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Short Paper
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Towards Risk-Informed Development: Making Use of Geospatial Data in Development Planning in Bosnia-Herzegovina

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Abstract

Despite commendable efforts to promote Disaster Risk Reduction (DRR) in development planning, current mainstreaming efforts are failing to keep pace with the increase in exposure, vulnerability and climate-related natural hazards. The recently developed inter-agency and multi-sectoral spatial risk assessments for Bosnia-Herzegovina (BiH) have proven to be effective research and communication tools that have the potential to convince busy policymakers and programme managers to scale up DRR. From the perspective of the UN in Bosnia-Herzegovina, we present geospatial hazard and exposure assessments that have helped to identify and visualize a range of natural hazards and socio-economic factors. In the information age, the internet, publicly available datasets and open source software have created hitherto unknown opportunities to undertake effective disaster risk management. This paper presents action-oriented, geospatial research with high relevance for policy makers and programme managers. We illustrate how the use of "big and open data" has a cost-saving potential for the DRR community.

Key words:

GIS, risk mapping, spatial planning, disaster risk reduction, development planning

1 Why are Spatial Disaster Risk Assessments Critical?

The human casualties, economic losses and socio-economic setbacks stemming from recurring disasters are gradually being recognized as fundamental development challenges. This recognition has come about via long-term advocacy initiatives such as the International Decade for Natural Disaster Reduction in the 1990s and the Hyogo Framework for Action 2005–2015. Climate change further aggravates the situation by increasing the frequency, intensity and unpredictability of extreme weather events (IPCC, 2012). The post-2015 development agenda that includes Sustainable Development Goals, the Sendai Framework for DRR 2015–2030, the Paris Climate Agreement, and the new resilience concept (e.g. Mitchell & Harris, 2012; Tanner et al., 2015a and 2015b) seek to mainstream DRR and climate change adaptation (CCA) within development in order to counter the increase in disaster risks.

In Bosnia-Herzegovina (BiH), the catastrophic floods in May 2014 were a wake-up call for the government and the international community. The damage and losses caused by the flood event amounted to more than 2 million Euros, or approximately 15% of the annual Gross Domestic Product (GDP) (Government of Bosnia-Herzegovina, UN, EU & World Bank, 2014), due to a combination of well-known socio-economic and environmental factors, including: low public awareness of flood risk, damaged ecosystems, outdated spatial plans, insufficient maintenance of public infrastructure, illegal constructions, poor enforcement of building codes, incompatible early warning systems, and competing and ineffective disaster management systems.

While the 2014 floods created an understanding of the necessity of improving disaster management systems, most attention was devoted to disaster response and much less to emergency preparedness and risk reduction. Without a geospatial understanding of hazards and risk factors in the country, discussions regarding DRR remained conceptual and focused on response-readiness rather than safeguarding development investments by making interventions risk-informed and climate-smart.

In order to transform the DRR agenda in Bosnia-Herzegovina from a theoretical discussion to an evidence-based and action-oriented debate, a geospatial understanding of the country and its hazard exposure was required. Within the development discourse in BiH, the spatial distribution of socio-economic progress is gradually being recognized as an important determinant of development inequalities (Hodzic-Kovac, 2016).

Modelling work on child-centred risk assessments in UNICEF Country Offices in Asia (Kjaergaard & Igarshi-Wood, 2014), we explored the potential of the UN's risk mapping in BiH with notable differences:

1. Whereas the UNICEF assessments projected child vulnerability data on existing hazard assessments, the UN assessments in Bosnia-Herzegovina went further by creating new single- and multi-hazard maps, as well as maps showing exposure to floods and earthquakes.
2. Whereas the smallest geospatial unit for the UNICEF assessments was the district/municipality, the UN assessments in Bosnia-Herzegovina went below administrative borders by using GIS.

Unlike standard scientific hazard assessments, we propose a hazard- and exposure-assessment methodology that investigates disaster risk from the perspective of municipal service providers and focuses on multiple hazards. Notably, political boundaries and socio-economic and environmental factors are included in the analysis to make two important points:

a) The inclusion of administrative borders at the lowest geographical level put local governments at the centre of DRR. Focusing on territory of jurisdiction is important not only for UN agencies but also for all development actors and disaster responders alike. Poor service-provision and low capacities at sub-national level are often singled out as key challenges in disaster risk management.
b) The inclusion of socio-economic and environmental factors indirectly communicates that all disasters essentially are a product of human (in)action and that the term "natural disaster" is misleading and a misnomer (e.g. O'Keefe et al., 1976; UN & WB, 2010).

The implication of these insights is that development practitioners need to undertake spatial analysis to fully comprehend disaster risk and provide effective policy advice and operational guidance to policy makers and programme managers. Understanding the location and distribution of disaster risk is, in other words, essential to target development assistance to the exposed areas and people most at risk.

The introduction of Geographic Information Systems (GIS) opened up a range of analytical options that are currently being implemented by the UN in Bosnia-Herzegovina in order to scale up DRR as part of the United Nations Development Assistance Framework 2015–2019. This discussion also has regional importance, since the UNDP's newly published Sub-Regional Human Development Report on Risk-Proofing the Western Balkans: Empowering People to Prevent Disasters adopted a similar spatial analytical approach (UNDP, 2016).

The methodologies used in this paper were evaluated against best international practices published in the Global Facility for Disaster Risk and Recovery's (GFDRR) detailed report on the evolution of disaster risk assessment (WB, 2014a). In addition, international experts from the Global Earthquake Model in Pavia, Italy and the Global Fire Monitoring Centre in Freiburg, Germany advised the authors on the choice of specific seismic and fire data sets.1 Furthermore, draft hazard and exposure assessments were shared with key stakeholders in Bosnia-Herzegovina, within the DRR community (e.g. PreventionWeb and Radical Interpretations of Disasters), and publicly in professional networks, including LinkedIn discussion groups.

