# AN EXAMPLE OF A SYSTEM SOLUTION FOR EFFECTIVE MANAGEMENT OF CLIMATE CHANGE ADAPTATION PROCESSES

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**Abstract.** This article introduces a system solution for managing climate change adaptation in transportation, highlighting the need for adequate institutional capacity. It emphasizes advanced digital technologies like GIS, neural networks, and AI for precise climate modelling and dynamic risk management. These technologies enable quick responses to evolving conditions, optimizing operations, and ensuring infrastructure sustainability. Adaptation to climate change involves continuous integration of measures at all planning levels. Implementing these methods strategically can significantly enhance the transport sector's resilience, thus protecting infrastructure and improving public welfare.

Keywords*:* Management of climate change, AI, climate modelling, transport sector

## 1. SCOPE OF THE ANALYSIS AND CONCEPT FOR ASSESSMENT OF THE POTENTIAL EFFECT OF CLIMATE CHANGE IN BULGARIA FOR REACHING SUSTAINABILITY AND SAFETY ON TRANSPORT SECTOR ELEMENTS

European Union Member States have developed strategic document packages to mitigate the impacts of climate change. Bulgaria's package, titled “National Strategy for Adaptation to Climate Change and Action Plan (2019 - 2030)”, was approved in

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October 2019. Related to sector “Transport,” the primary document is Appendix No. 7 [1, 2]. As defined in the context of the “UN Framework Convention on Climate Change”, the term “adaptation to climate change” means the adjustment of a "natural or human system in response to climate risks”.

### 1.1 Strategies for climate change adaptation of critical transport infrastructure

Adaptation of critical state infrastructure to climate change can be done in two main ways: reactive (in response to changes that have already occurred) and proactive (in advance, before the changes). In both cases, the development of specific adaptation procedures and strategies is necessary to integrate the dynamic aspects of the environment into the management systems of critical infrastructure, such as transport. The main components of such strategies include:

- Monitoring of climatic conditions in Bulgaria: Analysis of the various climatic elements and their variability, including extreme phenomena and irregularities.
- Monitoring the vulnerability of transport infrastructure: Continuous monitoring of the impact of climate change on all types of transport routes and facilities, including roads, railways, ports, and airports.
- Data collection and analysis: Creation of databases on climate conditions with specific on the Transport sector climate-induced effects.
- Optimization of risk management: Development of improved methodologies for risk management, including scientometric analysis and digitalization of processes.
- Challenges in infrastructure adaptation: The main challenge is related to uncertainty about future climate changes – their intensity, speed, and time frame, which makes planning and investment in transport infrastructure difficult.

### 1.2 Methodological framework for climate change impact assessment on Transport Infrastructure

Due to the multidisciplinary nature of the project, the first methodological tools that were applied to solve the complex task were abstraction and decomposition. Thanks to them, the task was decomposed into a series of 6 tasks, simplified in scope:

1. Analysis of the implementation of the National Strategy for Adaptation to Climate Change (ACC) for the "Transport" sector in Bulgaria.

Objective: Identification of the reasons for the non-implementation of the strategy and proposals for methodical approaches and solutions.
Methods: Policy and document analysis, stakeholder evaluation.

2. Climate change analysis and climate data search.

Purpose: Description of the climate data collection and analysis process.
Methods: Climate data collection and analysis.

3. Impact of climatic elements on the transport sector.

Objective: Analysis of how climate change may affect transport infrastructure.
Methods: Description of impact assessment methodology.

4. Collection of data on crisis events and their impact on transport infrastructure.
Purpose: Description of the data collection process.
Methods: Review of event records, creation of a database, and analysis of incident reports.

5. Application of ANN for modeling climate and solar data for transport infrastructure purposes.
Objective: Model basic climate and solar data using ANN to identify potential relationships between climate parameters and their impact on transport infrastructure.
Methods: Description of the modeling process, including data selection, training, and testing of the models.

