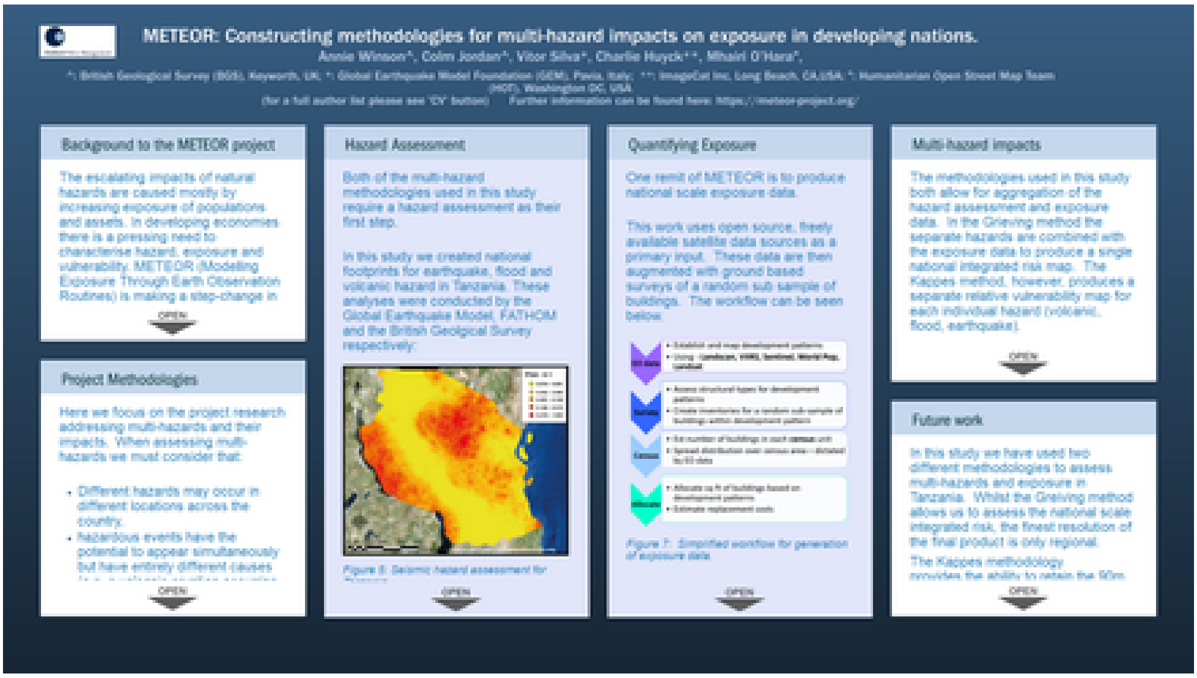
METEOR: Constructing methodologies for multi-hazard impacts on exposure in developing nations.



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PRESENTED AT:

BACKGROUND TO THE METEOR PROJECT

The escalating impacts of natural hazards are caused mostly by increasing exposure of populations and assets. In developing economies there is a pressing need to characterise hazard, exposure and vulnerability. METEOR (Modelling Exposure Through Earth Observation Routines) is making a step-change in the application of coEarth Observation exposure data by co-developing and co-delivering rigorous and open routines (protocols) and standards to allow quantitative assessment of exposure, with explicit uncertainties. These exposure protocols and standards are being co-developed and validated in Nepal and Tanzania to assure that they are fit-for-purpose.

Here, for Tanzania, we present a comparison of semi-quantitative and qualitative approaches for assessing the impact of multi-hazards on exposure, grounded in earth observation data, in the context of data paucity and high levels of inherent uncertainty.

The aim of this quantitative assessment is to support Disaster Risk Management (DRM) decisions and increase resilience. Our partners in Tanzania include the Disaster Management Department (Prime Minister's Office), Oxford Policy Management, OpenMap Development - Tanzania, with expert input from The Geological Survey of Tanzania, the Tanzania Meteorological Authority and UDSM amongst others.

Figure 1: METEOR's Theory of Change - this framework shows the planned progression of the work from the METEOR project from Outputs to Impacts. These Impacts are aligned with SDGs 1 (No Poverty), 11 (Sustainable Cities and Communities), 13 (Climate Action) and 17(Partnerships for the Goals).

PROJECT METHODOLOGIES

Here we focus on the project research addressing multi-hazards and their impacts.
When assessing multi-hazards we must consider that:

- Different hazards may occur in different locations across the country,
- hazardous events have the potential to appear simultaneously but have entirely different causes (e.g. a volcanic eruption occurring at the same time as a drought) and
- Hazards may trigger each other (cascading hazards)

Many multi-hazard mapping approaches focus on the frequency of events and use historical dollar losses as a proxy for infrastructure impact or exposure. Due to the limited data inventories this approach was not possible in this study. As a consequence we tested two semi-quantitative approaches to assess the impact on the resulting multi-hazard maps.

The approaches tested here are outlined in: Greiving et al., 2006 and Kappes et al., 2012.

Greiving Methodology

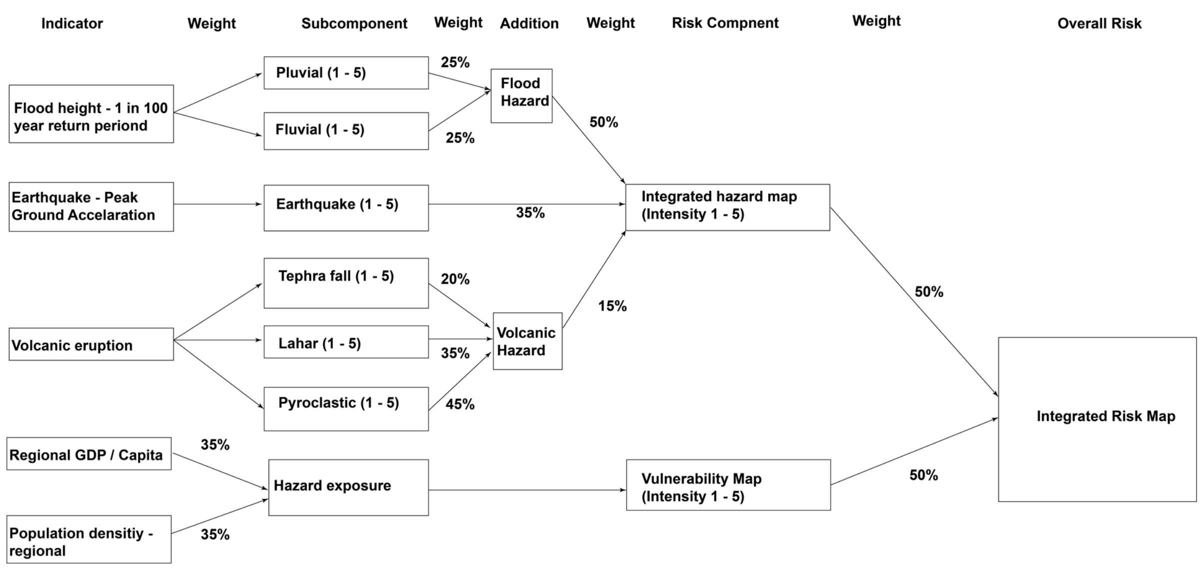

Figure 2: After Greiving et al's methodology and adapted for this study - comprised of 4 components. 1) Hazard maps: separate hazard map for each spatially relevant hazard showing intensity, 2) Integrated hazard map: Showing combined hazard potential, 3) Vulnerability map: Economic and social data showing overall vulnerability of each region, 4) Integrated risk map: hazard and vulnerability maps are combined to produce an integrated risk map.