2 How Can DRR Practitioners Make Use of New Data and Open Source Software?

With the rise of "big data", disaster risk data is becoming increasingly accessible on the internet. Global risk platforms now provide quality datasets available to download for disaster risk practitioners. Examples include UNISDR's GAR Risk Data Viewer, Desinventar, EM-DAT and INFORM. In combination with open source software, these new, comprehensive platforms provide comprehensive datasets allowing disaster risk practitioners to generate, store, model, visualize and share information in hitherto unprecedented manners. Governments, research institutes, multilateral organizations and development organizations are increasingly realizing the value of the free exchange of data for a better mutual understanding of disaster risk. From NASA remote sensing to EU Corine Landcover data, the amount of information available on the web is enormous and in most cases free of charge with proper citation.

Witt (2015) provides good examples of how remote sensing technology allowed geologists to conduct a wide range of studies through the use of digital elevation models to measure the contours of the Himalayas, and through the use of light detection and ranging (LiDAR) to study landslides in the US. The sources mentioned in his paper were included in the multi-hazard analysis of Bosnia-Herzegovina. While some geo-engineers have highlighted

[1] We wish to thank Professor Johann G. Goldammer from the Global Fire Monitoring Centre and Carlos Villacis from the Global Earthquake Model for their valuable advice and support during the risk mapping process.

discrepancies between datasets (Sabesan et al., 2007) when comparing the two widely used population grids from Oak Ridge National Laboratory (Landscan, licensed) and Columbia University (Gridded Population of the World GPW4, free access), these datasets are regularly updated and improved. In the case of Bosnia-Herzegovina, the latest version of the Gridded Population of the World (v4) contains improved projections of population densities in the country. By combining these datasets with land use grids such as Corine, which easily identifies densely populated areas, the accuracy of the findings will increase.

It is important to note that scientific and modelled data should not disregard the importance of participatory mapping and crowd sourcing in risk assessments. Participatory methods are an integral part of community-based DRR, which has delivered some of the most promising risk reduction results in the world. Examples from the Philippines show how the use of participatory data in integrated DRR strategies increases the quality and validity of exposure and vulnerability information (Cadag & Gaillard, 2012). Other case studies are included in WB, 2014a. Interactions with municipal authorities and community members are therefore an important step to validate and further refine the geospatial maps included in this paper.

Simultaneously, open source software is becoming more powerful and user-friendly, thereby providing easy access to reliable GIS processing capacities at no cost. The open source mapping community has developed software that is capable of completing the vast majority of data manipulations that proprietary software are capable of. Examples include Quantum GIS (QGIS) and GRASS GIS.2 The growing community of open GIS users constitutes an important forum for information exchange and technical support for risk analysis and mapping. This community of users includes the GIS Stack Exchange platform, a large Q&A forum that is free and requires no registration. In 2016, the website had a total of more than 62,000 questions stored. It is worth noting that the systematic use and improvement of open source software is one of the recommendations in the GFDRR report on disaster risk assessments (WB, 2014a), and of the World Bank's Open Data for Resilience initiative (Crowley, 2014; WB, 2014b).

Public availability of reliable data and free data-processing tools represent a good opportunity for the DRR community to encourage development professionals, communities and governments to take risk-informed development forward.

3 Why Focus on Hazard Mapping at the Municipal Level?

The authors began their exploration into spatial hazard and exposure mapping with a review of the available assessments of Bosnia-Herzegovina. While multiple international studies and reports refer to the risk profile of the country, including INFORM (UN & EU, 2016), GAR 15 (UNISDR, 2015) and UNDP BiH's risk assessment (Ministry of Security, UNDP, EU, 2011), none of these contains geospatial data at the subnational level. Although scientists in the country have access to cadastres of natural hazards, such data is rarely mapped, seldom digitalized, and never available for public dissemination. The absence of local hazard maps

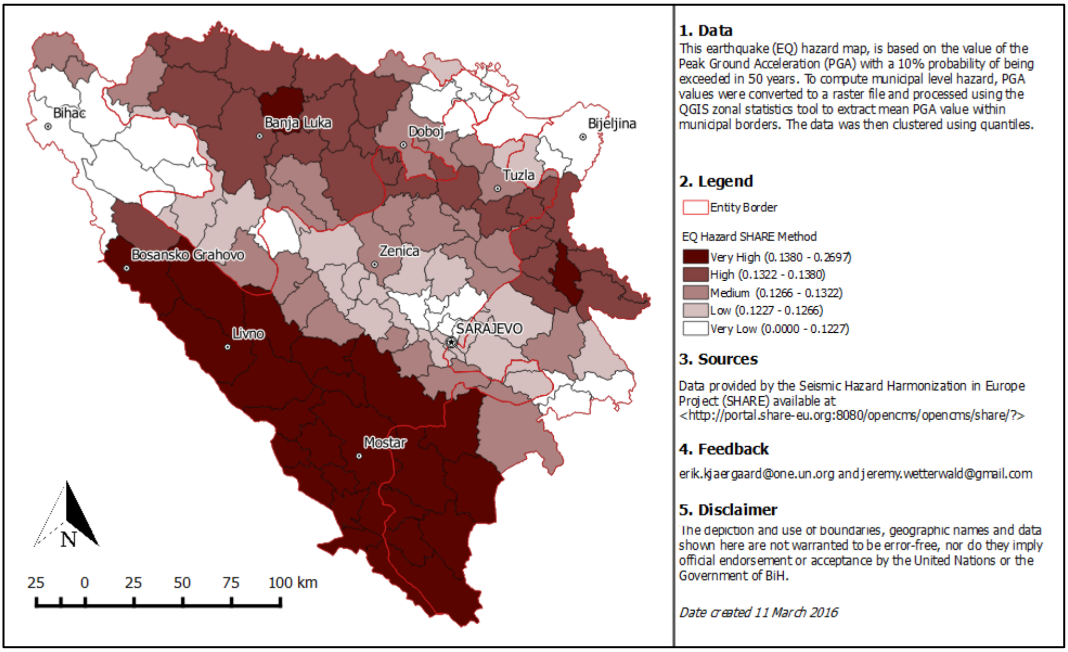
[2] Proprietary software packages usually come with a high price tag (more than 900 USD for a standard licence), which can be a significant barrier for local DRR actors in the field.

significantly hampers local communities' capacities to understand disaster risk in their area and plan accordingly.

The complex administrative structure of Bosnia-Herzegovina, composed of two constitutional entities, cantons and municipalities, also contributes to the absence of available and comparable data sets. The existing hazard (often entitled risk) maps from government sources have several limitations (Ministry of Security, UN, EU 2011; Civil Protection RS, 2013): they are at low resolution, do not include municipal borders, and pay little attention to exposure and vulnerability data. In essence, the absence of GIS files prevented the authors from combining these maps with other data sets and thereby making use of them.