6. Application of GIS for the analysis of the influence of climatic parameters.
Objective: Using GIS to visualize and analyze the impact of climate change on transport infrastructure.
Methods: Spatial data processing, mapping, and GIS-based analysis.

## 2. BUILDING A METHODICAL APPROACH FOR TASKS 1 TO 4

A consistent climate change adaptation analysis has been carried out in relation to the Transport sector. Within the framework of the scientific project, data were collected and analyzes were performed regarding the changing climate of Bulgaria and its impact on the transport infrastructure.

The main framework of the project was to develop a comprehensive strategy to optimize the recommendations in the two strategic documents [1, 2] in order to increase the degree of practical applicability to the sector. All analyzes of the series of six simple tasks and model examples are prepared for the road infrastructure with the prerequisites that they are also applicable to the other carriers by types of transport, taking into account their specificities.

### 2.1 Objectives and results of the analysis of the implementation of the National Strategy for Adaptation to Climate Change for the "Transport" sector in Bulgaria

The implementation of the project includes an analysis and assessment of the degree of implementation of the National Strategy for Adaptation to Climate Change for the „Transport" sector until 2030. Due to the serious lack of official and accessible information, the work to minimize the shortcomings identified in the abstract was summarized in a few key points:

- An analysis of the effects of climate change on the transport infrastructure was made. Stage of theoretical justification of the tasks. Selection of a representative of the sector to limit research to, according to the project proposal.
- The state of the NSACC five years after defining the action framework until the end of the 11-year period in 2030 is analyzed. In this part, a structural analysis of the implementation of the National Strategy for Adaptation to Climate Change for the "Transport" sector in Bulgaria is made. The impact of crisis events on a national and global level that occurred after 2019, which are related to the lag according to [1, 2], is reported. Reasons for the backlog and non-implementation of the strategy's recommendations were summarized. The more important reasons are the need to expand the elements of the ACC in [2] and remove inapplicable recommendations regarding the regulatory framework for correction and maintenance.

### 2.2 Objectives and results on the climate change analysis, climate data search and the impact of climate elements on the transport sector

An assessment of the impact of climate elements on the transport sector has been made. The scope was set. Relevant databases were studied, but there are no records of manifested climatic risks in relation to the studied sites (from the road infrastructure). Data collection was carried out on crisis events and their impact on the transport infrastructure. The following significant gaps in the baseline provision of models for the study of climate components, their change, and impacts on critical infrastructure have been identified and addressed:

- For the available accessible data of any nature in relation to risk assessment, numerous problems, limitations, and shortcomings were identified in terms of the required and available information base.
- For the unavailable and inaccessible climate data – a multi-complex problem for Bulgaria, a high degree of ignorance of the parties interested in the demand for the needs of the analysis, and for the needs of restarting the ACC activities. A persistent underestimation of the importance of quality climate and access to climate models has been registered.

Despite severe accessibility and visibility difficulties, data were collected and processed to serve as a base for models verifying the transport medium–climate environment interaction. The collected data is available digital file document.

### 2.3 Key focus areas for climate resilience of the transport infrastructure

The key areas of focus were identified in order to achieve results within the designated timeframe. The analysis of climate-induced crises was conducted with regard to the two primary phases of the transport infrastructure investment process: design and maintenance, with prevention. Two major types of analyses were carried out:

- Assessment of the impacts of climate change on transport infrastructure based on examination of design regulations and maintenance guidelines. Incorporating adaptation measures, methodological approaches, and solutions into the design and maintenance of road infrastructure is proposed. Appropriate adaptive strategies to address climate risks are indicated. A basis for integrating climate resilience into infrastructure projects is summarized. Opportunities for optimization of design and maintenance in relation to climate change consideration and adaptation are presented.
- Evaluation of data collection methods, crisis scenarios, and institutional capacity. Recommendations for building institutional capacity at the ACC are listed. An exemplary micro-model of inter-institutional connectivity is drawn up where the element of institutional connectivity can work, including in terms of risk prevention and crisis management.

