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Tomorrow's Cities risk agreement approach: utilising the analytical, communication and convening power of science for inclusive, risk-sensitive urban planning

Roberto Gentile [a,*], Tanvi Deshpande [b], Erdem Ozer [c], Sukirti Amatya [d], Nisha Shrestha [d], Ramesh Guragain [d], Mark Pelling [a], Hugh Sinclair [e]

[a] *Department of Risk and Disaster Reduction, University College London (UCL), London, United Kingdom*
[b] *London School of Economics and Political Sciences (LSE), London, United Kingdom*
[c] *Anofa Engineering, Planning, Informatics & Trade Ltd, Istanbul, Türkiye*
[d] *National Society for Earthquake Technology (NSET), Kathmandu, Nepal*
[e] *School of Geosciences, University of Edinburgh, Edinburgh, United Kingdom*

A R T I C L E I N F O

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A B S T R A C T

Global disaster risk reduction in urban development frameworks calls for people-centred, participatory, and integrated approaches to addressing urban risk and building resilience. This paper presents a methodology that engages communities at risk and policy actors to assess scientifically projected impacts of multiple hazards on locally defined future urban scenarios and co-develop measures to reduce future hazard impacts. The methodology enables stakeholders to identify barriers and strategies to support more people-centred, participatory, and risk-sensitive future urban development. Within a workshop, selected community groups are first introduced to an interactive dashboard that simplifies the communication of projected multi-hazard impacts (e.g., human displacement, casualties, loss of education capacity). Community groups identify and discuss the effects of different hazards, exposure, and vulnerability features along with projected impacts on community-led future urban scenarios. Such evidence-based and participatory discussions lead to a set of revisions of the urban scenarios. Finally, the groups discuss existing community, urban planning, and local decision-making challenges that could hinder the implementation of the urban scenarios. The proposed methodology is presented within the framework of the Tomorrow's Cities Decision Support Environment (TCDSE) and illustrated through a deployment in Rapti, Nepal. Findings confirm the ability of the approach to facilitate a shared understanding of context-specific risk amongst diverse local and policy actors. The combination of scientific and local information improves awareness and gives agency to marginalised groups for improved communication with urban planners in disaster risk reduction decision-making.

1. Introduction and motivation

Cities are vulnerable to natural hazards (e.g., floods, earthquakes, heatwaves, landslides, droughts) due to the compounding impacts of development and climate change. By 2050, cities will house 66 per cent of the global population [1], calling for disaster

* Corresponding author.
E-mail address: r.gentile@ucl.ac.uk (R. Gentile).

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risk-oriented urban planning and decision-making processes. Equitable and risk-sensitive urban development is the process of designing urban environments by explicitly considering relevant risk estimations and avoiding the disproportionate impact of hazards on groups with different socio-economic characteristics (e.g., age, gender). It requires participatory and integrated decision-making approaches to address multi-hazard risk. Several scholars advocate for participatory approaches ([2–8] along with integrating disaster risk reduction and climate adaptation with urban planning processes ([9–12]). Such claims are reinforced by international frameworks such as the Hyogo Framework for Action [13], Sendai Framework for Disaster Risk Reduction [14], and the Urban Agenda Habitat III [15] that promote people-centred and participatory disaster risk reduction measures [10,16,17]. Furthermore, these frameworks strongly advocate for multi-hazard and multi-disciplinary approaches addressing the interconnected and cascading impacts of risk [18]. Participatory approaches to multi-hazard risk reduction require involving relevant stakeholders (planners, decision-makers, scientific community, practitioners) and communities at risk in generating and assessing risk information including scientific results, hazard and risk assessments, and indigenous/local knowledge required for decision-making processes [12,19–21]. Such approaches increase inclusivity (i.e., the inclusion of all stakeholders) and proactivity (i.e., the act of taking actions to activate change, rather than reacting to change) [22] as they distribute decision-making power and foster collaborations between communities and governments [16].

While participatory approaches to disaster risk reduction (DRR) are increasingly endorsed, the literature reveals persistent limitations in how these methods are implemented. Many traditional participatory frameworks have been criticized for being overly consultative, often engaging communities only superficially and failing to meaningfully address underlying power asymmetries that marginalize vulnerable groups from decision-making processes [8,20,22–24]. Furthermore, previous DRR methods have seldom integrated participatory processes with rigorous, evidence-based risk modelling, leading to a disconnect between local knowledge and technical planning tools [25,26].

Therefore, it is reasonable to state that effective decision-making for urban planning should be grounded in an estimation of the risks relevant to a specific community, obtained at the highest level of confidence consistent with the available data and technical capacity. Within this paper, the scope is limited to disaster risk due to natural hazards. Refined risk modelling requires quantifying the event characteristics of potential hazards (e.g., frequency and severity) and their interactions. Moreover, it is required to characterise exposure (e.g., people and built environment), as well as social and physical vulnerability (respectively involving the probability of people and physical assets to be impacted by hazard events of different intensities). Model interpretation and risk communication (i.e., the process of exchanging information and opinions among individuals, groups, and institutions regarding the impact of potential hazards) are fundamental aspects of risk assessment, which improve understanding of risk and aid risk reduction measures. Such scientifically derived risk results can only influence decision-making processes when they are communicated in a simplified and accessible manner for a non-scientific audience (Sinha, Aditya, Gupta, 2008). Therefore, risk communication becomes a paramount tool to effectively engage communities, since their perceptions of risk are shaped/influenced by their lived experiences and socio-cultural norms, while the scientific community uses scientific evidence to determine risk.

Traditionally, risk communication follows a unidirectional flow of information from scientific community members who share risk information with decision-makers, who in turn inform the public with the intent to correct perceptions and practices [22]. Consequently, risk assessment is limited to scientific communities with no involvement of urban planners and communities at risk. Involving them is crucial for decision-making as they are the first victims of and responders to disasters [10]. The above challenge can be overcome by adopting bottom-up risk communication strategies [27–29] which lead to a multi-directional flow of risk information amongst scientists, practitioners, communities at risk, and decision-makers.

Any objective risk quantification resulting from a reliable computational modelling may be interpreted and appraised differently by actors with different sensitivities, priorities, and individual knowledge. For example, community members with different social characteristics (e.g., age, gender, income level) may be more/less interested in (the reduction of) different hazard impacts (e.g., displaced population, lost access to educational or working facilities). Moreover, officials of the local government may have, for example, a large-scale, systemic view of the risk assessment while community members may compare the modelling assumption in smaller areas with their local knowledge. Therefore, effective decision-making requires a participatory approach able to account for several of the above sensitivities, especially including the most marginalised communities (i.e., the urban poor). Moreover, such an approach should allow for a synthesis among such subjective "understandings of risk", defined in a process of cross-learning, in turn, fundamental to making effective decisions. Such synthesis should be defined in a process of mutual agreement among the involved stakeholders.

To fulfil the above needs, this paper discusses a methodology that engages communities at risk, urban planners and local government officials to appraise projected impacts of multi-hazard events on future urban scenarios, co-develop pro-poor and risk-reducing revisions to the urban scenarios, and identify barriers and enablers to ensure effective implementation. The methodology is called "Risk Agreement", recognising that co-producing an agreed understanding/definition of risk is the component that enables an inclusive and equitable decision-making for urban planning. The required inputs to engage in the risk agreement methodology are the following: 1) disaggregated social groups - community groups defined based on one or more context-specific social characteristics (e.g., gender, age, profession), allowing to minimise power unbalances and foster inclusivity; 2) one or more future urban scenarios - such scenarios involve a GIS (geographic information system) definition of land use types, building and infrastructure, household and individual characteristics; 3) disaster impact modelling quantified for each urban scenario and for relevant future multi-hazard scenarios, 4) policy challenges identified considering pre-disaster situations. The details of such required inputs are defined in Section 2.2 and users are free to adopt any methodology to obtain them. However, the risk agreement is conceived as part of the Tomorrow's Cities Decision Support Environment (TCDSE; [30], described in detail in Section 2.1, and this paper suggests deriving such requirements according to the TCDSE.

The Risk Agreement methodology deployed through a workshop is composed of three parts. First, disaggregated social groups are introduced to an interactive dashboard that simplifies the communication of projected multi-hazard impacts (e.g., human displacement, casualties, loss of education capacity), calculated with state-of-the-art modelling techniques. A set of activities is designed to assist community groups to identify and discuss projected impacts of different hazards, exposure, and vulnerability features on community-led future urban scenarios. In the second part, social groups use the previously acquired knowledge to agree on a definition of risk and interpret the modelled future risk on the urban scenarios. Such evidence-based and participatory discussions, facilitated from social and technical points of view, lead to a set of revisions to future urban scenarios. To ensure a comprehensive appraisal, the methodology incorporates qualitative discussions on existing community, urban planning, and decision-making challenges and strategies that are beyond the interpretations and assumptions of the adopted risk models. In a final group discussion, the community groups -together with urban planners and local government officials-assess selected revisions against prevalent political, socio-economic, and physical challenges that act as implementation barriers. Finally, strategies (solutions, actors and agencies and time-frames) are identified to overcome such implementation barriers.

The proposed Risk Agreement methodology addresses the identified research gaps by deliberately disaggregating community groups based on social characteristics, enabling more inclusive deliberation. It also facilitates equitable participation through structured workshops and the use of interactive tools, such as the risk dashboard, which democratises access to technical knowledge. In doing so, the methodology supports the co-development of future urban scenarios that are not only risk-sensitive but also shaped by a synthesis of scientific projections and lived experiences. This strategic integration builds on emerging best practices in participatory DRR seeking to rebalance power dynamics and give agency to marginalised actors in disaster and urban governance [31–33].

The paper is structured as follows- Section 2 describes the TCDSE as the framework and context of the proposed methodology, suggesting such a framework as one of the possible solutions to obtain the required inputs of Risk Agreement. Section 3 details the proposed methodology and suggestions to contextualise the related workshop for different communities. Section 4 shows an illustrative application of the methodology and related learnings in the town of Rapti (Nepal), which is the first of seven Global South cities where the methodology has been successfully deployed and Section 5 provides a discussion about the active learning due to the methodology and concludes with some final remarks.

2. Context and methodological requirements

As discussed in Section 1, the Risk Agreement methodology depends on some qualitative and quantitative requirements. Before describing them in detail in Section 2.2, the TCDSE is described (Section 2.1) as the preferred way to derive them. However, users are free to adopt any methodology to derive them, as long that they share the same conceptual features as those described.

2.1. Tomorrow's Cities Decision Support Environment (TCDSE)

The TCDSE is a comprehensive, evidence-based framework and toolkit designed to shape future cities that use inclusive decision-making processes for equitable disaster risk reduction [34]. The TCDSE has been co-developed as part of a five-year research project called 'Tomorrow's Cities' (www.tomorrowscities.org). Deployed in full, the TCDSE provides world-class, cutting-edge, natural hazard risk assessment (including that of climate change) using physics-based methodologies to inform decision-making towards people-centred future urban development. The TCDSE is designed to specifically explore the risks of tomorrow's urban environment, using a simulation-based approach to rigorously capture the uncertainties inherent in future projections [30].

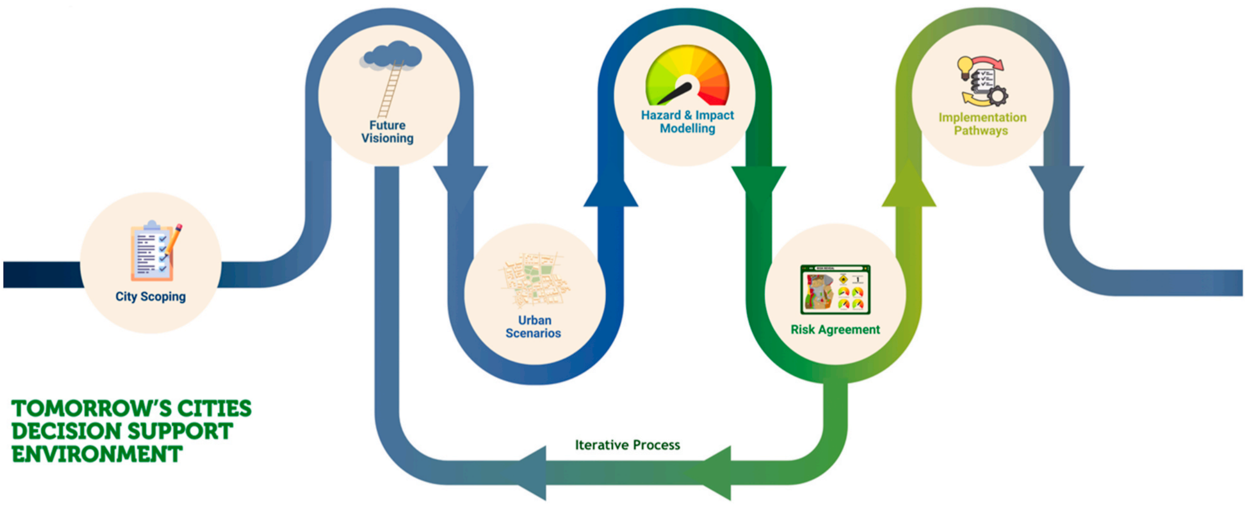

Fig. 1. Tomorrow's Cities Decision Support Environment (tomorrowscities.org; Last accessed: September 2024).

The TCDSE comprises different stages (Fig. 1), with different interlinked objectives (Table 1). *City Scoping* involves a careful identification of a city with sufficient hazard exposure, growing population, and political commitment to participate in the TCDSE framework. *Future Visioning* is a creative and interactive engagement approach that enables urban planners and decision-makers to grasp the aspirations of different social and community groups [35]. These groups include those who express aspects of social vulnerability and marginalization from decision-making processes, or that represent diverse perspectives on the past, present and future. Future Visioning is facilitated through a two-day workshop, in which participants engage in storytelling, co-mapping, and co-design methods. Subsequently, a validation workshop is conducted as part of the Urban Scenarios stage, where groups' proposals are reviewed and refined. The *Urban Scenarios* component entails a technical translation of Future Visions elaborated by each group, into digitally framed land-use plans and policies [36]. Land-use plans incorporate the disaster risk reduction policies selected by participants and are enhanced by future exposure datasets generated by technical teams. Future exposure modelling involves generating detailed representations of physical and social environments, such as future buildings and future populations/households that utilize those buildings. *Hazard and Impact Modelling* contributes to the design of more effective disaster risk reduction policies by addressing hazard impacts that extend beyond physical infrastructure and are directly relevant to the affected communities [37–39]. The *Risk Agreement* approach encompasses a series of activities that empower participants to evaluate Urban Scenarios derived from Future Visioning considering the available multi-hazard simulations (ibid). Through collaborative efforts, groups revise and propose interventions that reduce the impacts of future hazard events, thus potentially iterating into future visioning, until the desired risk level is reached. The final TCDSE component refers to the *Implementation Pathways* and is designed to deliver detailed Action Plans that facilitate collaborative city shaping, involving civil society and government actors at various levels. These plans also ensure a commitment to implementing the lessons learned. The broader ambition is for pro-poor, participatory, risk-informed planning to become a sustainable feature of decision-making cultures.

2.2. Methodological requirements

The first requirement for the Risk Agreement methodology is the definition of *Disaggregated Social Groups.* Those are community groups defined based on one or more context-specific social characteristics (e.g., gender, age, profession), allowing to minimise power unbalances and foster inclusivity. These groups include those who express aspects of social vulnerability and marginalization from decision-making processes, or that represent diverse perspectives on the past, present and future. Emphasis on gender (women's group), intergenerational justice (elders and youth) and socio-spatial inequalities (tenants, migrants) are common (Deployment toolkit [40]: Participants' guiding booklet). For example, in the community of Kibera (Nairobi, Kenia), the selected groups were Business-people, Women, Elders, Youth (two separate groups).

One or more *Urban Scenarios* must be available (i.e., the same for each group or group-specific ones). Such scenarios involve a set of GIS representations at least including natural-hazard exposure features of land use types, buildings, household, and individual characteristics (stored in separate layers). Additionally, infrastructure may be also defined, including for example transport, water, and power networks. It is suggested that the same participants of the Risk Agreement workshop co-produce such scenarios, although this is not a strict requirement. Usually, the process starts with a base map of the involved community area and a co-mapping exercise producing a (hand drawn) land-use map that reflects the different land use types defined by the group according to their vision of the future (usually involving a ~30-year time span). A team of GIS experts digitise and complement these producing an exposure dataset according to a bespoke data structure ([36], Fig. 2). First, the planning extent is selected and subdivided into zones defining the aggregated projected land-use types (stored in the land-use plan layer). The land-use information is used in conjunction with assumptions on future hazards, buildings/physical infrastructure, and socio-economic characteristics to generate spatial information on building locations and their attributes (stored in the building layer) as well as on households living in those buildings. The building layer is enriched with building taxonomy information to facilitate the physical infrastructure impact quantification within disaster risk assessments. Socio-economic and demographic projections are used for characterising data on households (stored in the household layer) and individual people within each household (stored in the individual layer). Examples of attributes are defined in Fig. 2, while extensive details are provided in Ref. [36], with examples available at github.com/TomorrowsCities/Tomorrowville.

Table 1
Summary of the TCDSE framework.

	Objective(s)	Methodology	Output(s)
City Scoping	Set context-specific goals	Stakeholder meetings	List of key stakeholders; Institutional analysis; Historical hazard database; Existing urban plans; Existing socio-economic data
Future Visioning	Capture diverse future aspirations	Community workshop	Future visions for each community group (~30 years in the future)
Urban Scenarios	Translate aspirations in urban scenarios	Community co-mapping; Expert GIS modelling	Urban scenarios for each community group, representing land use, infrastructure, buildings, households, and individuals
Hazard and Impact Modelling	Quantify impacts of hazard events	Expert-based modelling	Hazard scenarios; Vulnerability characterisation; Impact metrics for each hazard scenario
Risk Agreement	Appraise quantified risk and revise urban scenarios	Community workshop (with urban planners, government officials)	Community interpretations and suggestions for reducing risk; Strategies to ensure effective implementation environment
Implementation Pathways	Foster institutional uptake	Community workshop; stakeholder meetings	Consolidated findings from the deployment; Policy recommendations/suggestions

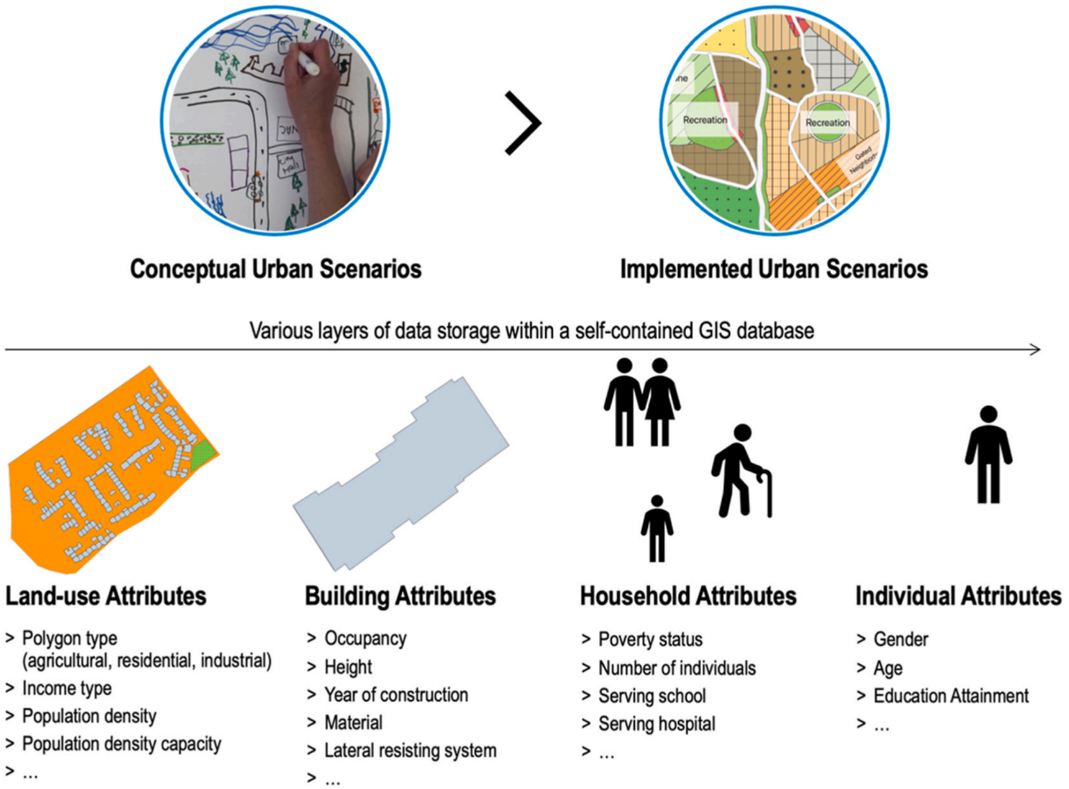

Fig. 2. Requirement for Risk Agreement: each disaggregated social group must define an Urban Scenario including, at least, a GIS representation of land use types, buildings, households, and individuals.

Each Urban scenario is usually accompanied, and defined by, a *List of Policies* (imagined for the future) derived by the disaggregated social groups purely based on the aspiration of the disaggregated social group, without any refined considerations of hazard and risk. Qualitatively derived policies are defined as actions that can potentially influence (increase or decrease) the exposure and vulnerability of any aspect of the Urban Scenarios. Table 2 shows three example policies derived by one disaggregated social group in Kibera, Nairobi, Kenya [41]. Policies must be accompanied by *Implementation Challenges*, which are defined as governance barriers that hinder marginalised communities, urban planners and local government officials from participating and influencing urban planning and DRR decision-making processes. Those derive from a process of "back casting" the future policies into present day implementation. These challenges may be categorised into three themes: political (e.g. lack of political will, corruption), socio-economic (e.g. no agency to make decisions), and natural/physical/infrastructural (e.g. inadequate land for housing).

One or more *Hazard Scenarios* must be co-defined by expert hazard modellers and community members according to the prevalent hazards for the considered community, and accounting for local information as much as possible. A hazard is a threat with potential to cause harm or damage [42]. A hazard scenario is an event (e.g., earthquake, flood, debris flow) with certain event characteristics (e.g., earthquake magnitude, epicentral distance) accompanied with the computed distribution of a local intensity measure (e.g., earthquake peak ground acceleration, water depth from flood or debris flow), obtained with an empirical or physics-based simulation. Examples of modelled hazard scenarios are provided in Fig. 3, referring to the virtual testbed "Tomorrowville, while details of the methodological implementations are provided in Ref. [38].

For each combination of urban scenarios and hazard scenarios, refined *Impact Modelling* must be provided by expert modellers to derive *Disaster Impact Metrics,* defined as objective measures of negative impacts of a specific hazard event on a community. To perform this quantification, every exposure feature of the urban scenarios (e.g., infrastructure, buildings, households, individuals) must be assigned a fragility and/or vulnerability model, which may be physical or social. Fragility refers to the probability of reaching or

Table 2
Three extracted policies (qualitatively defined before any refined hazard and risk considerations) for the city of Kibera, Nairobi (Kenya).

Policy 1	Policy 2	Policy 3
Properly design and build residential and commercial houses that explore the vertical space with basement parking to attract local and external businesses and investors.	Introduce a strict policy and heavy fine to preserve trees and green spaces. Implement a reward or bonus scheme for tree planting in the community to enable tree planting and growing.	Implement a local content policy which provides for 80 % of labour to be from Kibera in implementing the vision plan.

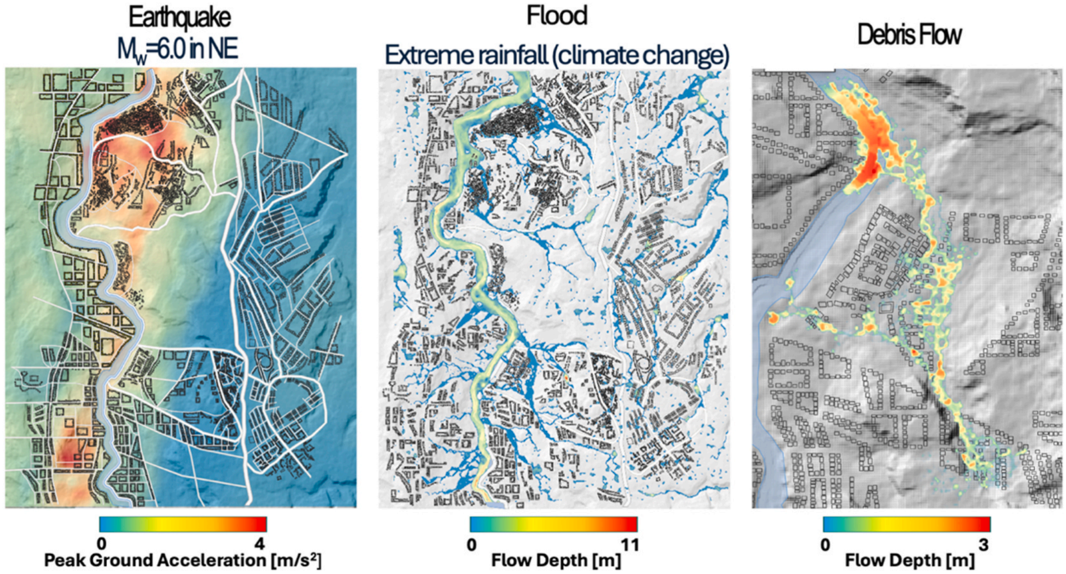

Fig. 3. Requirement for Risk Agreement: intensity simulations for selected hazard scenarios (modified after Jenkins et al., 2022). Mw: moment magnitude.

exceeding a certain damage state given a specific hazard intensity while vulnerability is the probability of reaching or exceeding a disaster impact metric given a specific hazard intensity.

Reference [39] suggests a procedure to 1) map the relevant asset classes (i.e., construction types for a given occupancy) in a region to a set of existing candidate fragility, vulnerability and/or damage-to-impact models, also accounting for specific modelling requirements (e.g., time dependency due to ageing/deterioration of buildings, multi-hazard interactions); 2) scoring the candidate models according to relevant criteria to select the most suitable ones for a given application; or 3) using state-of-the-art numerical or empirical methods to develop fragility/vulnerability models not already available.

Cremen et al. [37] provide a refined procedure to estimate disruptions/damage to physical infrastructure such as individual buildings and critical infrastructure systems) and to assess the effects of the hazard on social infrastructure and different social groups. The computational engine is embedded in an open-access interactive webapp (webapp.tomorrowscities.org, last accessed November

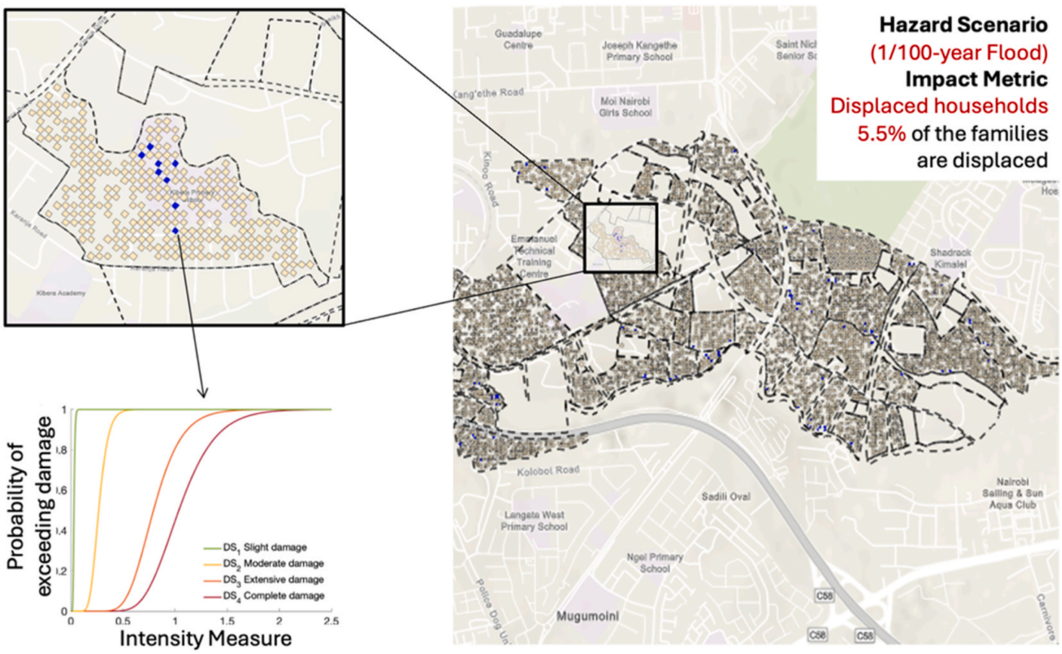

Fig. 4. Requirement for Risk Agreement: Computed damage and impact metrics for each combination of urban and hazard scenarios.

2024). For each combination of urban scenario and hazard scenarios, the result is a set of disaster impact metrics, added to the GIS data structure, with emphasis on the so-called people-centred impact metrics. Examples of such metrics are the number of workers unemployed, children with no access to education, individuals/households with no access to hospitals or displaced. Fig. 4 shows an illustrative computation of displaced households due to a scenario earthquake.

3. Methodology

Risk Agreement allows a community to assess different urban scenarios subjected to several future multi-hazard scenarios and co-develop revisions of such layouts leading to reduced disaster impacts (e.g., human displacement, casualties, loss of education capacity). Urban scenarios may involve current snapshots of communities or future projections related to urban planning. The methodology is deployed in the form of a workshop divided into three parts (Fig. 5). Community members –who are organised into locally appropriate, disaggregated social groups– are the main participants of the workshop. Representatives from the local government, urban planning officers, senior government officials (from sub-national and national levels), and super-national DRR representatives (e.g., United Nations) should be strongly encouraged to participate. This mix of stakeholders acts like a collective task force pushing for an inclusive, equitable and low-risk future urban plan. First, a group-wise *Tutorial* allowing the workshop participants to interrogate the interactive Risk Dashboard to quantitatively answer questions on the modelled hazard and impact (Section 3.1); 2) a group-wise discussion named *Appraisals and Revisions* (Section 3.2), facilitated from the technical and social point of view, allowing the groups to identify and discuss different hazard, exposure, and vulnerability features of the considered urban scenarios that may drive different shares of the modelled impact, and propose potential revisions to reduce it; 3) a group-wise discussion named *Policy Implications* (Section 3.3), in which the selected revisions are assessed against the social, political, and governmental challenges that may hinder implementation and/or effectiveness. The proposed methodology adopts a hands-on approach, as opposed to a lecture-based one. Moreover, checkpoints after each activity allow the facilitators of the group discussion to monitor how the participants assimilate the conveyed concepts and modulate the time of the activities accordingly.

Acknowledging that every geographical/community context has its own peculiarity, the Risk Agreement workshop requires to be fine-tuned -or contextualised-considering the hazard, exposure, and vulnerability data available to the deploying team, their specific expertise and available human resources, and time constraints of the involved stakeholders. Appendix A provides instructions for such workshop planning and contextualisation. The appendix includes several references to aid material useful for planning and deploying the workshop, which is collated in a deployment toolkit and stored in an online repository [40].

Risk Agreement generates both tangible and intangible outputs. The tangible ones include lower-risk revisions of the urban scenarios, thanks to the designed potential revisions. A further output includes enabling strategies to overcome implementation challenges and make the considered urban scenarios implementable. Intangible outputs refer to the participants developing a shared understanding of risk/impact. Moreover, the participants gain confidence in the computational risk model underlying the impact quantification. Due to their active participation in the planning process, the participants build confidence in it.

3.1. Part 1: tutorial on the risk dashboard

The activities and the methodological details of this part of the workshop make use of the risk dashboard, which is discussed first. A dashboard is a graphical user interface designed to display multiple datasets that work together cohesively on a single screen, offering a comprehensive view of data. The dashboard required for the Risk Agreement methodology is called the Risk Dashboard (an example is shown in Fig. 6). To be used for the workshop activities, the Risk Dashboard should be equipped with a fully interactive map allowing for panning and zooming. Moreover, the dashboard should include a basemap (e.g., OpenStreetMap, www.openstreetmap.org, last

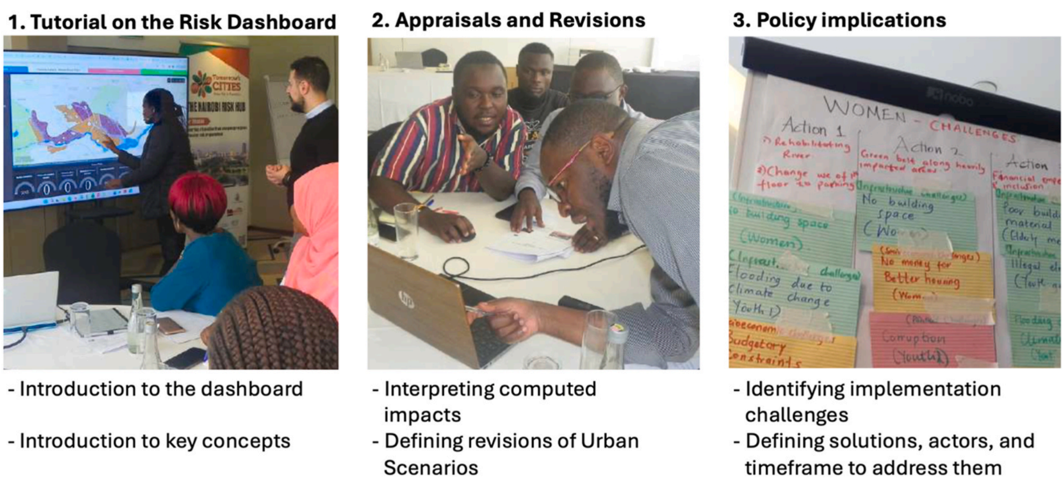

Fig. 5. Overview of Risk Agreement.

accessed January 2025), and layers showing the land use, buildings and other assets, and intensity fields for each hazard scenario. A panel should allow individual selection of the layers to view in the map. Moreover, for each hazard scenario, a hidden layer should contain information about damage on buildings and other physical assets, as well as different impact metrics computed at the level of individuals within the urban scenario. It is quite common to have no visualisation for the households' and individuals' layers, which are defined at a scale too small to allow for meaningful representations within a GIS map. Each layer should be represented through a symbology designed to aid the effective perception and interpretation of the results. In particular, the hazard intensity layer is visualised through a heatmap, for example showing darker shades of blue to represent higher flood water depths. The land use areas may be represented with different colours according to established schemes for urban planning (e.g., Ref. [43]), or with colours/hatching dependent on selected socio-economic characteristics (e.g., darker shades of red in Fig. 6 represent higher average population density). Buildings may be coloured based on exposure characteristics (e.g., height, construction material) or, more conveniently, based on the computed level of damage for a specific hazard scenario (according to the adopted fragility models).

The Risk Dashboard should also contain a dynamic representation of the impact metrics, able to automatically filter the results based on the showed extent of the map (i.e., a table quantifying the selected impact metrics only referring to the portion of the map currently visualised). The quantified impact metrics must also be affected by results filters applied on several characteristics of the land use, building, and infrastructure layers, as well as the damage levels. In relation to the workshop activities, this is the most important feature of the Risk Dashboard, since it allows to examine the risk modelling results according to different perspectives and allow answering hazard-, exposure, and vulnerability-related questions with an evidence-based approach. Filters allow to show/hide any combination of: land use occupancy (e.g., showing only residential areas); building occupancy (e.g., showing only school buildings); building height (e.g., only showing high-rise buildings); building code level (e.g., only showing low-code buildings); building material (e.g., only showing masonry buildings); building damage state (e.g., only showing collapsed buildings); individual socio-economic characteristics (e.g., showing impact metrics only referring to individuals of a certain income, gender, age).

The Risk Agreement makes full use of the capabilities of the Risk Dashboard, which are fundamental to achieve the goals of the methodology. The first part of the workshop (summarised in Fig. 7) aims to provide participants, who are generally not experts in risk modelling, with the basic command of the dashboard -and the related risk modelling concepts-to formulate questions useful to appraise the drivers of risk creation within an Urban Scenario, use the dashboard to quantitatively answer them and use the results to revise the Urban Scenarios.

To do so, six fundamental risk-modelling concepts are selected: hazard, exposure, vulnerability, hazard scenario frequency, impact metrics, and equitable impacts. A short activity (5–20min long) to be conducted in disaggregated social groups is designed for each selected concept. Each activity first includes a short introduction of the concept by an expert risk modeller facilitator using one simple example (using 1–2 presentation slides provided in the deployment toolkit [40]: Facilitators' slides). This is followed by a hands-on activity based on a specific prompt that the group members should carry out using the dashboard (a large screen or projector is suggested for these activities). Since this part of the workshop is a tutorial, prompts only refer to objective features of the Urban Scenarios so that facilitators can safely refer to the correct reading of the dashboard results without biasing participants towards any specific interpretation that can affect decision-making. Indeed, before the workshop, facilitators prepare a guiding document (Deployment toolkit [40]: Facilitators' guide) including the correct execution of each prompt, which also serve as checkpoints: i.e., facilitators can modulate the time of each activity depending on how easily the participants carry out the prompt and the amount of help they require. Table 3 shows the prompts for each activity, clearly designed such that each activity builds on the successful implementation of the previous one, therefore gradually introducing complexity. The group takes note of the results of each activity in a workshop booklet (Deployment toolkit [40]: Participants' guiding booklet) prepared in a context-specific fashion (Appendix A). Facilitators should maintain a minimal-intervention approach as much as possible, letting the participants operate the dashboard to attempt resolving the prompt while being ready to provide a demonstration if required by the participants. To allow for a uniform experience to participants, facilitators can use a workshop script (Deployment toolkit [40]: Workshop script) providing step-by-step

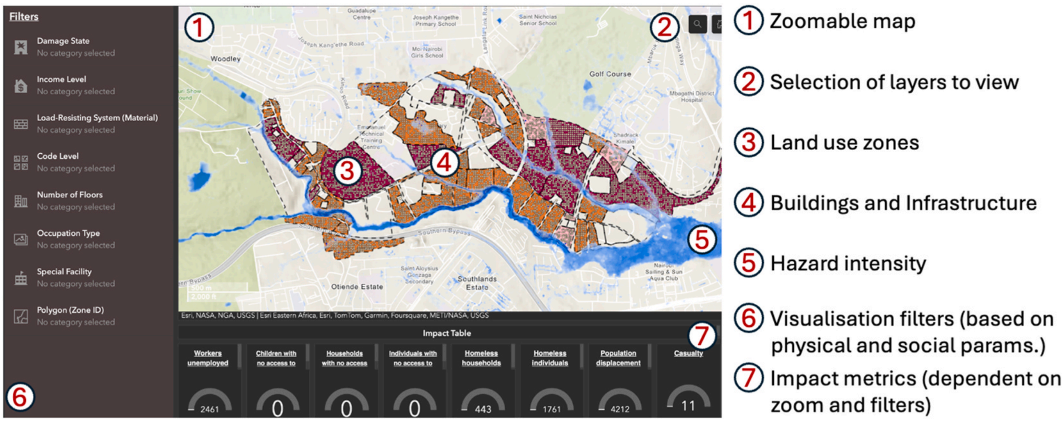

Fig. 6. Instance of the Risk Dashboard (https://experience.arcgis.com/experience/3bd8a991c2164bed9a447a26d217055b/, last accessed November 2024). Note: the available Risk Dashboard implementations will be openly available for the foreseeable future.

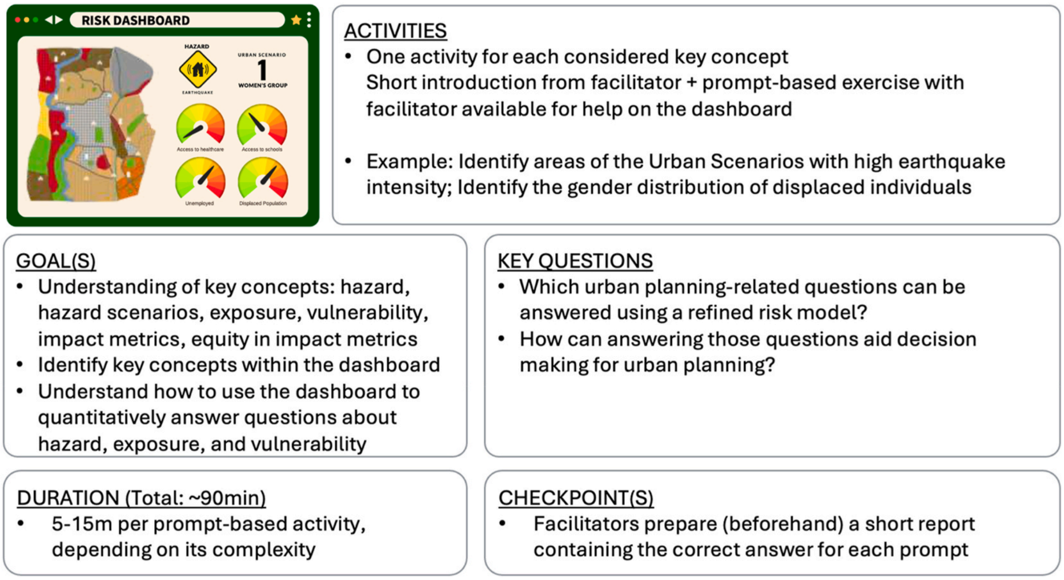

Fig. 7. Risk Agreement, part 1: Tutorial on the Risk Dashboard.

instructions to carry out each prompt.

As an example, the activity referring to “equitable impact” is discussed in detail. It requires the following steps: 1) choosing a hazard scenario and turning on the layer showing the related hazard intensity (e.g., flood depth); 2) let the group identify areas with the highest intensity (i.e., the land use polygon most covered by high flood depth, showed in dark blue in the dashboard); 3) filter the dashboard results for that land-use polygon; 4) inspect the displaced population (and other impact metrics) referring to the all individuals within the selected polygon; 5) inspect the distribution of income (and other socio-economic characteristics) within the polygon; 6) filter the dashboard according to different income levels, and take note of the distribution of displaced population (and other impact metrics) specifically referring to different income levels; 7) compare the distribution of population by income with the distribution of displaced population by income: the closer the two distributions are, the more equitable impact is within this polygon. Similar descriptions are provided in the workshop script.

3.2. Part 2: Appraisals and revisions

The second part of the methodology (summarised in Fig. 8) aims to reveal to the participants the distribution of impact within their Urban Scenarios, to guide a discussion that employs the Risk Dashboard to interpret the drivers of such impact, and design revisions of the Urban Scenarios to mitigate such drivers and consequently reduce impact. At this stage, the participants should have an increased

Table 3
Prompts for each activity within the tutorial on the Risk Dashboard. Note: the definitions are, as much as possible, consistent with the UNDRR nomenclature [18].

Concept	Definition	Prompt
Hazard	Threat with potential to cause harm or damage	Identify areas with high/low hazard intensity. Repeat for at least one hazard scenario per hazard typology
Exposure	Anything that has a value and can be affected by a hazard	Identify the most common building occupancy in a high hazard intensity area. Repeat for material, and other building characteristics. Repeat for socio-economic exposure characteristics such as income, gender, age
Vulnerability	Link between different exposure classes and the impact under a given hazard intensity	Identify buildings in a selected damage state (e.g., flooded/not flooded) within a high hazard intensity area. Identify most common building material of damaged buildings.
Hazard Scenario Frequency	Frequency with which hazard events with similar characteristics recur, on average	Compare number of damaged buildings, within the same selected area, for a high- and low-frequency hazard scenarios (e.g., 1in2-year flood vs 1in100-year flood)
Impact Metrics	Objective measures of the negative effects of a specific hazard event	Identify the number of displaced individuals in a high hazard intensity area. Repeat for other impact metrics. Repeat for the entire Urban Scenario
Equitable Impact	An impact which distributes across a social characteristic (e.g., income) similarly to the distribution of that social characteristic	Identify the number of low-income displaced individuals in a high hazard intensity area. Repeat for other socio-economic characteristics. Repeat for the entire Urban Scenario

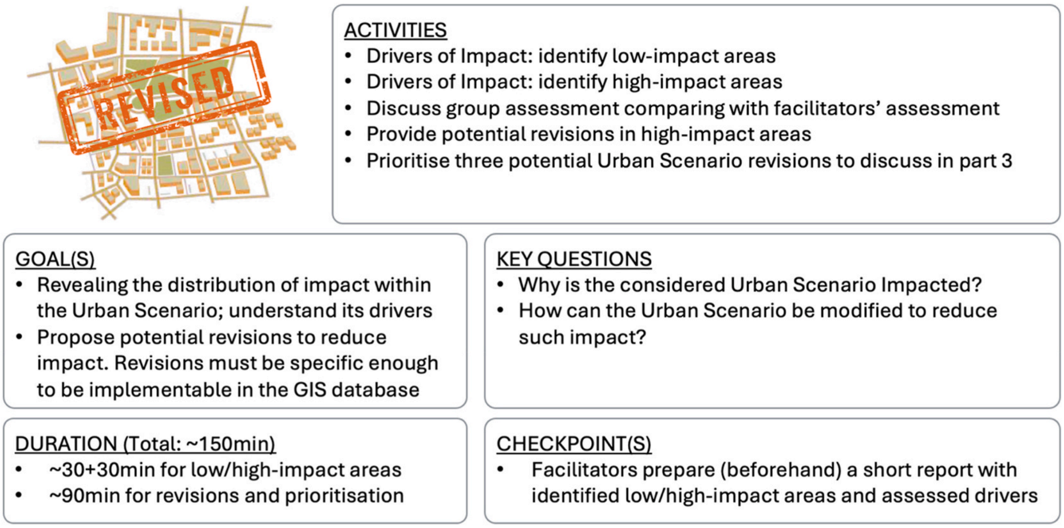

Fig. 8. Risk Agreement, part 2: Appraisals and Revisions.

understanding of the basic concepts and a reasonable level of command on the dashboard. Therefore, they should engage in an open discussion that includes any risk-related question on different areas of the Urban Scenario and use the Risk Dashboard to help answering them (i.e., the activities should be driven by the discussion rather than by a predefined script). To keep the discussion within the desired scope, this process is aided in two ways: 1) facilitation - one social science facilitator acts as a moderator while one facilitator with risk-modelling expertise clarifies any required technical content and takes control of the Risk Dashboard any time the community group asks for it; 2) guiding structure - the discussion is structured in three parts, and it includes guiding prompts to keep the discussion within the desired scope.

The first portion of the discussion (~60min) allows identifying low- and high-impact areas within the Urban Scenario. Most importantly, it is fundamental to identify if such low/high level of impact is mainly driven by a low/high hazard intensity, small/large quantity of exposure (e.g., buildings, population), a particularly low/high vulnerability (e.g., non-compliance to building codes), or a combination of them. Clearly, this "troubleshooting" process is highly dependent on the extent and characteristics of the considered Urban Scenario, as well as the different features of it which are considered within risk modelling (e.g., building, road network, lifeline damage). Although it is not possible to define a standardised way to organise this activity, a guiding procedure for the technical facilitator to identify high-impact areas may involve to: 1) select a Hazard Scenario to focus on; 2) use the Risk Dashboard to visualise all modelled buildings and infrastructure; 3) filter the results only showing the highest damage state (e.g., collapsed buildings, roads, power networks), visually identifying hotspots; 4) filter the dashboard results to a land-use polygon enclosing one such hotspot, and remove all filters; 5) take note of the total population in the polygon and compare it to the total population in the Urban Scenario. Using filters, note the population distribution by income, gender, age, or other desired socio-economic characteristics; 6) take note of the

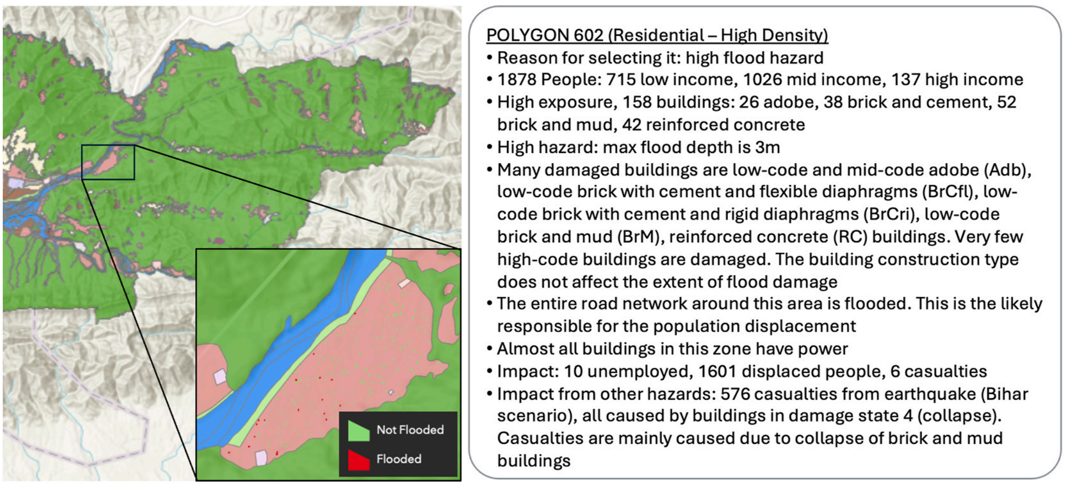

Fig. 9. Example high-impact area assessment (from deployment in Rapti, Nepal).

total number of buildings/infrastructure nodes in the polygon and compare to the total in the Urban Scenario. Using filters, note their distribution by material, height, year built or other desired characteristics; 7) use the hazard layer to identify a representative hazard intensity level for the polygon, and compare it to the maximum identifiable within the Urban Scenario; 8) take note of the population displaced in the polygon, as well as other impact metrics, and compare it to the total within the Urban Scenario. Using filters, note the impact metric distribution by income, gender, age, or other desired socio-economic characteristics.

With a reasonable degree of context-specific modifications defined by the technical facilitator, these general steps allow the community group to identify impact-prone areas and draw connections between policy choices and impact. To further aid this process, and promote a uniform experience to participants, it is suggested that the technical facilitators carry out the above activity before the workshop, collating the identified high-impact areas assessments in a document (Fig. 9 shows an example from the case of Rapti, Nepal).

The identification of the low- and high-impact areas within the Urban Scenario is a fundamental tool to generating a list of potential revisions to reduce such impact, which is the focus of the subsequent discussion within this part (∼90min). Urban Scenario revisions are herein defined as interventions/measures able to influence any aspect of its exposure and/or vulnerability. Revisions may be defined as "spatial", when they specifically target selected land-use areas (e.g., changing the land use type of a specific polygon), physical construction (e.g., changing height or material for a set of buildings within a specific polygon; moving hospitals from one high-hazard to a low-hazard polygon), or people (e.g., changing the distribution of income level within a selected polygon). Common spatial revisions include dams, flood embankments, ocean wave barriers, earthquake-resistant construction, and evacuation shelters. "Non-spatial" revisions may be defined as those not specifically targeting selected features of the Urban Scenario but affecting its entirety. Those normally involve policies (e.g., social housing), laws and bylaws mainly related to urban planning, improvement of building codes and their enforcement, public awareness programmes, training, and education.

Considering that the commonly adopted Urban Scenarios are defined at a scale of hundreds of hectares, and that they involve a granular definition of individual buildings, infrastructure, households, and individuals, several thousand possible revisions may be defined. Therefore, identifying potential Urban Scenario revisions is an activity that cannot follow a structured script and should instead entail an open discussion allowing the group to freely explore possibilities. The social facilitator has a delicate role in this discussion, since they should moderate it to gather possible ideas from the group without introducing bias.

On the other hand, the technical facilitators should emphasise the links between the high-impact areas, and their drivers, to the ideas raised by the group that would be able to address such drivers. Making use of the low-impact areas is fundamental, because it allows designing revisions while conserving the overall population of the Urban Scenario (e.g., moving buildings from a high-impact polygon to a low-impact one). The group should use the booklet (Deployment toolkit [40]: Participants' guiding booklet) to take note of any identified potential revision to the Urban Scenario, without any upper bound limit. To address instances in which the discussion does not naturally lead to solutions, the facilitators should make use of a (previously prepared) set of Urban Scenario revisions included in the facilitators' material (e.g., Deployment toolkit [40]: Facilitators' guide). They can encourage the group resuming the discussion by accepting/modifying/rejecting one of such potential revisions every time the pace of the discussion drops below a desired threshold.

The last step of this activity involves prioritising three potential revisions of the Urban Scenario to be discussed in the next part of the workshop. The facilitators may use any method (e.g., ranking, rating, or pairwise comparison; [44]) to reach group consensus on the three revisions to prioritise. Usually, however, a group-wise ranking method [45] within an open discussion is sufficient. This involves assigning each potential revision with a rank starting from 1 (most important) to n (least important) – where n is the total number of revisions.

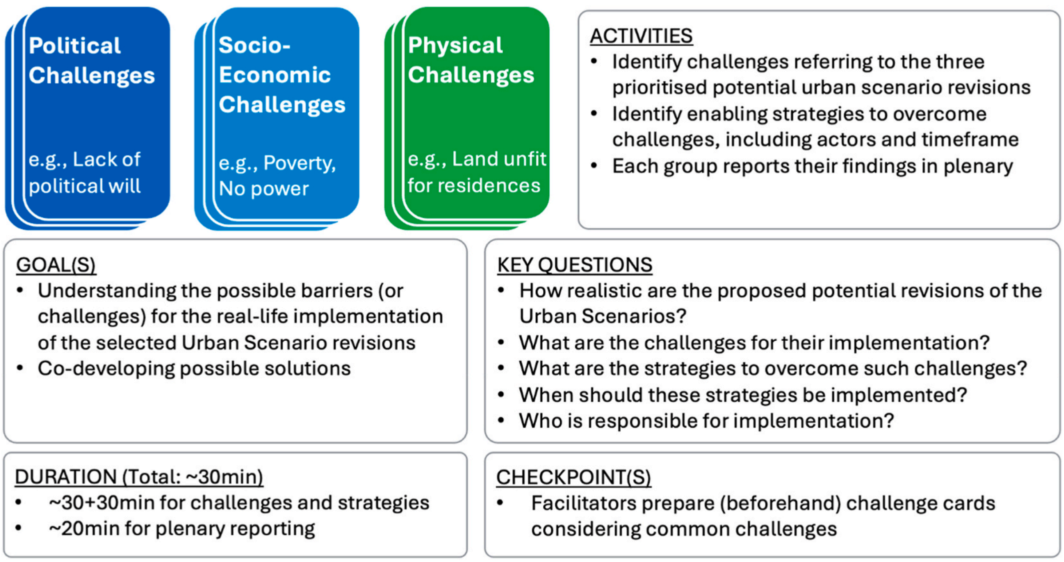

Fig. 10. Risk Agreement, part 3: Policy Implications.

3.3. Part 3: policy implications

The Policy Implication part of the methodology (summarised in Fig. 10) allows to connect the evidence-based learnings obtained using the results of risk modelling with the real world challenges of communities (i.e., interested stakeholders) and local government officials and urban planners (i.e., stakeholders with power in planning and decision-making). The potential revisions of the Urban Scenarios identified in the previous part of the workshop, as well as the Urban Scenarios themselves, are defined for an envisioned future, roughly considering 30 years as a time span. This part of the Risk Agreement methodology allows back casting of three prioritised potential revisions in the present, identifying the real-life implications foreseeable for the implementation of specific Urban Scenario revisions. This is done by focusing on the challenges that can hinder the implementation feasibility of such revisions, and the possible enabling solutions to overcome such challenges. This discussion is driven by community members in disaggregated groups, which are accompanied by one or two urban planners and/or local government officials. Such stakeholders both act as observers of the workshop, so they can include any learnings in their policies, and they are also invited to share their experiences with community members.

The first activity (~30min) focuses on identifying implementation challenges for the three prioritised Urban Scenario revisions. To incentivise a focused discussion, the facilitators use “challenge cards” (Deployment toolkit [40]: Challenge cards) that provide examples of implementation challenges classified as political, socio-economic and physical. The cards should be group-specific, and facilitators should prepare them starting from the general examples listed in Table 4, applicable to all groups within the workshop, while adding any group-specific challenge, if available, recorded in previous community engagement (e.g., those mentioned in Section 2.2 referring to engagements not including any refined hazard and risk considerations). Empty cards should be provided to account for any non-standard challenge identified during the discussions.

This discussion should start with the social facilitator asking the group open questions such as “How realistic are the prioritised Urban Scenario revisions?” or “What are the likely implementation challenges for the prioritised Urban Scenario revisions?”. Open questions allow for the conversation to start freely, and after taking notes of the first general answers of the participants, the facilitator introduces the challenge cards. The group will associate the relevant cards to each prioritised revision, while using the back of the card to provide a context-specific description of the selected challenges. Contributions from the selected government official and/or urban planners will allow a description of the selected challenges with more precision, thus stimulating a two-way transfer of knowledge between the community members and the expert planners. Usually, five or six implementation challenges are identified for each prioritised Urban Scenario revision. The facilitators list the identified challenges on one separate flipchart for each prioritised Urban Scenario revision. As an example, a group may have prioritised an Urban Scenario revision involving the introduction of building-free terraces within 20m of a river within a specific land-use area. Such revision may be accompanied by the challenge of a lack of the political good will to enforce such non-construction policy, as well as lack of accountability in the process of enforcing such policy.

The second activity (~30min) allows the community groups to identify enabling strategies for each identified challenge. This activity takes the form of an open discussion in which the social facilitator considers one challenge at a time, and invites the group to identify the main components of an enabling strategy: solution – identifying how can an implementation challenge may be overcome; responsible agencies – identifying who would be responsible for implementing the solution (e.g., community members, local/national government, civil societies); timelines – identifying if the solution refers to the short- (0–2years), medium- (3–5years), or long-term (5+ years). Considering the above example Urban Scenario revision, a solution may involve the formation of an oversight unit that monitors the terraced areas. The actors involved in such solutions are the community members that would nominate the members of the unit, and the unit members themselves. This is likely a medium-term solution since it requires a constant monitoring of the interested areas.

Table 4
Examples of implementation challenges for Urban Scenarios. The list should be complemented considering challenges (if available) identified in previous community engagements without any refined considerations of hazard and risk.

Political Challenges	Socio-Economic Challenges	Physical Challenges
Lack of political will	Budgetary constraints to policy (e.g., health)	Lack of space for building construction
Corruption	Lack of financing schemes for communities	Poor construction materials
Lack of inclusion in policies	Lack of finances to comply with building codes or ensure high-quality materials	Illegal connection to power lifelines
Lack of inclusion in public discussions	No empowering for specific community groups (e.g., young people)	Resource exploitation
Lack of risk awareness	Lack of land ownership. No rights to land tenure	Large extent of high hazard areas makes risk reduction measures more complicated to implement
Poor implementation of urban policies	Conflicts of interests between owners and tenants	Insufficient recovery (e.g., for agricultural land flooded yearly)
Clashing responsibilities between local and national governments.	Inability of uneducated groups to raise concerns	
Lack of coordination among different authorities	Gentrification	
No affordable housing for low-income groups		
Lack of development plans		
Lack of clarity of government strategies		

At the end of such activities, one spokesperson from each group reports their results in a plenary session (~20min), to allow for cross-group learnings. The reporting from each group should be brief and only include the three identified Urban Scenario revisions, their associated challenges, and the identified solutions to overcome them.

4. Illustrative application: risk agreement in Rapti (Nepal)

The Risk Agreement methodology evolved in the context of the Tomorrow's Cities research project, and it has been deployed in 10 Global South communities around the globe, including Nepal (Kathmandu, Rapti), Kenya (Kibera, Nairobi), Türkiye (Istanbul), Ecuador (Quito), Tanzania (Dar-es-Salaam), Bangladesh (Cox Bazar and Chattogram). The first deployment of the Risk Agreement methodology, in its finalised form described in this paper, took place in Rapti (Nepal). This is the capital city of the Lumbini province (mid-western Nepal), located at the foothills of the Chure mountains and along the banks of the Rapti river. The city encompasses an area of 480 km^2, and it houses 76,194 people (according to the 2021 census; [46]) pertaining to different communities characterized by diverse socio-economic backgrounds.

The Risk Agreement workshop took place at the community hall of the rural municipality office between November 30 to December 1, 2023. The workshop was jointly hosted by the Provincial Infrastructure Development Authority (PIDA), three municipal governments (Rapti, Gadhwa and Shitaganga), and the Tomorrow's Cities research team. The workshop hosted 62 participants including 33 Rapti community members, 6 PIDA representatives (chief executive officer and senior officials), and 23 municipal government officials (Mayor of Shitaganga Municipality, chairpersons of Gadhwa and Rapti rural municipality).

4.1. Community groups and available data

Participants were selected based on a disaggregation strategy emphasising intersections between land ownership and cast or ethnicity [35]. Some groups represented indigenous identities who own most of the land, while others represented marginalised castes. Newly arrived migrants were also included. A consideration of internal diversity against group coherence, intersectionality and gender balance was also a criterion for disaggregation [47]. As a result [47],community members were disaggregated into five social groups: 1) Tharu, or farmers; 2) Pahadi, or migrants; 3) Squatters, or unauthorised inhabitants; 4) Madhesi, or marginalised; 5) Magar (Ethnic), or people from the hills. Moreover, to incentivise encounters between community groups, decision makers and scientists, and facilitate a multi-dimensional transfer of knowledge, a distinct group of planners/institutional actors was also selected for the activities. Each group comprised six to seven participants.

An Urban Scenario was defined for each group. To do so, community members first participated in a co-mapping exercise [47] to define the land-use for their envisioned futures for the capital city, as well as defining desired policies (Table 5). The GIS representations of the Urban Scenarios include road and power infrastructure, buildings, households, and individuals – they can be explored within the Risk Dashboard [48]. They [36]are generated based on collected demographic, socio-economic, and infrastructure data to project development trends over the next 30 years (approximately for 2051), targeting a population of approximately 140,000, obtained linearly extrapolating the 2011 and 2021 censuses [49,50]. Based on data from the Nepal Labor Force Survey 2018 [51] and the Rapti Village Profile [52], the average income distribution categories are classified into very low, low, medium, and high-income groups, respectively corresponding to a monthly income lower than NRs 7600, between NRs 7601 to 13500, between NRs 13500 to 25000, and above NRs 25000 [48].

The scenario-based disaster impact modelling was conducted for earthquakes and floods (reported in Ref. [53]) [53–56].The Risk Dashboard [48] allows exploring the computed earthquake peak ground acceleration and flood water depth for the resulting Hazard Scenarios:

Table 5
Group-selected policies for Rapti (Nepal) qualitatively defined before any refined hazard and risk considerations.

	Policy 1	Policy 2	Policy 3
Ethnic	Policy related to access to housing and employment for Mukta Kamaiya	Policy for construction of earthquake-resistant buildings/infrastructures	Tenant (Mohi) and Unregistered land (Ailani jagga) Management Policy
Madhesi	Policy for economically affordable Building Permit Process (BPP)	"Policies for prioritising conservation of Rapti River and Chure area (Chure is a range of hills in lower himalaya with a very fragile geology)"	Policy to guide the selection and promotion of industrial zones and vehicle/auto village, that aimed at mitigating the problem of youth migration for foreign employment
Pahadi	Policies for distribution of land certificate assuring land and housing right	Policy to ensure free education and health services, and end discrimination	Disaster Management policy including embankment and bridge construction programs to control the flow of seasonal rivers
Planners	Policies for implementing an income and wealth-based approach rather than ethnicity in the risk-resilient social housing program, focusing on the low-income group.	Disaster Risk Reduction and Management Policy and Program	Policy for mandatory access to irrigation on agricultural land
Squatter	Policy for conservation of water sources	Policy for waste management	Policy for construction of green city
Tharu	Building and Infrastructure Development Bylaws	Disaster Risk Management policy	Local landuse policy

1. EQ (1)_**8.2Mw:** An earthquake resembling the 1934 Nepal-Bihar earthquake with epicentre at Rukum with a rupture of about 175 km length and 60 km width at 15 km depth with $8.2M_w$ magnitude
2. EQ (2)_**7.8Mw:** An earthquake resembling the 2015 Nepal Gorkha Earthquake with epicentre near Rukum with a rupture of about 160 Km length and 70 km width at 15 km depth with $7.8M_w$ magnitude
3. EQ (3)_**8.6Mw:** An earthquake resembling the 1505 Earthquake with epicentre near Rukum with a rupture of about 250 Km length and 90 km width at 15 km depth with 8.1 M_w magnitude
4. **FL1_20yr, future, 173 mm:** This scenario assumes that the peak 24-h rainfall for the wider West Rapti catchment is equal to 173 mm, calculated projecting climate change effects 30 years in the future. This results in a flood event that has an estimated frequency of 1/20 years (20-year return period flood).
5. **FL2_70yr, future, 212 mm:** This scenario assumes that the peak 24-h rainfall for the wider West Rapti catchment is equal to 212 mm, calculated projecting climate change effects 30 years in the future. This represents the most likely maximum event to occur in Rapti in the next 70 years.

Impact modelling included earthquake and flood vulnerability models for buildings, transportation and power networks [53], selected according to the procedure in Ref. [39]. The impact modelling procedure in Ref. [54], carried out using the Tomorrow's Cities web app [55], was carried out for each combination of Hazard and Urban Scenarios to compute people-centred impact metrics defined as follows:

- **Number of workers unemployed.** A worker is considered unemployed based on any of the following conditions: the associated workplace is damaged beyond a selected threshold; the associated workplace has lost electricity; the associated workplace cannot be reached from the building that the individual lives in due to a failed transportation network
- **Number of children with no access to education.** A child cannot access education based on any of the following conditions: the associated school is damaged beyond a selected threshold; the associated school has lost electricity; the associated school cannot be reached from the building that the individual lives in due to a failed transportation network
- **Number of individuals/households with no access to hospitals.** An individual/household cannot access their associated hospital based on any of the following conditions: the associated hospital is damaged beyond a selected threshold; the associated hospital has lost electricity; the associated hospital cannot be reached from the building that the individual lives in due to a failed transportation network
- **Number of homeless individuals/households.** Households/individuals associated to a residential building damaged beyond a selected threshold are considered homeless

Table 6
Assessment of high- and low-impact areas provided by the Madhesi group.

High Impact areas	Low Impact Areas
Polygon 320 (as defined in the Risk Dashboard)	**Polygon216**
High-density commercial and residential zone	Medium-density residential zone
Population: 3774; Buildings: 318	Population: 3800; Buildings: 309
Building typologies:	Building typologies:
adobe = 51, brick and cement = 109, brick and mortar = 86, reinforced concrete = 72	adobe = 106, brick and cement = 224, brick and mortar = 154, reinforced concrete = 138
Height: 1 to 5 stories	Height: 1 to 6 storeys
Flood depth: between 1m and 5m	Flood depth: 1–1.5m
53 buildings are flooded. 268 casualties	7 buildings are flooded. No casualties
All roads in the area are flooded	All roads in the area are flooded
Drivers of high impact	Drivers of low impact
High flood hazard intensity	Lower flood hazard intensity
The portion of the Rapti river in the eastern side of the valley is particularly narrow	Most buildings are away from the high flood intensity areas
No green belt/buffer zone is provided to prevent construction in high flood intensity areas	
Polygon 223	**Polygon 214**
Medium-density residential and agricultural zone	Medium-density residential zone
Population: 3201; Buildings: 258	Population: 3179; Buildings: 258
Building typologies:	Building typologies:
adobe = 16, brick and cement = 109, brick and mortar = 65, reinforced concrete = 50	adobe = 42, brick and cement = 95, brick and mortar = 66, reinforced concrete = 55
High code compliance = 120, Medium code compliance = 92, Low code compliance = 46	High code compliance = 138, Medium code compliance = 75, Low code compliance = 45
Height: 1 to 6 storeys	Height: 1 to 6 storeys
Peak ground acceleration: 0.4g, uniform in the area	Peak ground acceleration: 0.3g, uniform in the area
Damage grades (DG): DG2 = 30; DG3 = 91; DG4 = 137.	Damage grades (DG): DG1 = 22; DG2 = 18; DG3 = 137; DG4 = 81.
1163 casualties	685 casualties
No roads are damaged	No roads are damaged
Drivers of high impact	Drivers of low impact
High earthquake hazard intensity	Lower earthquake hazard intensity

- **Number of individuals displaced.** An individual is assumed to be displaced when any of the following condition holds: the associated household is homeless; the individual's workplace, school, or associated hospital is damaged; the individual cannot reach to workplace, school, or associated hospital due to a failed transportation network; the individual's workplace, school, or associated hospital has no electricity
- **Casualties.** Residential buildings damaged according to increased levels (hazard dependent) correspond to increased rates of casualties. Casualties are calculated based on a weighted average of such rates.

4.2. Description of the workshop

Section A.4 summarises the workshop preparation activities and deployment agenda. All workshop activities, as well as the detailed results for each disaggregated social group, are listed in detail in a workshop report [56]. In the context of this paper, results are described for one selected group: i.e., Madhesi. The Risk Dashboard tutorial allowed identifying regions of the Urban Scenario respectively characterized by high and low impact of earthquakes and floods.

Table 6 shows their selected high- and low-impact areas, and the assessments provided by the group, also identifying the drivers of impact. Participants were encouraged to operate the dashboard with the help of facilitators.

The Risk Reveal activities resulted in the following list of potential revisions of the Urban Scenario (while the prioritised ones are listed in Table 7):

- **Revisions to reduce earthquake impact**
  a. Implementation of the building code by the concerned authority for the Rapti city municipalities
  b. Production of the necessary skilled manpower required for the earthquake resistant building construction
  c. Conducting public awareness programs related to earthquakes
  d. Consulting skilled and qualified engineers before constructing houses
  e. Identify the open spaces (for evacuation) in each ward and communicate their to the public
  f. Training the necessary manpower for search and rescue so that they are available during the disaster events
  g. Provision of making the old buildings also earthquake resistant by retrofitting
  h. Regular practice of earthquake preparedness activities
  i. Regular training to masons involved in constructing earthquake resistant buildings.
- **Revisions to reduce flood impacts**
  a. Construction of houses only outside the flood prone areas
  b. Construction of embankment in rivers
  c. Consideration of proper water drainage system during all development works such as road construction
  d. Adopting the alternate agriculture system in the flood prone regions
  e. Avoid political interference in flood control work
  f. Construction of bridges in rivers wherever required
  g. Public awareness programs related to floods
  h. Proper system for flood early warning
  i. Identifying the flood prone areas
  j. Arranging the necessary skilled manpower for search and rescue
  k. Construction of more hospitals and ambulance services so that they are easily availability during floods.

4.3. Feedback from participants and facilitators

Feedback from the participants of the workshop was collected with an evaluation questionnaire, with 37 respondents, including four closed questions and a space for an open review. As shown in Fig. 11a, when asked if they had learned something new, 97 % of participants agreed, and only one disagreeing. With the same statistics, participants agreed that the workshop experience was encouraging and inspiring (Fig. 11b). Similarly, 92 % of the participants stated that their ideas were effectively considered and included in the discussions, with only 3 participants stating the opposite (Fig. 11c). Finally, only two participants stated that the pace of the activities was inappropriate, with one asking for a faster and one asking for a slower pace (Fig. 11d). 95 % of the participants, on the other hand, were satisfied with the pace of the activities.

Finally, Table 8 shows a collection of quotes extracted from the open part of the participants' questionnaires, as well as including the opinions of the facilitators collected during the workshop debrief. The quotes allow to identify several themes that drive the discussion in Section 5: inclusion, effectiveness of the risk dashboard, risk communication and shared understanding of risk, decision-

Table 7
Prioritised Urban Scenario revisions of the Madhesi group, together with identified implementation challenges.

Challenges	Solutions	Responsible actors	Timeframe
Revision 1 Construction of all new houses to be earthquake resistant with priority level as first hospitals, second Schools and then residential building			
Lack of coordination between concerned stakeholders Political interference in the construction industry Lack of risk awareness Financial problems Opinions of low-income people are not listened Lack of skilled manpower in construction Building code not implemented	Coordinate stakeholders Monitor the quality of construction materials Conduct public awareness programs in every ward Provide security loans for low-income people for construction of earthquake resistant buildings Convey problems of low-income people to the relevant bodies Technical training for technicians, workers, houseowners Implement building code	Rural municipalities, wards, public representatives, social workers, non-governmental organizations	Immediately, as soon as possible (short term)
Revision 2 Provision of at least one open space in each ward			
Lack of suitable land	Identify available land and provide land pooling Conduct public awareness program in every ward	Local government, public representatives, political party representatives	Immediately, as soon as possible (short term)
Revision 3 Construction of houses away from flood prone area as per bylaws			
Lack of prioritization to low-income people Population displacement Technical problems in relocation	Identify low-income people and prioritize them during relocation Identify suitable relocation areas Arrange accommodation for displaced households	Local government, public representatives, political party representatives	Immediately, as soon as possible (short term)

impact link, policy implications and reality checks, willingness to contribute to disaster risk reduction, policy influence, and areas of improvement of the workshop. The similarity of opinions of the participant reported in Table 8 constitute fundamental evidence for the discussion in Section 5, with particular reference to the points “shared understanding of risk”, and “decision-impact link”.

5. Discussion and conclusion

This paper presents Risk Agreement, a methodology that engages communities at risk in a workshop to assess scientifically projected impacts of multiple hazards on future urban scenarios and co-develop measures to reduce future hazard impacts. Finally, the methodology enables identification of barriers and enabling strategies to ensure effective implementation of a people-centred, participatory, and risk sensitive future urban scenario. Risk Agreement showcases an active learning environment for the participants of the deployed workshops and the communities in general, also considering the local authorities with responsibility for urban planning. The following points are identified:

- **Inclusion.** Quantified risk is collectively appraised by community members using interactive tools and group exercises. This interdisciplinary approach helps overcoming disciplinary silos as it combines social and physical sciences and integrates urban planning processes in risk reduction. This deliberative and interactive approach fosters the active participation of diverse and underrepresented voices in the appraisal of risk, allowing them to interact with urban planners and risk authorities, with which they normally do not interact
- **Effectiveness of the Risk Dashboard.** State-of-the-art risk modelling results are communicated to community members in a simple and user-friendly manner using the Risk Dashboard. This helps visualising the spatial distribution of disaster impacts and identify high-risk areas for different hazards. The interaction among scientist and community members validated the computed results and supported decision-making. The results show that participants can gain command of the dashboard regardless of their education level and experience/knowledge in disaster risk assessments. The dashboard allows learning new skills, including identifying disaster-specific revisions of the Urban Scenarios to reduce the predicted impact
- **Shared understanding of risk.** The understanding and perceptions of risk varies amongst diverse city stakeholders and communities. By using a scientific evidence base, interactive exercises in a native language, and locally relevant examples, the methodology assists diverse stakeholders to collectively co-develop a shared understanding/definition of risk, which is rooted in state-of-the-art modelling results, as well as being sensitive to the diverse risk perceptions of the community. This helps creating a collective sense of responsibility in making a risk safe urban future

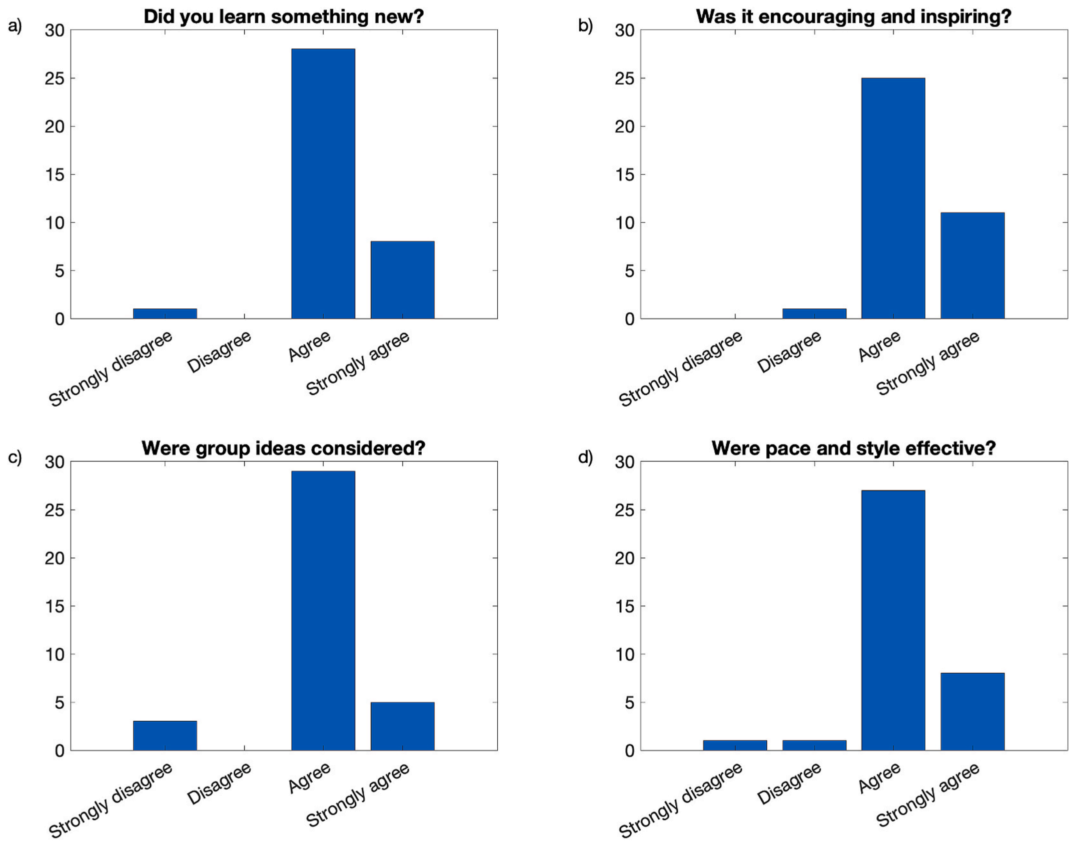

Fig. 11. Participants' evaluation questionnaire.

- **Decision-Impact link.** Risk Agreement enables participants to identify connections between different choices or decisions (e.g., on urban plans or social policies) and predicted future impact using people-centred impact metrics (e.g., human displacement, lack of access to education or health). Understanding this connection enables participants to design focused disaster reduction measures to reduce impact in their future vision for their city, demonstrated by the designed revisions of the Urban Scenarios.
- **Policy implications and reality checks.** Discussing the real-life implications of implementing the designed impact-reducing revisions of the Urban Scenarios allows participants to go beyond the assumptions of the adopted risk models and connect such revisions to practical societal issues. The methodology allows participants to feel empowered and responsible of their opinions, as those are considered to ensure effective implementation of urban plans
- **Willingness to contribute.** The methodology improves the awareness of the community of the need for integrating disaster policymaking in urban planning and the influence of public involvement. The workshop activities improve the commitment of community members to work together to create a safer and more resilient urban environment by adhering to regulations
- **Policy influence.** Although the proposed methodology is standalone, it has been conceived within the Tomorrow's Cities decision support environment (TCDSE), which facilitates a people-centred, participatory approach to risk-sensitive and pro-poor urban planning for the future. In this context, Risk Agreement has been deployed in 10 global South communities around the globe, including Nepal (Kathmandu, Rapti), Kenya (Kibera, Nairobi), Türkiye (Istanbul), Ecuador (Quito), Tanzania (Dar-es-Salaam), Bangladesh (Cox Bazar and Chattogram). By providing a scientific knowledge-base and techniques for multi-stakeholder participation (e.g., urban planners, risk authorities and communities at risk), Risk Agreement contributed generating concrete policy opportunities. The described deployment in Rapti influenced the master plan of the city. provides and collaborative decision-making
- **Implementation barriers.** The implementation challenges identified through the Risk Agreement workshops (e.g., lack of political will, institutional fragmentation, limited technical capacity, and unequal access to decision-making) align with those reported in prior research on participatory disaster risk governance. Studies have shown that even when participatory methods are adopted, their effectiveness can be undermined by structural and contextual barriers that limit the translation of collective insights into actionable policy [57]. For example, research highlight a how the integration of social innovation in disaster mitigation planning is frequently constrained by bureaucratic rigidity and uneven stakeholder agency. Similarly, in our deployment, the transition from community-generated revisions to institutional implementation was often hindered by a lack of inter-agency coordination and practical enforcement mechanisms. However, by explicitly identifying the implementation barriers, coupled with co-developed enabling strategies, represents a critical advancement of the Risk Agreement methodology in bridging the gap between

Table 8
Selected quotes from workshop participants.

Participant role	Theme(s)	Quote
CEO, Local authority	Policy influence; Inclusion	*We are planning the new provincial capital city of Rapti and the collaboration with Tomorrow's Cities provides an opportunity, not only to work with international experts, but also to deploy a framework that includes the voices of the residents in shaping our provincial capital. Together we will build a safer Rapti*
Community member, Male	Risk communication; Decision support	*The most important aspect of this workshop is that it incorporated all information about prevailing disaster risks of Rapti in a single system and bringing out the solution of it, so that the data can be used for planning purpose and overcome the disasters*
Community member, Female	Inclusion; Risk communication	*We made visions and urban plans for our group, but risk will affect all of us in Rapti, so we need to work together. This workshop changed the way of thinking on disaster risk, urban planning and policy implementation*
Community member, Male	Policy influence; Risk communication	*With the use of dashboard, the places which are badly affected by floods and earthquake are well known. We learnt new things* e.g., *locations where there are high possibilities of risk, to develop risk maps etc*
Facilitator, Female	Risk communication; Dashboard effectiveness	*The dashboard was quite helpful. Many participants had never even touched a computer, so they struggled a little at first, but after some time they felt confident using the dashboard*
Community member, Female	Reality check; Policy influence	*I learnt how and who will ensure implementation of mitigation measures in a time frame. Development of policy and action for the mitigation of disaster/risk was useful to share as next steps with governments*
Community member, Male	Evidence-based discussions; Decision support	*Discussions done without refined consideration of hazard and impact allowed people to come up with all kinds of policies to make a good city, but the difference in the policy discussion this time was it was disaster specific and action-oriented*
Community member, Male	Reality check; Policy influence	*Second day policy discussion was very effective and important as it helped us to find out the possible ways to implement mitigation measures*
Community member, Female	Inclusion; Risk communication	*My thoughts were taken into consideration. With the use of this process, I can say what I have understood risk in my community*
Local authority, Male	Inclusion; Risk communication; Decision support	*I found the workshop very inclusive. The program has made sure that there is participation of all the parts of society irrespective castes and languages*
Community member, Male	Decision support	*We as a community must make Rapti safe from disasters like earthquake and floods, as risk affects all of us*
Urban planner, Male	Risk communication; Policy influence; Inclusion; Dashboard effectiveness	*This has been a very good workshop from the learning point of view. We need to have another workshop with 20 key personnel including representatives from PIDA, municipalities, provincial ministry and one person representing each disaggregated group to work on the Dashboard and the doable iterations*

participatory analysis and policy influence. Future work, currently under preparation, will provide a comparative synthesis across multiple city contexts, allowing us to deepen our understanding of systemic obstacles and identify transferable lessons for fostering institutional uptake of community-driven DRR strategies.

The Risk Agreement methodology effectively provides agency to marginalised groups for improved communication with urban planners in disaster risk reduction decision-making. Nonetheless, improvement opportunities are identified, calling for further research. Many participants expressed the need to enhance the dashboard features, especially deploying the interface in the relevant local language to ensure more active interactions. Some groups, especially urban planners, expressed the need of a dashboard learning toolkit and a pre-workshop training session. The facilitating team felt more time could be spent on further refining the strategy for effective risk communication. Despite the initial difficulties in using the dashboard, internet connectivity issues, and language barriers, participants adapted well to the methodology, which fostered productive discussions.

Moreover, while the Risk Agreement methodology significantly enhances inclusion by promoting dialogue between disaggregated community groups and decision-makers, it does not engage participants in the co-construction of foundational categories such as hazard typologies, vulnerability dimensions, or impact metrics, which are defined a priori by technical experts. Consequently, participation is situated along the 'consultative' or 'co-appraisal' end of the participation spectrum, rather than reaching levels of full co-creation or co-action [58]. As discussed in the literature, participatory approaches vary widely in their intent and structure, from informing and consulting to truly co-producing knowledge and decision-making [59,60]. Risk Agreement takes meaningful steps toward democratising access to risk information and fostering agency among historically marginalised groups, but further methodological refinement would be needed if a new framing of the concept of risk is seeked. Future deployments could expand the participatory scope to involve communities in the conceptual and modelling stages of the process, allowing them not only to react to predefined risks but to help define them.

Building upon this reflection, we further clarify that we define inclusivity as the deliberate design of decision-making spaces that ensure the meaningful, equitable participation of diverse social groups, particularly those historically marginalised in urban planning and disaster risk governance. In this regard, our approach actively seeks to address internal power asymmetries between participants. By organising stakeholders into disaggregated social groups such as by gender, caste, ethnicity, income, or migration status, the Risk Agreement methodology enables more balanced discussions and reduces the risk of dominant voices overriding others. This is complemented by the neutral interface of the Risk Dashboard, which facilitates evidence-based and accessible interaction with complex risk modelling outputs. Together, these features help operationalise inclusivity not merely as the presence of diverse participants, but as their structured influence within the process. While the methodology does not yet fully achieve co-creation, it represents an intentional shift toward more equitable participatory practice within the constraints of scientific modelling workflows.

CRediT authorship contribution statement

Roberto Gentile: Writing – original draft, Supervision, Project administration, Formal analysis, Conceptualization, Methodology, Data curation, Writing – review & editing, Visualization, Software. **Tanvi Deshpande:** Conceptualization, Writing – original draft, Methodology, Writing – review & editing, Project administration, Formal analysis. **Erdem Ozer:** Data curation, Software. **Sukirti Amatya:** Investigation, Project administration. **Nisha Shrestha:** Investigation, Project administration. **Ramesh Guragain:** Project administration, Supervision. **Mark Pelling:** Project administration, Conceptualization. **Hugh Sinclair:** Project administration.

Ethics

This research has been conducted in compliance with the ethical procedures of the institutions of the authors. The ethical approval related to the deployment workshops was obtained at University College London.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Practical deployment considerations

Three phases may be identified when applying the Risk Agreement methodology in a selected community (Fig. 12): 1) pre-workshop activities, involving the identification of the facilitators team and their training, the contextualisation of the methodology with appropriate collection of the required data, the logistic preparations and planning of the workshop, the engagement with participants to invite; 2) deployment of the workshop, with facilitation and MEL activities (monitoring, evaluation, and learning); 3) post-workshop analysis and reporting. This section includes several references to aid material useful for planning and deploying the workshop, which is collated in a deployment toolkit and stored in an online repository [40].

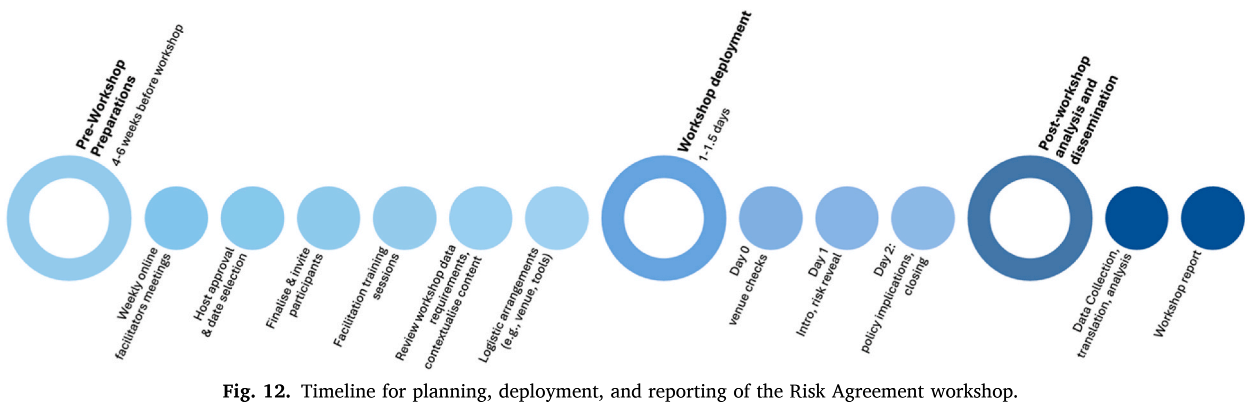

Fig. 12. Timeline for planning, deployment, and reporting of the Risk Agreement workshop.

A.1 Pre-Workshop Activities

The pre-workshop preparation should start four to six weeks before deployment, and it is aided by a workshop preparation checklist

(Deployment toolkit [40]: Workshop checklist). Weekly meetings should involve a team composed of a lead deployer and two facilitators per community group: one *technical facilitator* must be specialised in risk modelling, taking a leading role in activities mainly involving the risk dashboard; one *social facilitator* must be specialised in social science, leading all the discussions in a fair and unbiased way. Before the first preparation meeting, all facilitators must be sufficiently familiar with the Risk Agreement methodology. Apart from using this paper, they should review the extensive material part of the Tomorrow's Cities capacity strengthening related to Risk agreement, which takes the form of recorded video lectures [61] and a report [62]. The first weekly meeting should only involve a question-and-answer session on the methodology, in which facilitators can clarify any doubts by asking questions to the lead facilitator (assumed to be more knowledgeable on the methodology).

The next 1:2 meetings should instead focus on contextualisation. Indeed, the activities of the Risk Agreement methodology are flexibly designed to be applicable to any geographical context (with particular emphasis to Global South contexts). Before deploying the workshop, however, some contextualisation is needed to render the activities locally relevant and directly relatable to the workshop participants. The first common form of contextualisation involves shaping the activities around local data (Section 2.2), thus ensuring that: 1) disaggregated social groups are defined, and contact details of the participants are available; 2) a GIS definition of an Urban Scenario for each group is available, including the definition of land use, infrastructure, buildings, households, and individuals; 3) one or more Hazard Scenario is defined, and the related hazard intensity fields are available; 4) disaster impact modelling is performed for each combination of Urban and Hazard Scenarios; 5) all the above data is encapsulated in a Risk Dashboard. It is worth repeating that any analysis methodology compatible with Section 2.2 may be chosen, but for simplicity it is suggested to adopt the TCDSE computational engine and its webapp (webapp.tomorrowcities.org, last accessed November 2024) which provides compliant results. According to the specific groups and datasets, the provided template workshop material must be fine-tuned accordingly.

At this stage, facilitators (and especially technical ones) should familiarise with the available risk modelling results, as well as gain sufficient command of the Risk Dashboard. In doing so, they should review the results to anticipate participants' questions related to relevant hazard, exposure, and vulnerability of their Urban Scenarios. To aid a systematic review of the results, a template for a *modelling debrief* document is provided (Deployment toolkit [40]: Debrief document). This includes:

- A link to the Risk Dashboard
- General characteristics of the available Urban Scenarios, such as the disaggregated groups they are defined for, their total population, the policies they include (similar to those in Table 2). Any other notes may be added, such as the team members responsible for developing any involved dataset
- An overview of the main risk modelling assumptions
- Exposure information, including: all possible land-use classifications for the Urban Scenarios; all possible building classes (with their material, height, etc.); all possible infrastructure classes (with their typology, material, etc.); all possible values for the social characteristics (e.g., ranges for age, gender, income levels)
- Hazard information, including: a brief description of the considered Hazard Scenarios, including the hazard event characteristics (e.g., earthquake magnitude and epicentre location), their characterised frequency (e.g., 1in1000 year earthquake), the computed intensity measures (e.g., peak ground acceleration) and their range values
- Vulnerability information, including: damage state definitions for buildings (e.g., no damage, slight, moderate, extensive, and collapse damage states); damage states for special facilities (e.g., accessible or not accessible hospitals or schools); damage states for infrastructure (e.g., functional or not functional power generator)
- Impact metrics information, including their definition and their range values for every combination of Urban Scenario and Hazard Scenario
- Predefined Urban Scenario Assessments, including three identified low-risk land-use polygons and three identified high-risk ones. For each Urban Scenario and each identified polygon, an assessment similar to the one in Fig. 9 should be provided, also including some identified Urban Scenario revisions to reduce the detected impacts.

The second common form of contextualisation involves deploying the workshop in a relevant local language, translating the workshop material accordingly, as well as adopting locally relevant examples within the slides (e.g., using the 2015 Gorkha earthquake for deployments in Nepal).

Contextualising the methodology allows gaining a better understanding of the number and typology of participants, as well as a detailed understanding of the required time for the activities (which, among others, depends on the number of considered Hazard Scenario). Once such information is available, the planning of the workshop can take place, usually involving 2 to 3 facilitators weekly meetings. First, the team should decide on the overall length of the workshop, with mainly two options: a two-day deployment, with the first day usually involving some opening activities, part 1, and portions of part 2; a condensed one-day deployment. Accordingly, the time of the workshop should be selected considering the specific availability of the participants to invite (e.g., choosing a weekday or the weekend; starting in the morning or in the afternoon; avoiding public holidays). In defining the workshop agenda (with a template provided in the deployment toolkit), the facilitators team should accommodate for opening activities (∼1–2 h) involving: 1) representatives of the authorities (e.g. mayor, ministry representatives) addressing the workshop participants and introducing the importance of the workshop to local urban planning; 2) a plenary session in which the methodology for defining the Urban Scenarios is introduced, as well as the common modelling assumptions adopted for the risk modelling approach. With tentative decisions on the above, local authorities should be informed and invited to host the workshop and participate in the activities, to foster an inclusive co-development stage able to influence future urban planning. Moreover, participants within the community groups should be invited. If needed, changes to the date and/or the duration of the workshop should be made to maximise the participation of both local authorities and participants.

The workshop logistical requirements first include a suitable venue, which could be a public space managed by the relevant local authorities. To accommodate the Risk Agreement activities, the venue should:

- be accessible by all participants
- accommodate one table for each disaggregated social group
- accommodate any activities in plenary (e.g., opening activities, results reporting)
- have a stable electricity source, with reasonable back-up generators to be used in case of power cuts
- have a stable internet connectivity
- have a space for any served catering, including coffee breaks and/or lunch

Each disaggregated social group within the workshop needs the following equipment: one laptop to run the Risk Dashboard, one large screen or projector to facilitate group interactions through the Risk Dashboard, one audio recorder to store the group discussions, one guiding booklet to take notes in parts 1 and 2, stationary and one flipchart to take notes in part 3. Further printable material includes name badges for the participants and implementation challenge cards, which could be defined based on the provided templates in the deployment toolkit.

At the end of the workshop, it is suggested to adopt two available monitoring, evaluation, and learning (MEL) tools: 1) a feedback form for facilitators (Deployment toolkit [40]: Facilitators' feedback), allowing to highlight good practices and challenges in the deployment; 2) an evaluation questionnaire for participants (Deployment toolkit [40]: Participants' evaluation), allowing to test the effectiveness of the methodology on the policy discussions and influencing the risk perception of the community.

A.2 Suggestions for Deployment

The day before the workshop should be dedicated to a general mock-up of the workshop. On the one hand, this allows checking that the venue has been prepared and organised effectively, and the equipment needed for the workshop activities is tested. On the other hand, a complete walkthrough of the methodology allows resolving any final doubts of the facilitators, thus ensuring a uniform facilitation experience for all the involved disaggregated social groups.

The workshop should be equipped with a reception desk, where participants can register their presence, sign a consent form for personal data treatment, including photography during the workshop (a template is provided in the deployment toolkit). Moreover, the facilitators' slides (Deployment toolkit [40]: Facilitators' slides) should be printed and made available for each disaggregated social group, as well as the participants' guiding booklets (Deployment toolkit [40]: Participants' guiding booklet). To aid a standardised reporting of the activities, a specific guideline for the workshop photos is provided (Deployment toolkit [40]: photo template), also showing examples. The group discussions should be recorded and transcribed (and translated, if needed) after the workshop. Those should be stored in conjunction with any notes taken by the facilitators (notes should be taken by the facilitator that is not leading the specific activities; i.e., the social facilitator in parts 1 and 2, the technical facilitator in part 3). At the end of the workshop, the abovementioned MEL instruments should be adopted.

A.3 Post-Workshop Analysis and Reporting

After the workshop is concluded, a debrief session for facilitators is strongly advised. Debriefing provides an opportunity to consolidate key insights and learnings in a cross-learning environment, evaluate the effectiveness of the sessions, identify areas for improvement, and ensure continued success throughout the workshop series. An integral part of the debriefing meeting is the collection and organization of all workshop materials, including flip charts, sticky notes, challenge cards, facilitators' notes, photographs, videos, participants' feedback forms.

An effective debriefing session is the first key step towards workshop reporting. A template for the workshop report is provided (Deployment toolkit [40]: Workshop report). Apart from general introductory information about the chosen community and the context of the deployment, the contents of the report should include a list of the participants and their groups, a description of the adopted Urban and Hazard Scenarios, a description of the workshop proceedings. Most importantly, the report should include a consolidated analysis of the outputs and learnings obtained within the workshop, both separately for each disaggregated social group, and with a comparative analysis. The report should indicate the impact generated through the deployment, for example on the local urban planning, as well as any challenges faced in the deployment. An example of such analysis is provided in Section 4.

A.4 Planning, training and deployment agenda in Rapti, Nepal

The preparations for the Rapti deployment started four weeks before the workshop, involving weekly online meetings of a team composed of two facilitators per disaggregated social group, one lead planner, and two lead facilitators. Team members belonged to UK and Nepal research teams from National Society for Earthquake Technology, Nepal (NSET), Centre for Disaster Studies, Institute of Engineering, Tribhuvan University (CDS), Southasia Institute for Advance Studies (SIAS), Practical Action Nepal (PA) and Nepal Development Research Institute (NDRI). Consistently with Section A.1, these meetings involved identifying participants, identifying facilitators and training them, fine-tuning the workshop agenda and facilitators' slides, translating all workshop material in Nepali, and logistical preparations (e.g. venue, IT equipment's, and stationary). The team coordinated with government authorities to seek necessary permissions and invite officials. Facilitators pre-assessed the impacts on the Urban Scenarios, compiling a report (Deployment toolkit [40]: Facilitators' guide) on the identified low- and high-impact areas and provided assessments similar to those in Fig. 9.

Given the presence of six disaggregated social groups, and the use of five hazard scenarios pertaining to two hazard types, the workshop was deployed in one and a half days, with the first day having morning and afternoon sessions, and the second only including a morning session. The day 1 workshop activities first involved a welcome and introduction session, approximately lasting 60 min. This plenary session featured: 1) comments from key government and planning authorities (Appendix A.4.a), including the PIDA chief executive officer (CEO) and Mayors of three municipalities); 2) a general introduction of the available Urban Scenarios and impact modelling results by Tomorrow's cities members (Appendix A.4.b); 3) a general introduction of the Risk Agreement methodology and the workshop agenda. The subsequent sessions involved the Risk Dashboard tutorial (Appendix A.4.c – 60 min) and the Risk Reveal (Appendix A.4.d – 180 min). After a quick recap of the learnings of day 1 (15 min) the day 2 activities involved the Policy implication session (Appendix A.4.e – 240 min), which also included the prioritization of three selected Urban Scenario revisions, and finally a session to share the group results in plenary (Appendix A.4.f – 60 min). A closing session was facilitated by PIDA representatives and was attended by representatives from NDRRMA, municipal government and TC researchers.

Fig. 13. Workshop timeline: a) Plenary addressing from authorities; b) introduction to available results; c) tutorial on Risk Dashboard; d) Risk Reveal; e) Policy Implications; f) results sharing.

Data availability

All adopted data is shared through links within the document

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