The development of spatial natural hazard assessments was therefore an important first step to map disaster risks in the country. In order to counter data restrictions and commercial interests, the authors deliberately relied on open source software, the large amounts of international data available on the internet, and datasets made available by UN colleagues in BiH.3 The following sections present the hazard maps of earthquakes, fires, floods and landslides and describe the formulas used for assessment purposes.

4 Earthquake Hazard Mapping



Map 1: Earthquake Hazard Map

[3] The authors wish to thank Aida Hadzic-Hurem, UNDP DRR Programme Manager for sharing local landslide data.

The earthquake hazard map, based on data provided in Map 1, was developed using the value of the peak ground acceleration (PGA) with 10% probability of being exceeded in 50 years. These values were inserted in a 3,478 by 2,430 raster grid ranging from 0 to 0.2714 (g). To compute municipal hazard levels, these values were aggregated within municipal polygons using the QGIS zonal statistics tool to calculate the mean PGA value within a municipality. For pixels that are separated by a polygon line, the calculator uses the proportional mean of the underlying pixel area:4

$$\boldsymbol{EQ\ Hazard_{mun}} = \frac{\sum_{i=1}^{n} \boldsymbol{PGA}}{\boldsymbol{n}}$$

where

PGA = pixel value of peak ground acceleration with a 10% probability of being exceeded in 50 years

n = all pixels within the municipal polygon

The resulting hazard values were then clustered using a quantile approach:

$$SSD_{i,\ldots,j} = \sum_{k=i}^{j} (A[k] - mean_{i,\ldots,j})^2$$

where

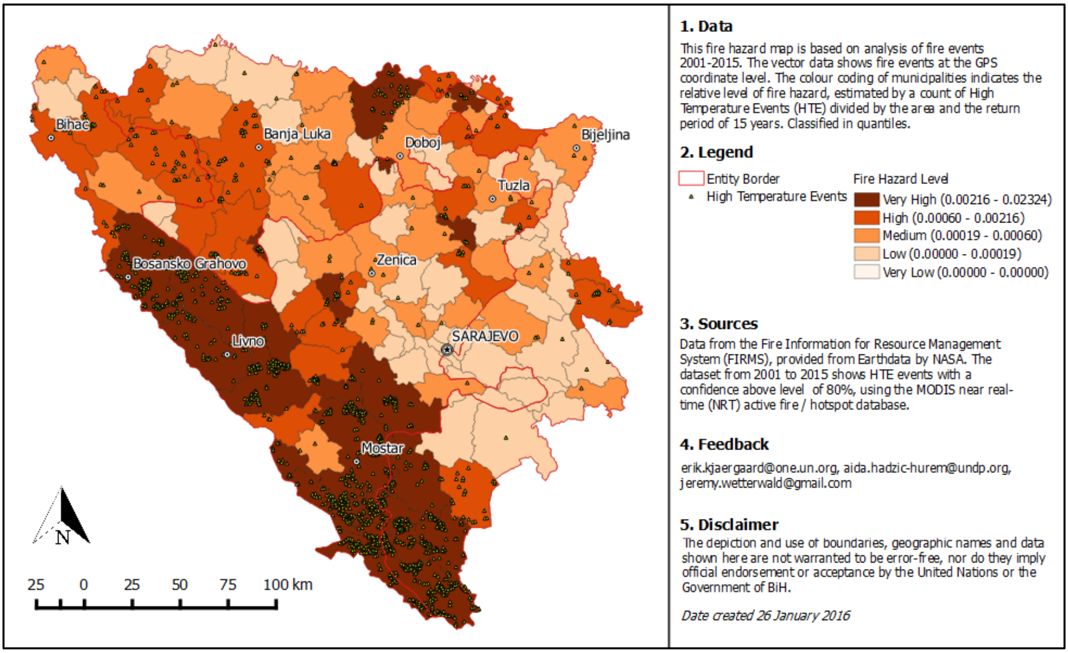
A = Municipal hazard values that have been ordered from 1 to N:

$1 \leq i < j < N$

and mean i,…, j is the mean of the class bounded by i and j.

[4] Full details of the algorithm used in zonal statistics are available on GitHub.

5 Fire Hazard Mapping



Map 2: Fire Hazard Map

The fire hazard map was developed using a slightly different approach. Using data from a global database provided by the NASA Fire Information for Resource Management System (FIRMS), the authors downloaded historical high temperature events (HTE) from 2001 to 2015 that had an 80% confidence interval. This query returned 1,845 observations, including date, longitude, latitude, confidence and brightness. In order to create a quantitative index of fire events at the municipal level, a points-in-polygon analysis was conducted showing the absolute number of events per municipal polygon divided by the area and by the return period of 15 years. This number represents the average probability of HTEs occurring within any given square kilometre within one year. While the HTE approach cannot distinguish between man-made and naturally occurring fires, this analysis provided an accurate picture of those municipalities that in the past had experienced the highest number of fires. Historical data were used as a proxy for the likelihood of experiencing fires in the future:

$$Hazard_{mun} = \frac{\frac{\sum_{i=1}^{n} HTE}{Area}}{Return\ Period}$$

where

HTE = HTE events

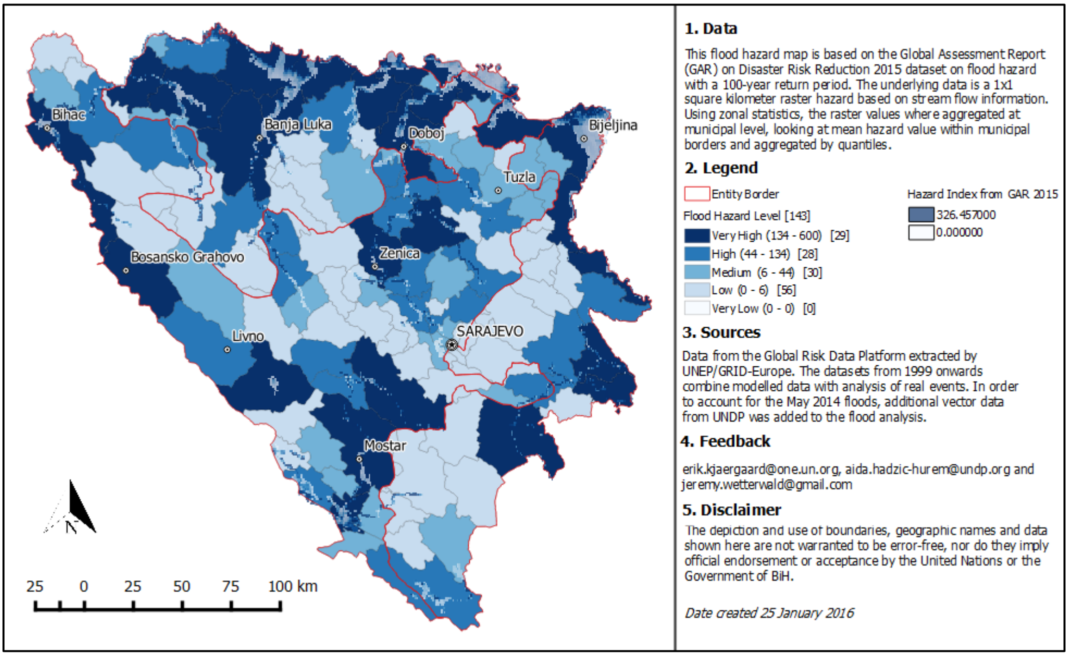
n = HTE events within the municipal polygon

Area = polygon area in square kilometres

Return period = 15 years

The resulting hazard values were clustered by quantiles.

6 Flood Hazard Mapping



Map 3: Flood Hazard Map

A similar approach to the one evidenced in the two previous maps was used to develop a flood hazard map. The authors downloaded a BiH raster file showing flood hazards with a 100-year return period from the Global Risk Data Platform of GAR 2015. This provided a 1x1 km raster map indicating flood hazard levels in BiH. Using the zonal statistics tool from QGIS, the pixel counts, the sum of frequency of all pixels, and the mean frequency of each pixel per municipality were calculated. In order to show the relative flood hazard level, the mean hazard index value that displays the average flood hazards per pixel within municipal borders was computed. The calculation is shown below:

$$\boldsymbol{Flood\ Hazard_{mun}} = \frac{\sum_{i=1}^{n} FH}{n}$$

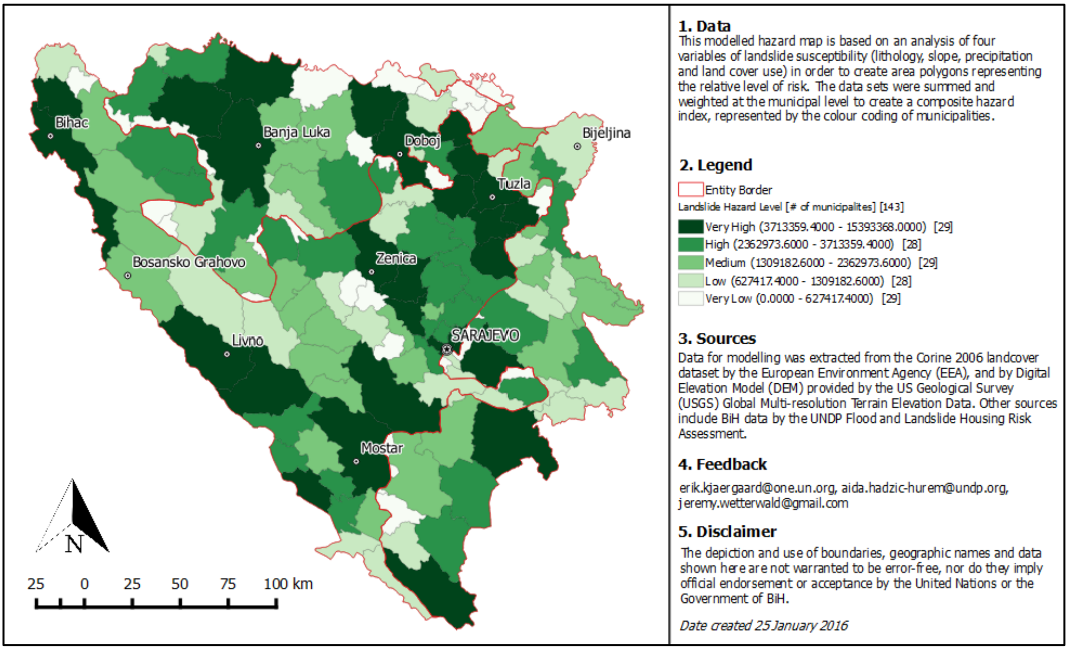
where

FH = value of the flood hazard pixel

n = number of pixels within the municipal polygon

The resulting hazard values were clustered by quantiles.

7 Landslide Hazard Mapping



Map 4: Landslide Hazard Map

A landslide hazard map was developed based on a methodology adopted by a team of consultants within UNDP. This modelled hazard map is based on an analysis of four variables of landslide susceptibility – lithology (Sarajevo Geodetic Institute, 2016), slope (USGS, 2016), precipitation (yearly average from 1980 to 2010), and land use (Corine, 2006) – in order to create area polygons representing the relative hazard level. The data sets were summed and weighted at the municipal level to create a composite risk index. For more details on the methodology, please refer to the European Union's Floods and Landslides Risk Assessment for the Housing Sector in Bosnia and Herzegovina (EU, 2015). Although the authors were not directly involved in the design of this analysis, the results were used in the multi-hazard analysis combining the findings of the four individual hazard maps.