## 3. ARTIFICIAL NEURAL NETWORKS MODELING OF THE INFLUENCE OF SOME CLIMATE ELEMENTS AND INDICATORS ON THE OPERATIONAL INDICATORS OF PARTS OF THE TRANSPORT INFRASTRUCTURE FOR THE SELECTED TERRITORY

This project aimed to demonstrate the potential use of artificial neural networks (ANNs) for modeling climate parameters that are crucial for transport infrastructure. ANNs can analyze, store, and provide finely interpolated data on various climate factors. In this case, the primary objective was to explore how this can be done in the context of road infrastructure design and maintenance, as it appears to be essential.

Various climate data sources, which are available for Bulgaria, have been repeatedly observed, but due to problems with data access, periods of time with missing data have led us to significant difficulties. The solution was to use international data sources to be used. The primary sources for training and performing tests with ANNs are PVGIS, NASA POWER, and NEO – NASA Earth Observations. The climate data used for ANN training is geographically bounded.

Instructions are provided for utilizing artificial intelligence in examining the effects of climate change on transportation infrastructure.

Analytical options for investigation using narrow artificial intelligence are proposed. Elements are summarized to create a basic parametric model for analysis in the field of transport infrastructure, taking into account the specific characteristics of road elements and the influence of climate conditions.

### 3.1 Use of ANN to model the effect of climate and solar data

In the project task 5, training of ANN was used – the preliminary trained artificial neural networks are loaded based on JavaScript in the developed HTML web pages. This approach was developed in [3] and has been extended and upgraded for the purposes of this research. The results are available at: https://ait.uacg.bg/Transport/index-en.html.

### 3.2 Website menu structure

The website menu structure is as shown in Fig. 1, Fig. 2, and Fig. 3.
1) Page "Climate data by geographic positions".
2) Solar data by geographic positions page.
3) Climate Data maps Page – generates user-queried maps per month or year.
4) Solar Data maps Page – generates user-queried maps per month or year.
The last two pages contain information about the development (input parameters and results by page) as well as a description of possible applications of the development results.
5) Page “Information for the website.
6) Page “Climate data application for transport infrastructure.

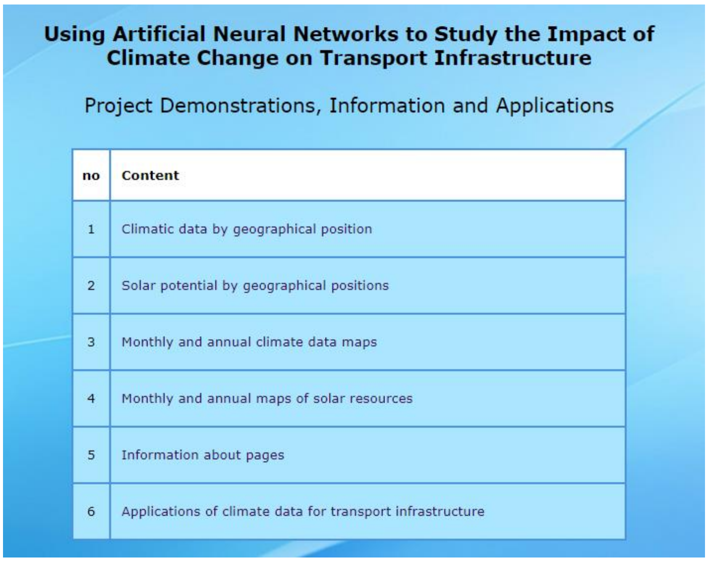



**Fig. 1.** Using artificial neural networks to study the effect of climate change over the transport infrastructure elements - website menu

