Harnessing Remote Sensing for Disaster Risk Management

Naji El Beyrouthy, RESALLIENCE by SIXENSE
Mario Alsayah, RESALLIENCE by SIXENSE
Camille Vignote, RESALLIENCE by SIXENSE
Mohamed Ouabou, RESALLIENCE by SIXENSE
Abla M. Edjossan Sossou, RESALLIENCE by SIXENSE
Nina Jirouskova, RESALLIENCE by SIXENSE

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The paper introduces an approach to the use of remote sensing for disaster risk management. It leverages Earth Observation for hazard mapping and risk management, with its effectiveness demonstrated during the 2023 Slovenian floods.

1. Introduction

In an era where climate challenges are escalating, disaster management faces significant hurdles. This paper focuses on addressing these challenges through an innovative approach. It leverages the capabilities of Earth Observation (EO) for comprehensive disaster risk management by predicting disaster-prone areas. The paper presents how this pioneering methodology, tested during the catastrophic floods in Slovenia in August 2023, not only enhances our understanding of exposure, vulnerability, and risk but also paves the way for future where predictive analytics redefine proactive disaster preparedness. The goal is to foster a safer and sustainable world, capable of effectively confronting escalating disaster risks.

2. The Current State of Affairs in Disaster Management

The field of disaster risk management has seen significant advancements in recent years, particularly with the integration of technology. The current state of the art involves the use of remote sensing and Earth Observation (EO) for mapping and monitoring natural hazards. These technologies have proven effective in providing near real-time data and insights, aiding in the prediction, mitigation, and management of disasters.

Various solutions leverage these technologies for disaster risk management. For instance, early warning systems utilize EO data to predict potential hazards and alert communities in advance. Similarly, during the response phase, remote sensing plays a crucial role in providing immediate and accurate information about the affected areas. High-resolution satellite imagery can be used to create detailed maps of the disaster-stricken regions, highlighting the areas of severe damage. These maps can guide rescue teams, helping them navigate through the debris and reach those in need more efficiently.

Moreover, remote sensing can assist in identifying safe zones for setting up temporary shelters and aid distribution centres. It can also help in monitoring the movement of natural hazards, such as the progression of a flood or a wildfire, enabling authorities to make informed decisions about evacuations and resource allocation.

In the recovery phase, remote sensing continues to be an invaluable tool. It can monitor the progress of rebuilding efforts and ensure that they are carried out in a manner that reduces future risk. For instance, by comparing pre- and post-disaster satellite images, planners can assess whether the rebuilt infrastructure is more resilient to similar disasters in the future.

Furthermore, remote sensing can aid in the assessment of environmental impacts caused by the disaster, such as changes in land use, loss of vegetation, or alterations to the water table. This information can guide environmental rehabilitation efforts and contribute to the sustainable recovery of the affected area.

3. The Role of Earth Observation (EO)

The EO plays a pivotal role in this innovative approach to disaster risk management. It serves as the backbone of the methodology, providing critical data inputs that are processed and integrated to calculate flood risk.

The strength of EO lies in its ability to capture comprehensive, high-resolution, and timely data about the Earth’s surface. This data is invaluable in understanding the complex interplay of environmental factors that contribute to flood risk. By processing and reclassifying these data inputs, EO enables us to create a nuanced and dynamic picture of flood risk across different areas.

Moreover, EO’s ability to monitor changes over time allows for the continuous updating and refining of the flood risk model. This ensures that the model remains relevant and accurate, even as environmental conditions change. In essence, EO is not just a tool for predicting disaster-prone areas, but a powerful instrument for proactive disaster risk management, paving the way for future where predictive analytics redefine our approach to disaster preparedness.

4. The Research and Development Path in ATLANTIS

The research and development path in ATLANTIS has been a journey of innovation and discovery. The project began with the identification of key challenges in disaster risk management where flood risk was identified as a major risk for multiple areas, one of them was Slovenia.