Greiving et al. relate vulnerability to regional GDP and Population density. This approach leads to one integrated risk map as its final product.

Kappes Methodology

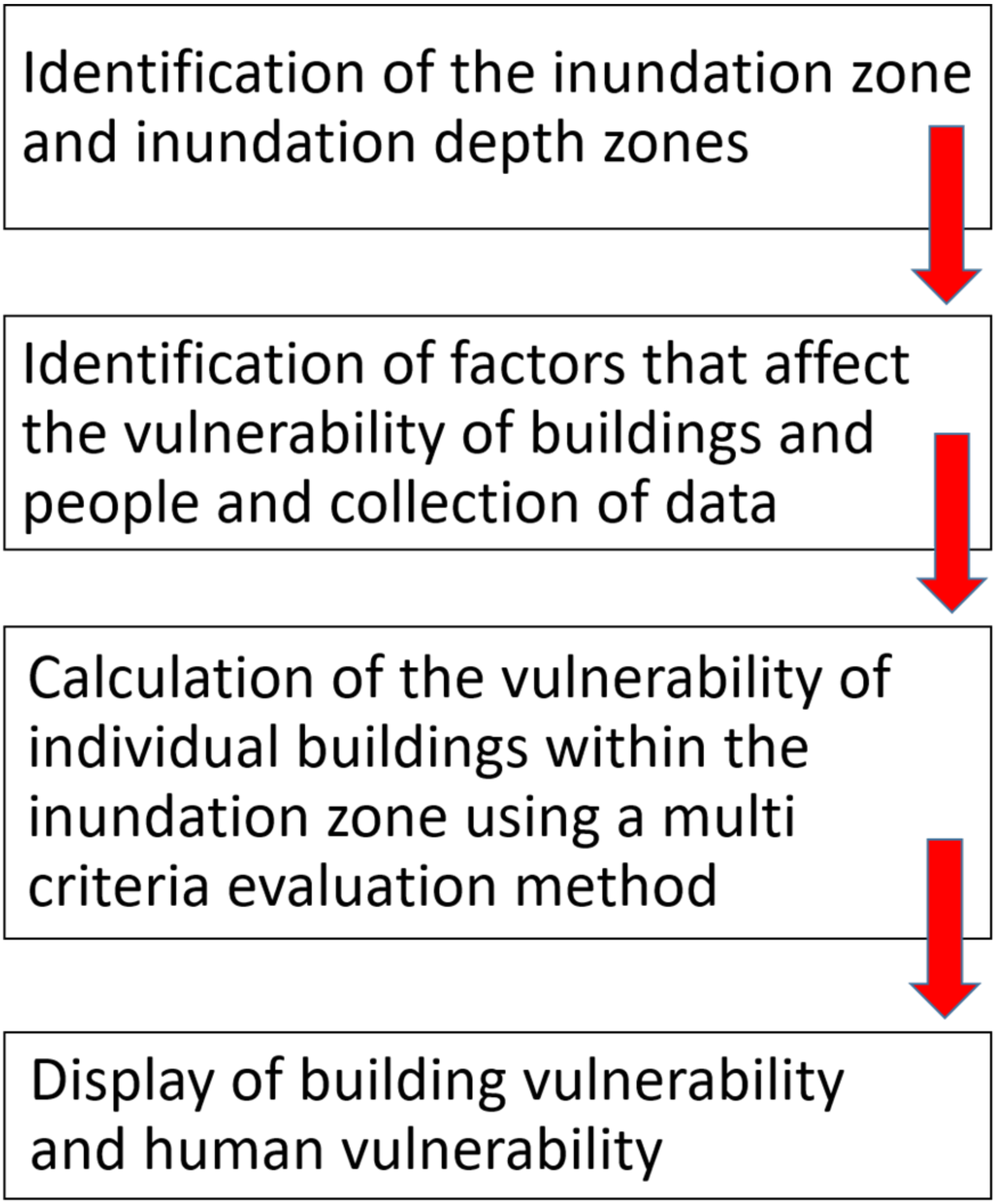

Figure 3: Kappes et al's methodology detailing: 1) The production of hazard maps, 2) the determination of exposure indicators, 3) the weighting of indicators, the effect of hazard interactions on overall vulnerability.

This methodology was originally designed for local scale assessments, where physical building surveys could be conducted and so has been adapted slightly for this national study.

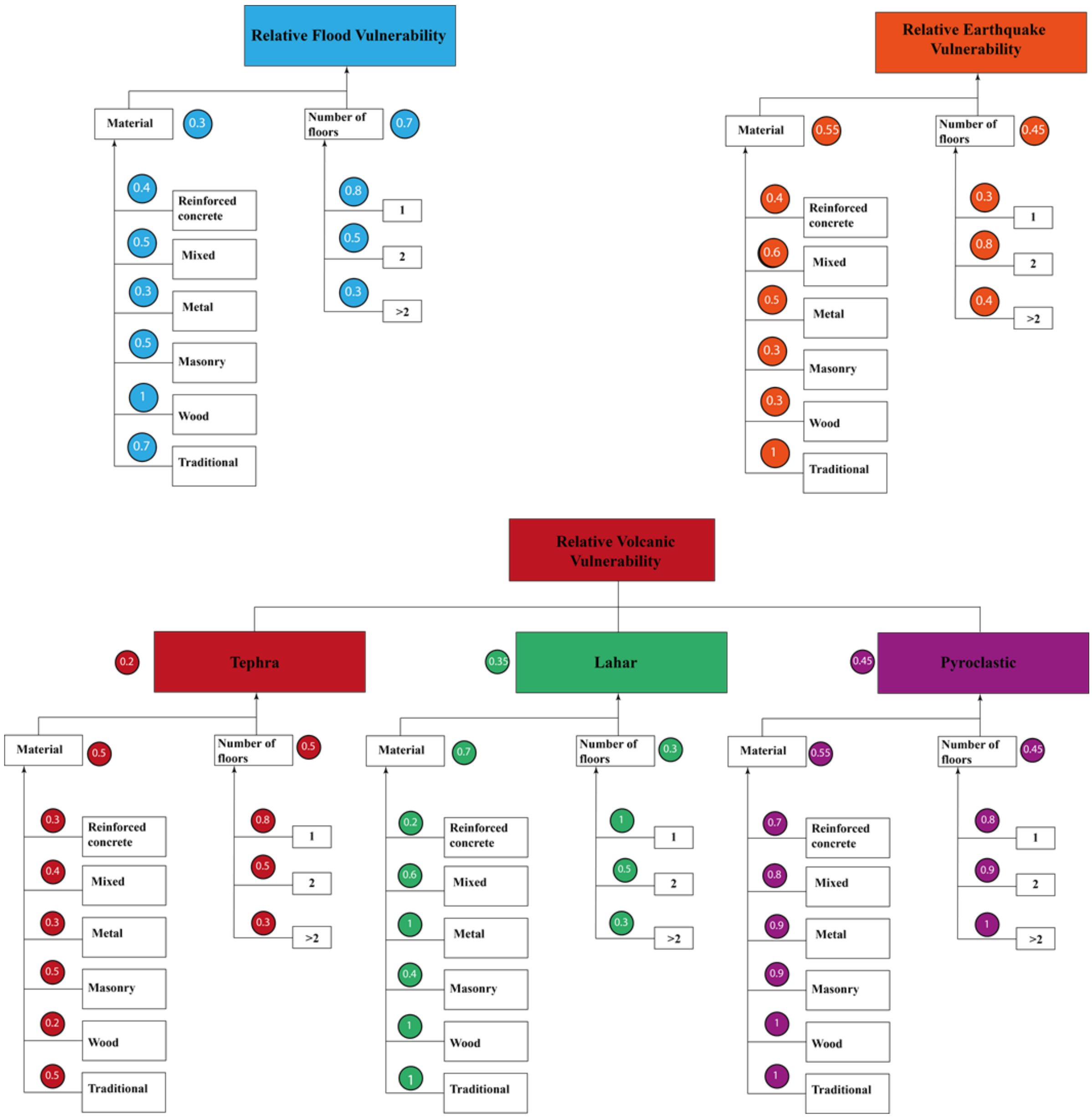

Figure 4: The frameworks for assessing each individual hazard are described above, the exposure factors considered in this study are limited to: Building material and number of floors.