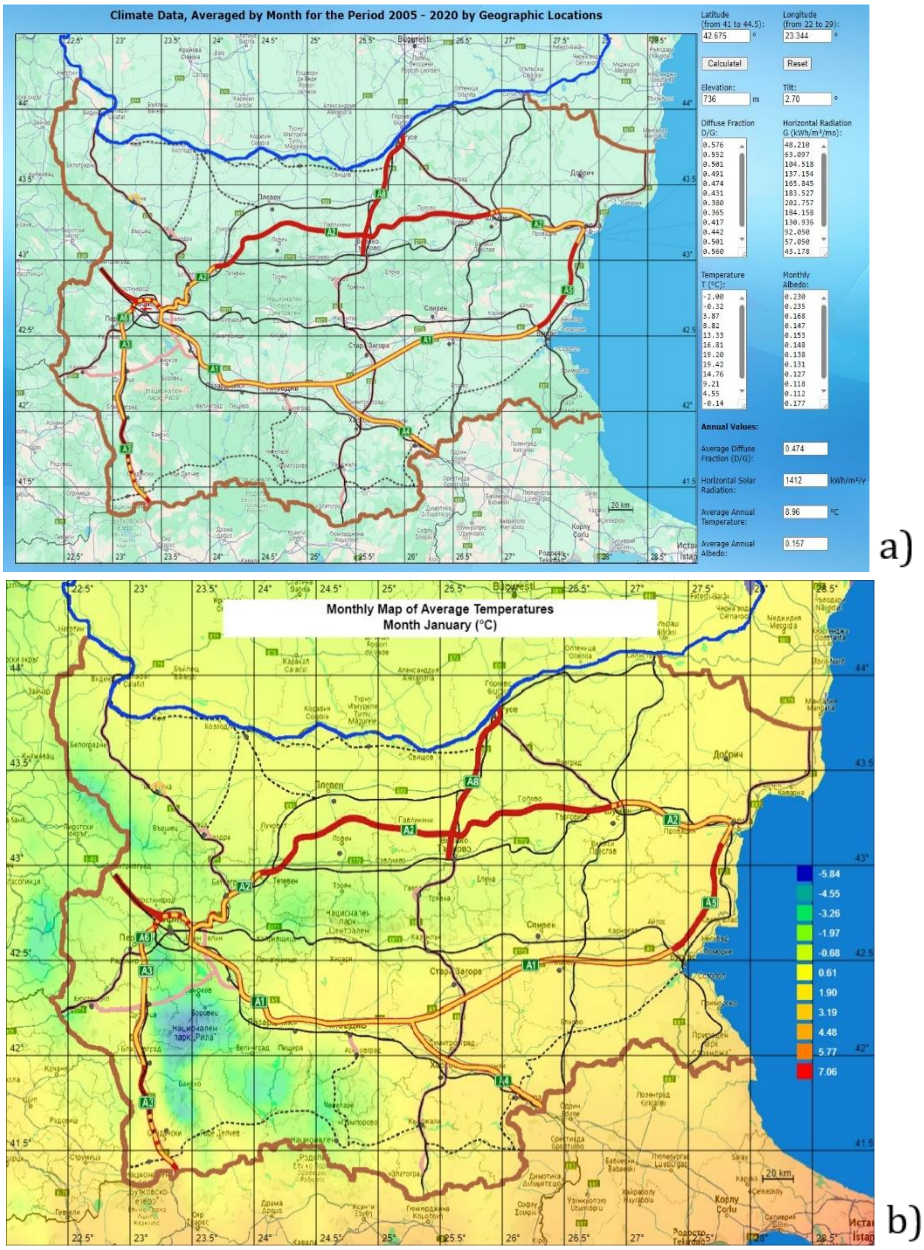
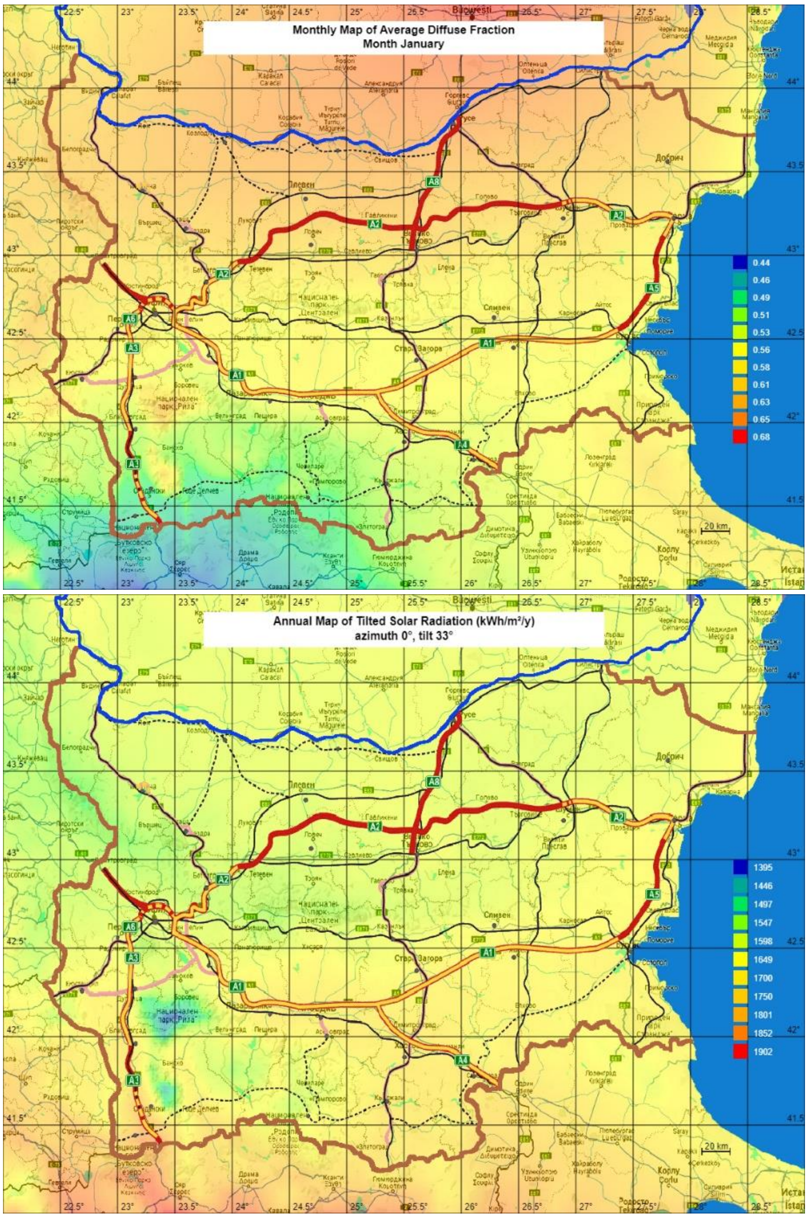



