Transcript: Methods for Modelling Multi-hazards in the METEOR project - Nepal

Slide 3: In this talk on modelling multi-hazard as part of the METEOR project I will cover: the testing of excising multi-hazard models, such as the Greiving and Kappe's models, the use of expert elicitation and weighting, the protocols for modelling the METEOR data and some initial model outputs and outline the sensitivity testing that is still ongoing.

Slide 4: In the previous presentations we have seen how the single hazard footprints and exposure data has been created for the METEOR project. In this presentation I will be describing how we have taken these separate hazard and exposure inputs and created a model that can aggregate them to give us a national multi-hazard map.

In Nepal the single hazards addressed in the METEOR project were: Landslide, Seismic and Flood.

Slide 5: In the Introduction to Multi-hazards slides we looked at how each single hazard exhibits its own characteristics such as time of onset, duration and extent and because of the fact that multi-hazard assessments have to be able to address: hazards may be related to each other, potentially generating hazard cascades, may have different impacts on buildings or infrastructure, have different hazards characteristics and therefore the methods to observe and monitor them. It is important therefore that any of the existing measures of hazard quantification need to be adapted to allow for comparison of multiple hazards.

To explore the best ways to combine the data created by the METEOR project and to develop robust models for analysing multi-hazards with exposure, we have reviewed a collection of the different models that have been designed to address multi-hazards.

Slide 6: Some of these models focus on the frequency of events and use historical dollar losses as a proxy for infrastructure impact or exposure (Bell & Glade, 2004; Tate et al., 2010; Schmidt et al., 2011; Kappes et al., 2012), whilst others are concerned with producing more qualitative results (Meroni et al., 2006, Delmonaco et al., 2007).

For some of the hazards considered in METEOR it may be possible to retrieve information that would satisfy a quantitative model e.g. the origin of an event (earthquake epicentre) and severity descriptors (maximum flood height). For others, the incomplete historic records make it difficult to estimate key factors such as historic frequency, probability of occurrence or losses.

This meant that developing a purely quantitative model for METEOR that allows for the determination of absolute values was not be possible.

Instead, a semi-quantitative model, including the development of indicators, helps to limit the effect of different types of data and the inherent differences in hazard characteristics.

As was discussed in the Introduction to Multi-hazards talk, Indices offer a continuous standardisation of differing, and therefore not directly comparable, parameters and so can be applied to the data collected in this project and allow for its integration.

After reviewing the existing models, two differing methodologies that were deemed most compatible with the data generated by the METEOR project were selected for testing.

The first, proposed by Greiving et al (2006) is designed to be a regional assessment and the second by Kappes et al. (2012a) a more local, town / catchment scale assessment. For the purposes of this methodology testing and development we used the hazard and exposure data for Tanzania because they were more complete than the Nepal data at the time of the analysis.

Slide 7: Greiving et al. (2006) developed an 'Integrated Risk Assessment for Multi- Hazards' method, in which the issue of main concern is risk, which is defined as the product of hazard and vulnerability.

Vulnerability in this assessment is defined as *'the degree of fragility of a system or community towards natural and technological hazards*' and is therefore place specific, integrating hazard, exposure and the coping capacity of different regions.

They consider three types of hazard exposure: 1) Economic – any factors that can affect the economy of a region that can be damaged by an extreme event; 2) Social – assess any factor that might make people more vulnerable (i.e. age, education, etc.); 3) Ecological – ecosystems and their environmental fragility.

This spatial risk assessment framework considers: multi-hazards, hazards with spatial relevance, for example river flooding and volcanic eruptions, but not hazards such as meteorite impacts or collective risks that have the potential to threaten the entire community. The method consists of four key components:

Slide 8: Generation of hazard maps: The aim of these maps is to display the location and intensity of spatially relevant hazards. Where possible this intensity should be representative of the hazards frequency and magnitude. As it is not possible to classify all hazards on the same scale, these maps are classified using an ordinal scale using five related hazard classes. This generates an index for each hazard, which means that they are compared and combined, whilst mitigating the effects of different types of data and varying levels of uncertainty. This figure is a representations of the indices developed for the relevant Tanzania hazards.

Production of an integrated hazard map: All hazard data are compiled into one map showing overall hazard potential. This aggregation is straight forward as all of the maps display the hazard potential as a 1 – 5 index. It is possible, however, that some hazards are considered as more important than others. In this case it is possible to weight the hazards contributions to the final aggregation. Greiving (2006) suggests using the Delphi method of expert elicitation to define these weights. In this METEOR example, the hazard potential is assigned, weighted and aggregated at the pixel scale.

