Workshop Report: Multi-Hazard Risk Scenarios for Tomorrow's Cities

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1. Introduction

The development and adoption of multi-hazard approaches to disaster risk reduction (DRR) is a core part of the GCRF *Tomorrow's Cities Research Hub* (*Tomorrow's Cities* throughout this report). In this context, we define the terms hazard, multi-hazards, exposure, vulnerability, and disaster risk reduction using the UN Office for Disaster Risk Reduction (UNDRR, 2017) terminology (**Table 1**).

Table 1. Key Definitions

Term	Definition (from UNDRR, 2017)
Hazard	"A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation."
Multi-Hazard	"Multi-hazard means (1) the selection of multiple major hazards that the country faces, and (2) the specific contexts where hazardous events may occur simultaneously, cascadingly or cumulatively over time, and taking into account the potential interrelated effects."
Exposure	"The situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas."
Vulnerability	"The conditions determined by physical, social, economic, and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards."
Disaster Risk Reduction	"Disaster risk reduction is aimed at preventing new and reducing existing disaster risk and managing residual risk, all of which contribute to strengthening resilience and therefore to the achievement of sustainable development."

The *Tomorrow's Cities* project includes an integrating theme of multi-hazards, working with and across the four Hub cities (Istanbul, Kathmandu, Nairobi, and Quito). This multi-hazards integrating theme aims to catalyse multi-hazard thinking, develop an understanding of multi-hazard knowledge and scenarios for each Hub city, understand how these scenarios can inform future urban planning, and collate and share learning both within and beyond the *Tomorrow's Cities* project.

Each of the four focus cities within the *Tomorrow's Cities* Hub is affected by multiple, potentially interrelated, natural hazards. Known case studies also highlight contexts where events may occur simultaneously or consecutively, thus contributing to disaster risk through changes to the hazard landscape, exposure, or vulnerability, during the scenario.

This report summarises the contents and discussions of two 60-minute virtual workshops (30 July 2020, 40 participants; 6 August 2020, 35 participants) delivered by the multi-hazards integrating theme for the *Tomorrow's Cities* consortium. Our aims in this workshop were the following:

- To introduce the multi-hazards integrating theme; and
- To explore the relevance of multi-hazard approaches and scenarios in the *Tomorrow's Cities* project.

Section 2 focuses on the first workshop examining multi-hazard interrelations and scenarios in the four focus cities in *Tomorrow's Cities*. **Sections 3** and **4** focus on the second workshop, discussing multi-hazard scenarios in the context of dynamic risk (**Section 3**) and reducing multi-hazard risk (**Section 4**). In **Section 5**, we offer our overall reflections on emerging themes from the workshops and their relevance to *Tomorrow's Cities*.

2. Multi-Hazard Interrelations in Tomorrow's Cities

2.1. Overview

Workshop 1 (30 July 2020) aimed to create a space for *Tomorrow's Cities* consortium members to identify, share, and reflect on relevant multi-hazard interrelations in each of Istanbul, Kathmandu, Nairobi, and Quito. In the workshop, we acknowledged that a comprehensive multi-hazard framework could include anthropogenic, technological, and financial hazards, but that we would focus on interactions between natural hazards only. During the workshop, participants:

- Explored the range of natural hazards that could affect each of Istanbul, Kathmandu, Nairobi, and Quito.
- Discussed the possible interrelations between each of these hazards.
- Co-created a few simple multi-hazard scenarios for each city, to be used in Workshop 2 to explore dynamic risk concepts.

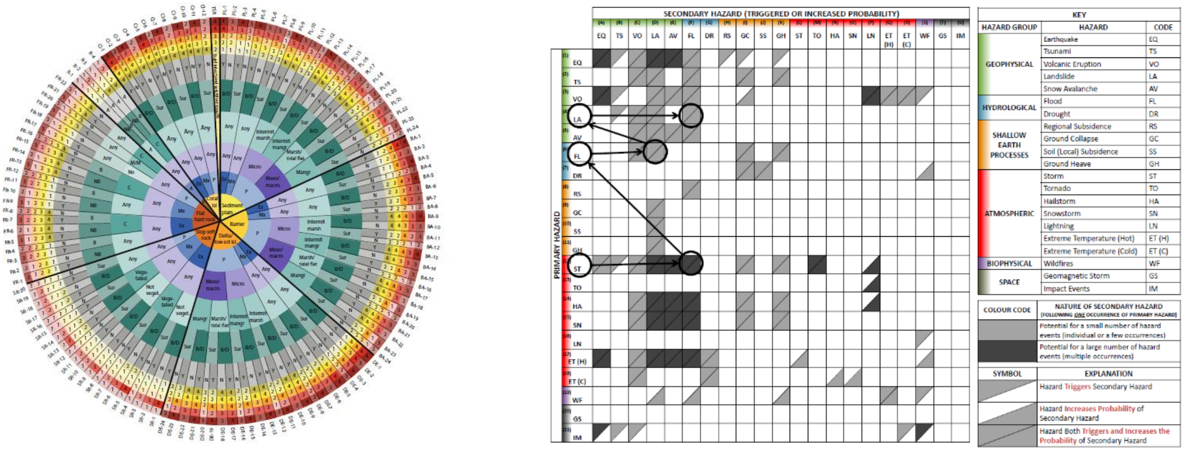
Workshop 1 also included a short presentation on (a) approaches to studying multi-hazards, and (b) why multi-hazard approaches are useful.

Approaches to studying multi-hazards. Ciurean *et al.* (2018) reviewed different approaches to studying multi-hazard interrelationships, including examples and relevant literature of the following:

- narrative descriptions
- hazard wheels (illustrated in **Figure 1a**)
- hazard matrices (illustrated in **Figure 1b**)
- network diagrams
- hazard maps
- hazard and risk indices
- systems-based or physical modelling
- probabilistic and statistical approaches (e.g., fragility functions, scenario trees, expert elicitation, fault tree analysis, life cycle cost assessments, Bayesian networks)

It is beyond this report's scope to describe each approach in detail; we refer readers to Ciurean *et al.* (2018) and other reviews (e.g., Kappes *et al.,* 2012*;* Gill and Malamud, 2014; Tilloy *et al.,* 2019).

Reasons for studying multi-hazards. Treating hazards as being independent can distort management priorities, underestimate risk (e.g., the vulnerability can increase between successive hazards), and result in decision making that increases vulnerability or exposure to other hazards. Understanding multi-hazard dynamics (including multiple relevant single hazards, potential hazard interrelationships, and the impacts of consecutive hazards) helps to understand the dynamic nature of risk and inform risk reduction, planning and response strategies, and actions. This was the focus of Workshop 2 and is discussed in more depth in **Sections 3** and **4**.