**Fig. 2.** Results from querying climate data per month or year, powered by ANN, averaged by geographic location and shown on maps: a) calculated values of the diffuse fraction, horizontal solar radiation, temperature, and albedo; b) averaged January temperature for the period from 2005 to 2020




a)

b)

**Fig. 3.** Instances of the web site functionality of compiling and displaying monthly and yearly solar maps utilizing ANN technology – horizontal, reflected, and oblique solar radiation: a) averaged diffuse fraction for January from 2005 to 2020; b) total annual oblique solar radiation on the receiving plane with an azimuth angle set at 0°and inclination maintained at 33°.

Based on the research done, we can formulate the following essential conclusions about the applicability of this kind of models for building adaptive capacity:

- Importance of data selection: The development highlights the importance of selecting appropriate data from trusted sources for ANN training (PVGIS and NASA POWER) to ensure accurate and objective analyses.
- Future directions are summarized to extend and refine the project, including the potential inclusion of new parameters and data sources, to increase the accuracy and applicability of ANNs in real-world conditions.
- Achieving desired results: The results of using ANN in this context should be seen as a step towards the desired goal, not as a final solution. They demonstrate the potential and capabilities of the method, but are still in the process of development and refinement.
- Future development: The next step involves training ANNs with data based on different climate scenarios, which can contribute to more accurate and complex prediction models.
- The role of Geographic Information Systems (GIS) can be used to solve many problems related to the visualization of geographic data and the analysis of climate parameters.
- Combining GIS with ANNs: Integrating GIS with trained ANNs through programming.