Vulnerability Map: Any available information concerning social and economic vulnerability is combined to create a map showing the overall vulnerability of each region. In this model, the exposure of infrastructure, buildings and production capacity are all defined by the regional GDP and the human damage potential is defined by the population density. We have not assessed the possible impacts on the ecosystem in METEOR, as it is not within the scope of this project.

Integrated risk map: The hazard and vulnerability maps are integrated to produce a map that shows the integrated risk each region is exposed to. This allows for the user to differentiate between areas that are simply hazardous and those areas that are risky due to a higher degree of inherent vulnerability.

This method was chosen as a test methodology for the METEOR project because it can be applied at any geographical scale and for any hazard and because it is fundamentally concerned with multi-hazards.

Slide 9: The method designed by Kappes et al. (2012) is an indicator–based vulnerability method that builds on the Papathoma Tsunami Vulnerability Assessment (PTVA) and adapts it for a multi-hazard context. It is a GIS-based method that assesses hazard-specific physical vulnerability, by selecting element characteristics that may be indicative of vulnerability. Vulnerability is considered as physical vulnerability of buildings, it does not take into account socio-economic indicators of vulnerability.

This methodology was developed to be used at local / regional scales – coupled with field studies of building damage data, which may limit its applicability to national surveys. This method was chosen as the second test methodology for the METEOR project because of its capacity to develop relative hazard vulnerability in a semi-quantitative manner at a variety of scales.

The simplified work flow for this model can been seen here.

The first step is to identify the relevant hazards for the study area and develop the relative hazard information – in this case the hazards defined by the METEOR project.

The second step is the identification of factors that affect the vulnerability of buildings. This figure shows how indicators can be organised and weighted to create a Relative Vulnerability Index. In METEOR the factors that have been assessed are controlled by the input exposure data that was produced by ImageCat. The factors that are available and comparable across the hazards included in the METEOR project are: the building materials, and the number of floors in each building. These vulnerability indicators selected need to be considered for each hazard individually. In the methodology defined by Kappes (2012

) the surroundings of the buildings are included in the assessment, for example the role of land cover and neighbouring buildings. As the METEOR project is producing relative vulnerability on a national scale, it has not been possible to include this component of the analysis.

For each indicator a weight is defined that reflects the relationship between the indicator and the hazard. This is an example of how the hazards from the METEOR project were included in this matrix.

In this study these weights were defined using a combination of fragility curves (when available), harvesting of literature where these figures were available and expert elicitation within the METEOR consortium.

Once these weights are defined, the Kappes method applies a weighted linear combination technique. This produces a Relative Vulnerability Index (RVI) that is not dependant on the hazard intensity but instead reflects the relative vulnerability for each building for different hazards.

Slide 10: The final stage of the Kappes method makes an assessment to understand the inter-relationships between the hazards in this study by means of creating a hazards matrix. The hazard matrix shown here is an example of a matrix that could be constructed for the METEOR project in Nepal. The user can read the matrix either left to right or right to left, starting at the blue boxes depending on which hazard interactions they want to consider. The red box here shows the impact of a landslide on increasing the flood potential of a region, for example (by reading the matrix left to right).   The yellow box highlights the possible effect an earthquake could have on making a building more vulnerable to landslides (reading the matrix from right to left).

Slide 11: To produce an integrated hazard index (including all relevant outputs) there must be an understanding of how hazard and vulnerability indicators interact with each other and what their relative weights are in the subsequent index. A summation of indicator scores per pixel would allow for a straightforward analysis, but it seems a more appropriate method would allow for these different components to be weighted differently, reflecting their relative severities or their frequencies relative to each other. These weights can be determined either using expert elicitation or statistically by weighted linear combination models – or a combination of both.

Both of the methods tested in this analysis require some component of expert elicitation (Aspinall et al., 2013). This allows for the users to define the rankings of hazards relative to each other and therefore their subsequent weighting in the resulting index. Where possible these have been underpinned by tools such as fragility curves and inventories of data. However, not all of the hazards considered in this analysis have complete historic inventories, making constructing frequency / magnitude distributions complicated. Expert elicitation allows for users to draw on experience from other locations and make a best estimate of the likely relationships between hazards and vulnerability indicators. The weights defined in this table have been solicited from experts in the METEOR consortium and were used in testing both methodologies.

Slide 12: The highest risk areas identified in the Greiving methodology are not linked with particularly high hazard for any of the hazards that are addressed in the METEOR project, instead the outcome highlights the regions associated with the highest Regional GDP per capita in the country (Iringa, Shinyanga and Dar es Salaam being the top 3). This suggests of course, that the factor controlling the risk in this analysis is the financial exposure component of this analysis. Whilst this is perhaps not surprising, it is potentially misleading. As the Greiving method produces a regional output it is not possible to disaggregate which parts of these regions are driving the higher risk scores.

Slide 13: The Kappes methodology in contrast produces a separate output for each hazard at compatible scales. Here is an example of the relative vulnerability map for seismic hazard. On the left side of the image is the simplified earthquake hazards map and on the right there are inserts for the regions around both Dodoma and Dar es Salaam.

The highest earthquake hazard areas in this analysis highlight the East African Rift valley. This means that Dar es Salaam is categorised 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, buildings on the periphery of the main urban areas have higher vulnerability. On reviewing the building information in this location, it appears that these regions have a higher proportion of traditional, unreinforced and wooden buildings than some of the areas closer to the city centre. It therefore follows that this analysis is correctly identifying areas where property is less likely to have been designed or retrofitted to withstand earthquakes.

Slide 14: In this test study we 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 developed a model that is a hybrid of the two presented here.

Slide 15: The initial step in this new METEOR model is very similar to the Kappes method as it produces a 'relative' hazard vulnerability map. For the purposes of this example, the steps necessary to produce a relative flood vulnerability map are shown here. This process is broadly the same for each hazard, in this example I am showing the process for flood hazard.

Firstly, Each data point from the hazard assessment is normalised and then converted to a classified floodvalue.

After this the Flood Index value per pixel is multiplied by the sum of the weighted percentage of each building type in that pixel (as a function of the total number of buildings per pixel). (Fluvial Flood Index * ((%Bld1 * BldW1) + (%Bld2* BldW2) + (%Bld3* BldW3) +…….))

If there is more than one output for a specific hazard (i.e. fluvial and pluvial flooding), these outputs are then weighted either through expert elicitation or, if necessary to reflect a frequency analysis of the hazard events and combined to produce a relative vulnerability map for that hazard, in this case flood.

Slide 16: Once the individual hazard vulnerability maps have been produced they can be weighted independently, combined and normalised (i.e. values are set to between 0 and 1) to create a national scale multi-hazard 'risk' map, like this weighted multi-hazard map of Nepal. These first results from the METEOR multi-hazard model highlight differences between Kathmandu and the rest of the country, the reasons for which need to be investigated further.

In creating this model we aimed to develop a pragmatic approach to integrate data sets that differ widely from each other. However, combining data, that has been generated by different processes, incorporates uncertainty into the model. We intend to review these final model outputs, as well as the relative vulnerability index as part of the final deliverables of the

METEOR project, where we will also perform sensitivity analysis to explore the effect of varying weighting factors on overall results.

Slide 17: The primary aims of our sensitivity analysis, is to examine the effects of varying model parameters on the final outputs of the model. By varying one model parameter at a time in a systematic way we are able to observe how a small change in a parameter can generate a larger change on the model outputs, by looking at residuals between the two final products. Assessing the difference in these outputs will allow us to infer the robustness of the current METEOR model and identify the inputs that have the greatest control on the final outputs. These may be the weights assigned to the exposure data or the threshold values that were assigned when creating the index for the hazard assessment data, for example. The red boxes on this diagram highlight the component of the model where these analyses will focus on.

As I have explained, the weights applied to different exposure categories were derived through a combination of expert elicitation, harvesting from existing literature and reviewing available vulnerability curves, like the one pictured here. They therefore form what we propose is a best estimate of the weights that should be attached to different building criteria and different types of hazard. We aim to validate these weights by comparing them to selected vulnerability curves that can be compared to the specific hazard value at a pixel scale. This will be an extremely computationally expensive process and for initially we will perform this analysis over a small sub-section of the national scale data.

We also plan to assess the impact of varying the hazard assessments and their subsequent weights. To do this we will explore the differences in outputs when the 1 in 10 year and 1 in 1000 year flood hazard data are included (instead of the 1 in 100 year return period). This will provide a sense of what the difference between a 'worst' case and 'best' case outputs are.

When this analysis is complete we will provide updated training material to include these final outputs and findings.

Slide 18: This talk gives an outline of the production of the modelling protocols developed for the METEOR project. Guided by existing literature, we have tested two differing approaches and used these as a basis to develop a model that is aligned with the goals of the METEOR project. We hope to share more information with you about the testing of this model in the coming months.

Slide 19: This is the end of this talk on modelling multi-hazards in the METEOR project, further information on some of the models reviewed as part of this process can be found in these key references. There are also two milestone reports available from the METEOR project that covers this work in detail, they are: M6.2 – Methods for analysing multi-hazards with exposure and M6.3 – METEOR: Draft protocols on hazard and exposure modelling.