The design choices in ATLANTIS were driven by the goal of addressing these challenges effectively. The decision to integrate new technologies with remote sensing was made to enhance the capabilities of EO, improving change detection, and the monitoring and prediction of natural disasters.

So far, significant developments have been made in the scope of ATLANTIS. The methodology was tested during the catastrophic floods in Slovenia in August 2023, demonstrating its effectiveness in predicting natural disasters. Over a few days, relentless rainfall caused widespread devastation. The numbers paint a grim picture – over two-thirds of Slovenia was affected by flash floods and landslides, impacting 181 out of 212 municipalities. This disaster necessitated the evacuation of 8,000 people and tragically claimed six lives. The infrastructure damage was significant, with at least seven major bridges collapsing and numerous local bridges suffering damage. Over 170 active landslides pose ongoing threats to homes, infrastructure, and power supply [1].

The tested methodology for flood risk calculation involves a multi-step process that begins with the processing and reclassification of various inputs related to flood risk, such as:

- Precipitation data (mm/year)
- Precipitation days (number of days with total rainfall above 20 mm, P20)
- Precipitation days (number of days with total rainfall above 50mm, P50)
- Consecutive dry days (CDD)
- Land cover classification
- Flow/Water accumulation
- Land elevation
- Land slope
- Historical presence of water
- Soil texture.

These processed inputs are then integrated into a single equation, which is a weighted sum of all the inputs. The weights, representing the relative importance of each factor in contributing to flood risk, are assigned to each input. The flood risk is then calculated by evaluating this weighted sum equation, resulting in a flood risk value for each point in the area of interest. Finally, these flood risk values are reclassified into distinct classes, which can be based on natural breaks in the data.

5. Results

Three study areas were chosen for testing the EO model presented herein, namely: East-part of Kamnik-Savinja Alps, Carinthia, and Mura River regions in Slovenia as shown in Figure 1 below. The maps depicting comparative analysis of the prediction results for the areas in the studied regions hit by the flood, are presented in Figure 2, Figure 3, and Figure 4 below.

The flood risk prediction model, underpinned by EO data, has demonstrated its accuracy and predictive power during the 2023 Slovenian floods for the three regions where major flooding was recorded: Mura River, Carinthia, and Central Slovenia (Kamnik-Savinja Alps).

The model processes and reclassifies various EO data inputs related to flood risk, enabling a nuanced understanding of flood-prone areas. The effectiveness of this model is visually validated in the provided images, where the predicted flood risk areas (marked in blue) significantly overlap with the actual flood detection areas (marked in red) in all three figures below. The flood detection was done by the Copernicus Emergency Management Service [2]. This overlap underscores the model's utility in real-world situations and its potential as a valuable tool for proactive disaster risk management. The successful application of this model not only enhances our understanding of flood risk but also paves the way for more accurate, timely, and effective disaster risk management strategies in the future. This transformative potential of EO in disaster risk management could lead to enhanced resilience of communities against future disasters.

