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The role of forensic investigation in systemic risk enquiry: Reflections from case studies of disasters in Istanbul, Kathmandu, Nairobi, and Quito

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ABSTRACT

The systemic nature of risk is increasingly acknowledged within scholarship, policy and practice relating to disaster management. However, a number of conceptual and methodological challenges arise in advancing empirical inquiry in this regard. These challenges relate to how the boundaries of the system are determined both spatially and temporally, how expertise from across disciplines is integrated to allow for consideration of institutional and broad socio-economic drivers of risk in addition to physical drivers, and, crucially, how causality operates within system complexity. The potential of forensic investigations of disasters that typically deploy in-depth case studies to overcome these obstacles is evaluated on the basis of causal mapping with experts from a range of disciplinary backgrounds in Istanbul, Kathmandu, Nairobi and Quito. It is found that such investigations can serve to interrogate the fundamental value of any given system and its spatial and temporal bounds, generate collective mental models of the system from which risk emerges, and drive reflection on its root causes. However, it is critical that forensic investigation approaches carefully consider participant selection and facilitation in order to effectively operationalise the systemic risk concept in complementarity with other approaches.

1. Introduction

The systemic nature of risk is increasingly acknowledged within scholarship, policy and practice relating to disaster management [41]. Systemic risk can be distinguished from conventional approaches to understanding risk that tend to presume linear relationships between cause and effect and tend to unduly bound both temporally and spatially the contexts from which risk arises. The concept thus challenges well-established approaches that seek to assess or govern risk by addressing individual elements of a system or sub-systems in isolation [49]. The systemic nature of risk is based on the notion that the drivers of risk, for instance a governance intervention, response action or a hazard event, depends on how the elements of the affected systems interact with each other [25]. These interactions either lead towards system stability or instability, creating the potential for cascading impacts on system elements that are distant in time or space from the first impact. Such interactions are less amenable to traditional risk assessment due to the latter's emphasis on prediction and control over the recognition of deep ambiguity and uncertainty ([40]: 55).

The introduction of the systemic risk concept into the disaster management field has the potential to significantly benefit from the extant work focusing on the structural or root causes of disaster. There has long been recognition of the need for further contextualisation of the causal roots of disasters within broader social, economic and institutional arenas ([13,26]; [39]: 227). The forensic investigation of disasters (FORIN) approach highlights the centrality of systemic conditions or root causes of risk, together with intervening pressures, in generating unsafe conditions [30,42]. It involves the investigation of disaster events beyond their immediate impacts to uncover the structural conditions and drivers of vulnerability and exposure. Ultimately, the FORIN approach aims to institutionalise causal investigation within disaster risk reduction practice [26]. A key part of achieving this objective is

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through the production of in-depth case studies of disaster events.

Despite similarities between the endeavours of understanding systemic risk interactions and forensically investigating the root or structural causes of disaster, there are important differences in focus. Systemic risk principally concerns the interactions between risks and their impacts. In contrast, FORIN emphasises the drivers of social vulnerability and the integration of concepts of social vulnerability into risk analysis. It thereby regards risk and disasters as a problematic of development, where the causes of risk lie much more in the domain of governance and social interaction. The analysis of systemic risks has yet to fully engage with the influence of multi-scalar governance and political context on the interaction of risks, impacts, and responses. Nonetheless, FORIN and other approaches to understanding risk root causes have been critiqued for needing to adopt enhanced methodologies for understanding the role of systems and system interaction in generating risk [43]. The key challenge is to therefore render the interacting physical, social and institutional systems that give rise to risk more readily amenable to empirical inquiry.

The paper firstly outlines the conceptual and methodological obstacles to successful engagement with the root causes of systemic risk within the field of disaster management. It then proceeds to evaluate the potential of long-standing forensic approaches in overcoming these obstacles. In this vein, the use of a causal mapping method within a FORIN-oriented project is discussed and the implications for understanding the systemic nature of risk is considered. The practical efficacy of similar methods in overcoming these obstacles is then evaluated.

1.1. Conceptual and methodological challenges to engagement with systemic risk

While the value of the turn towards systemic risk is not in doubt, the state of systemic risk science is still primordial ([53]: 19; [41]: 146). Extant scholarship concerning social-ecological systems offers a potential entry point for understanding how situated, adaptive, diverse individuals as well as materials interact to produce higher-order structures that result in self-organisation and emergence ([4,29]: 22). Studies of complex systems incorporating a social science alongside a natural science dimension encounter a challenge of reconciling the distinct ontologies and epistemologies presented by the social and natural worlds ([46]; [28]). This reflects a wider ongoing discussion within the literature concerning how studies of complex systems are best operationalised [22,28]. It is thus increasingly recognised that new strategies are needed to render the concept conducive to investigation ([47]; [48]).

Against this backdrop, a forensic approach to systemic risk has the potential to transcend a number of fundamental inter-related conceptual and methodological challenges encountered by the introduction of the systemic risk concept to the field of disaster risk reduction. Key conceptual challenges concern the value to be accorded to any given system and the extent to which it is to be bounded both in time and space. Conceptually, the discussion of systemic risk to date has largely eschewed such a priori questions. For example, what value is to be accorded to the system of interest, i.e., do all systems need to be protected from risk? If not, which systems need to be protected from risk and why? Such questions prompt essential probing around what systems or aspects of systems can or ought to be allowed to fail in order to enhance the longer-term sustainability of other systems or sub-systems. Assessment of system continuity or failure is ultimately not free from considerations of value. Human value judgments are fundamentally and inescapably brought to bear in discerning how risk manifests within the system. Determining the system to be valued is an a priori matter, one imbued with considerable ethical and political significance and carries important methodological implications. Statistical modelling approaches tend towards reliance on researcher and/or elite stakeholder judgment in the construction of models to assess risk and are ultimately agnostic as to the value of the continuity or failure of systems. In contrast, in-depth FORIN case studies have the capacity to elicit perspectives of diverse research participants concerning the value of the continuity or failure of systems and to interrogate habitual or implicit understandings ([41]: 81–91).