This approach leads to 3 seperate outputs for each hazard.

Both the Greiving et al. and the Kappes et al. methodologies require that weighting factors be assigned at various stages of the analysis - the weights used in this study were derived through expert consultation and use of fragility curves and are described in the table below.

Hazard	Pluvial	Fluvial	Tephra	Lahar	Pyroclastic	Earthquake
	0.25	0.25	0.03	0.0525	0.0675	0.35
Indicator – Material	0.2	0.2	0.5	0.7	0.55	0.55
Reinforced Concrete	0.4	0.4	0.3	0.2	0.7	0.4
Mixed	0.5	0.5	0.4	0.6	0.8	0.6
Metal	0.3	0.3	0.3	1	0.9	0.5
Masonry	0.5	0.5	0.5	0.4	0.9	0.3
Wood	1	1	0.2	1	1	0.3
Traditional	0.7	0.7	0.6	1	1	1
Indicator – Number of floors	0.7	0.7	0.5	0.3	0.45	0.45
1	0.8	0.8	1	1	0.8	0.3
2	0.5	0.5	0.5	0.5	0.9	0.8
>2	0.3	0.3	0.3	0.3	1	0.4

Table 1: Weighting factors for data aggregation.

HAZARD ASSESSMENT

Both of the multi-hazard methodologies used in this study require a hazard assessment as their first step.

In this study we created national footprints for earthquake, flood and volcanic hazard in Tanzania. These analyses were conducted by the Global Earthquake Model, FATHOM and the British Geolgical Survey respectively:

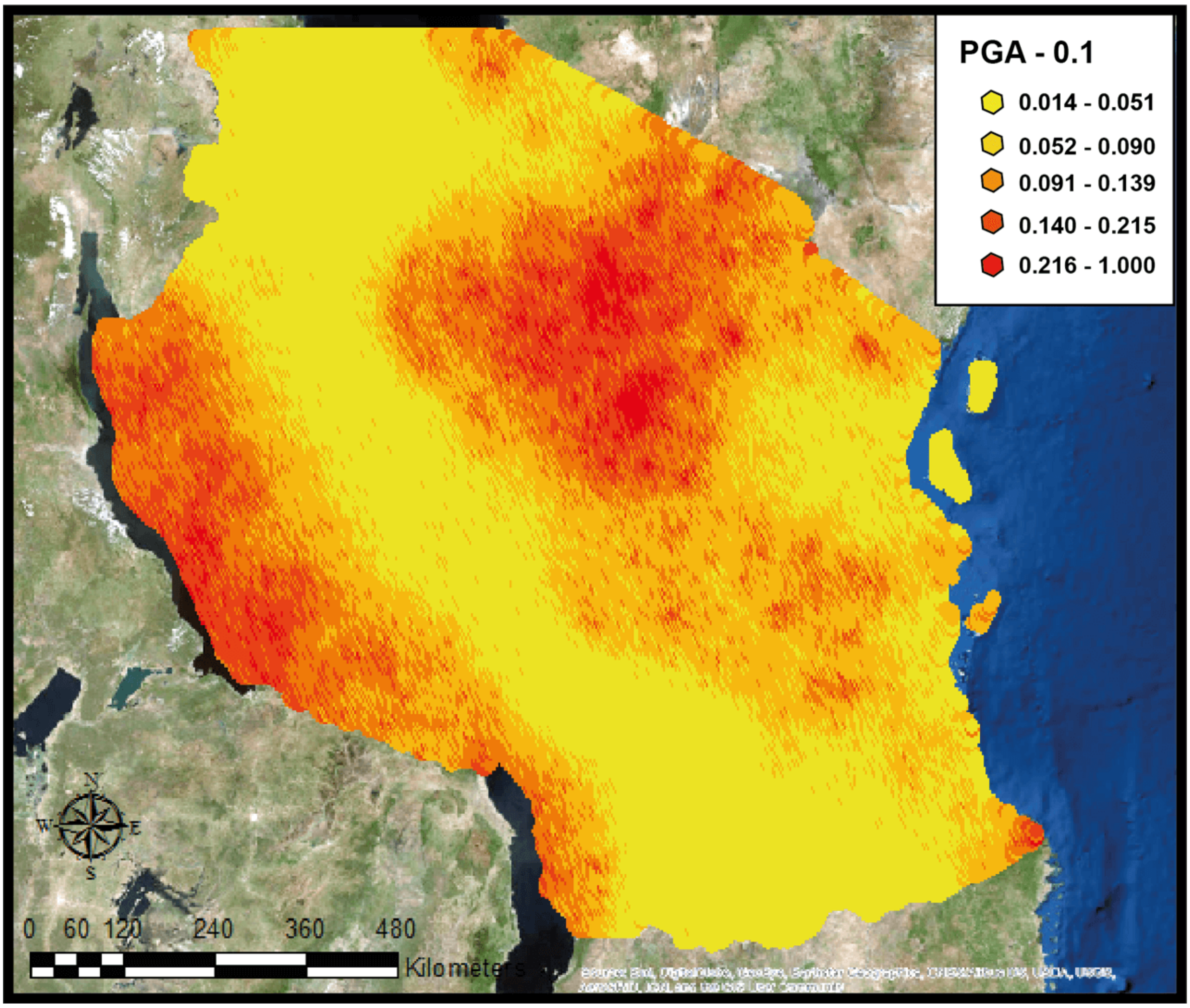

Figure 5: Seismic hazard assessment for Tanzania.

Figure 5 shows the peak ground acceleration values due to earthquake ground shaking in Tanzania with a 10% probability of exceedance in 50 years.

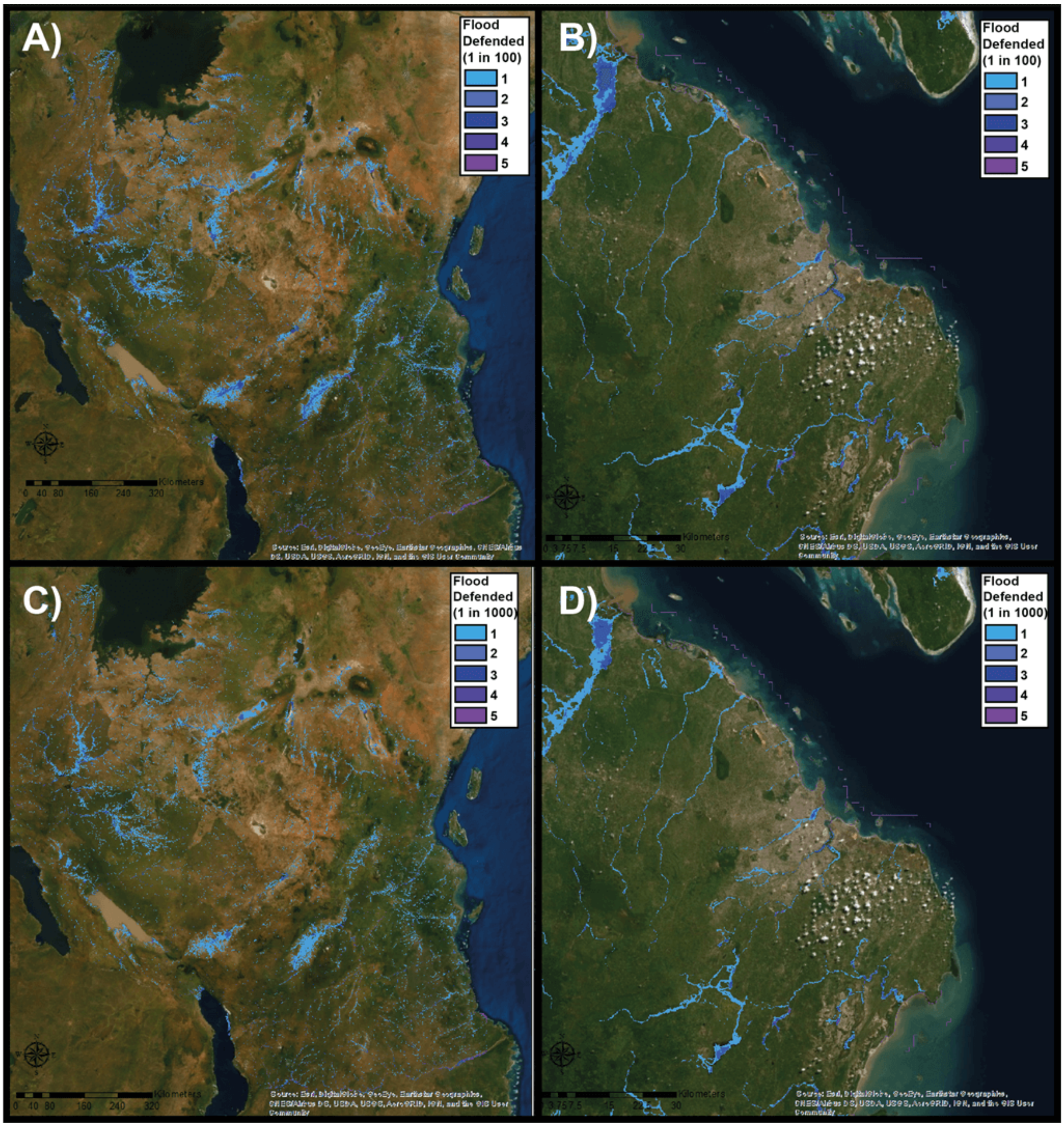

Figure 6: Fluvial flood hazard for Tanzania (images A and C) and Dar es Salaam (images B and D) for return periods of 1 in 100 years and 1 in 1000 years.

A total of 48 flood models have been produced for the METEOR project for: return periods ranging from 1 in 5 to 1 in 1000, fluvial and pluvial flooding and well as 'undefended' flooding. These models follow the methodologies laid out in Sampson et al., 2015.

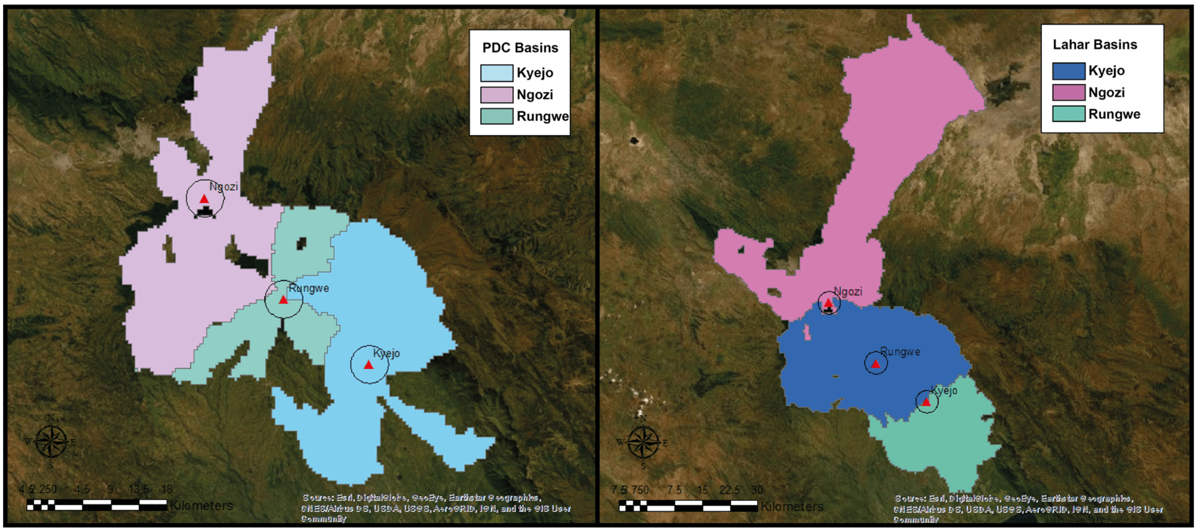

Figure 7: Volcanic pyroclastic flow and lahar hazard for Tanzanian volcanoes.

The volcanic history in Tanzania is relatively incomplete. As a consequence it has not been possible to model pyroclastic and lahar hazard informed by field studies on existing deposits. Instead we have performed a topographic basin analysis that assumes a maximum credible run out distance for both of these hazards.

Ash fall hazard was modeled for one eruption scenario at Rungwe volcano but at this time credible values for modeling at other volcanoes could not be determined.

QUANTIFYING EXPOSURE

One remit of METEOR is to produce national scale exposure data.

This work uses open source, freely available satellite data sources as a primary input. These data are then augmented with ground based surveys of a random sub sample of buildings. The workflow can be seen below.

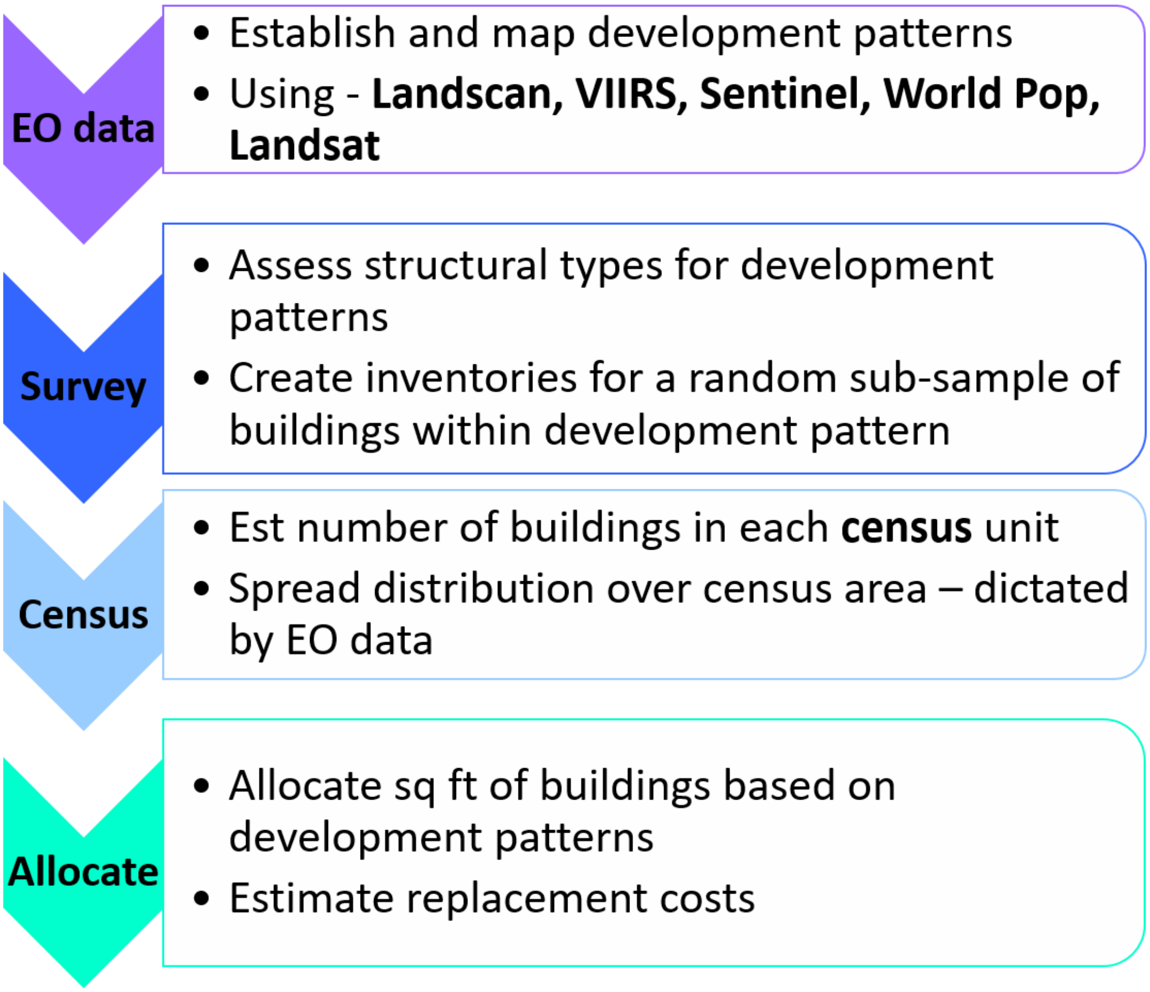

Figure 7: Simplified workflow for generation of exposure data.

This produces data at 90m resolution.

The main sources of uncertainty are:

1) the census data,

2) average number of people per building and

3) the rebuilding costs.

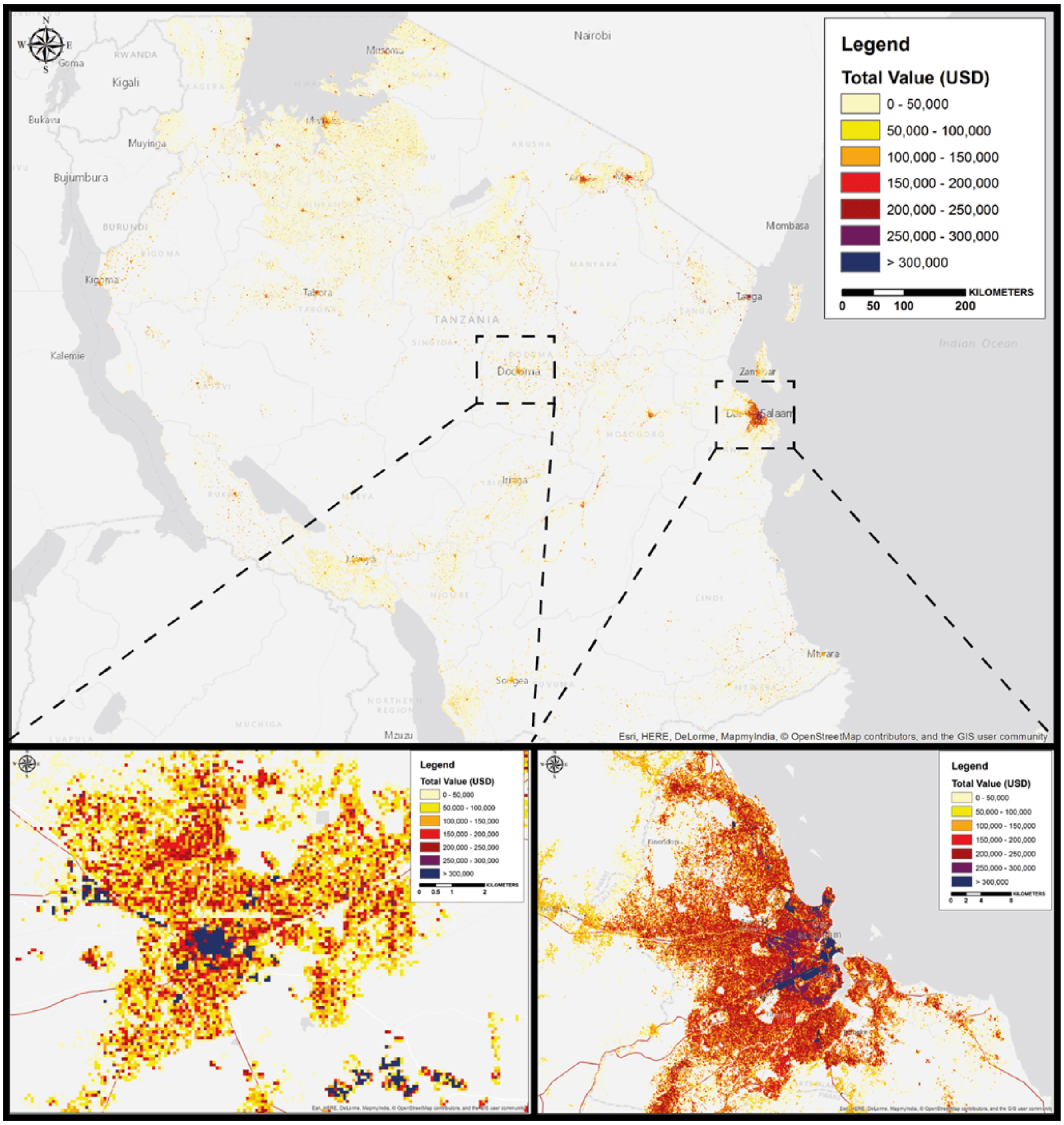

Figure 10: Total Value of buildings (USD) – highlighting Dar es Salaam and Dodoma.

The building classes defined in this exposure analysis allow us to infer the likely building material and number of floors in buildings of specific types. This information is tied to fragility curves that are hazard specific and therefore allow for these different criteria to be weighted in the Kappes et al. analysis.

(Further details will be discussed by Shubharoop Ghosh: IN43B-05: Addressing the disaster risk reduction needs of end users in emerging countries using Earth Observation (EO) data and innovative risk products as a part of the "Modelling Exposure through Earth Observation Routines (METEOR)" project. 12/12/19. Moscone West - 2020)

MULTI-HAZARD IMPACTS

The methodologies used in this study both allow for aggregation of the hazard assessment and exposure data. In the Grieving method the separate hazards are combined with the exposure data to produce a single national integrated risk map. The Kappes method, however, produces a separate relative vulnerability map for each individual hazard (volcanic, flood, earthquake).

The results of these two aggregation methods are shown below.

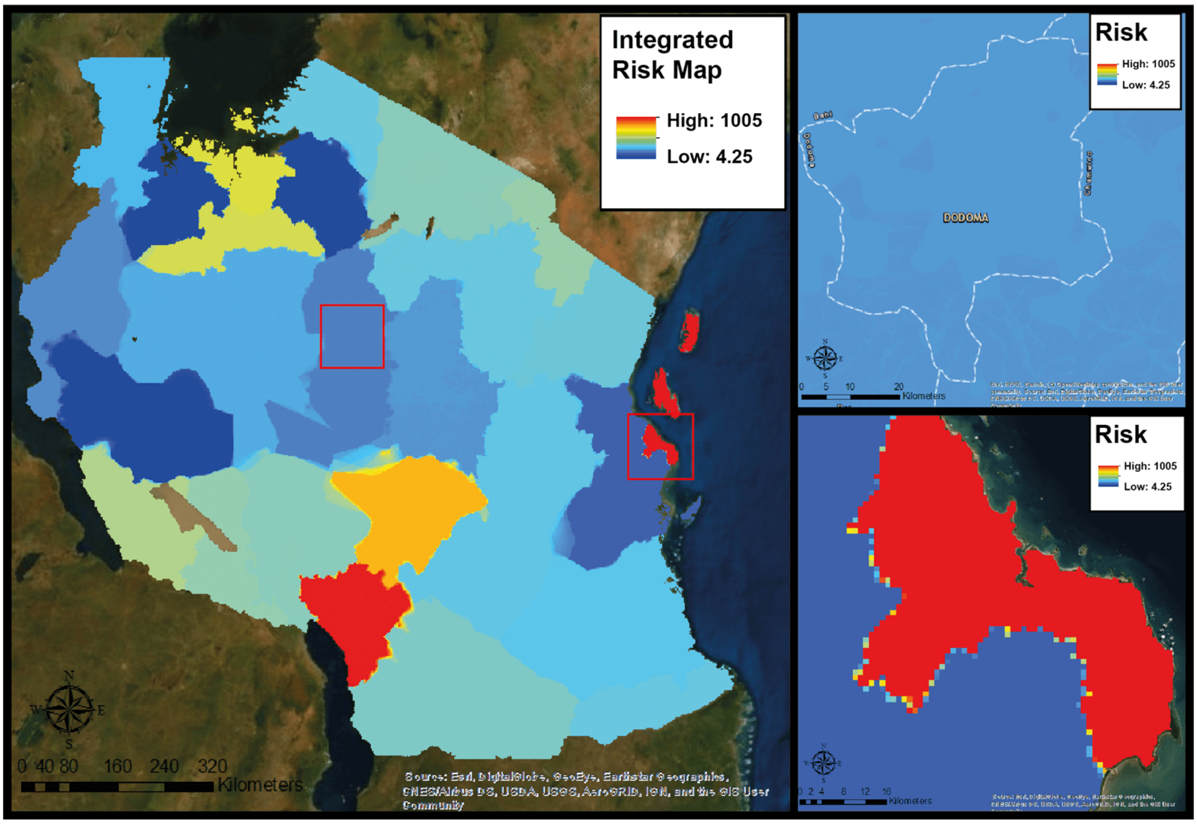

Figure 11: Integrated risk map, produced following Greiving et al., 2006.

The Greiving et al. methodology identifies the highest risk regions in Tanzania as: Dar es Salaam, Iringa, Mwanza, Njombe, and Shinyanga. These are not regions associated with particularly high hazard for any of the multi-hazards addressed in this study (see hazard assessments). These regions do have, however, some of the highest Regional GDP per capita in the country (Iringa, Shinyanga and Dar es Salaam being the top 3). This suggests that the financial exposure component of this analysis may be a controlling factor.

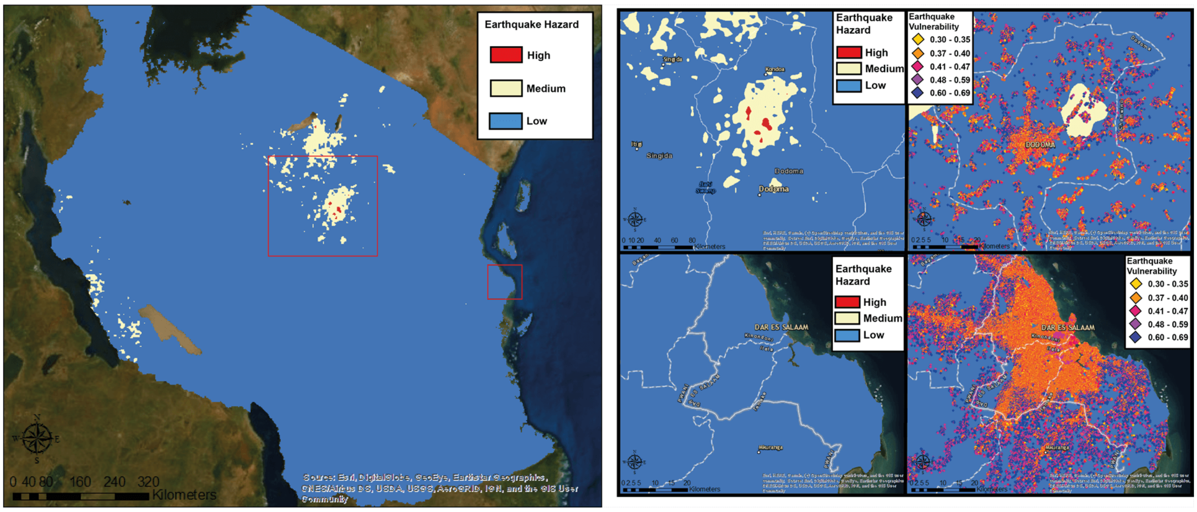

Figure 12: Earthquake hazard and vulnerability for Tanzania, with focus on Dar es Salaam and Dodoma. These relative vulnerability maps were produced by following Kappes et al., 2012.

The highest earthquake hazard areas in this analysis highlight the East African Rist valley. This means that Dar es Salaam is categorized as low risk but areas of Dodoma, where the capital has moved to is medium to high risk. When we assess the vulnerability of buildings in Dar es Salaam to seismic hazard, it appears that areas on the edges of the city have higher vulnerability. Similarly in Dodoma building on the periphery of the of the main urban areas have higher vulnerability.

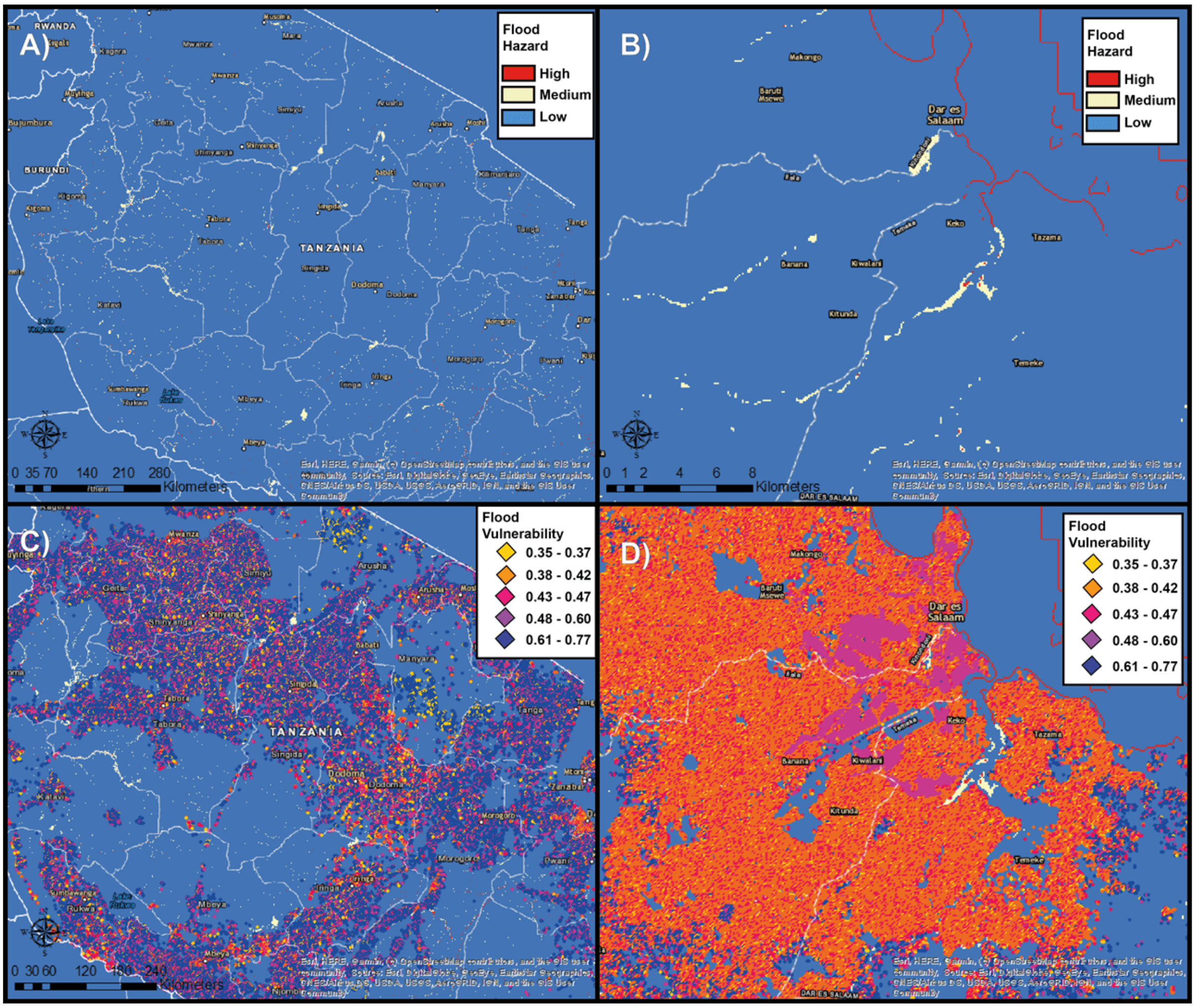

Figure 13: Flood hazard in A) Tanzania, B) Dar es Salaam and Flood vulnerability in C) Tanzania and D) Dar es Salaam. This flood hazard map was calculated for a 1 in 100 year event. This analysis takes into account existing flood defenses.

Flooding in Tanzania is a persistent hazard with large events occurring frequently. When assessing the building stock vulnerability to flooding in Tanzania we see high vulnerability in many regions including: Geita, Shinyanga, Iringa, Dar es Salaam, Rukwa and others. This suggests that for larger events much of the country could be considered vulnerable. Whilst GDP per capita is not included in this analysis, it is important to note that some of these regions do have high economic output tied to industries vulnerable to flood events. Iringa, for example, has a strong agricultural industry that could be heavily impacted by flooding.

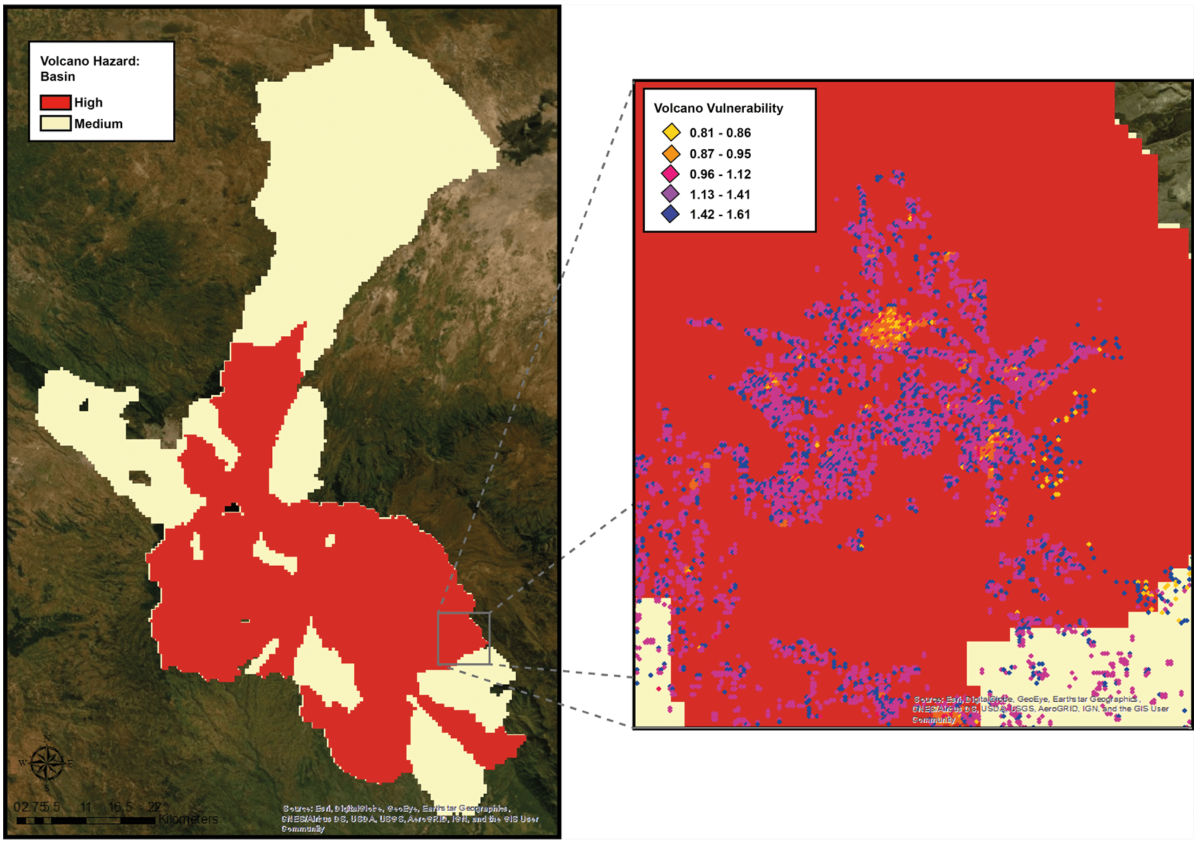

Figure 14: Volcanic hazard and vulnerability around Rungwe, Ngozi and Kyejo - following the Kappes methodology

Due to the available data regarding Tanzanian volcanoes it was only possible to assess the pyroclastic and lahar basins.

The high hazard zones in this analysis can be assumed to be areas where there could be impact from pyroclastic flows and lahars whereas the medium hazard zones are areas that could only be impacted by lahars. These phenomena are highly destructive and as a consequence the vulnerability of buildings in these areas is generally high.