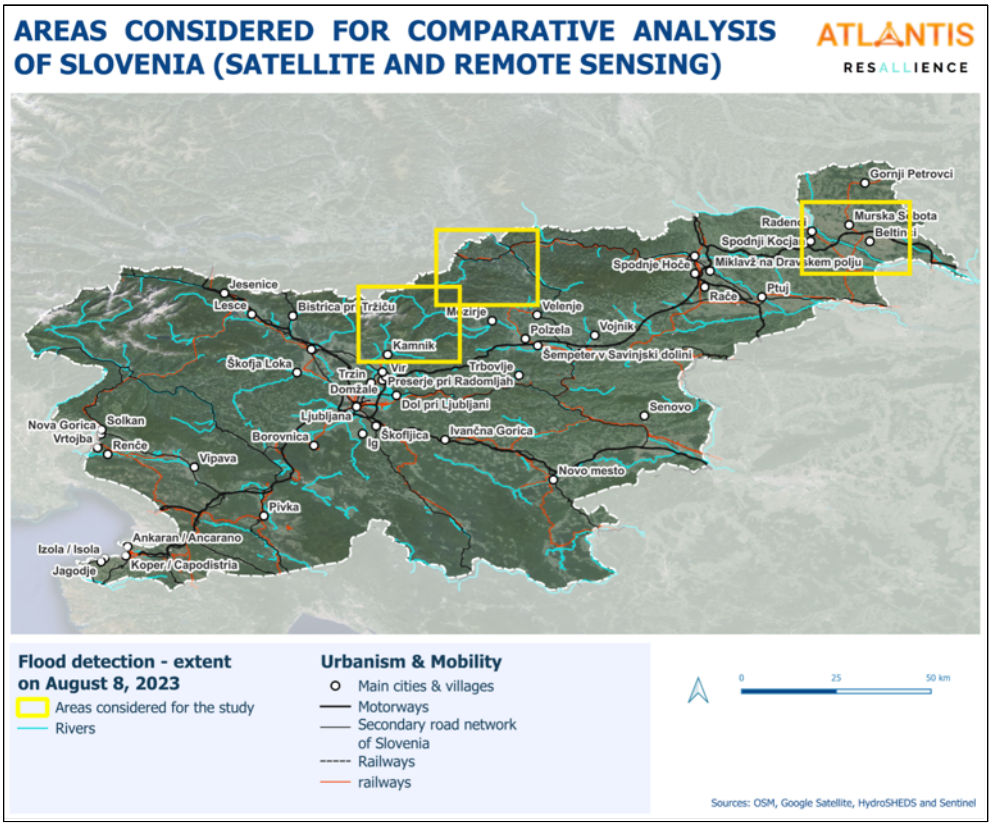

Figure 1. Slovenian flood study areas for results comparison.