8 Multi-hazard Mapping

In order to create a multi-hazard map, the authors exported all the calculated polygon values from QGIS to Excel and created an index based on a normalized value using a cumulative distribution function:

$$f(x,\mu,\sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

where

x = municipality hazard

μ = municipality mean of hazard

σ = municipality hazard standard deviation

Normalization of all hazard values to a range between 0 and 1 allowed comparison of data sets for individual hazards. Based on the distribution of the four natural hazards across 143 municipalities in Bosnia-Herzegovina, the authors assessed the multi-hazard level of all municipalities in the country. The normalized values were summed to generate a quantitative indicator of municipal exposure to the four natural hazards in question:

$$Multi\ hazard\ index_{mun} = \sum_{i=1}^{n} (w_i \times h_i)$$

where:

WI = WEIGHT OF EACH SINGLE HAZARD

hi = normalized value of each single hazard

n = number of single hazards

In order to demonstrate that a multi-hazard risk assessment is not a clear-cut exercise, we assigned different weights to different hazards depending on the focus of specific multi-hazard assessments. Four different scenarios were tested:

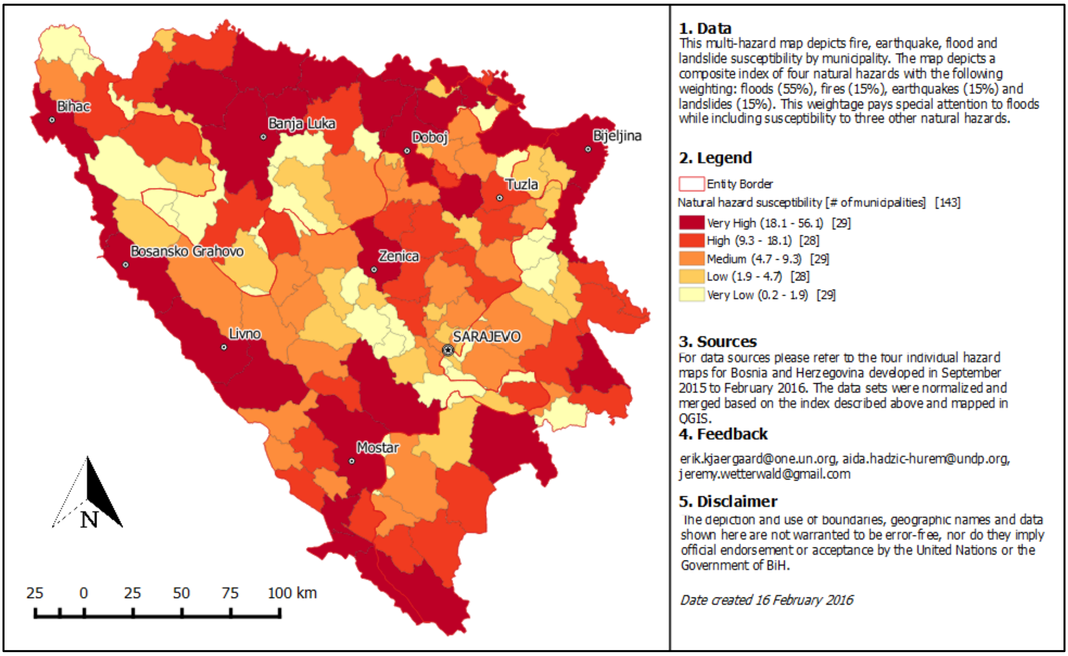
1. **Equal weight (useful for multi-hazard planning)** to all four hazards.
2. **Flood focus (useful for recovery planning)**, assigning highest weight to floods and equal weights to the remaining three hazards.
3. **Livelihood focus (useful for development planning)**, assigning higher weights to floods and fires than to earthquakes and landslides.
4. **Sudden-onset focus (useful for humanitarian action)**, assigning higher weights to earthquakes and landslides than to floods and fires.

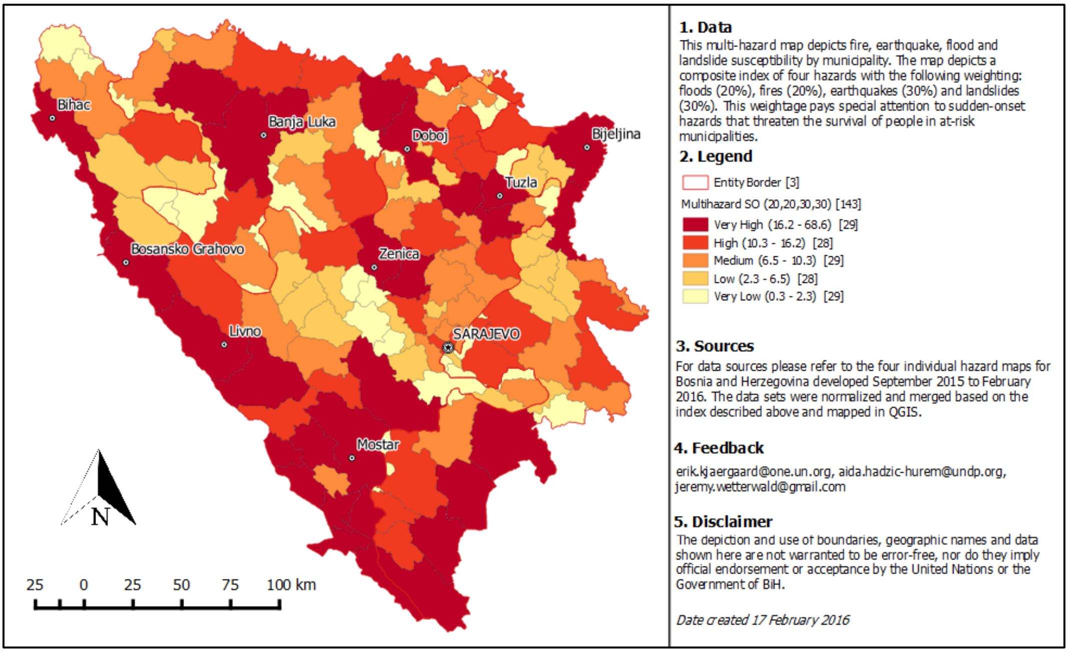
The table below shows the weights assigned for the different scenarios.

Table Fehler! Es wurde keine Folge festgelegt.: Differential Weighting of Hazards in Four Multi-Hazard Risk Scenarios.

	Fire	Flood	Earthquake	Landslide
Equal Weight	1/4	1/4	1/4	1/4
Flood focus	1/6	3/6	1/6	1/6
Livelihood Focus	3/10	3/10	2/10	2/10
Sudden-Onset Focus	2/10	2/10	3/10	3/10

These values were classified in five equal intervals. Maps 5 and 6 below illustrate the findings of the flood-focused and the sudden-onset multi-hazard maps: the darker the shade of red, the higher the multi-hazard level.





Maps 5a & 5b: Flood Focus Multi-Hazard Map (Top) and Sudden Onset Multi-Hazard Map (Bottom)

The above methodology helped to communicate that risk assessments can be tailored to specific purposes and that these purposes affect the findings of the assessments. While the Ministry of Security and civil protection officials are interested mainly in disaster response, UN agencies might focus more on flood recovery and/or the livelihood implications of natural hazards. Similarly, flood recovery has gradually given way to a multi-hazard DRR approach. Despite differences, the data also shows that natural hazards are concentrated in a few municipalities. In a context of scarce resources for development, multi-hazard risk assessments allow policy makers and development practitioners to target interventions in locations that are most at risk.

In order to advance the understanding that disaster risk is a result of human (in)action and poor development choices, it is important to extend the analysis beyond natural hazards. DRR practitioners usually rely on population and economic data to assess where natural hazards are likely to have the greatest impact on the lives of human beings and the assets of communities.

Subnational risk assessments typically assess exposure to hazards by using population numbers, the value of buildings/infrastructure, and/or GDP (at subnational level) as indicators. Such assessments often sum these values based on risk indexes. While these assessments give some indication of exposure levels, they do not take the varying geographic sizes of administrative units into consideration or allow analysis below the lowest administrative unit.

The following sections describe the authors' approach to exposure assessments, one focusing on assessing the people at risk, and the other on GDP exposure to natural hazards. The use of GIS allowed the authors to produce exposure maps with a high level of accuracy and to assess the relative risk levels of individual municipalities. The proportion of population and GDP exposed to floods and earthquake have often proven to be important indicators of disaster risk and resilience (e.g. UNESCAP, UNISDR 2012 and UNISDR, 2015).

9 People at Risk

In order to produce population exposure maps, the authors used the Gridded Population of the World (GPW) v4 dataset developed by the University of Columbia as it can be downloaded for free, in preference to the LandScan data from Oakridge National Laboratory. More information on the methodology employed for the GPW map can be found on their website.5

Using the QGIS raster calculator tool, the authors multiplied hazard and population data in the following way:

$$\begin{bmatrix} efp_{1,1} & efp_{1,2} & efp_{1,n} \\ efp_{2,1} & efp_{2,2} & efp_{2,n} \\ efp_{m,1} & efp_{m,2} & efp_{m,n} \end{bmatrix} = \begin{bmatrix} hf_{1,1} & hf_{1,2} & hf_{1,n} \\ hf_{2,1} & hf_{2,2} & hf_{2,n} \\ h_{m,1} & h_{m,2} & h_{m,n} \end{bmatrix} \times \begin{bmatrix} p_{1,1} & p_{1,2} & p_{1,n} \\ p_{2,1} & p_{2,2} & p_{2,n} \\ p_{m,1} & p_{m,2} & p_{m,n} \end{bmatrix}$$

[5] Dataset and methodology available at <sedac.ciesin.columbia.edu/gpw/>

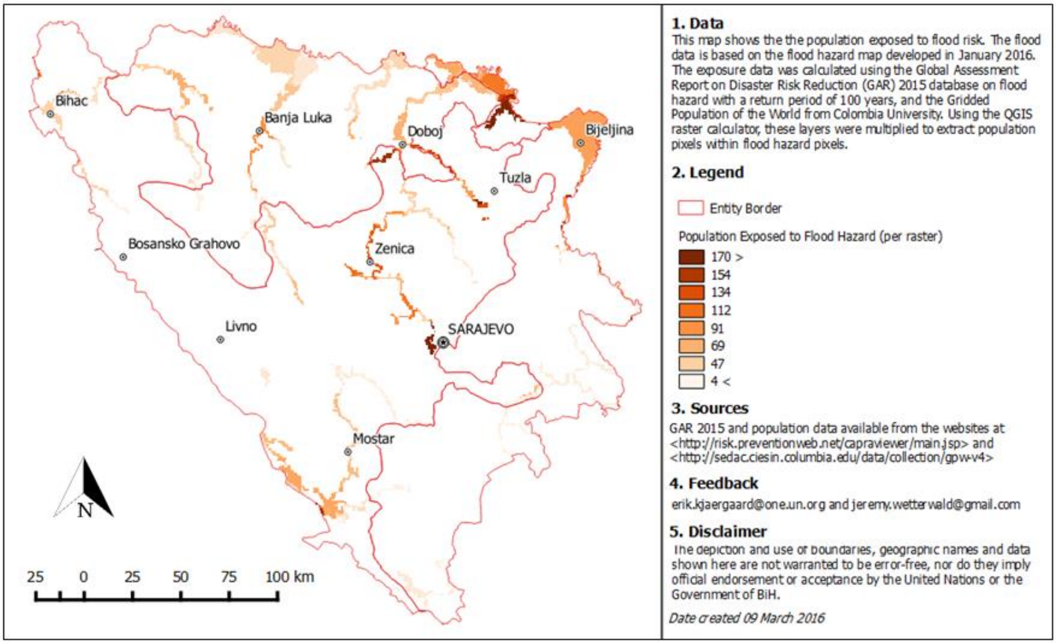
where

hf = presence of hazard with a raster pixel as 0 (no hazard) or 1 (hazard)

p = population within a raster pixel as absolute value

efp = population within the flood hazard pixel

The resulting map is presented below (Map 7).



Map 7: Population Exposed to Flood Hazard Map

In order to include municipalities in the analysis, the authors used the zonal statistics tool to aggregate the total number of people exposed to flood hazard at municipal level. Data was aggregated as for the hazard maps:

$$Population\ exposed\ to\ flood\ hazard_{mun} = \sum_{i=1}^{n} \boldsymbol{efp}$$

where

efp = population within a flood hazard pixel

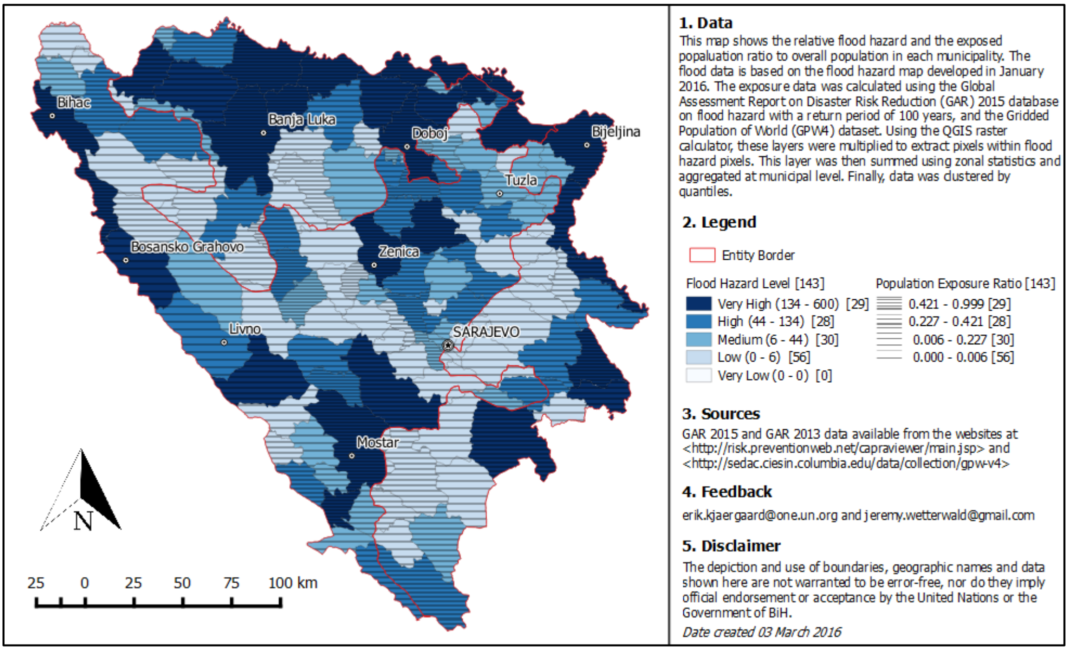
n = pixels within the municipal polygon

The value of population exposure could then be divided by the total population per municipality in order to obtain the relative exposure level of people to flood hazards at municipal level:

$$Relative\ flood\ population\ risk_{mun} = \frac{Population\ exposed\ to\ flood\ hazard_{mun}}{Total\ Population_{mun}}$$

The result of this calculation was added as a new layer in QGIS and imposed on the hazard map to show a two-dimensional result: the relative level of a specific natural hazard (here floods) and the relative level of population exposure at municipal level to the hazard in question.

The population-based exposure maps to floods are shown below (Map 8).



Map 8: Population-based Exposure to Floods

10 Elements at Risk

To assess GDP exposure, the authors replicated the above method using a raster dataset, provided by the Global Assessment Report on DRR from 2013, representing modelled GDP produced within a 427 by 327 grid of Bosnia-Herzegovina. The calculation is presented below.

$$\begin{bmatrix} efg_{1,1} & efg_{1,2} & efg_{1,m} \\ efg_{2,1} & efg_{2,2} & efg_{2,m} \\ efg_{n,1} & efg_{n,2} & efg_{n,m} \end{bmatrix} = \begin{bmatrix} hf_{1,1} & hf_{1,2} & hf_{1,m} \\ hf_{2,1} & hf_{2,2} & hf_{2,m} \\ hf_{n,1} & hf_{n,2} & hf_{n,m} \end{bmatrix} \times \begin{bmatrix} g_{1,1} & g_{1,2} & g_{1,m} \\ g_{2,1} & g_{2,2} & g_{2,m} \\ g_{n,1} & g_{n,2} & g_{n,m} \end{bmatrix}$$

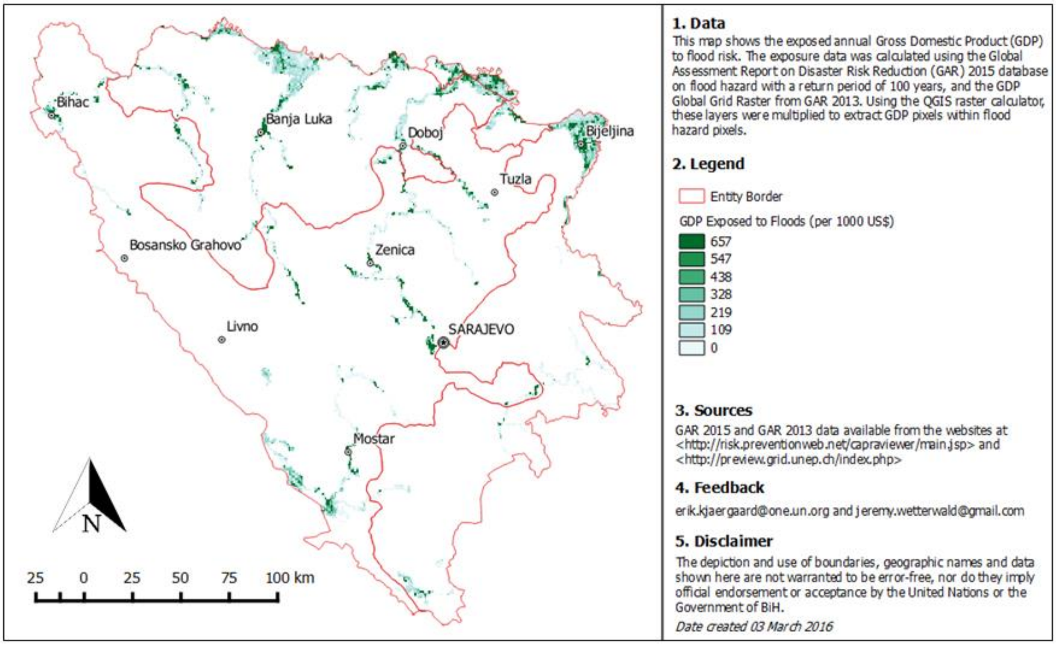
where

hf = presence of hazard within a raster pixel, as 0 (no hazard) or 1 (hazard)

g = GDP within a raster pixel as absolute value

efg = GDP within the hazard pixel

The map that emerges from this calculation is presented below (Map 9).