FUTURE WORK

In this study we have used two different methodologies to assess multi-hazards and exposure in Tanzania. Whilst the Greiving method allows us to assess the national scale integrated risk, the finest resolution of the final product is only regional.

The Kappes methodology provides the ability to retain the 90m resolution of the original data and therefore produces greater detail for assessing exposure. This method, however, generates unique outputs for each hazard and it is therefore not possible to assess the integrated multi-hazard risk. We therefore propose an hybrid of these two models presented here.

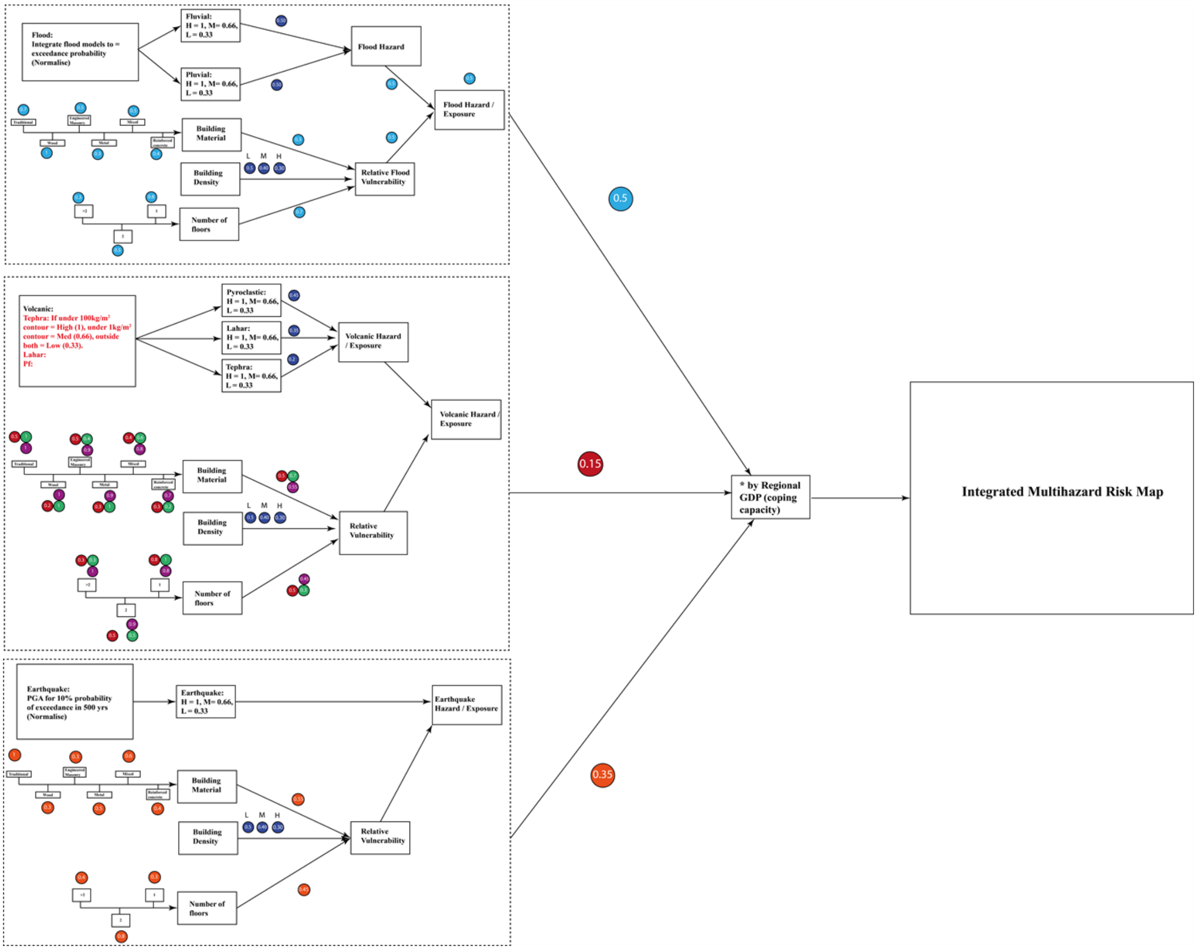

Figure 15: Hybrid model for an Integrated Multi-hazard Risk Map for Tanzania.

Future work will focus on aggregating the data from METEOR within this framework. We will test this network with available average annual loss data to assess its use in forecasting potential losses from future events.

The work outlined here addresses multi-hazards in a spatial context. Future work will also need to address more of the temporal hazard connections - such as cascading hazards.

Flooding (1.1)	Flooding can increase erosion in river valleys and increase slope instability (1.2) (Siwauli lanslide - Dadu River)	No Interaction (1.3)	No Interaction (1.4)
Landslides can cut of the natural flow of rivers, causing damming of water courses and consequential rapid outburst (2.1) (Usoi Dam)	Landslide (2.2)	No Interaction (2.3)	Sector collapse can cause unroofing of magmatic bodies (cryptodomes), leading to rapid destabilisation and eruption. (2.4) (Mt St Helens)
Seismic activity can offset rivers causing flooding (3.1) (Hawkes Bay - Tutaekuri River)	Seismic motion can cause landslides (3.2)(Gorkha earthquake)	Earthquake (3.3)	In some rare cases regional seismictiy can trigger volcanic eruptions (3.4) (Cordon Caulle, Mt Fuji)
Crater lakes can be disrupted in eruptions, leading to wide spread flooding (4.1) (Tarawera - OVC)	Increased volcanic activity can destabilise the volcanic edific and lead to sector collapse / mass movements (4.2) (Krakatau)	Volcanic unrest periods can cause distal and promixal earthquakes (4.3) (Santa Maria (?), Pinatubo)	Volcano (4.4)

Figure 16: Cascading hazard matrix demonstrating potential hazard interactions in the METEOR project.

Further details about the METEOR project can be found at: https://meteor-project.org/

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ABSTRACT

The escalating impacts of natural hazards are caused mostly by increasing exposure of populations and assets. In developing economies there is a pressing need to characterise hazard, exposure and vulnerability to allow for comprehensive Disaster Risk Management (DRM) plans and pre-positioning. METEOR (Modelling Exposure Through Earth Observation Routines) is making a step-change in the application of Earth Observation exposure data by co-developing and co-delivering rigorous and open routines (protocols) and standards to allow quantitative assessment of exposure, with explicit uncertainties. These exposure protocols and standards are being developed and validated in Nepal and Tanzania to assure that they are fit-for-purpose.

As part of the METEOR process we are also co-developing methodologies to produce and integrate national scale hazard susceptibility footprints (landslide, flood, earthquake and volcano), exposure data and vulnerability / fragility assessments to address the multi-hazard impacts to which these nations are susceptible. Many multi-hazard mapping approaches focus on the frequency of events and use historical financial losses as a proxy for infrastructure impact or exposure (Bell and Glade, 2004: Tate et al., 2010: Schmidt et al., 2011: Kappes et al., 2012). Whilst such approaches may be appropriate for hazards with good records of the distribution and scale of events, for others estimation of key factors such as historic frequency, or probability of occurrence or losses, is much more complex.

Here we will present a comparison of semi-quantitative and qualitative approaches for assessing the impact of multi-hazards on exposure, grounded in earth observation data, in the context of data paucity and high levels of inherent uncertainty. We explore a subset of the METEOR data to discuss the relative merits of these differing approaches in Tanzania and Nepal and assess the main variances in outputs. We use this study to illuminate the areas where earth observation has the greatest positive impact in augmenting data sets to allow for greater DRM in future events.