A further, related conceptual challenge that the turn towards systemic risk raises concerns the extent to which the relevant system can or ought to be bounded both spatially and temporally. The systemic risk concept as it has been deployed within the disaster risk reduction field to date emphasises relationships across time and space and the embeddedness of systems within wider systems [43]. As such, the systemic risk concept presumes the openness of systems. This reflects the origin of the concept in the realm of finance, whereby the embeddedness of financial systems within a global one is emphasised. It is often deployed in relation to large-scale challenges such as the global financial crisis of the late 2000s or the prospect of multiple breadbasket failure [40]. These systemic risks cascade downwards to the local level and processes at the local level carry implications for risk at higher levels. Modelling approaches within this context tend to be reliant on the subjective judgment of the researcher concerning the variables to be included within the analysis [44]. Forensic and other similar approaches on the other hand facilitate greater openness to learning about the properties of systems ([41]: 83). As such, they are coherent with an open system understanding insofar as they do not carry preconceived assumptions concerning the spatial and temporal origins of risk; a disaster event is taken as a starting point and the causes of risk are traced backwards in time and space with no pre-determined end point. While some systems approaches such as complexity science or soft systems methodology have emphasised the epistemological constraints imposed by the very nature of the complex environment [6,37], certain other extant fields of relevance such as system dynamics assume system boundaries in order to allow for the construction of models. Assumptions around the existence of system boundaries and how such boundaries are drawn carry significant methodological implications for the assessment of systemic risk.

A further conceptual challenge to both systemic risk investigation and forensic investigations of disaster root causes relates to the nature of causality within the system of interest. A key feature of complex systems is emergence, the primary means by which system change occurs [35]. Emergence arises from the synergistic and/or antagonistic interactions between elements, positive and/or negative feedback loops, indeterminate delay periods between cause and effect, as well as intervening variables [36]. The process of emergence contrasts with linear understandings of cause and effect. It challenges extant approaches to conceptualising the origins of extreme events, in particular concerning how the drivers of disaster risk interact and are manifested in time and space. While the introduction of a systems approach provides a more sophisticated understanding of the ontological nature of risk pathways, it potentially further complicates the epistemic challenge of explaining causality [50]. This arises as a result of the emphasis that is placed on emergent system properties in explaining change. Such properties can include risk propagation (the triggering of several risk drivers by a single risk driver), risk concatenation (the amplification of risk through the combination of risk drivers), in addition to feedback loops and delays between cause and effect [14]. These properties eschew the linear causal relationships upon which Humian experimental methods rely and militate in favour of more relational, open-ended and collaborative approaches ([41]: 89–90).

A further conceptual challenge posed by systemic risk stems from the recognised need for multiple lines of evidence in order to ensure adequate assessment (Sillman 2021). Increased attention to complexity and the recognition of emergence as the basis of change demands approaches to understanding risk drivers that integrate the physical and social sciences from planning through data collection, analysis, reporting and learning [26,36]. Following other frameworks for investigating disaster causation [14,26], risk drivers can be categorised broadly in line with the 'social domains of disaster responses' outlined by Hilhorst ([16]: 37): the technical-scientific disaster management domain (physical drivers), the bureaucracy of disaster governance (governance-institutional drivers), and the local knowledge and coping strategies of communities (socio-economic). Each of these domains ought to be considered in light of the turn towards systemic risk.

Firstly, approaching the physical drivers of risk through the lens of systemic risk demands greater attention to the interactions between hazards across time and space. A systemic risk perspective draws attention to the complexity that arises from interaction between hazard types as well as from recurrent hazards. It is recognised that multi-hazard interaction and recurrent events can have a cumulative effect upon the wider system that exceeds the sum total of their primary impacts [14]. Nonlinear processes can thereby lead to amplified secondary impacts [31]. Secondly, the role of governance arrangements and institutional drivers in determining disaster risk has been well recognised within policy and the scholarly disaster risk reduction literature [26]. Within the broader risk assessment literature there is an increasing shift away from the mechanics of risk assessment to understanding the embeddedness of risk analysis within wider social and institutional processes [21,24]. There is a shift in scholarship and policy rhetoric, if not always in practice, towards a differentiated responsibility and deliberation in which expertise, experience, and tacit knowledge are integrated, forming the core of legitimate collective decision-making concerning risk. A systemic risk approach endorses these developments. Complexity requires multi-faceted, inter-disciplinary inquiry and governance arrangements that are inclusive, exploratory and dynamic, and that are equipped to respond to uncertainty and emergence [4]. Horizontally, the central role of a cross-sectoral range of actors within disaster governance has been recognised and will continue to be a fruitful subject of inquiry [9,11,17]. Vertically, a systems approach demands sensitivity to inputs across varying scales from the local through municipal to the regional, national and international ([5]: 417; [31]). A systems approach to understanding causality draws on these trends and evaluates governance and institutions with respect to the expectations of adaptive governance [12,19]. There are also implications for the extent to which institutions can intentionally engage with risk when a systems perspective is adopted and linear assumptions underpinning interventions are jettisoned [8]. Finally, a range of socio-economic drivers such as poverty, urbanisation, land ownership and marginalisation are key to understanding the dynamism of vulnerability and so are critical in understanding risk more broadly. They are intimately linked with institutional drivers as shifts in wider policy regimes can reconfigure the socio-economic conditions of risk [14].

A systems approach recognises that physical, socio-economic and institutional drivers need to be considered not only in their aggregate but also in terms of their interactions [51]. Nonetheless, discussion of systemic risk has tended to focus on the physical drivers of risk and overlooked the latter institutional and socio-economic dimensions, methodologically if not conceptually. A more holistic systems approach can serve to integrate these dimensions and thereby emphasise the deep interaction between, and integration of, physical, socio-economic and institutional risk drivers within socio-ecological systems.

There have been calls to enhance statistical methods within the study of systemic risks in order to address some of the methodological challenges outlined above [18]. Moreover, the 2022 Global Assessment Report envisages that increased computer power will provide insight into ever more complex relationships through the enhanced incorporation of “climate data and projections, literature values and expert knowledge” ([41]: 154). Nonetheless, such modelling approaches to systemic risk face ongoing fundamental epistemological challenges relating to causality within the context of complexity, how the boundaries of the system are to be defined in terms of space and time and remain dependent on the input of human judgment in determining the appropriate nodes or variables to be included and the nature of their relationships. These challenges as well as the relative contributions of approaches associated with forensic investigations of disasters are summarised in Table 1.

Table 1
Key conceptual and methodological challenges relating to systemic risk and the relative contribution of statistical modelling and forensic investigation (FORIN) approaches (Table developed by authors).

Conceptual and methodological challenges to understanding systemic risk	Contribution of statistical modelling approaches	Contribution of forensic investigations of disaster (FORIN) case study approaches
Lack of value judgments concerning system continuity and failure	Tendency towards reliance on researcher and/or elite stakeholder judgment; potentially agnostic as to value of the continuity or failure of systems ([41]: 81–91).	Capacity to elicit perspectives of diverse research participants concerning value of the continuity or failure of systems and to interrogate habitual or implicit understandings ([41]: 81–91).
Unclear how appropriate system boundaries are to be identified	Reliant on set of variables included on the basis of researcher judgment [44].	Capacity to elicit open-ended reflection on the appropriate boundaries of the system of interest ([41]; [43]).
Causality within complex systems is not adequately understood	Variable-oriented; emphasis on general explanations of causality to the detriment of local contextual factors [41]	Process-oriented; emphasis on local explanations of causality to the detriment of general explanations of causality ([23]; [45])
Interdisciplinarity to comprehend systems and emergent risk underdeveloped	Interdisciplinary input mainly limited to model development and analysis and interpretation of results ([27]; Cairney 2012; [28]).	Significant capacity to facilitate inter-disciplinary deliberation from research planning, through data collection and analysis phases of research [26]

The precision and ultimately the utility of modelling approaches are inevitably determined by the quality of judgments around scales of analysis and the input variables to be included. This is too often overlooked within risk assessment methods and results in the incapacity to sufficiently integrate uncertainties and unprecedented or unforeseen disruptions such as those associated with climate change ([52]; [53]: 18; [41]: 147). While modelling approaches are being adjusted to address these weaknesses, there is a recognised need to complement these with more qualitative, holistic case studies ([31]: 255; [32]) that also foster participation by a wide range of stakeholders and provide alternative accounts of the progression of systemic risk.

Historical, ethnographic, visual and other methods associated with forensic investigations offer fine-grained analysis of the aspects of complexity at work in a given context, how those aspects arose, and how they interact [54]: 79. They thereby have the potential to address some of the conceptual and methodological challenges outlined above. Firstly, through open-ended engagement and deliberation of the included participants the system of value and aspects thereof can be determined from the outset. In this way, in-depth FORIN-oriented case studies of disaster events can bring to the fore the affective and relational aspects of how systemic risks are experienced, including in governance. Relatedly, through the interactive engagement of human participants the appropriate spatial and temporal scales can also be discerned according to context. The process of reflecting on and articulating systemic risk allows for the surfacing of implicit understandings of the boundaries of the system.

FORIN approaches also present significant opportunities in terms of the explanation of causality. While in-depth case studies tend not to test hypotheses as quantitative methods can, they can nonetheless confirm or undermine claims of causality within quantitative research. They can thereby help to identify variables for inclusion within quantitative models as well as to confirm and validate causal relationships between variables for which quantitative methods have identified correlations

([2,41]: 845). Moreover, in-depth case studies can provide detailed accounts of the causal mechanisms at play, i.e., the precise nature of the interaction between the variables of interest. This is of particular advantage in case studies of causal mechanisms spanning longer time frames. As such, in-depth case studies ultimately shift the focus from variable-oriented to process-oriented explanations of causality [23]. In so doing they can illuminate local causality or the sequence of events and processes that lead to specific outcomes (Miles and Huberman 1984:132) and allow for the more nuanced understanding of differential impacts of risk on individuals, households and communities that might be otherwise obscured through aggregation. This concern for open-ended exploration of causal mechanisms within small-n studies resonates with the recent tendency towards the recognition of interdependencies and relationships rather than the measurement of probabilities within risk analysis [18].

Forensic approaches render systemic risk more tractable by recognising that disasters can serve as effective case studies, or 'focusing' events, to help illustrate the systemic nature of risk through retrospective analysis of the underlying risk drivers [20]. In understanding the complexity of causality such approaches rely on the careful selection of case studies of disaster events that can yield understanding of the processes and broader causal mechanisms at play. Compared to large-n studies, case study research allows for greater confidence in understanding the link between causes and particular outcomes of interest and the nature of such links ([2]: 843).

The in-depth qualitative investigation of small numbers of cases provides opportunities for the collection of rich data, often through intensive, long-term and reflexive involvement that benefits from the implicit and explicit expertise of participants in the lifeworld of the phenomenon in question. Through their ability to accommodate and synthesise different approaches, qualitative methods deployed within such case studies also provide the scope to reconcile diverse disciplinary perspectives and foster deliberation. Indeed, one of the features of qualitative research involving focus group discussions for example is that they can convene broad sets of stakeholders in order to deliberate on contested, uncertain phenomena. In so doing the deep tacit knowledge and lived experience of multiple sets of expertise and stakeholder viewpoints can, with due care in planning and implementation, be a potential resource in discerning the system to be valued and how it operates.

The flexibility of the case study approach as foreseen by FORIN allows for the generation of multiple lines of evidence deemed important in order to adequately capture systemic risk [53]. In this respect the particular value of the graphic or visual representation of systemic risk has been acknowledged [55]. Visual methods deployed in the context of (disaster) risk management and governance have taken forms that carry a range of different labels, including qualitative system dynamics, visual influence diagrams, causal maps, causal loop diagrams, soft systems methodology, agent-based modelling, Bayesian belief networks as well as storylines. In relation to the latter the 2022 Global Assessment Report on Disaster Risk Reduction outlines the role of storylines in the rendering of systemic risk tractable and for the generation of quantitative models [41]. While the conceptual framing and practical application of these methods vary, they all involve the identification of a set of nodes representing elements of a system that are linked to one another by means of directional arrows. This allows for the visualization of the network of non-linear causes-and-effects underlying a system ([1,3]: 351). While influence diagrams tend to focus on positive linear relationships, causal loop diagrams can include arrows indicating either positive or negative relationships between any two nodes. Such diagrams can be generated through literature review, expert elicitation or a combination of both [3].

Causal loop diagrams have been used for a range of purposes of relevance to disaster management, including to understand the impact of cascade effects of natural disasters on disaster relief operations [15] as well as hospital preparedness for extreme weather events [7]. The visual nature of causal loop diagrams and causal mapping more generally helps to facilitate deliberation amongst disparate stakeholders and to generate collective mental models of a dynamic and complex system (Schweizer et al. 2021). Their key contribution is that they serve to illustrate the assumptions underlying these mental models, the cascades and interdependencies involved and hence any unintended consequences [10]. As such, they can be deployed not only to inform quantitative modelling approaches but also to serve a broader and more critical role in the illumination of the inherently political and value-laden process of the identification of risk drivers.

Despite these advantages, a number of limitations of causal mapping have been identified. While collective mental models can be generated, their value is reliant on the input of the stakeholders generating them. It has been identified that key aspects of dynamic complexity including feedback loops, time delays, interactions across scales and nonlinearity can be challenging to construct mentally [10,14,38]. Thus, the narratives that are elicited from participants can (re-)produce the very linear, static, and chronological structures that the systemic risk concept eschews ([1,23]: 256). Moreover, causal mapping is prone as a method to masking contestation amongst participants concerning the causal origins of risk. However, it may be possible to offset such limitations through good facilitation and the creation of a rich environment for intensive cross-disciplinary, multi-stakeholder deliberation [10]. Combination with other methods that do not rely on personal narratives such as document analysis may also address this limitation.

2. Methods

The empirical basis of this paper emerged from a project investigating the 'root causes' of urban disasters that formed part of Tomorrow's Cities, a large-scale UK GCRF-funded project focusing on Istanbul, Quito, Kathmandu and Nairobi. In order to evaluate the potential of forensic investigation of disasters in addressing the conceptual and methodological challenges posed by systemic risk, case studies of disasters in each of these cities were undertaken. Causal mapping was the key method deployed in collaboration with academic and non-academic participants with expertise in relation to disaster management in each of the cities. This was undertaken during early 2021 and the Covid pandemic and associated restrictions, requiring engagement with participants to be conducted in an online setting. By generating causal maps in such diverse case studies, a broad range of hazard, socio-economic and institutional contexts are represented.

The process involved two phases. The first phase consisted of a workshop in which participants were informed concerning the general aims of forensic investigation of the root causes or risk and the centrality of the systemic conditions of risk. The importance of considering the socio-economic, institutional and physical risk drivers was discussed as well as the complexity of their inter-relationships. It also engaged participants in the consideration of the complex interactions between the risk root causes of disaster events, the importance of inter-disciplinary investigation to comprehend them, and the implications for identifying entry points of change. The second phase involved the conducting by participants of causal loop diagram exercises during four parallel break-out sessions. Each session involved the creation by participants of a causal loop diagram relating to a disaster event in one of the four cities. Participants self-identified the nature of their expertise across categories of social science, natural science and operational expertise as detailed in Table 2. This allowed for consideration of the role of cross-disciplinary engagement and deliberation in each of the groups in informing how systemic risk is conceived. An exemplar causal map and an overview of the methods was provided in order to guide participants. Each group was instructed to select an event, either historical or exemplary, in the

Table 2
Self-reported expertise of participants per case study.[a]

Case study	Social sciences	Physical sciences	Operational expertise	Total no. participants
Istanbul	5	1	3	5
Kathmandu	5	2	3	6
Nairobi	7	3	5	9
Quito	12	1	7	12

[a] Please note that some participants indicated have reported more than one area of expertise.

city concerned and place it in the centre of a Padlet wall.[1] They were then instructed to input all potential causes of the event, working from more immediate and proximate causes of the selected event outwards to more temporally and spatially distant causes. Participants were then requested to consider the complex interactions between the different causes, including propagation (spreading to greater number), cascades, feedback and concatenation. The relationship between these causes were to be identified using Padlet's "connect" function. An exemplar causal loop diagram was provided. A total of thirty-two participants were involved across the four groups.

The process of engagement by participants and the causal map diagrams produced provided the basis for analysis. First, the analysis considered how participants from different disciplinary perspectives consider the relevant spatial and temporal scales, identify and label risk drivers within the system, and engage with the complexity of their interrelationships. Second, the diagrams were coded on the basis of the spatial and temporal scales of the risk drivers as well as the three dimensions of risk: physical, institutional and socio-economic. These codes were deductively generated from the prior literature review. Where appropriate, risk drivers were assigned to multiple codes. For example. The lack of maintenance of buildings was considered an institutional as well as a socio-economic risk driver. Third, the number of risk drivers relating to each dimension was compared within each diagram and the manner in which risk drivers from different dimensions inter-relate was analysed. Finally, the system properties emerging from the relationships between components was analysed, including risk propagation, concatenation, feedback loops, delay and emergence.

Each group selected a rapporteur to report on the development of the CLD. Audio-visual recordings of the workshops were made, allowing for the generation of transcripts of the contributions of the group rapporteurs concerning the exercise. This allows for exploration of how the causal loop diagrams are presented or audienced by the participants producing them, a key consideration within qualitative visual methodology [34]. The authors were also engaged in supervising the exercise, allowing for a form of participant observation in order to triangulate with the other methods and ultimately enhance the validity of the results.

A number of practical limitations of the approach undertaken can be identified. Such practical limitations arose from the online setting in which the diagrams were generated as well as the related time constraints imposed on their generation. As a result, some of the diagrams are incomplete and there was some confusion concerning the direction of arrows. The Padlet application did not allow for the input of + − symbols to allow for the indication of the nature of the causal relationship, either positive or negative. A further limitation of the approach is that while participants were given scope to freely define elements and their inter-relationships this may have undermined precision and comparability between groups. Moreover, as mentioned previously, the focus of the exercise is on risk drivers leading to extreme events and post-event cascading or secondary and tertiary impacts remain outside of the scope of the paper. While the diagrams ultimately produced were relatively simple given the time constraints, the exercises nevertheless serves as a preliminary point of reflection on the potential of forensic investigation case studies to illuminate systemic risk.

2.1. Findings

Table 3 details the events selected by each of the four groups. A range of hazard types and magnitude were selected. As detailed, groups were free to select an extreme event that had occurred in their city or to consider a typical event that might occur in their city. The Nairobi group took the latter approach by selecting a typical urban fire event taking place within an informal settlement.

The Istanbul group consisted of five participants with backgrounds mainly in the social sciences. The group selected the 1999 Marmara earthquake that resulted in 18,000 fatalities in Istanbul and beyond as the focus of their causal map, which is illustrated in Fig. 1. The map included 17 components. In terms of the spatial and temporal scales considered, there is recognition of the broader tectonic system that generates the risk of earthquake in more localized settings. Otherwise, the spatial and temporal scales addressed are relatively limited and centred on city-scale dynamics (e.g., low quality buildings). The institutional drivers extend to broader spatial scales, exemplified by the inclusion of insurance mechanisms, construction standards and their control, as well as broader risk planning and management, presumably at the city level primarily and in any case no higher than at the national level.

Turning to the balance between risk driver types, the bulk of the components identified are linked with the institutional and to a lesser extent the socio-economic drivers. This may be due to the physical drivers for earthquakes being considered relatively straightforward by participants. It may also reflect the disciplinary composition of the group engaged in the exercise. In terms of the relationship between the risk drivers included in the diagram, the Istanbul group generated the most complex inter-play between the different risk driver elements identified by the four groups. The broad tendency identified is one of inadequate governance leading to planning and housing conditions that enhanced vulnerability to the seismic risk posed to this region. There are a number of examples of risk concatenation highlighted in the diagram. For example, low quality buildings arising due to illegal housing and the community not being informed about the risks and preparedness. An example of risk propagation is the linking of the lack of legislation to both low quality of buildings on the one hand and the lack of relevant institutional structure on the other. Despite other references to complexity, there is no reference to feedback loops. There is also some linking of different types of drivers, for example illegal housing (an institutional driver) being linked to low quality buildings (a physical driver).

The Kathmandu group consisted of six participants with diverse and multiple backgrounds; five reported a background in social sciences, two a background in the physical sciences and three an operational background. The group included twelve unique risk drivers manifesting in the 2015 Great Nepal Earthquake. Fig. 2 illustrates the causal map developed. In terms of the spatial and temporal scales considered, as in the Istanbul diagram the physical drivers stemming from Nepal's position on a seismic fault line is recognised. Similarly, however, the socio-economic and institutional drivers of risk are solely traced spatially to

Table 3
Event selected per city stakeholder.

City	Event selected by group
Istanbul	1999 Marmara Earthquake
Kathmandu	April 2015 Nepal or Gorkha earthquake
Nairobi	Small-scale fire event in Mukuru informal settlement
Quito	Flood in Pomasqui

[1] Padlet is an open-source software application that facilitates virtual engagement by multiple participants.

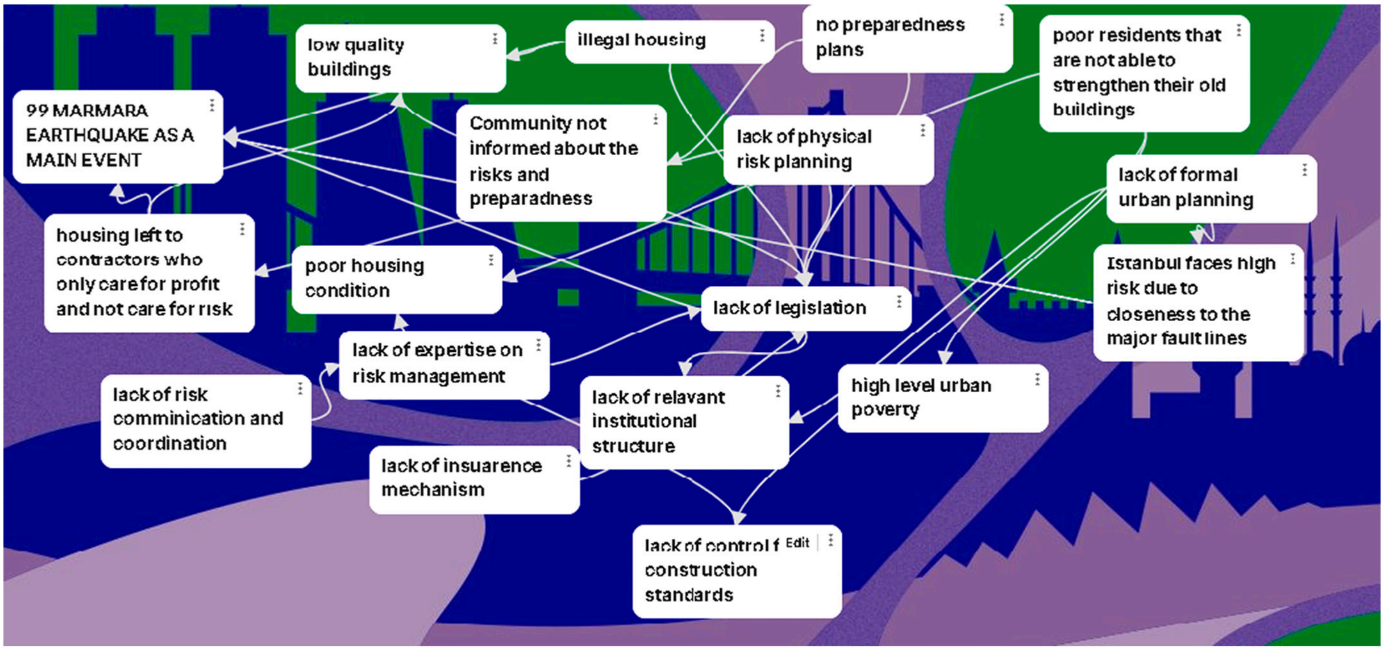

Fig. 1. Causal map of 1999 Marmara Earthquake in Istanbul.

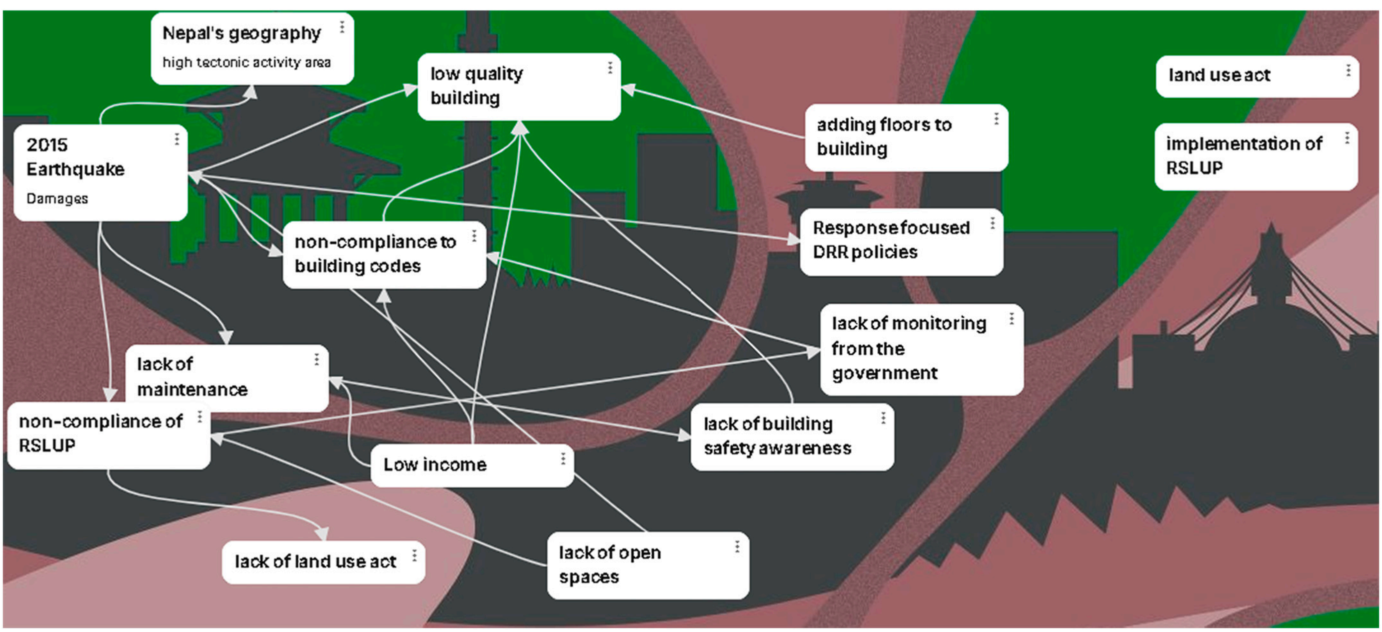

Fig. 2. Causal map of April 2015 Nepal Earthquake.

the city and national level scales. In terms of frequency and range the dominant risk drivers are located within the institutional risk driver category. Poor housing and income straddle both socio-economic and institutional drivers, highlighting the interaction between these categories. Turning to the relationship between the elements included in the diagram, there are a number of examples of risk concatenation highlighted in the diagram. Non-compliance with building codes arising due to lack of monitoring by government, an institutional driver, as well as the community not being informed about the risks and preparedness. Moreover, a number of drivers of low-quality building are identified, including non-compliance with building codes, low income, the lack of building safety awareness, and the addition of floors to buildings. In terms of risk propagation, the lack of monitoring by the government was associated with non-compliance with both building codes and the principles of risk-sensitive land use and urban development planning. Low income is considered a driver of three other identified elements: lack of building maintenance, non-compliance of building codes and low-quality building. A positive feedback loop between the lack of ongoing building maintenance and awareness of building safety is also represented in the diagram.

The Nairobi group consisted of nine participants with seven reporting a background in social sciences, three a background in the physical sciences and five reporting an operational background. Fig. 3 illustrates the causal map developed by the group. 24 unique components were included in the diagram produced, the most components across the four groups. In terms of the spatial and temporal scales considered, the

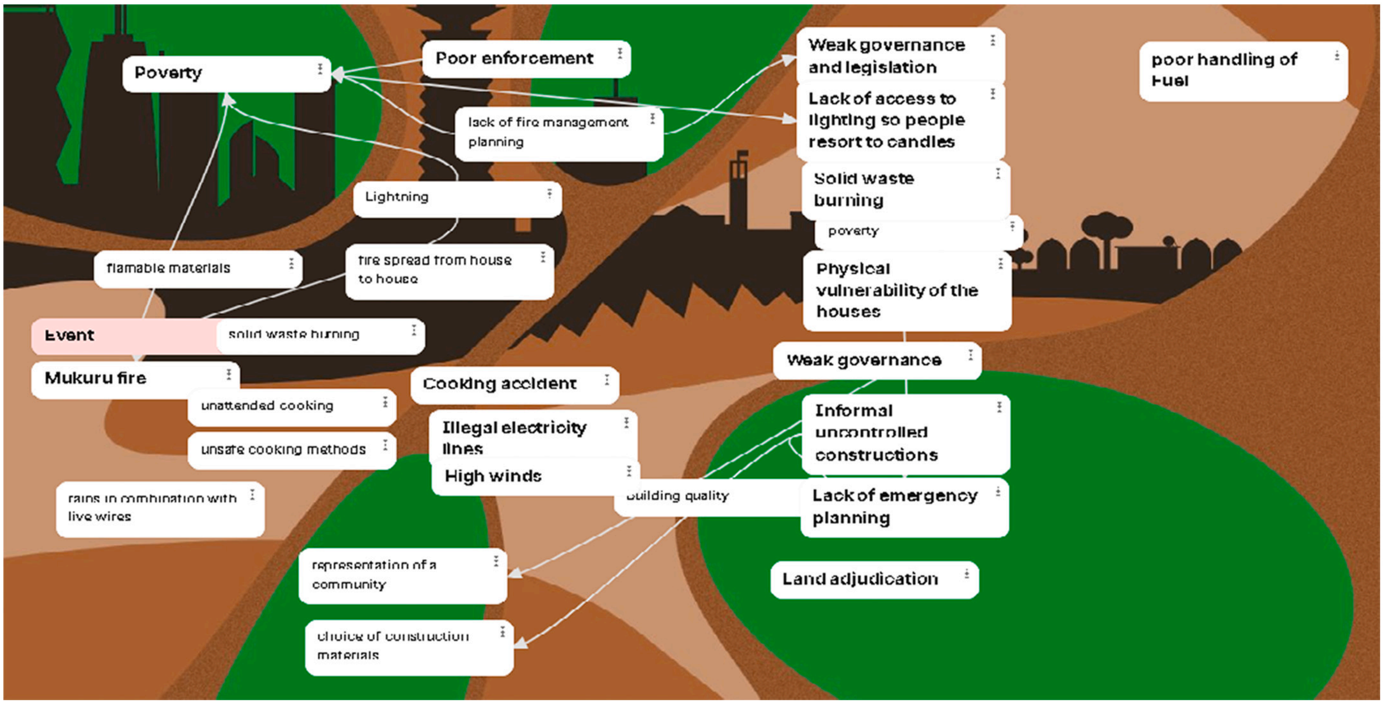

Fig. 3. Causal map of typical urban fire event in Mukuru, Nairobi.

spatial scale represented in the diagram is again confined largely to lower spatial scales such as household (e.g., unsafe cooking method), local informal settlement (e.g., inadequate political representation), the city and, at broadest, the national level (e.g., legislation for risk reduction, emergency planning, lack of land adjudication). Spatially, the focus mainly remains on the governance inadequacies that drive risk at the city (Nairobi County) and national levels.

In terms of the relative balance between risk drivers identified, a greater focus on the physical drivers of risk that manifest in fire events can be discerned. This may be reflective of the disciplinary composition of the group engaged in the exercise. The number and range of socio-economic and institutional elements included in the exercise indicates the importance of these dimensions of the root causes of risk to vulnerability to events of this nature. The relationship between the components was not completed by the group due to the time constraints involved. However, a number of relationships can nonetheless be identified in the diagram. In terms of risk concatenation, poverty is considered to be driven by poor enforcement and lack of fire management planning, but it is possible that the inverse relationship was intended by participants. In relation to risk propagation, it is identified that informal uncontrolled construction impacted upon building quality and choice of construction materials. A positive feedback loop is also detailed between poverty and lack of access to electric lighting.

The Quito group consisted of twelve members with all twelve

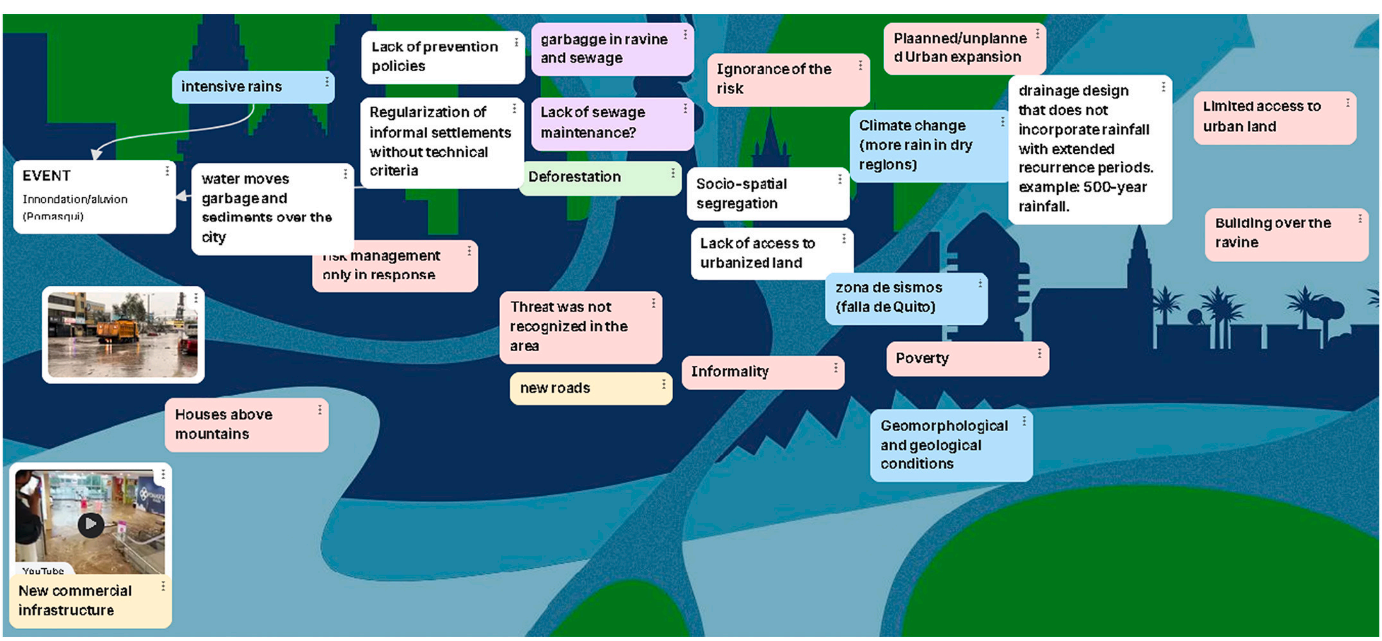

Fig. 4. Causal map of flooding event in Pomasqui, Quito.

reporting a background in social sciences, one reporting a background also in the physical sciences and seven reporting an operational background. Fig. 4 illustrates the causal map developed by the group. 23 components were included within the diagram produced. As with the other groups the spatial and temporal scales are bounded at the national level in terms of the socio-economic and institutional drivers. However, an exception is the inclusion of the element of climate change, a global driver of risk. Inclusion of deforestation and geomorphological conditions as risk drivers may indicate consideration of broader temporal scales. The participants strove to colour-code the different elements within their diagram according to the physical, institutional and socio-economic dimensions. The group identified eight physical driver elements, four socio-economic driver elements and eleven institutional driver elements. Compared to the other groups there is inclusion of a greater number of physical drivers. This may be due to the more complex combination of physical drivers involved in the triggering of flooding events as compared to seismic events. However, this emphasis on physical drivers runs counter to expectations given the primarily social rather than physical science-orientated nature of the group. Nonetheless, there is a higher rate of self-assessed operational expertise in this group compared to other groups, which may be significant. Having identified the different elements contributing to the manifestation of the flooding event, the group was unable to depict the envisaged inter-relationships due to time constraints. As such, the direct linkage between for example climate change and other physical (or socio-economic or institutional) drivers are not made.

3. Discussion

The worked examples relating forensic investigations of disaster to systemic risk and the contribution of qualitative methods, in particular qualitative visual methods can be considered in light of the assertions outlined in the second section and summarised in Table 1.

In terms of the system of value and the appropriateness of the system boundaries, each case study grouping developed its own understanding of the systemic context in which risk manifested in the form of the disaster event selected. The spatial and temporal scales are largely confined to city and national level across all four groups. Consideration of broader scales is confined to physical drivers, for example climate change in the Quito diagram. Socio-economic and institutional drivers with origins above the national level are not considered. Although the potential for risk to originate in international and global structures and processes was highlighted during the two workshops, participants largely confined their focus to the city or at the highest the national level. This suggests a potential challenge in considering risk drivers at broader spatial scales and is reflective of prior forensic investigations pointing towards the need to address obstacles to qualitative, cross-disciplinary engagement with the manner in which sources of risk at distant spatial and temporal scales come to be manifested in localized settings [14]. Moreover, it suggests that the facilitation of such engagement ought to take these scales into account to a greater extent, and potentially draw on wider sets of expertise.

In terms of the nature of causality underpinning systemic risk, the exercise pointed towards conclusions concerning how relationships are to be conceptualized that cohere with literature identifying the challenge to articulating complexity [10,14,38]. Few feedback loops were depicted in the diagrams, which would tend to support the potential bias in human cognition towards linear relationships and away from complexity. While two positive feedback loops were depicted in the diagrams, no diagram included a negative feedback loop. Incomplete relationships between elements in the diagram indicate that participants may have found it more straightforward to identify a range of elements across driver type and spatial and temporal scales than to understand the relationship between the elements. Moreover, while there is scope for considering the temporal dimension in terms of delays and emergence in the development of the diagrams, these are difficult to identify explicitly. Causal loop diagrams, and the data elicited through in-depth case study methods more generally, inevitably represent an abstraction of reality and struggle to precisely represent the complexity that systemic risk strives to conceive. As the worked examples illustrate, there can be a tendency towards the simplification or even the overlooking of complexity that reflect human biases towards chronological and linear understandings of cause and effect over time and space.

Turning to the interdisciplinarity displayed within the case studies and the relative representation of physical, institutional and socio-economic drivers within the causal maps produced, it is clear that institutional drivers of risk dominate. Such findings may be linked to the expertise represented in the groups, the nature of the event considered or a combination of both. The political and institutional dimension being heavily represented resonates with the comparative advantage that case study methods more generally are reported to have over more mechanistic modelling approaches. While the latter may straightforwardly accommodate aspects of the socio-economic and physical dimensions of risk, they may struggle to engage with concepts less amenable to calculative measurement [27,43]. Nonetheless, little linking of risk drivers across dimensions of risk was identified, for example the linking of poverty, a potential socio-economic driver, with natural resource depletion, a physical driver. Such an absence arose despite the multi-disciplinary expertise and deliberative engagement of the participants. This may indicate that the perceived strength of case study methods in allowing for the holistic appraisal of causality may not manifest in all circumstances [23]. Moreover, it speaks to balancing the entirely stakeholder-led ‘grounded theory’ type approach, with one in which potential forms of causality are raised for discussion by facilitators. Clearly there is a danger of ‘leading’ the discussion, but it may be possible at a generic level, for example through facilitators probing in relation to links between risk driver types or whether all risk driver types have been considered.

A number of critical dependencies can thus be identified in terms of the harnessing of the advantages of causal mapping method that has relevance to the range of methods deployed within in-depth FORIN case studies. Firstly, it is clear that the provision of sufficient time is critical in allowing participants to deliberate on the range of drivers to be included in the diagram, the relationship between them and ultimately the spatial and temporal boundaries of the system. All participants were members of a single research project, which enhanced prior familiarity and may have facilitated collaboration within groups. Furthermore, the composition of the group in terms of expertise represented was critical in determining key aspects of the causal map produced. The groups with a predominantly social science background opted to include a greater proportion of institutional and socio-economic drivers of risk to a greater extent than the Nairobi group, the group with the most members reporting expertise in the physical sciences. Such observations relating to the methodological procedures adopted reinforce the acknowledged need within the literature for researchers to create the requisite bridges between participants to achieve common purpose and the related modes of deliberation to effectively undertake FORIN-related research [27]. It should also be noted that even with the careful selection of events to explore with respect to their root causes, the possibility to infer to a wider range of cases is inevitably limited. However, given the complex nature of systemic risk, the trade-off of representativeness for the validity that is accordingly achieved is arguable a tolerable one.

Despite these acknowledged weaknesses, causal mapping and other methods deployed within forensic investigations of disaster, display clear strengths in systemic risk enquiry. Although an abstraction of reality, causal maps and other qualitative methods can provide a clear illustration of the mental models and narratives of a diverse range of participants concerning how risk manifests itself in relation to a concrete case study of disaster [10]. They can also serve to elicit cross-disciplinary deliberation concerning risk root causes in the context of complexity [21,26,36]. Through the open-ended development of diagrams or the elaboration of narratives amongst participants the relevant system boundaries can be articulated despite some limitations in this regard highlighted by the worked examples. In-depth FORIN case studies can especially probe those drivers of risk (especially institutional drivers) that may otherwise remain overlooked in computational models for determining systemic risk that can relatively straightforwardly integrate physical and economic drivers [14]. While causal diagrams may ultimately remain somewhat simplistic, the value of causal mapping and other methods deployed within FORIN case studies lies in their capacity to approximate and represent the subjectivities of the participants involved. In so doing they serve to build relationships and recognition of the legitimacy of competing knowledges between differently positioned stakeholders, for example between stakeholders from different sectors such as spatial planning, transport as well as disaster management, or between governmental authorities and citizens. FORIN case studies can ultimately offer a comparative advantage over modelling approaches in assessing systemic risk insofar as they convey complexity in a transparent and open-ended manner.

4. