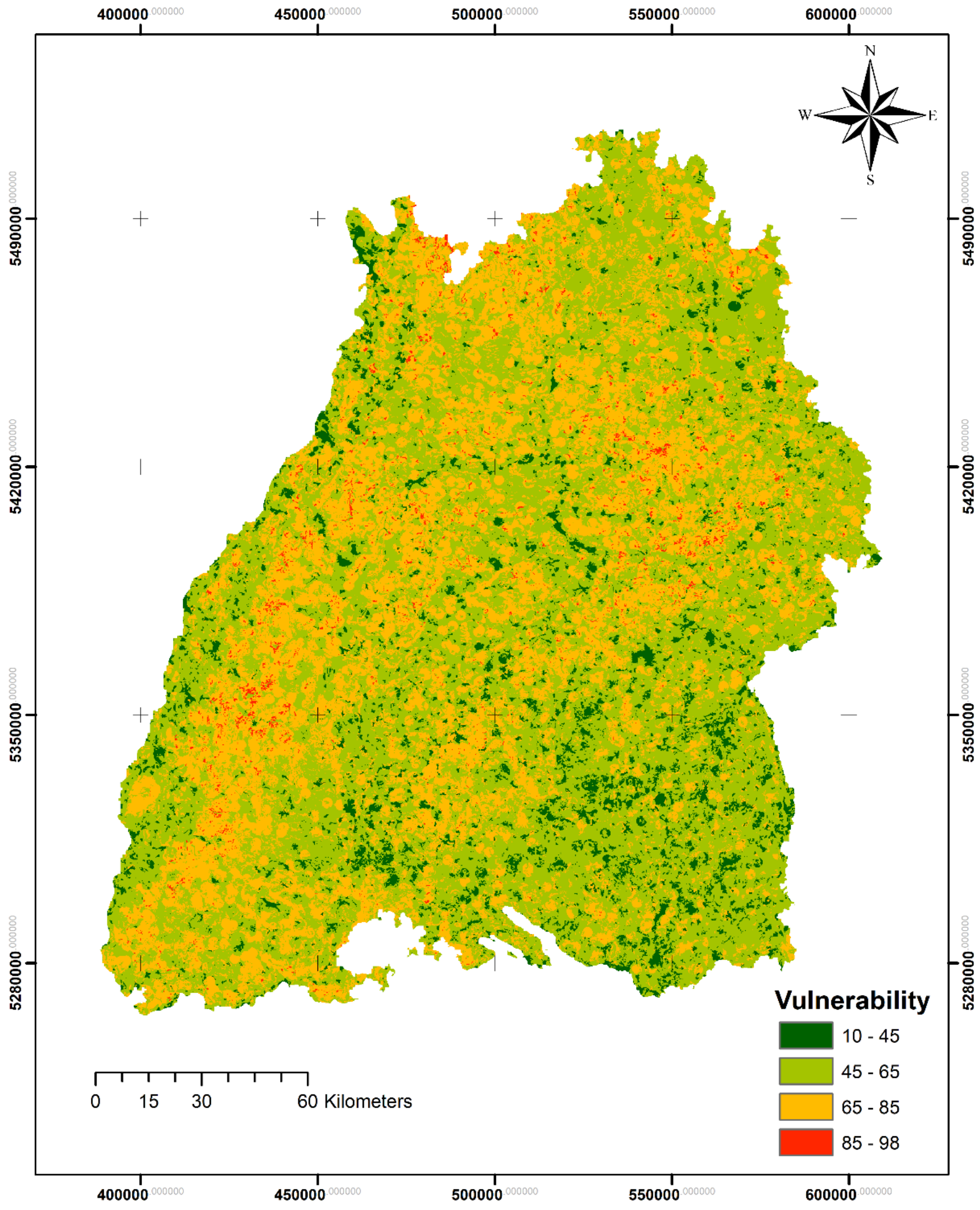

Figure 5 - Vulnerability map of Federal State Baden-Württemberg

The risk areas of Baden-Württemberg can be subdivided into three larger parts. The first and largest part is the Black Forest, which extends over the entire western side from south to almost north. It is one of the largest forest areas in Germany and a popular place for hiking and camping holidays. Therefore, it is logical that this area is a risk area. A second area is very high up in the north. Here begins a new forest area. Also, the third region northeast of the middle of the federal state is known for a large forest region.

The limit of 85 percent was set to identify the highly risked areas. Thus, these are areas that have a particularly flammable land cover and are drier due to lower rainfall and higher temperatures. In addition, the human factor was given special consideration, as it is responsible for a large part of the fires in Baden-Württemberg. Due to the statistic that nearly all fires were caused by campers, the factor camping sites was included to a large extent.