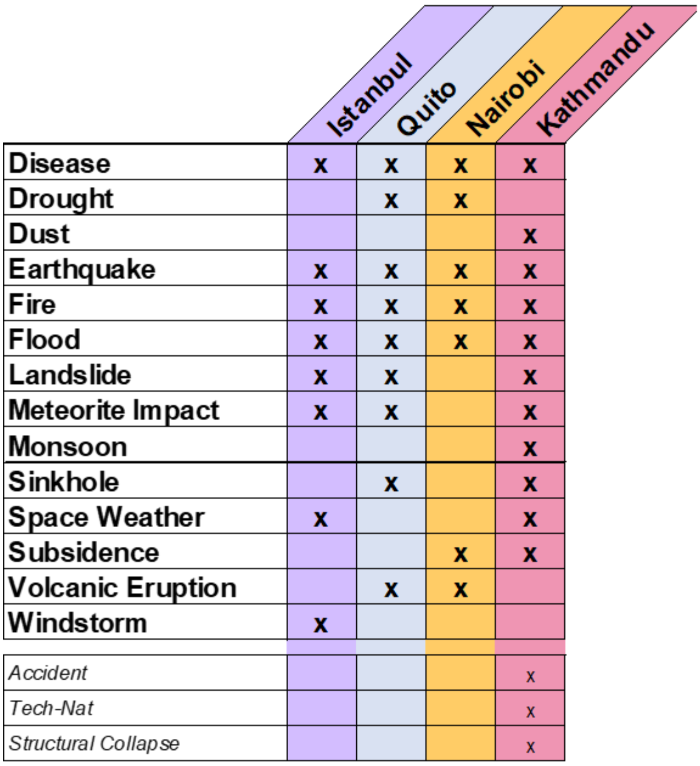


(a) Hazard Wheel **(b) Hazard Matrix**

Figure 1. Different approaches to consider hazard interrelationships. Select examples of approaches to identify potential hazard interrelationships, including (a) hazard wheel (from Appelquist and Halsnæs, 2015) and (b) hazard matrix (from Gill and Malamud, 2014). All images reproduced under the terms of the CC BY 4.0 license (https://creativecommons.org/licenses/by/4.0/legalcode).

2.2. Single Natural Hazards in Hub Cities

There is a range of different single hazards that might impact each of Istanbul, Kathmandu, Quito, and Nairobi. The spatial and temporal footprints of these single hazards vary, and a single hazard does not have to occur in the city to have an impact. For example, a volcanic eruption elsewhere in Ecuador may still affect lives and livelihoods in Quito. In an initial exercise in plenary, we asked participants to list all the possible natural hazards that could affect their chosen city. This exercise was done using an online tool (Padlet) that allowed all participants to see others' contributions in real-time. The responses, set out in **Figure 2**, show the diverse range of natural hazards that could impact each city, including those from geophysical, hydrological, and climatological origins.



	Istanbul	Quito	Nairobi	Kathmandu
Disease	x	x	x	x
Drought		x	x	
Dust				x
Earthquake	x	x	x	x
Fire	x	x	x	x
Flood	x	x	x	x
Landslide	x	x		x
Meteorite Impact	x	x		x
Monsoon				x
Sinkhole		x		x
Space Weather	x			x
Subsidence			x	x
Volcanic Eruption		x	x	
Windstorm	x			
Accident				x
Tech-Nat				x
Structural Collapse				x

Figure 2. Single hazard summary. A summary of the single hazards that can affect the Hub cities collected through participant response using Padlet.

The lists of hazards in **Figure 2** are not exhaustive. Examples of potential reasons for hazards not being identified by participants in this exercise include:

- **Limited time** to complete the exercise, limiting the number of hazards documented.
- Conscious or unconscious decisions to **focus on higher-impact events**, thus excluding hazards that have a lower impact even though they may occur more frequently (e.g., extreme temperatures).
- Conscious or unconscious decisions to **focus on more frequent hazards**, therefore excluding those hazards that a low probability of occurring, even though the impact may be high (e.g., space impact events, geomagnetic storm).
- Evidence that participants may use to assess what single hazards could impact a city tends to be based on past events and their own experience. This evidence then introduces **a bias towards past 'recorded history' records**, with the completeness and extensiveness in time differing by hazard.
- **Disciplinary biases** and the professional backgrounds of those participating in the workshop resulting in minimal professional engagement with some hazards.

A comprehensive overview of relevant single hazards is an essential step in building an understanding of the multi-hazard landscape. It enables analysis of what multi-hazard interrelationships may occur and how these connect into more complex multi-hazard scenarios.

2.3. Multi-Hazard Interrelationships and Scenarios in Hub Cities

As noted in **Section 1**, the term multi-hazards includes in its definition "...*the specific contexts where hazardous events may occur simultaneously, cascadingly or cumulatively over time, and taking into account the potential interrelated effects"*. Many different types of multi-hazard interrelationships could be considered (see Kappes *et al.,* 2012; Gill and Malamud, 2014; Ciurean *et al.,* 2018; Tilloy *et al.,* 2019). One categorisation is to break interrelationships into three groups:

- **Triggering Relationships.** One hazard causes another hazard to occur, which can result in hazard chains, networks, or cascades. For example, a volcanic eruption may trigger a landslide, which then causes a tsunami.

- **Amplification Relationships.** One hazard can change the likelihood and/or magnitude of additional hazards in the future. For example, drought can increase the likelihood of wildfires, which increases the likelihood of debris flows and floods.

- **Compound Relationships.** Two or more hazards may impact the same region and/or time period with impacts different (greater, lesser) than their sum. These compound relationships can take several forms:

    - *A primary hazard triggering multiple secondary hazards simultaneously* (e.g., a tropical storm triggering floods and landslides simultaneously).

    - *Two independent hazards impacting the same region and/or time period* (e.g., extreme temperature event and an earthquake).

    - *Consecutive hazards, with one hazard changing the vulnerability making exposed assets more susceptible to the impacts of any successive hazards* (e.g., an earthquake followed by a period of extreme cold, with those forced to sleep outdoors due to damaged homes being more susceptible to the impacts of the low temperatures).

Examples of these three relationship types are shown in **Table 2**.

Table 2. Three contrasting examples of hazard interrelationships: (a) Triggering relationship (1792 Mt. Unzen eruption, Japan). (b) Amplification relationship (2014 and 2015 Silverado, California drought, high temperature, wildfire, and debris flow). (c) Compound relationship (1991 Pinatubo, Philippines).

Triggering	Amplification	Compound	
1729 Mt. Unzen Eruption, Japan	**2014 and 2015 Silverado, California, USA**	**1991 Pinatubo eruption and Typhoon Yunga, Philippines**	
Volcanic Eruption	Drought and high temperatures (August and September 2014)	15 June 13:42 Volcanic Eruption (with 400 km wide ash columns)	15 June 08.00 Typhoon Yunya (landfall)
Triggers	*Increased likelihood of fire*	*Triggers*	*Results in*
Landslide	Wildfire (12–14 September 2014): Area burned 6.5 km^2	Global Cooling	Strong Winds Heavy Rainfall
Triggers	*Increased likelihood of floods and debris flows*		*Triggers*
Tsunami	Debris flow (19 July 2015)		Floods
		Ash + Rain *Results in* Lahars	

Information from Umbal and Rodolfo (1996); Self *et al.* (1996); Scott *et al.* (1996); Robock (2000); Self (2006); Yoshida and Sugai (2007); and USGS (2018).

The interrelationship types illustrated in **Table 2** can combine in any individual scenario, thus developing a complex multi-hazard situation. For example, in Guatemala on the 27 May 2010, Pacaya Volcano erupted.

- On 29 May 2010, Tropical Storm Agatha impacted Guatemala (*compound relationship*).
- The volcanic ash generated by the eruption of Pacaya blocked the drainage system and increased the likelihood of flooding (*amplification relationship*).
- Tropical Storm Agatha then resulted in flooding and an incident of ground collapse (*both triggering relationships*).

In the final exercise of Workshop 1, we asked participants in six breakout groups to create two or three plausible multi-hazard scenarios for their city. Scenarios might involve triggering relationships, changes in the likelihood of a hazard given the occurrence of another or scenarios where two or more hazards coincide in spare and/or time. **Figure 3** provides a summary of the multi-hazard scenarios identified by the six breakout groups.

City	Natural Hazards scenarios for each city *(triggering, increased probability, coincidence)*
Istanbul Group 1	• Scenario 1: **Earthquake→ fire**, **landslide**, **liquefaction**, **tsunami**, **coastal flooding**, **aftershocks** • Scenario 2: **Blocked rivers** (from **landslides**) → outburst **flooding** → transport/logistics heavily affected → poor sanitary conditions + aid supply → disease outbreak • Scenario 3: **Extreme weather** → exacerbated **flooding**
Quito Group 1	• Scenario 1: **Pichincha eruption (7 Oct 1999)** → created a **steam, gas, ash column, ash fall,** especially at the northwest. **Lahars** and **pyroclastic flows** in an inhabited area • Scenario 2: **New eruption→ash fall** [if **rain** might cause **lahars**]
Quito Group 2	• Scenario 1: **Earthquake** that coincides with the **rainy** season in Quito. The earthquake produces large **landslides,** and they are larger because of soils that are oversaturated by water. The landslides can become **debris flows** that reach more distant zones. **Earthquakes** can damage water pipelines and roads that increase water in the soil • Scenario 2: A **volcanic eruption** that coincides with an **epidemic**
Quito Group 3	• Scenario 1: **Eruption** of Pichincha → **ash deposits** on slopes + **rain** → **lahars** • Scenario 2: **Eruption** of Pichincha → **ash deposits** in drains + **rain** → **flooding** • Scenario 3: **Earthquake** and **volcano eruption** at the same time
Nairobi Group 1	• Scenario 1: **Cyclone** - **landslide** - enhanced probability of **flooding** - infectious **diseases** (meteorite) • Scenario 2: **Drought**/**heatwave** - **fire** - increased potential **landslide**, **flooding** • Scenario 3: **Space weather**, impact power - lose communications
Kathmandu Group 2	• Scenario 1: Moderate continuous **rainfall** in Kathmandu > short-lived 2-3 hour long **flooding** > **landslides** on new roads along the highways > blocking highways going in and out of Kathmandu Valley

Figure 3. Multi-hazards scenarios. The hazard scenarios created by participants for each of the four Hub cities.

Reflecting on the results in **Figure 3**, we make the following three observations.

1. While most of the responses described in **Figure 3** are of hypothetical multi-hazard scenarios, Scenario 1 by the Quito Group 1 was of a real event:

   > ***Pichincha eruption (7 October 1999)*** *→ created a* ***steam, gas, ash column, ash fall,*** *especially at the northwest.* ***Lahars*** *and* ***pyroclastic*** *flows in an inhabited area*.

   Considering events that have occurred previously, and events that could occur in the future given our understanding of hazard interrelationships, can contribute to the generation of multi-hazard scenarios.

2. Based on their responses, some participants did not distinguish between *hazard* and *impacts*. For example, Istanbul Group 1 included the following scenario, with the natural hazards in **bold**, and other aspects of the scenario describing the impacts of these hazards:

   > ***Blocked rivers*** *(from* ***landslides****) →* ***outburst flooding****. Transport/logistics heavily affected → poor sanitary conditions + aid supply →* ***disease*** *outbreak*.

   This example highlights the complex interactions between hazards and impacts (i.e., the impacts of one hazard can trigger or amplify another hazard or its impacts). Documenting multi-hazard scenarios may need consideration of both hazards and their impacts.

3. Most of the examples listed in **Figure 3** are of triggering or amplification relationships. Few people included compound hazard interrelationships in their multi-hazard scenarios. This could be due to compound relationships being less intuitive to consider compared to linear chains (e.g., through consecutive triggering relationships), or that these relationship types are outside the participant's previous experiences.

After Workshop 1, we chose and simplified one multi-hazard scenario (from **Figure 3**) for each of the four Hub cities to use in Workshop 2 to explore dynamic risk. These scenarios are visualised in **Figure 4** and can be considered exemplars of multi-hazard interrelationship scenarios for each Hub city. The scenarios in **Figure 4** include triggering, amplification, and compound relationships.

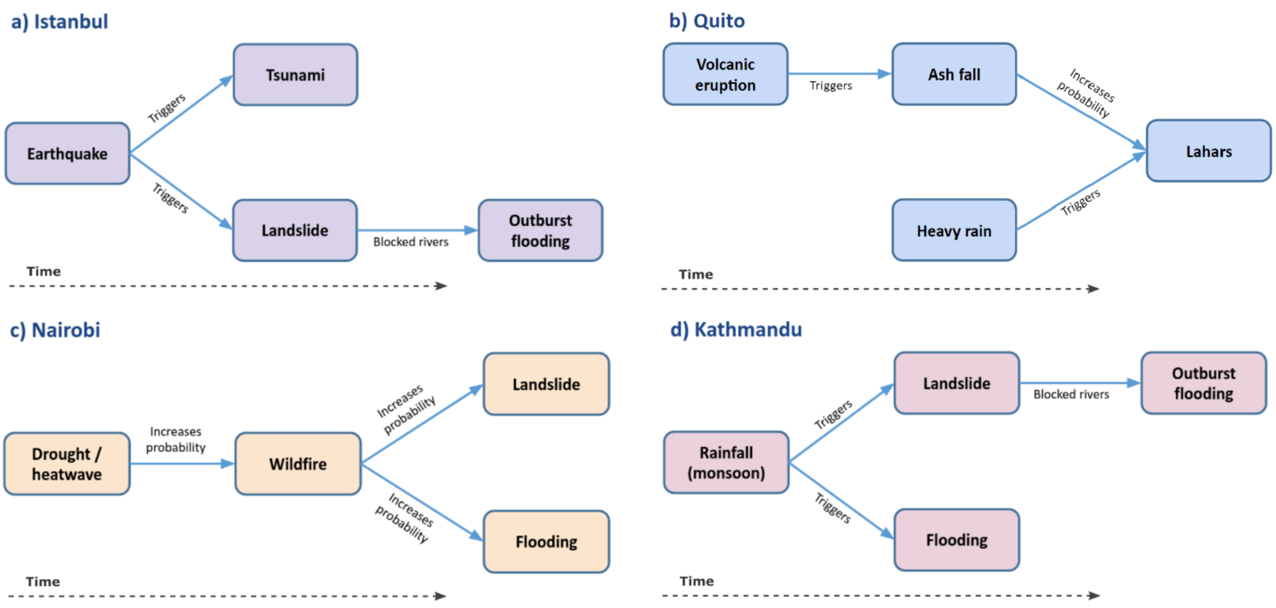


Figure 4. Four multi-hazard interrelationship scenarios. An example of a multi-hazard scenario for each of the cities in *Tomorrow's Cities* based on **Figure 3** for (a) Istanbul, (b) Quito, (c) Nairobi, (d) Kathmandu. These were used later to explore dynamic risk in Workshop 2.

3. Multi-Hazard Scenarios in the Context of Dynamic Risk

Workshop 2 built on Workshop 1 to explore relationships between multi-hazard scenarios and the risk relationship variables (**Figure 5**): hazard, exposure and vulnerability. Workshop 2 aimed to explore how understanding multi-hazard scenarios can help explore the dynamic nature of risk (described further below) and reduce risk (described in **Section 4**).

We started with a 5-minute presentation that first defined the risk equation variables (**Section 3.1**) and then explored the dynamic nature of this relationship through the lens of multi-hazard scenarios (**Section 3.2**). This presentation was followed by an interactive exercise (**Section 3.3**)

3.1. Components of the Risk Equation

The variables of the risk equation have been defined by UNDRR (2017), as described in **Table 1**. These variables combine to result in the risk of or actual disaster impacts, as in **Figure 5**.

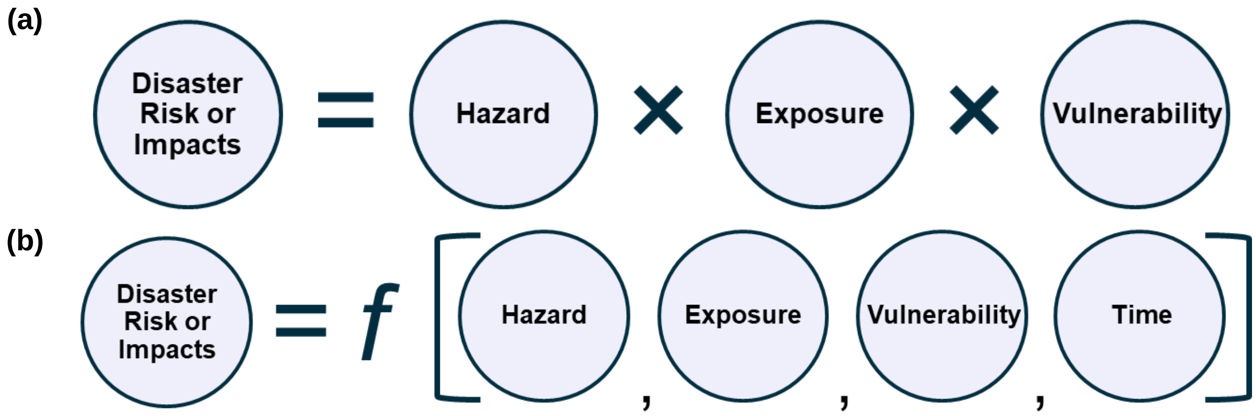


Figure 5. Two Versions of the Risk Equation. (a) A typical representation (e.g., PreventionWeb, 2020) of disaster risk, shown as the multiplication of hazard, exposure, and vulnerability terms. **(b)** A slightly more nuanced representation of disaster risk, shown as a function *f* [ ] of hazard, exposure, vulnerability, and time, where terms are not simply multiplied and each of the first three terms can change over time (i.e., they are dynamic).

3.2. Multi-Hazard Relationships and Dynamic Risk

In the next part of Workshop 2, we explored risk's dynamic nature through the lens of multi-hazard relationships. We used the following four statements, each helping to evolve the visualisation of risk (**Figure 5)** to one that illustrates the dynamism that is of interest to *Tomorrow's Cities*.

1. **The HAZARD term can involve multiple hazards, with relationships between hazards.** While the risk equation's hazard term is commonly represented in the singular, it can involve multiple hazards. Hewitt and Burton (1971) advocate for an "*all-hazards-at-a-place*" framework, recognising that multiple hazards in any given location may contribute to risk. These hazards do not always occur independently (as explored in Workshop 1), but may be linked through one or more types of hazard relationship (i.e., triggering, increased probability, and compound events). Examples include:
   - *Earthquakes triggering landslides, which block rivers and trigger floods.*
   - *Heavy rain and a volcanic eruption coinciding in space and time to trigger lahars*
   - *Forest fires increasing the likelihood of debris flows and floods*

   The hazard term's potential complexity contributes to risk changing over time, as one hazard results in another occurring simultaneously or consecutively.

2. **The HAZARD landscape is dynamic.** Building on the multi-hazard understanding set out in the previous point, we note that the likelihood or magnitude of single natural hazards and multi-hazard scenarios can change over time (i.e., is dynamic). The hazard landscape of a given region can change because of anthropogenic (human) activities (see Gill and Malamud, 2017, for a detailed discussion) or by changes in the hazard-forming environment (Liu *et al.,* 2016). For example, take the scenario an *earthquake triggers landslides, which block rivers and trigger floods.* The triggered-landslides can be **catalysed** (made more likely) by anthropogenic activities such as vegetation removal, road construction, poor drainage, or by changes to the hazard-forming environment such as heavy rain preceding the earthquake. Landslides can also be **triggered directly** by anthropogenic activities such as surface construction and quarrying at slope bases.

3. **Changes in EXPOSURE and/or VULNERABILITY can influence multi-hazard scenarios.** Both the exposure and vulnerability components of the risk equation can change over time, either increasing or decreasing due to complex multi-scale processes. These changes can contribute to the triggering, amplification (or reduction) of multi-hazard events. In the context of *Tomorrow's Cities*, we are interested in the differential impact of various development trajectories on exposure and vulnerability. For example, different development trajectories may result in new and amplified anthropogenic processes (e.g., groundwater abstraction, agricultural practice change, vegetation removal, surface and subsurface construction, quarrying, dewatering) that can influence multi-hazard scenarios.

4. **Progression through multi-hazard scenarios can result in changes to EXPOSURE and/or VULNERABILITY.** In the previous point, we illustrated how changes to *exposure* and *vulnerability* could influence the *hazard* (or multi-hazard) term of the risk equation. We now consider the other direction, how the *multi-hazard* term can influence or drive changes in both the *exposure* and *vulnerability* terms. A given multi-hazard scenario may involve two or more consecutive hazards. Before the first hazard event, the vulnerability to this hazard will be at a certain level (illustrated by the size of the 'Pre-Disaster Vulnerability' box in **Figure 6**). Following a disaster triggered by *Hazard Event 1*, pressures on society, infrastructure and coping capacity are likely to be increased. Thus, the vulnerability of a community and its systems/assets to further shocks or hazards (i.e., *Hazard Event 2*) may increase. For more information, see de Ruiter *et al.* (2020) and Gill and Malamud (2016).

Exposure can also be dynamic. For example, the occurrence of one hazard (e.g., a volcanic eruption) results in the evacuation of people from Community 1 to Community 2, thereby reducing exposure to the ongoing volcanic eruption but potentially increasing exposure to other hazards affecting Community 2 (e.g., landslides, floods, drought).

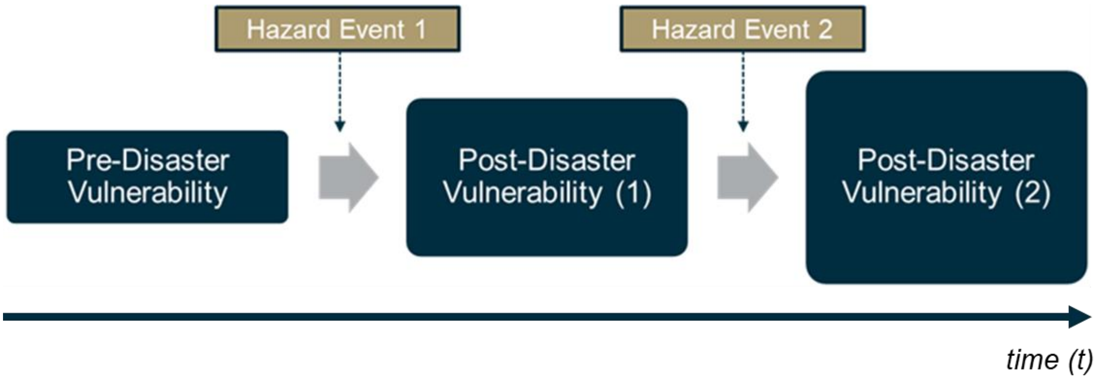


Figure 6. Example of vulnerability changes within a network of hazard interactions (cascade). A representation of dynamic (changing with time) vulnerability during a hazard cascade, where the vulnerability magnitude is proportional to the box's size (adapted from Gill and Malamud, 2016).

The four statements set out above illustrate the dynamic nature of each component of the risk equation and the existence of relationships between each term. Furthermore, they demonstrate how understanding the multi-hazard landscape and potential multi-hazard scenarios can enrich understanding of dynamic risk, as illustrated in **Figure 7**.

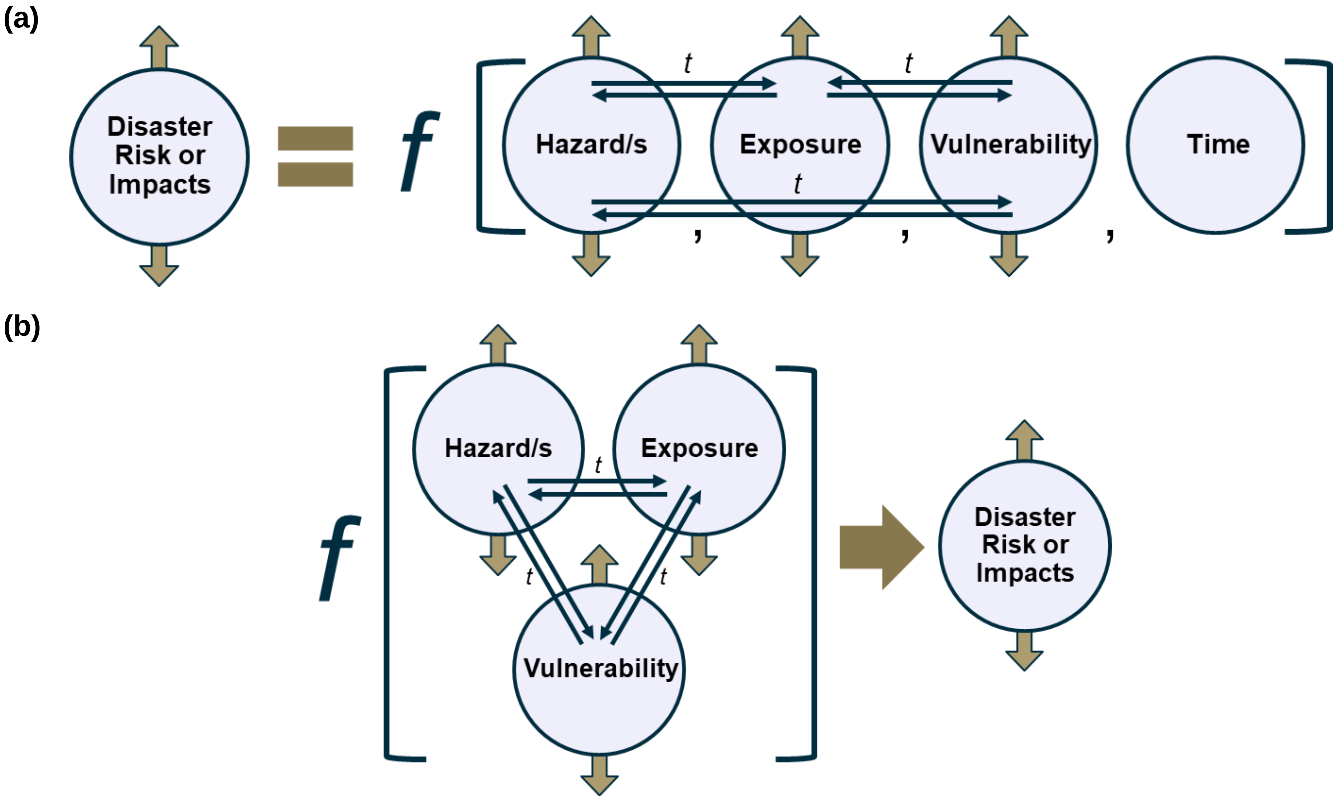


Figure 7. Examples of 'Dynamic Risk' Equations. Two representations of risk that build on **Figure 5b**, shown as a function f [ ] of hazard, exposure, vulnerability, and time, where terms are not simply multiplied and interactions between them are recognised. As each of the three terms and their interactions can change over time (i.e., they are dynamic), this equation also includes a time variable.

3.3. Results of Interactive Exercises on Dynamic Risk

In the third part of Workshop 2, we conducted two related interactive exercises.

- **Exercise A** (plenary): Participants were asked to (i) consider a generic and typical multi-(natural) hazard scenario (**Figure 8**) and (ii) list responses to three related questions. Both the questions and participants' responses are set out in **Table 3**. The purpose of this exercise was not to create an exhaustive list for any of the three questions, but rather to encourage participants to think about factors contributing to multi-hazard scenarios and impacts of multi-hazard scenarios that change risk to future hazards.
- **Exercise B (**city-specific breakout groups of approximately 4 to 8 people): Participants were given 15 minutes and asked to discuss two examples of how exposure and vulnerability might change during a city-specific scenario they generated in Workshop 1 (see **Section 2**). **Table 4** gives scenarios and examples of group responses.

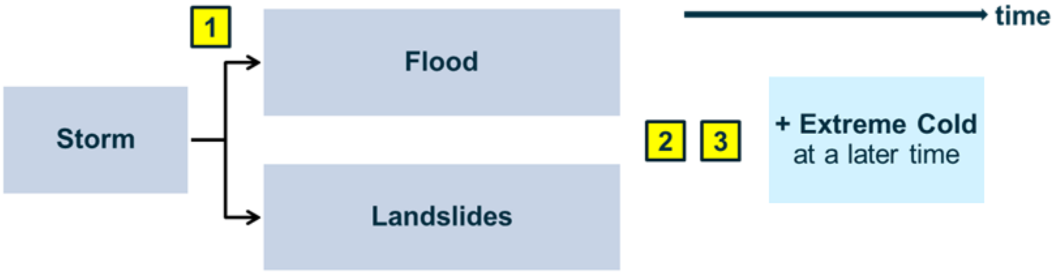


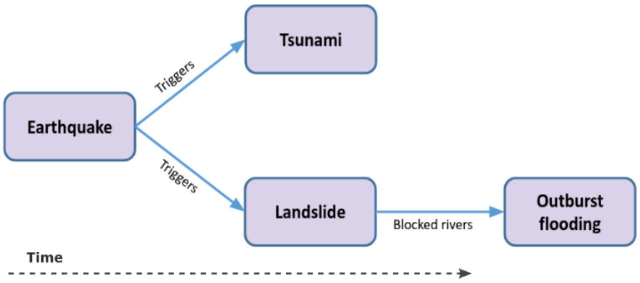
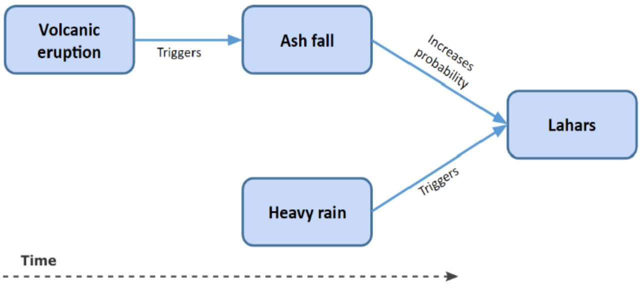
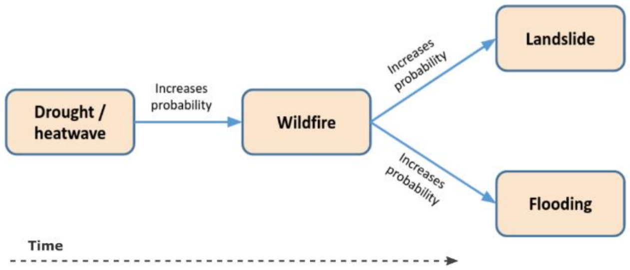
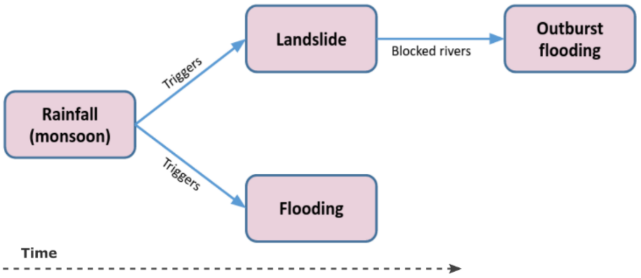
Figure 8. Exercise A. A multi-(natural) hazard scenario (a storm triggers floods and landslides, followed in time by a period of extreme cold), with time advancing from left to right in the diagram. Numbered boxes (1, 2, 3) relate to three questions, outlined in **Table 3**.

Table 3. Responses to dynamic risk during a generic scenario (Exercise A) with three questions (Q) asked of participants to consider while in Workshop 2 Plenary.

Q. What ANTHROPOGENIC PROCESSES could catalyse storm-triggered floods	Q. What CHANGES IN VULNERABILITY may have occurred at [3] vs [1]?	Q. What CHANGES IN EXPOSURE may have occurred at [2] vs [1]?
• Urbanisation of hillslopes / construction in slopes (changing surface run-off) • Paving over soil / soil sealing and impermeabilisation • Deforestation / forest degradation and clearance / vegetation removal • Construction and developments in floodplains / encroachment of floodplains and waterways / construction near to water streams • Unplanned settlements • Road construction • Dam construction • Drain construction • Poor waste management (e.g., plastic bags used for water getting caught up in a road's run-off canals) • Unmaintained (or otherwise poor) sewerage systems	• Displacement and resettlement might increase vulnerability in the area of resettlement • Displaced people living in temporary shelters / people lose their house • Changes to building fragility • Limited transportation • Limited communications • Livelihoods affected • Crop damage • Poor nutrition / increases in hunger • Ill health, especially for elderly and young • Gender characteristics of a given region might change • Structural inequalities may change	• Displacement and resettlement can temporarily decrease exposure in the affected areas • People relocated from one region to another region / moved away from flood zone • People relocated to camps tents, and caravans. • People pushed to stay home • Buildings are rebuilt in new locations • Road layouts might be changed, due to damage to them • Damage to flood defences

Note: Some examples above could change both exposure and vulnerability (e.g., relocation of people may change exposure to a given hazard, and the people's vulnerability if access to livelihoods or support mechanisms change).

Table 4. Breakout group responses to dynamic risk during city-specific scenarios exercise, using the scenarios first set out in Figure 4.

Scenario	**During this multi-hazard scenario:**	
	How may exposure change?	**How may vulnerability change?**
(a) Istanbul City Breakout Group 	*Not recorded*	*Not recorded*
(b) Quito City Breakout Group 	During ash fall, people are encouraged to stay at home, potentially increasing their exposure to lahars. Ash fall increases the exposure of sewerage systems.	Volcanic ash loaded on ceilings can increase the physical vulnerability of houses. A lack of redundancy in systems means if a system is damaged by one hazard, there will be no alternative that can be used.
(c) Nairobi City Breakout Group 	People move out of the city during drought to places where food is more accessible.	Health changes from heat. Health changes due to drought-induced malnutrition. Diminished coping capacity due to earlier damage.
(d) Kathmandu City Breakout Group 	A landslide may change the physical landscape as increased sediment from the landslide leads to changing river height (discharge). This leads to changes in number of people and buildings exposed. Floods could result in people moving location (including to higher land). Exposure may be seasonal, changing over time in regular patterns (e.g., due to high rainfall season).	Changes to health - people get sick due to flooding contaminating water supplies Breakdown of communications Transportation halted due to road blockage [preventing access and movement] Changes to physical vulnerability as building foundations become weak

Workshop 2 was not designed to examine specific scenarios comprehensively, instead it aimed to demonstrate a process and how multi-hazard scenarios could be used within *Tomorrow's Cities*. Therefore, the results in **Table 4** are illustrative of the potential of using scenarios, rather than presented as complete and for further analysis. During an open discussion on the usefulness of multi-hazard scenarios, participants contributed to the following points:

- *[Types of hazard interrelationship, building on a contribution from Brian Golding]* There are differences in how hazard interrelationships are classified. For example, the COST Action DAMOCLES project (DAMOCLES, 2020) has identified different compound hazard classes. A review of different classifications and the development of standard terminology (incorporated into UNDRR terminology) would benefit the hazard and risk community.
- *[Changes to scenarios based on time of day/week/season, building on a contribution from Brian Golding]* Quick changes in exposure and vulnerability can occur due to regular daily (e.g., work, commuting, sleep), weekly (e.g., working week vs. weekend), or seasonal patterns (e.g., national holidays) that change the exposure to a given hazard or the vulnerability profile. Fast changes in these can outweigh slower-moving changes that occur between successive hazards in a multi-hazard scenario. While some variations in exposure and vulnerability are predictable (e.g., by understanding working patterns), other changes resulting from behaviour changes and contributing to dynamic risk are harder to predict.
- *[Usefulness of multi-hazard scenarios, building on a contribution from Mark Pelling]* Multi-hazard scenarios can offer a useful way to explore changes in variables contributing to risk and present uncertainties to stakeholders through a range of viable scenarios. Scenarios can vary from those with minimal impact to those that can be considered a reasonable worst case. Scenarios can also lead to inaction if they are poorly framed or present too many options. Consideration should be given to what scenarios are identified and how these are used to drive action rather than inaction.
- *[Communication of multi-hazard scenarios, building on a contribution from Francisco Vásconez]* The usefulness of scenarios in the context of dialogue with stakeholders may depend on *how* they are presented. Select examples of approaches that could be used to present scenarios include written narratives, maps, or flow diagrams. One needs to consider audience, complexity of the scenario, and the purpose or desired outcomes of any dialogue.

4. Reducing Multi-Hazard Risk in Tomorrow's Cities

In the final part of Workshop 2, we discussed how understanding multi-hazard scenarios could help reduce risk. We started with a 5-minute presentation (**Section 4.1**), then broke into city-specific breakout groups to identify pathways to reduce dynamic risk from multi-hazards in *Tomorrow's Cities* (**Section 4.2**).

4.1. Reducing Risk from Multi-Hazard Scenarios

The first 'Priority for Action' in the Sendai Framework for Disaster Risk Reduction 2015–30 is to understand risk in all its dimensions (UNDRR, 2015). Understanding multi-hazard risk can help to improve risk mitigation, preparation, response and recovery (de Ruiter *et al.,* 2020), as illustrated in **Figure 9**.

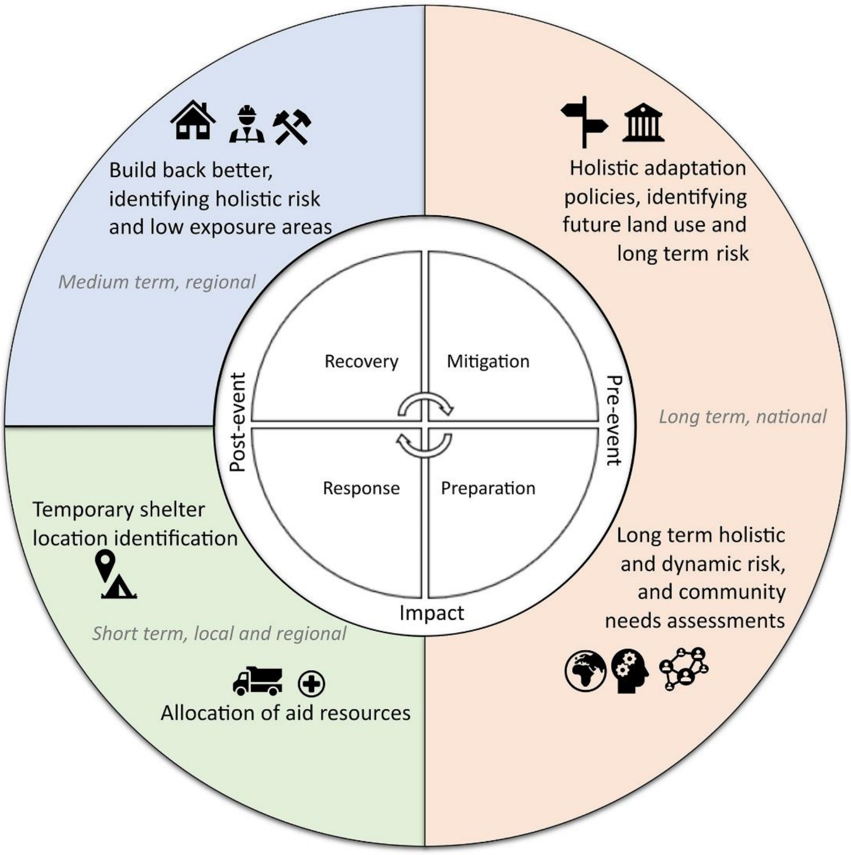


Figure 9. Disaster risk management cycle for consecutive disasters (from De Ruiter *et al.,* 2020, reproduced under the terms of the CC BY 4.0 license - https://creativecommons.org/licenses/by/4.0/legalcode). When accounting for the risk of consecutive disasters, the dynamics of the different risk components should become part of all phases of the DRM cycle. Background DRM cycle is adapted from UNOCHA (2013).

In this project's context, and therefore this workshop, we are particularly interested in how identifying and understanding multi-hazard scenarios, and integrating these into decision-making and future planning, can reduce risk in *Tomorrow's Cities*. We suggested five ways:

1. **More holistic land-use planning.** Characterising the multi-hazard landscape in terms of the following can inform decisions about the appropriate land use in *Tomorrow's Cities*: (a) the multiple single hazards that any given region is susceptible to, and (b) identifying feasible multi-hazard scenarios. For example, new urban development will require the extension or initiation of anthropogenic activities in a region (e.g., vegetation removal, dewatering, subsurface construction, quarrying), which may trigger or exacerbate multi-hazard scenarios.

2. **Integration of compounding and consecutive effects into building codes.** Infrastructure development in *Tomorrow's Cities* may include public services, industrial facilities, transport infrastructure, and housing. For such infrastructures to be resilient, they will need to withstand the compounding effects of feasible multi-hazard scenarios (e.g., an earthquake followed by a tropical storm that triggers a flood). While trade-offs may be required, doing so in a way that reduces rather than amplifies risk, will benefit from a knowledge of multi-hazard scenarios. Reduction of risk related to hazards *not* taken into account in the building code can also be considered using other tools.

3. **Identification of efficient and effective risk reduction interventions.** Understanding multi-hazard scenarios may help determine how to invest resources to minimise disruption. If we can identify interventions that act early in a hazard chain to reduce their propagation

of additional hazards, this may reduce the overall impact of the multi-hazard scenario. For example, consider the scenario of a storm triggering landslides that trigger floods. An efficient risk reduction intervention here could be effective drainage measures to reduce the storm's likelihood of triggering landslides and flooding.

4. **Avoidance of 'asynergies' in risk reduction interventions.** One wants to avoid interventions that reduce vulnerability and exposure to one hazard while increasing vulnerability and exposure to another hazard, known as asynergies (de Ruiter *et al*., 2021). Avoiding such asynergies is helped by integrating multi-hazard scenarios into planning risk reduction interventions in *Tomorrow's Cities*. This is true at all scales, from national-level policy to household-level actions. For example, suppose community-level initiatives focus on each individual hazard without considering other hazards and their interrelationships. Then there is a risk that actions may be implemented that increase their vulnerability and exposure. There is also a risk of 'fatigue' and inaction. The use of scenarios could help communities consider the range of hazards they face, and the most effective and appropriate actions to reduce risk.

5. **Strengthening cross-organisational (or cross-hazard) communication mechanisms.** Dialogue focused on potential multi-hazard scenarios can strengthen communication across organisations responsible for different hazards or different aspects of risk reduction. For example, consider a multi-hazard scenario that involves the simultaneous occurrence of a tropical storm with a volcanic eruption, and the subsequent generation of landslides, lahars and floods. Thinking through how a city would prepare for and respond to this scenario (e.g., how actors would work together) requires involvement of meteorologists, hydrologists, volcanologists and engineering geologists, who may or may not sit within four different organisations, as well as various other agencies. Identifying multi-hazard scenarios is a way to bring these groups together, initiate dialogue around roles and responsibilities, and strengthen trust and cooperation.

This list of five ways by which identifying multi-hazard scenarios can support risk reduction is not exhaustive, and we invite others across (and beyond) *Tomorrow's Cities* to contribute their perspectives also. We recognise location- and hazard-specific contexts may make some of the above ideas challenging or more complicated than others. Nevertheless, we argue that (i) the consideration of multi-hazard scenarios can help us to inform planning processes, thus proactively reducing risk in *Tomorrow's Cities*, and (ii) that the *process* of exploring multi-hazard scenarios with stakeholders can result in positive outcomes, as well as the outputs themselves (see Gill *et al.,* 2020 for a more detailed discussion and examples from Guatemala).

4.2. Results of Group Discussions on Reducing Risk from Multi-Hazard Scenarios

During the breakout groups completing the activities described in **Section 3**, participants were asked to consider steps that could help to reduce the risk from their exemplar scenario. Ideas are summarised below.

- *Land-use management.* Using single-hazard risk maps to inform urban planning and improve risk awareness.
- *Codes.* Consider how multi-hazards can be embedded into building and infrastructure codes.
- *Improved infrastructure.* Improved sewage systems were identified by a Quito breakout group, as helping to reduce risk from their specific multi-hazard scenario.

5. Reflections

As set out in **Section 1**, our aims through Workshops 1 and 2 were to introduce the multi-hazards integrating theme and explore the relevance of multi-hazard approaches and scenarios in the *Tomorrow's Cities* project. The conversation on these themes is captured in **Sections 2** to **4** of this report. Through these workshops, several themes emerged, and we reflect on these below:

- *[Hazard types and impact]* When generating multi-hazard scenarios, it is necessary to consider a broad range of hazard types and recognise that hazard impacts may trigger or exacerbate further hazards.
- *[Types of hazard relationship]* There are differences in how hazard interrelationships are classified, and a lack of consistent terminology that may contribute to confusion about how to integrate these into multi-hazard scenarios.
- *[Integration of hazard relationships into multi-hazard scenarios]* During breakout groups, it was generally easier to engage participants in discussions about linear triggering relationships between hazards, rather than amplification or compound relationships. The latter two types of hazard relationship are relevant to *Tomorrow's Cities*, with consideration needed as to how to integrate these relationships into multi-hazard scenarios.
- *[Vulnerability and exposure in the context of multi-hazards scenarios]* There are complex relationships between hazard, exposure, and vulnerability that can contribute to disaster risk and impacts. Multi-hazard scenarios can help to explore these relationships. A participant working on the social elements of disaster risk indicated that using multi-hazard scenarios could be a useful framework to explore how social vulnerabilities might change over time. For example, how might poverty change through a multi-hazard scenario, and what policies could be implemented to minimise this risk? Or, how might the poor be adversely affected by a given multi-hazard scenario?

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