## 4. APPLICATION OF GIS FOR THE ANALYSIS OF THE INFLUENCE OF CLIMATE PARAMETERS ON THE TRANSPORT INFRASTRUCTURE

Given the very limited data for parameterization through neural networks, it was also proposed to continue research in the direction of GIS-based analysis of climate impacts. The focus of the test research on this project was set on landslides, as they are defined as one of the climate-induced main risks for the Bulgarian transport system, according to [1] in the medium and long term. Physicogeographical, climatic, geological, and other data for the territory were combined with those for the road infrastructure, and analyses were carried out to determine the places with the highest risk of landslides. The scope of the study is the Sliven region, as shown (Fig. 4), and an overview map of the region, which presents the registered landslides for the territory, classified by their location in municipalities (Fig. 5).

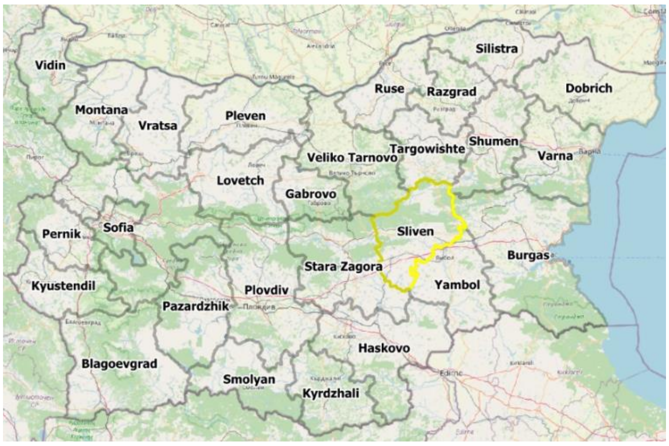



**Fig. 4.** The studied territory for the assessment of climate-induced geological risk – Sliven region, Bulgaria

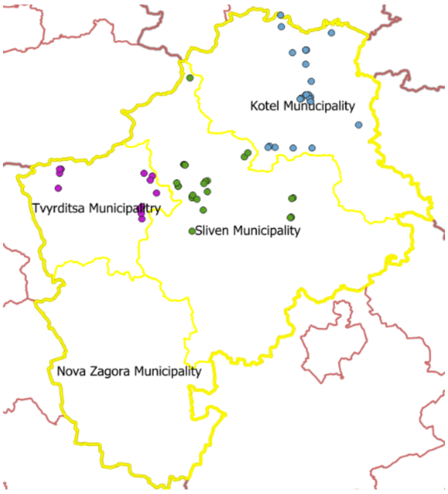



**Fig. 5.** An overview map of the region with the registered landslides for the territory, classified by their location in municipalities.

## 4.1 Methodology - preliminary preparation, data

In this case, a GIS-based modeling structure was given, which is an optimization, given the lack of data, in order to more functionally provide part of the recommendations made in the report [2]. It was performed by Ch. Assist. Prof. Tamara Ilieva, and the datasets used were as follows:

- Vector data – administrative division from open data portal [6] and landslides from the GIS of the MRRD [7] in BGS2005 Cadastral coordinate system, which in the

GIS environment is set with EPSG code 7801. The data from OpenStreetMap (populated places, road and railway networks, and hydrographic objects) [8] and those from the landslide register [9] are in geographic coordinates, with EPSG code 4326. All vector data, except the first two described above, is transformed to the BGS2005 projected Cadastral coordinate system.

