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TOMRAP: Tool for Multihazard Risk Analysis in Python

Winson[1], **Valters**[1¶], **Smith**[1], **and Leeming**[1]

1 British Geological Survey, United Kingdom ¶ Corresponding author

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Summary

Multihazards are defined as the major multiple hazards that an area might face and the specific context in which they occur, which may be simultaneously, cascadingly, or cumulatively through time (UNDRR, 2017). TOMRAP is an open-source python toolbox capable of generating a compounding / coincident multi-hazard risk assessment at national scale, incorporating any available hazard and exposure data with user defined weighting factors to reflect the changing vulnerability of building stock to various hazards.

Statement of need

Globally individual and interrelated hazards have the potential to result in large socio-economic losses (Tilloy et al., 2019). There is a growing body of literature highlighting the need to move from single risk to multihazard risk assessment (Ciurean et al., 2018; De Angeli et al., 2022; Gill & Malamud, 2016; Kappes, Keiler, et al., 2012; Kappes, Papathoma-Koehle, et al., 2012; Tilloy et al., 2019; Ward et al., 2022; Zschau, 2017). Past studies have investigated a range of potential methods for modelling these interactions, from purely qualitative to purely quantitative approaches. These include tools such as: Hazard Wheels (Rosendahl Appelquist & Halsnæs, 2015), Hazard Matrices (Gill & Malamud, 2014; Kappes, Papathoma-Koehle, et al., 2012), Hazard / Risk Indices (Kappes, Keiler, et al., 2012) and Probabilistic frameworks (Mignan et al., 2014). With more quantitative models requiring increasingly dense inventories of events to support the appropriate level of statistical analysis. These approaches vary, but fundamentally they attempt to quantify the nature, intensity and return period of specific hazards. Each single hazard has a different standardised unit of measurement for magnitude, and it is this lack of common standardisation that can make multi-hazard assessments complex (Kappes, Keiler, et al., 2012). In practice multi-hazard assessments are complicated by the differences between hazard characteristics and therefore the methods used to analyse them and that the impacts on exposure can be different for differing hazards and occasionally opposing (Kappes, Keiler, et al., 2012).

As part of METEOR project, funded through the UK Space Agency's International Partnership Program funded METEOR project, we developed a framework for modelling multihazard risk, which aggregates hazard, building exposure and vulnerability data to produce a national level semi-quantitative risk assessment. This framework allows the aggregation of various probabilistic and inventory-based susceptibility and hazard assessments (developed for earthquake, volcano, flood and landslide), with satellite derived building exposure data and an assessment of building vulnerability, defined either by the input of fragility failure curves or through expertly elicited weighting factors. This methodology can therefore be adapted dependant on what data is available to the end users and can be pushed to either a more qualitative or more quantitative output, as the data supports.

Modelling Multihazard Risk

TOMRAP is a modelling toolbox written in Python that: 1) Creates an index value to allow for the combination of hazard footprints for 4 natural hazards, 2) Identifies the factors that affect the exposure and vulnerability of buildings to these specific hazards, 3) Calculates the vulnerability of individual buildings within hazard zones, 4) Applies weights for each building type to express the potential vulnerability of individual buildings to a specific hazard to generate relative single hazard vulnerability maps and then 5) Combines these single hazard 'relative vulnerability maps' to generate a multi-hazard vulnerability map which is weighted to reflect single hazard frequency / magnitude relationships. The basic structure of the modelling framework can be seen in Figure 1.

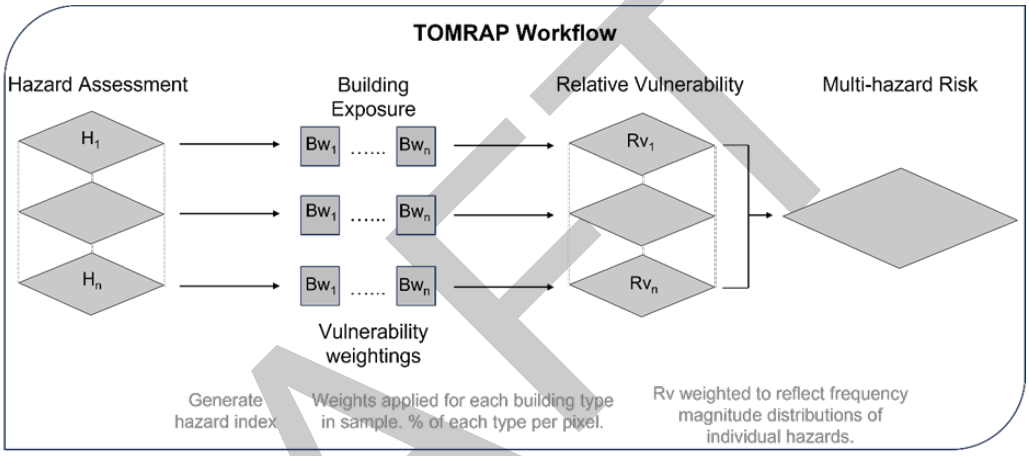

Figure 1: Generic workflow for the TOMRAP tool. The toolbox aggregates multiple hazard layers with exposure data, that can be weighted over a range of hazard specific vulnerabilities at a pixel scale. This process creates relative vulnerability outputs for each hazard, a weighted sum of these outputs reflects the frequency magnitude distribution of the single hazards and generates a multi-hazard risk product.

The hazard map for a particular location, i, is a sum over individual hazards and can be defined as such:

$$H_i = \sum_{k \in K} \beta_k h_{ki}$$

where the map value for each hazard is given by:

$$h_k i = \Sigma_{l \in L_k} \alpha_l g_{li} (\Sigma_{m \in M} \gamma_{ml} b_{mi}).$$

Where: H_i is the final hazard map at location *i*, *K* is the set of hazards combined in the final map, for example volcanic, seismic and flooding, B_k is the weight of hazard *k*, where $\Sigma_{k \in K} \mathrm{B}_k = 1$, h_{ki} is the value of the hazard *k* at location *i*, L_k is the set of sub-classes within a hazard, for example pluvial and fluvial flooding. (If a hazard does not have sub-classes L_k only has one entry and the sum is over one class), α_l is the weight of sub-class *l*, where $\Sigma_{l \in L_k} \alpha_l = 1$, g_{li} is the hazard index for sub-class *l* at location *i*, *M* is the set of building classes, γ_{ml} is the building weight for building class *m* and sub-class *l*, b_{mi} is the proportion of building type m at location *i*, where $\Sigma_{m \in M} b_{mi} = 1$ for all locations *i*.

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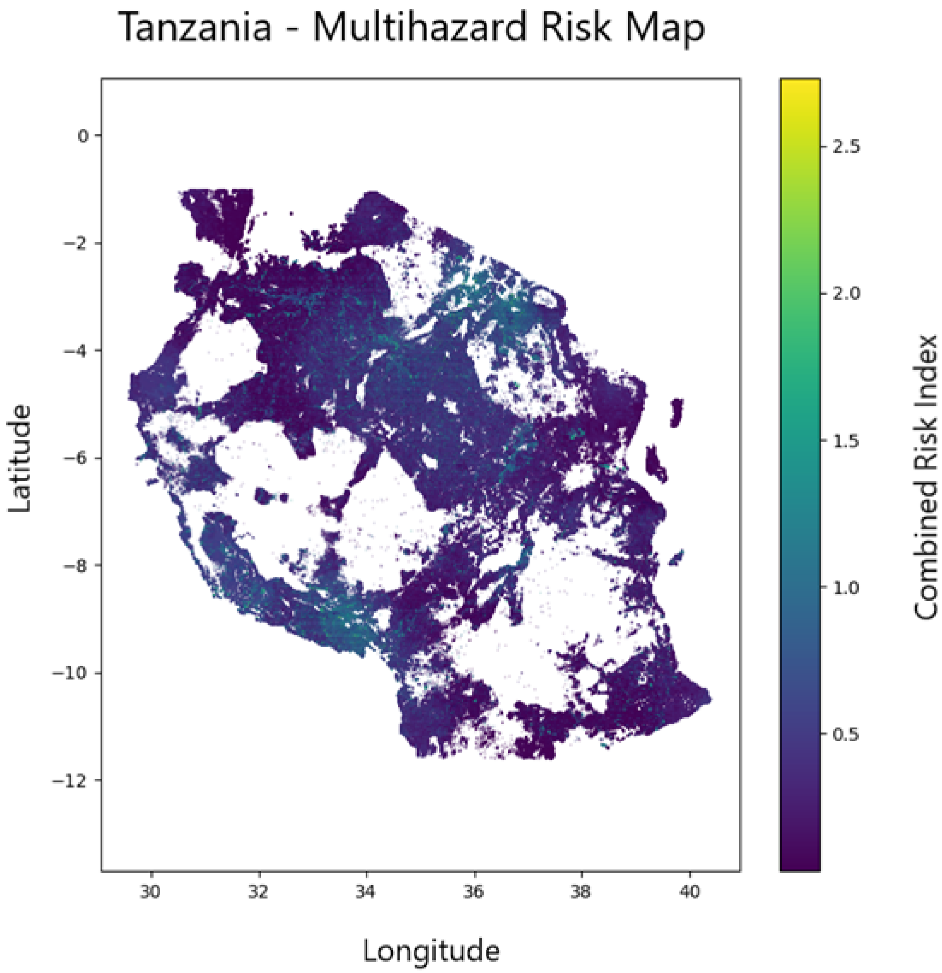

Figure 2: Map of multihazrd risk index for the test country of Tanzania. This output combines hazard data for earthquake, flood and volcanic hazard and combines it with building exposure, weighted for hazard specific vulnerabilities. Separate hazards are then weighted together to generate a multihazard risk map.

The TOMRAP software package is released under an open source licence and distributed via GitHub. The interface to the software is via running a command line script that invokes the TOMRAP code, and a config file supplied allows the user to configure the input data sources, and any weighting factors. The sofware can also be configured to calculate weighting factors for hazards based on the user supplying vulnerability curve data (Figure 3) The config file also allows the user to determine which output figures are produced from the analysis. (E.g. Figure 2)

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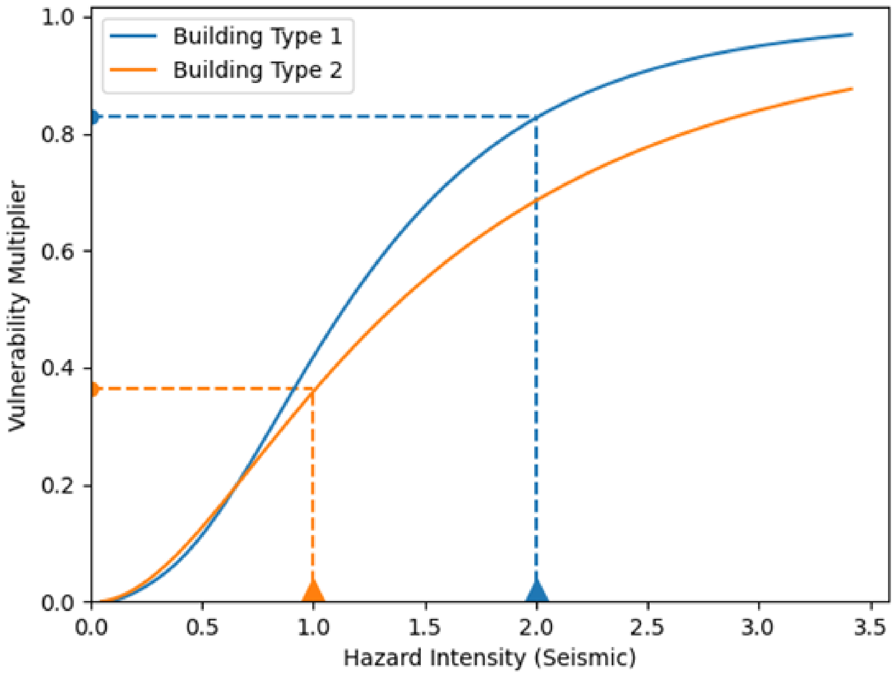

Figure 3: Illustrative diagram of how a supplied vulnerabiltiy vulnerability curve or curves for a each building type can be used to determine the weighting factor/vulnerability multiplier based on a given hazard intensity. The vulnerability curve data is supplied in csv format.

TOMRAP was designed to be used by decision makers and stakeholders who are responsible for pre-positioning of resources prior to a disaster event and for those who are assessing the potential efficacy of interventions such as adapting building codes. The products from this toolbox are intended to provide guidance on the relative risk from multihazards at a national scale. It is important to note that any uncertainty associated with the input datasets is likely to be compounded by the aggregation of data within the model. It is therefore important to bear in mind that any data generated by this tool should be assessed for uncertainty. Methodologies for this are outlined in the publications attributed to the METEOR project (Winson et al., 2020) as are all of the data sets created to support it (https://meteor-project.org/ and https://maps.meteor-project.org/). Risk products generated by this tool should not be considered absolute risk assessments but rather a measure of the relative risk of areas in the context of specific natural hazards. (E.g. Figure 2)

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References

Ciurean, R., Gill, J., Reeves, H. J., O'Grady, S., & Aldridge, T. (2018). Review of environmental multi-hazards research and risk assessments. *BGS Internal Report OR/18/057*. http://nora.nerc.ac.uk/id/eprint/524399/1/OR18057.pdf

De Angeli, S., Malamud, B. D., Rossi, L., Taylor, F. E., Trasforini, E., & Rudari, R. (2022). A multi-hazard framework for spatial-temporal impact analysis. *International Journal of Disaster Risk Reduction*, *73*, 102829.

Gill, J. C., & Malamud, B. D. (2014). Reviewing and visualizing the interactions of natural hazards. *Reviews of Geophysics*, *52*(4), 680–722.

Gill, J. C., & Malamud, B. D. (2016). Hazard interactions and interaction networks (cascades) within multi-hazard methodologies, earth syst. *Dynam.*, *7*, 659–679. https://doi.org/10.5194/esd-7-659-2016

Kappes, M. S., Keiler, M., Elverfeldt, K. von, & Glade, T. (2012). Challenges of analyzing multi-hazard risk: A review. *Natural Hazards*, *64*, 1925–1958.

Kappes, M. S., Papathoma-Koehle, M., & Keiler, M. (2012). Assessing physical vulnerability for multi-hazards using an indicator-based methodology. *Applied Geography*, *32*(2), 577–590.

Mignan, A., Wiemer, S., & Giardini, D. (2014). The quantification of low-probability–high-consequences events: Part i - a generic multi-risk approach. *Natural Hazards*, *73*, 1999–2022.

Rosendahl Appelquist, L., & Halsnæs, K. (2015). The coastal hazard wheel system for coastal multi-hazard assessment & management in a changing climate. *Journal of Coastal Conservation*, *19*, 157–179.

Tilloy, A., Malamud, B. D., Winter, H., & Joly-Laugel, A. (2019). A review of quantification methodologies for multi-hazard interrelationships. *Earth-Science Reviews*, *196*, 102881.

UNDRR. (2017). Terminology for disaster risk reduction. *UNDRR, Geneva, Switzerland*, *19*, 2023. https://www.undrr.org/terminology

Ward, P. J., Daniell, J., Duncan, M., Dunne, A., Hananel, C., Hochrainer-Stigler, S., Tijssen, A., Torresan, S., Ciurean, R., Gill, J., & Sillmann, J. (2022). Invited perspectives: A research agenda towards disaster risk management pathways in multi-(hazard-)risk assessment. *Natural Hazards and Earth System Science*, *22*(4), 1487–1497.

Winson, A. E. G., Jordan, C. J., Garcia-Bajo, M., & Smith, K. B. (2020). *METEOR : Methods for analysing multi-hazards with exposure*. Report M6.2/P. Nottingham, UK, British Geological Survey, 52pp. (OR/20/074) (Unpublished). J.: Where are we with multihazards, multirisks assessment capacities?, in: Science for disaster risk management 2017: knowing better; losing less, edited by: Poljansek, K., Marin Ferrer, M., De Groeve, T.,; Clark, I., European Union, Brussels, Belgium, https://drmkc.jrc.ec.europa.eu/knowledge/science-for-drm/science-for-disaster-risk-management-2017 (last access: 19 July 2023), 2017. https://nora.nerc.ac.uk/id/eprint/535120/Zschau

Zschau, J. (2017). *Where are we with multihazards, multirisks assessment capacities? In: Science for disaster risk management 2017: Knowing better and losing less, edited by: Poljansek, k., marin ferrer, m., de groeve, t., and clark, i., european union, brussels, belgium, https://drmkc.jrc.ec.europa.eu/knowledge/ science-for-drm/science-for-disaster-risk-management-2017 (last access: 19 july 2023), 2017.*