Map 9: GDP Exposed to Flood Hazard Map

In order to include municipalities in the analysis, the authors used the zonal statistics tool to aggregate the total value of annual GDP exposed to flood hazard at municipal level. This was aggregated as for the hazard maps.

$$GDP\ exposed\ to\ flood\ hazard_{mun} = \sum_{i=1}^{n} efp$$

where

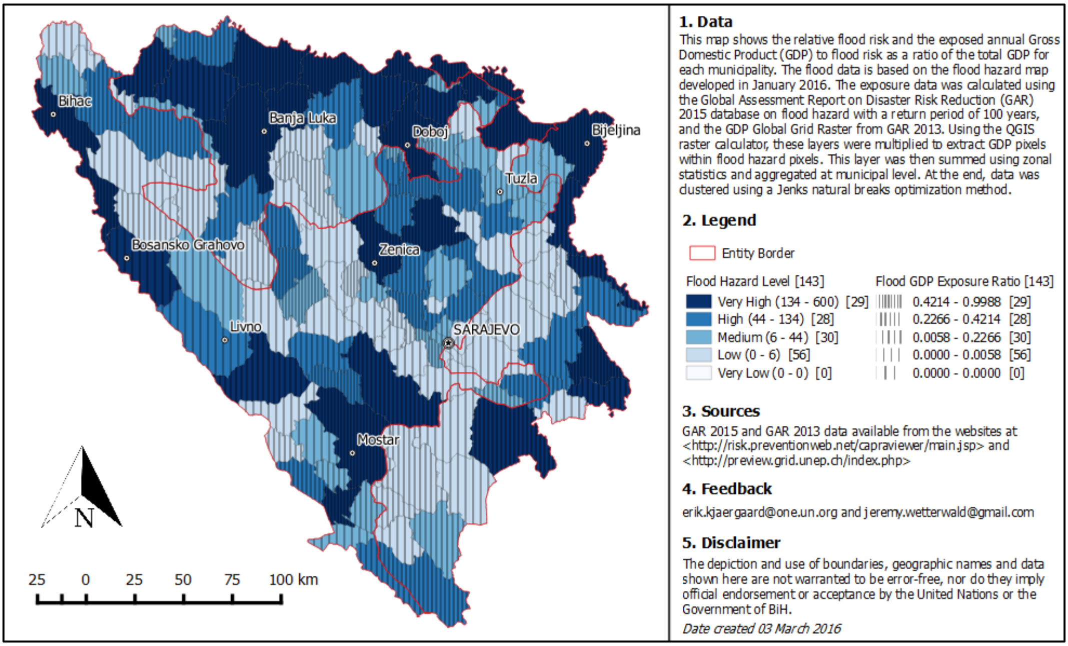
efp = population within a flood hazard pixel

n = pixels within the municipal polygon

The value of GDP exposure could then be divided by the total GDP per municipality to obtain the relative exposure of GDP to flood hazards at municipal level.

$$Relative\ flood\ GDP\ risk_{mun} = \frac{GDP\ exposed\ to\ flood\ hazard_{mun}}{Total\ GDP_{mun}}$$

The result of this calculation was added as a new layer in QGIS and overlaid on the flood hazard map to show the relative flood risk and the proportion of GDP exposed to flood risk at municipal level. The resulting map is shown below (Map 10).



Map 10: Flood Hazard and GDP at risk of Flood

This process can be replicated for other hazards, including earthquake ($heq_{i,i}$) or fires ($hfi_{i,i}$), using the raster calculator to calculate exposure and the zonal statistics to aggregate data at municipal level.

$hf_{i,i}$ can be replaced by $heq_{i,i}$ = presence of earthquake hazard with a raster pixel given as 0 (no hazard) or 1 (hazard) for any value of the Peak Ground Acceleration (PGA) above 0.18(g) with 10% probability of being exceeded in 50 years.6

$hfi_{i,i}$ = presence of fire hazard within a 0.05 raster grid based on a probability of high temperature events occurring in the next year greater than 1.

[6] The value of 0.18 is the lower limit of 7th stage from the European Macroseismic Scale 1998 (EMS-98) in which the perceived shaking is strong and buildings suffer moderate damage (USGS Website).

11 Conclusion and Way Forward

This paper described the motivation, approaches and calculations behind the operational use of risk assessments in UN development planning in Bosnia-Herzegovina. When moving from disaster response and recovery to emergency preparedness and risk reduction, it is critical to obtain an overview of natural hazards and disaster risk at the sub-national level.

We have demonstrated how four single natural hazard maps could be created with the available datasets in such a way as to increase their relevancy for government officials, service providers and development practitioners. The paper also presented how single hazard assessments were combined in multi-hazard assessments tailored for specific purposes.

By making use of GIS and statistics, the analysis went below administrative borders and included detailed risk mapping of people and assets exposed to floods and earthquakes. Such exposure maps help to communicate that disaster risk is a product of human (in)action and wrong development choices. They further encourage adoption of preventive risk management approaches by quantifying potential disaster losses. The use of GIS and global data sets contributed significantly to the findings, while the inclusion of administrative borders at sub-national level makes the assessments useful for policy makers and development practitioners.

By drawing on different open source data sets and combining various methodologies from global, regional and local sources, the authors were able to develop sophisticated risk assessments at the subnational level. Such risk maps empower government authorities and the international community to target future development and DRR interventions in areas most at risk.

While the hazard and exposure maps have been well received amongst DRR practitioners at global (e.g. Kjaergaard & Wetterwald, 2016) and country-level, they also need to be validated at the local level. Next steps therefore include taking the assessments to the field and presenting them to stakeholders, municipal authorities and community members. Crowd sourcing would be the preferred option to obtain local GPS coordinates of critical institutions and communities, and families and households that suffer from various aspects of socio-economic risk. Crowd sourcing would also allow triangulation of country-level datasets with municipal and community sources.

Vulnerability and capacity data would also need to be incorporated, based on multiple vulnerability indicators and the result of a "Who Does What Where?" exercise in DRR (Ministry of Security, UN & Embassy of Switzerland, 2016). The results of such an analysis would allow service providers to target specific population groups most at risk, and to invest in their capacities.

Last but not the least, the risk maps need to be used by the Ministry of Security, subnational Civil Protection authorities and development practitioners in Bosnia-Herzegovina. Only in this way will the assessments have contributed to risk-informed development planning, which remains a priority in order to safeguard development investments and effectively reduce disaster risk.

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