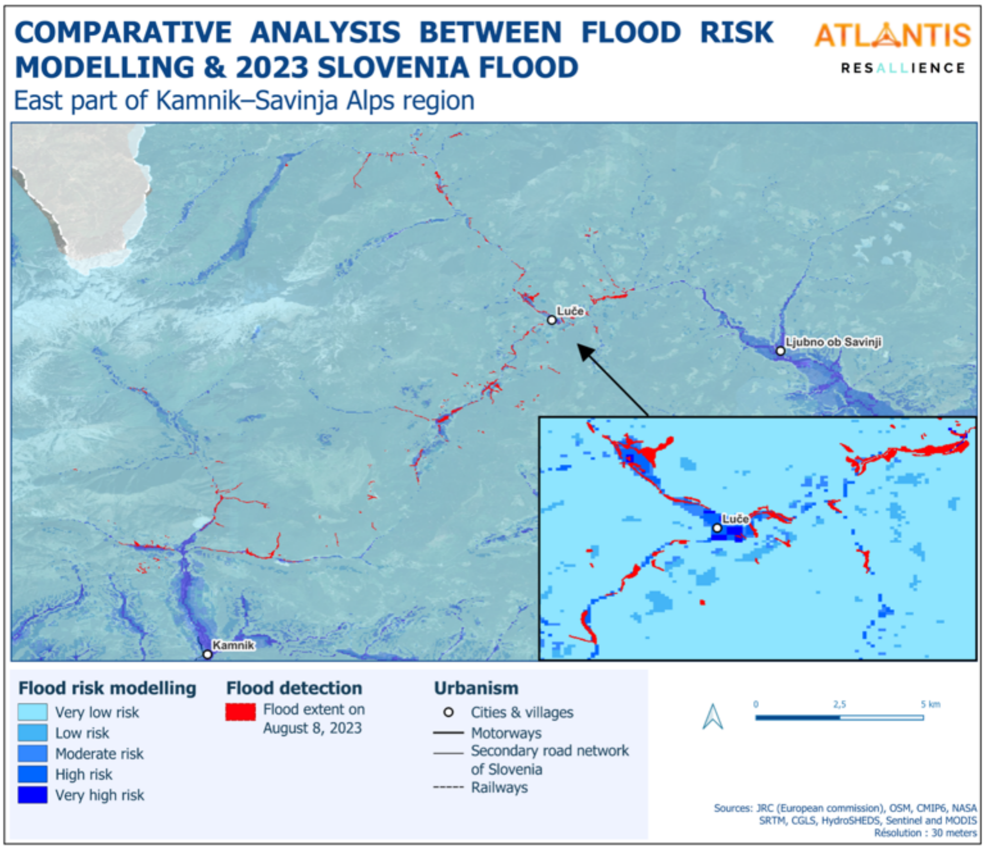

Figure 2. Kamnik-Savinja Alps region flood detection vs. flood prediction.

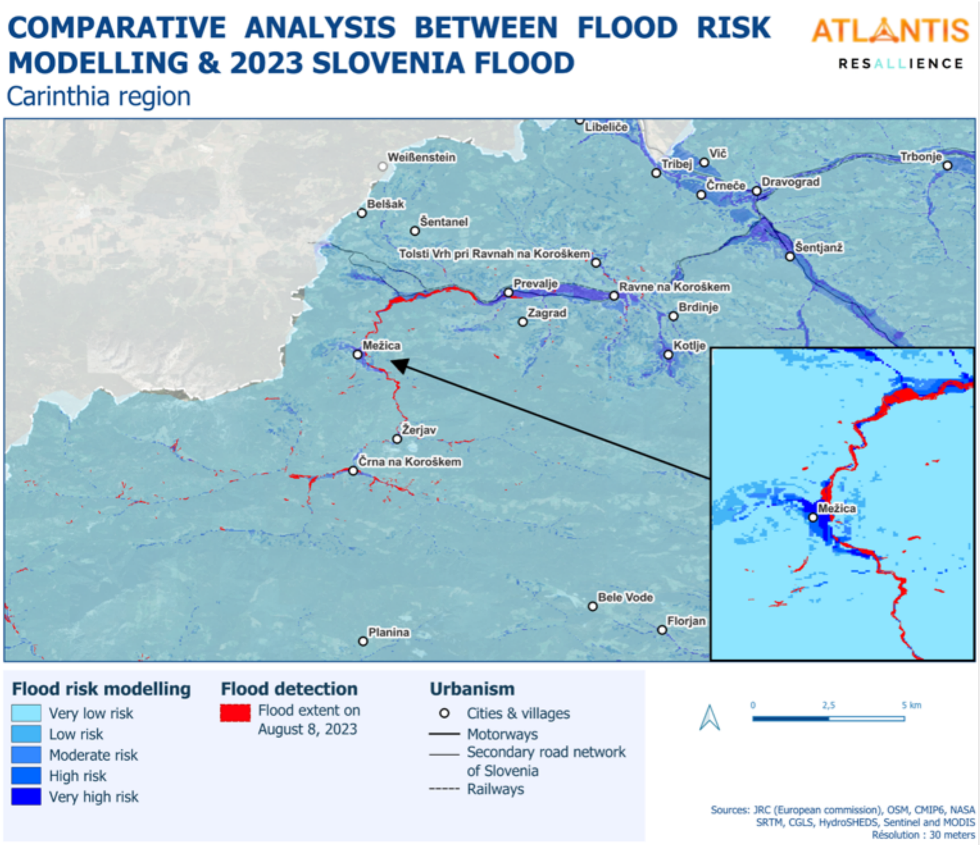

Figure 3. Carinthia region flood detection vs. flood prediction.