- Raster data – digital elevation model [10] in the EPSG:3035 (ETRS89-extended / LAEA Europe) coordinate system, and the land cover [11] and precipitation data [12, 13] are in geographic coordinates (EPSG code 4326) – all these raster layers have been transformed to BGS2005 Cadastral coordinate system.
- The remaining raster data - for faults and rock types [14], for the deep hydrogeological division [15,16], for underground water bodies [17], soils [18, 19, 20], and geological risk [7] are georeferenced with accuracy assessment directly to the BGS2005 Cadastral coordinate system.
- Web services - Spatial data services from OpenStreetMap [21] and Google Satellite [22] were also used, which were loaded directly into QGIS in the coordinate system of the project (EPSG code 7801) for visual assessment of landslide locations.

### 4.2 Spatial modeling – estimation of landslides proximity to roads and rivers

For the road network, buffers with distances of 20, 50, and 100 m were created around the roads, and the number of landslides in them was determined. With a buffer of 20 m, 42 landslides fall into the range. At a buffer of 50 m – 58 and 100 m – 63 of a total of 64. For the hydrographic objects, buffers with distances of 20, 50, and 100 m were also created around the rivers, and the number of landslides in them was determined. With a buffer of 20 m, 6 landslides fall into the range. At a buffer of 50 m – 22 and 100 m – 28 landslides.

### 4.3 Spatial modeling – DEM, rainfall data, land cover, geological, hydrogeological and soil data

Based on the distribution of landslides, the data layers are given weights that represent the risk parameters, and the datasets are reclassified. The determination of the risk sections of the road infrastructure (their locations) in relation to the occurrence of landslide processes was made by combining the factors analyzed above, so as to determine the general level of risk. Combining the factors was done using coefficients obtained based on the frequency of past events.

The values from the cells of the reclassified rasters are summed using the raster calculator in the GIS environment, after which the data is stylized and visualized. The maximum possible sum S of the selected parameters is 6.9, and the risk levels are calculated based on it. The classification is intended for 5 risk categories:

- 0-20% of S low risk level,
- 20-40% of S moderate risk level,
- 40-60% of S average level of risk,
- 60-80% of S high risk level,
- 80-100% of S very high-risk level.

Since the purpose of the analysis is to determine the risk to the road infrastructure, the rasterized layer of the 120 m buffer zone around the road network was used as the basis for factor summation.

### 4.4 Results, validation, concluding remarks

After summing the factors listed above, one resulting raster layer is obtained. The values of this raster range from 3.85 to 6.85, classifying them into three categories with the accepted limits (the first two categories have no values). The obtained results (Figure 5) are compared with the data from the geological risk map (Figure 6). In 3 areas (marked in yellow), a higher level of compliance was obtained, but in the rest of the locations shown, there are many differences.

For the places other than those shown in yellow circles, with few exceptions, road sections near already registered landslides, as well as similar to them, are obtained, which is logical, considering that the criteria were chosen on the basis of the available data, therefore for validation of the results and evaluation in the future can be used data for new events. Given the very limited data for parameterization through neural networks, it was also proposed to continue research in the direction of GIS-based analysis of climate impacts. The focus of the test research on this project was set on the landslides. The scope of the study is the Sliven region, but a model for performing data analysis has been derived, which can be applied to the territory of the entire country.

A way in which the risk of occurrence of landslide processes, which could negatively affect the road infrastructure, can be investigated through GIS is presented:

- Landslide occurrence has been analyzed both temporally and spatially, but the data are too few to be analyzed jointly both temporally and spatially.
- Regarding the time of occurrence of landslides, the months February, March, May, June, and October are risky, with the greatest risk in March.
- Regarding the location, 10 factors accepted as risk parameters were studied, and for each of them, on the basis of a frequency analysis of the data for the already registered landslides, coefficients were derived to account for their influence. The analysis shows that the geological, topographic and other characteristics of the territory are of great importance, and in most cases, there are pronounced trends, despite the small volume of the data sample, but the key is human activity, given that all registered landslides in the area Sliven are near roads or on the outskirts of populated areas.

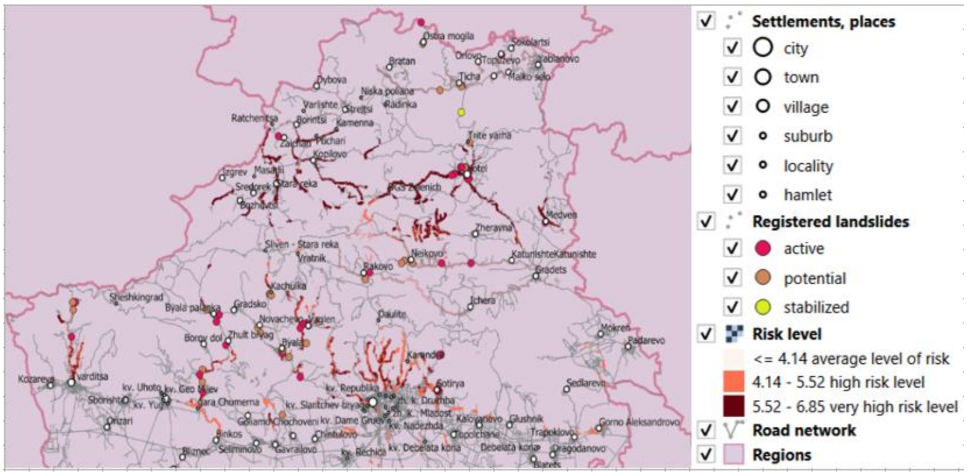



**Fig. 6.** Visualization of the obtained results – displayed road sections with a high and very high level of the risk of occurrence of landslide processes.

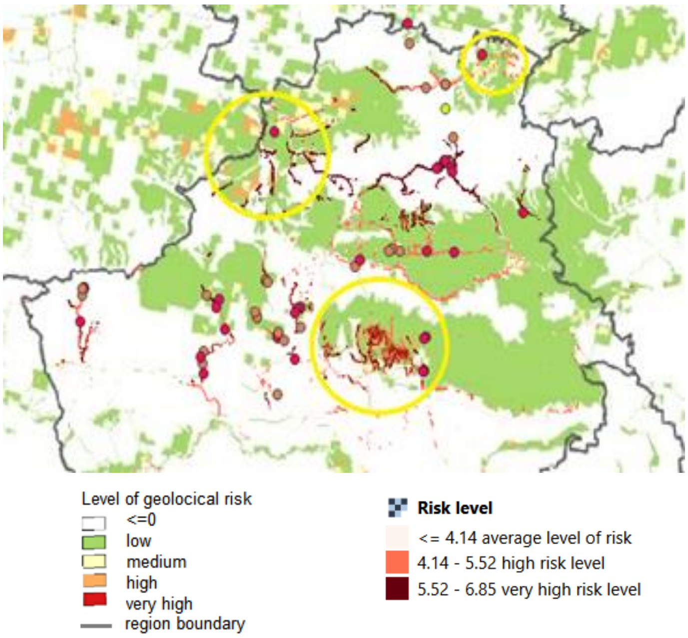



**Fig. 7.** Comparison of the obtained results with the data from the geological risk map

## 5. CONCLUSION

This study underscores the critical need for adapting Bulgaria's transport infrastructure to the growing challenges posed by climate change. By integrating advanced methodologies, such as climate data analysis, neural network modeling, and GIS-based assessments, the research provides a robust framework for enhancing the resilience and sustainability of transport systems. The findings emphasize the importance of updating regulatory frameworks, improving institutional capacity, and prioritizing strategic initiatives that address both immediate and long-term climate risks. Moving forward, a coordinated and proactive approach will be essential to safeguard the functionality and safety of transport infrastructure in a changing climate.

## 6. ACKNOWLEDGMENTS

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