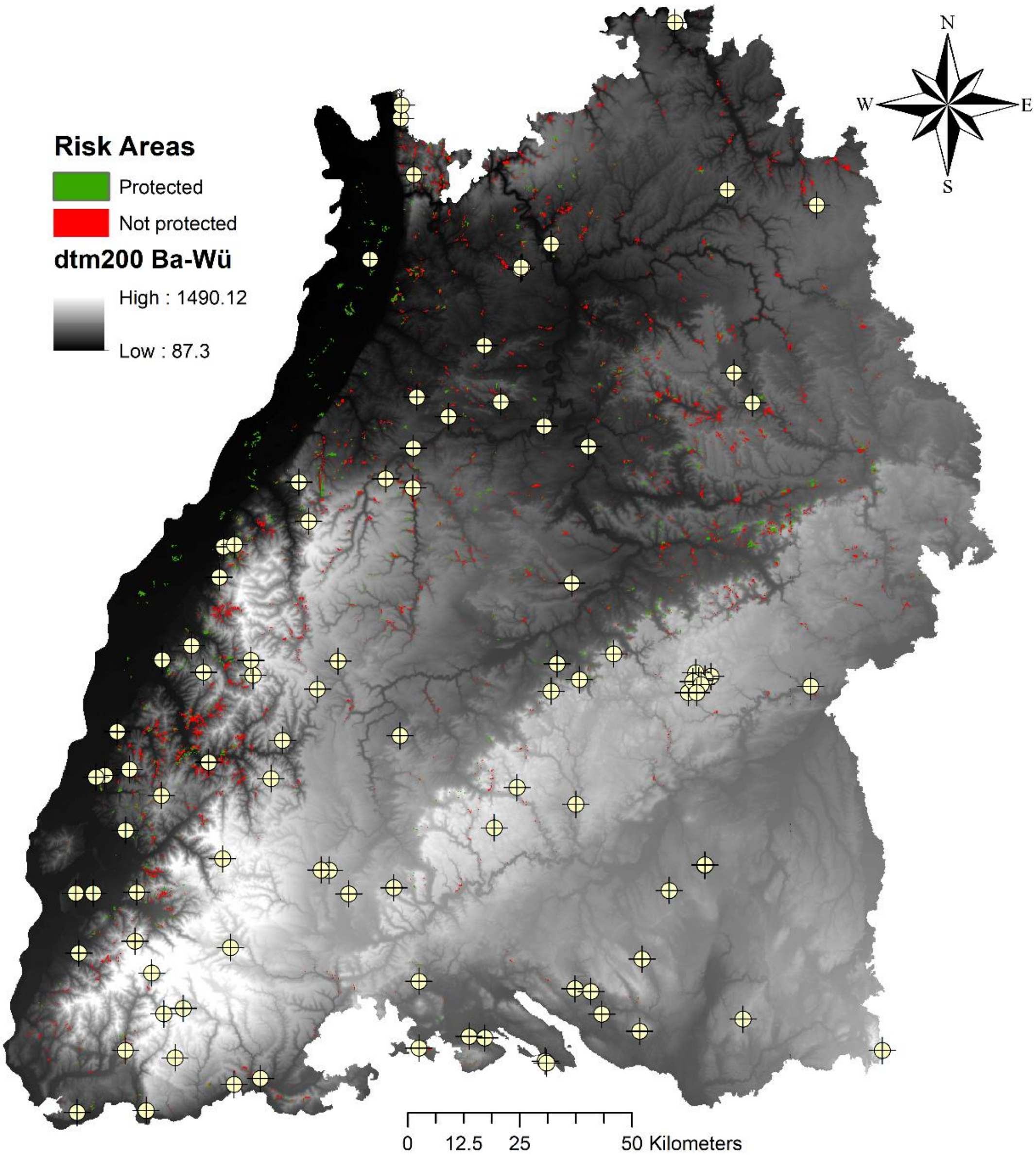

Figure 6 - Protected and Not Protected vuln. areas

Figure 6 illustrates all risk areas. Subdivided into the regions that are visible from observation towers and thus "protected" and those regions that are not visible and thus "not protected".

It is obvious that even a high density of observation towers does not allow a good coverage due to the topography of Baden-Württemberg. This is particularly evident in the area of the Black Forest. This region is characterized by many mountains and valleys. There are therefore many winding valleys and it is almost impossible to cover this area with an acceptable number of towers. The region west of the Black Forest proves that this is possible in a flatter area. In the very flat terrain all risk areas are covered by the observation tower.

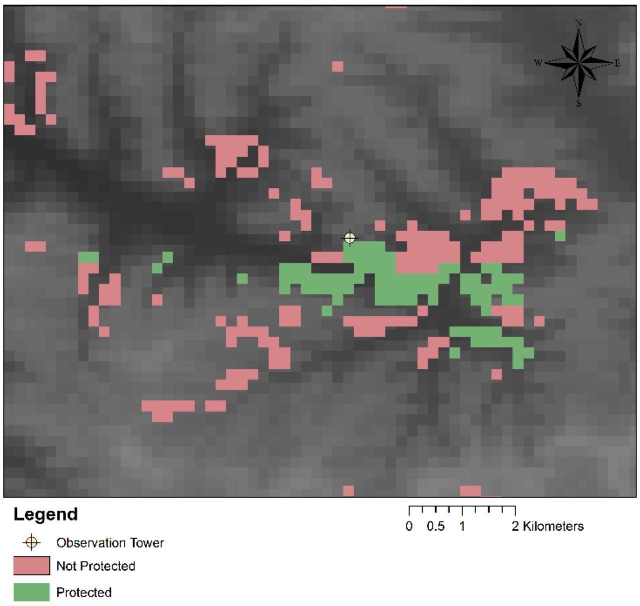

Figure 7 - Example for problems with obs. towers in mountainous topography

Many experiments have been carried out to see how it is possible to efficiently build observation towers. New towers have been installed at various locations and the added value of this tower has been tested. Due to the mountainous topography it is almost impossible to efficiently use a few towers for large observation areas. Figure 7 illustrates the problem. A valley always consists of several smaller valleys, which are also angled. Due to this situation, many observation towers would have to be built for a very small area. However, since all risk regions in Baden-Württemberg are in mountainous areas, it can be said that the observation towers system is not possible in Baden-Württemberg.

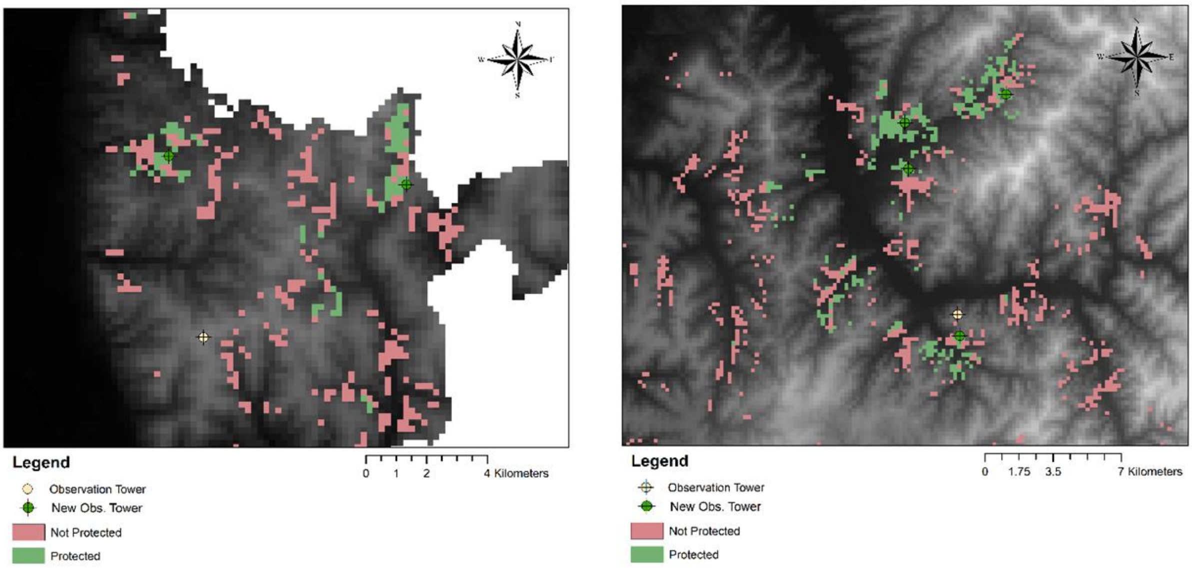

Figure 8 - More examples for problems with topography and obs.tower

The examples in figure 8 illustrate this problem once again. Therefore, no complete map with new observation towers was created, because there is no region where the observation towers could be used in a meaningful and efficient way.