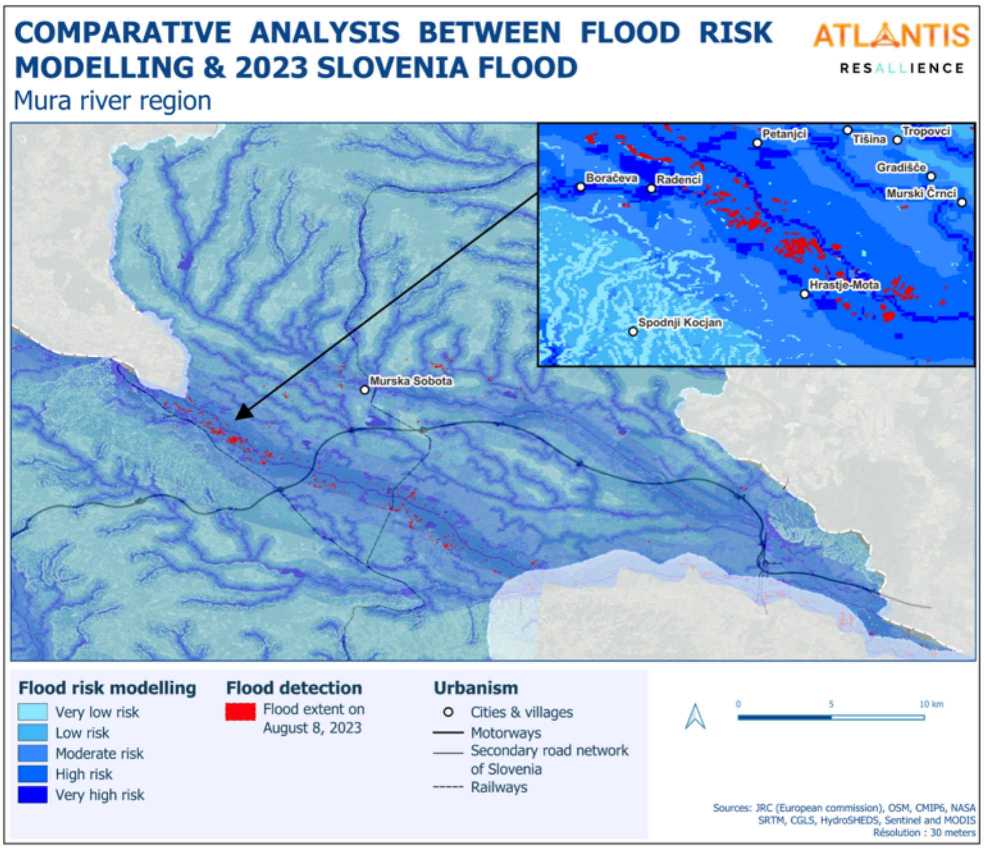

Figure 4. Mura River region flood detection vs. flood prediction.

6. The Challenges and Barriers

The tested methodology for flood risk calculation, while comprehensive, presents several significant barriers and limitations. First, data availability and quality present major challenges. Incomplete, inaccurate, or low-resolution datasets can undermine the accuracy of the model, particularly when critical variables like precipitation patterns, soil texture, and historical flood data are either unavailable or unreliable. The reclassification of these diverse data inputs into standardized categories introduces further complexity, as it requires careful consideration to ensure that different data types are meaningfully integrated without much subjectivity. Increased difficulty also results from the need to harmonize data from various sources, which may differ in scale, and spatial resolution, leading to potential biases.

A particularly sensitive issue is the subjectivity involved in assigning weights to each input factor within the model, even if these weights stem from expert knowledge of the study area. These weights, which are crucial in determining the relative importance of different variables, are often based on expert judgment rather than empirical evidence, introducing a significant degree of uncertainty. The sensitivity of the model to these weights can result in skewness, which complicates decision-making.

Furthermore, accuracy and reliability of the methodology are difficult to validate without extensive real-world testing against actual flood events, which is often hampered by a lack of historical flood data and the inherent unpredictability of such events. Additionally, the dynamic nature of environmental conditions, driven by climate change and human activities like urbanization and deforestation, can quickly challenge the model.