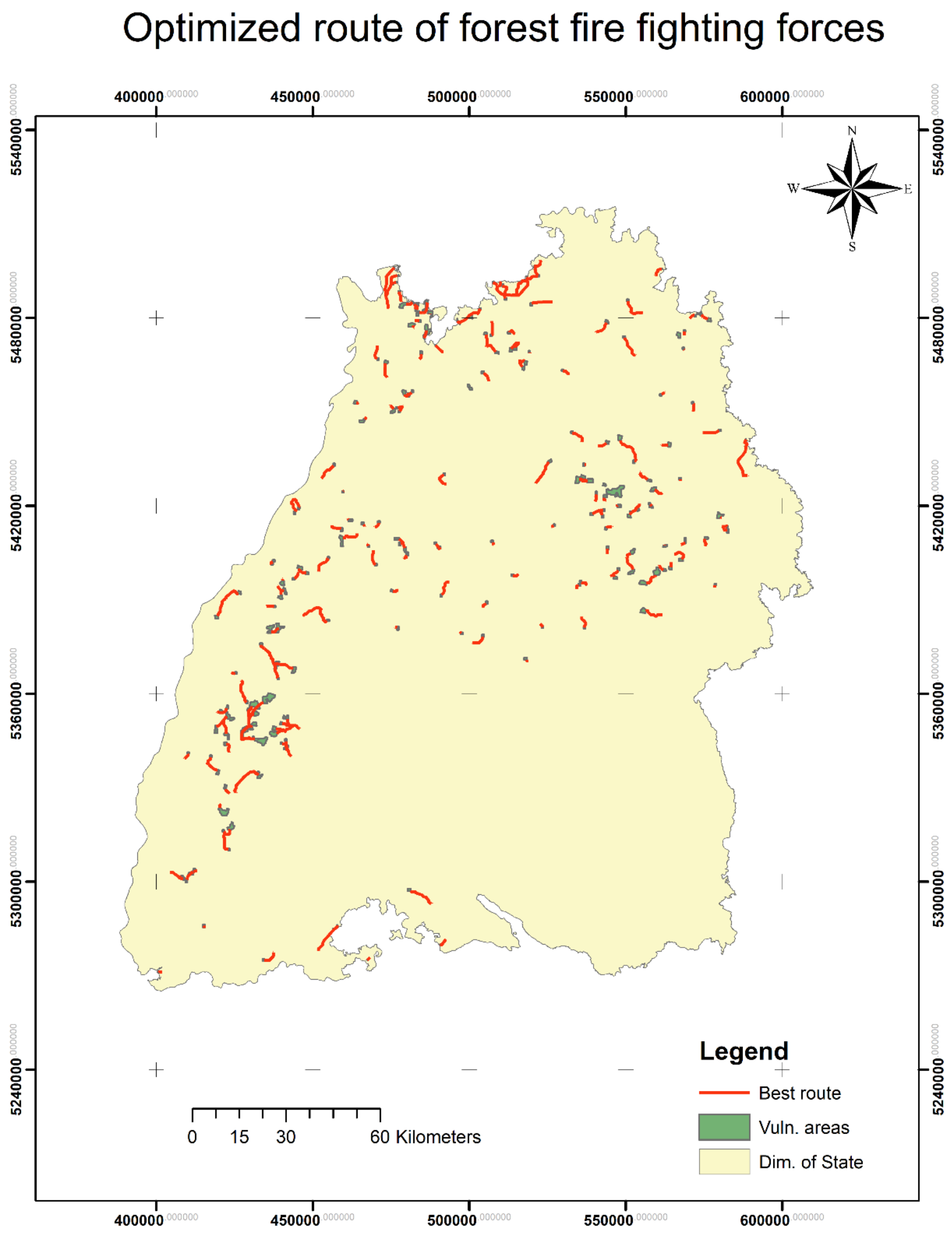

Figure 9 - Optimized routes to the vuln. areas

Figure 9 shows the risk areas in green. The optimized routes to the risk areas are shown in red.

4. Conclusion

The vulnerability model is useful and makes sense. However, as there are not many forest fires in Baden-Württemberg, it can rather be used as a warning map in which regions fire must be handled with particular care. Or, as an authority, can also issue barbecue and fire bans in certain regions.

The selected factors for the weak points are meaningful and conclusive. The factor values can still be improved. Furthermore, it can be considered to add further factors. For example, the air humidity. Other types of POIs can also be considered, where there is a greater risk of people igniting a fire without considering its cause.

However, the map for the not protected areas of the observation tower is only partially informative. The analysis of which regions have already been covered by viewpoints offers added value. However, it cannot be used to define points for new observation towers.

The model for the analysis of the optimized routes of the fire brigade to the risk areas was successful. However, the analysis would offer even greater added value if the DTM offered a better resolution.

References

[1] http://forstbw.de/schuetzen-bewahren/waldinventur/bundeswaldinventur/bwi3.html

[2] https://www.forstwirtschaft-in-deutschland.de/fileadmin/content/pdf/Waldbrand/Waldbrandstatistik-2016_BLE.pdf

[3] https://www.umweltbundesamt.de/daten/land-forstwirtschaft/waldbraende#textpart-3

[4] CIMOLINO, ULRICH. Einsatzleiter-e-book Feuerwehr. 2015