Communicating the results of the flood risk calculations also poses a significant challenge, particularly when conveying the inherent uncertainties to decision-makers. The reclassification of continuous flood risk values into distinct categories may oversimplify complex realities, leading to misinterpretations that could affect land-use planning and flood management decisions. Moreover, the methodology implementation is resource-intensive, requiring significant technical expertise which may be beyond the reach of resource-constrained regions or organizations.

Finally, there are legal and ethical considerations, such as data privacy concerns related to the use of satellite imagery for land cover classification, and the potential for legal liability if inaccurate flood risk predictions lead to inadequate flood defences or improper land-use planning. Furthermore, as these data drive decisions which may impact people, their activities and their environment, legal and ethical issues are of great significance.

7. The Benefits and Impact

The technology offers significant benefits and impacts in the realm of disaster risk management. It enhances security and safety by enabling accurate prediction of natural disasters.

In terms of business processes, this can optimize disaster risk management strategies. By providing actionable information, it allows stakeholders to make informed decisions, allocate resources effectively, and build resilient communities. This not only improves efficiency but also reduces costs associated with disaster recovery.

From an environmental perspective, this contributes to reducing the environmental footprint of disasters. By predicting natural disasters, it can prevent or minimize environmental damage, preserving ecosystems and biodiversity.

However, realizing these benefits and impacts is not without challenges. Data availability, regulatory issues, and stakeholder cooperation are potential hurdles. To overcome these, we plan to collaborate closely with relevant authorities and organizations, ensure compliance with regulations, and invest in research to improve data collection and algorithms. By addressing these challenges, we aim to maximize the potential of ATLANTIS and contribute to a safer and more sustainable world.

8. Future Outlook

The future outlook is promising, particularly in terms of scalability and adaptability. The technology is designed to be scalable, and capable of handling data from a wide range of sources and varying volumes. This scalability allows it to be deployed in diverse contexts, from local communities to regional systems, effectively addressing disaster management needs at different scales.

Looking ahead, the plan until the end of the project involves further refinement and expansion of the methodology. Research efforts will be directed towards improving the algorithms with remote sensing. The goal is to develop a robust and effective system that remains effective in the face of rapidly evolving natural disasters. Additionally, efforts will be made to further validate the methodology in different disaster scenarios and to scale it for wider application. The ultimate aim is to be positioned as a leading solution in proactive disaster preparedness and recovery, contributing to a safer and more sustainable world.

9. Conclusions

In conclusion, the integration of EO in disaster risk management represents a significant advancement, as demonstrated by its application during the catastrophic floods in Slovenia in August 2023. The tested methodology effectively leverages EO data to provide a nuanced and dynamic understanding of flood risk, allowing for accurate predictions and timely interventions. However, the implementation of this methodology is not without challenges, including issues related to data availability, processing complexities, and the subjectivity of weight assignments. Additionally, the model sensitivity to these weights and the inherent uncertainties in predicting natural disasters pose further obstacles. Despite these challenges, the benefits of this technology are substantial, offering improved disaster preparedness, enhanced resilience, and reduced environmental impact. Looking forward, ongoing research and development efforts aim to refine and scale this approach, ensuring its adaptability to various contexts and its continued relevance in an era of escalating climate risks. By addressing the identified barriers and continuing to innovate, this methodology has the potential to become a cornerstone of proactive disaster management, ultimately contributing to a safer, more sustainable future particularly with the advances and increasing access to high resolution satellite imagery.

References

[1] Slovenia flood maps, European Civil Protection and Humanitarian Aid Operations (ECHO), 2023. https://reliefweb.int/map/slovenia/slovenia-floods-dg-echo-daily-map-08082023

[2] EMSR680 – Flood in Slovenia, Obtained from Copernicus Emergency Rapid Mapping, 2023. https://rapidmapping.emergency.copernicus.eu/EMSR680/

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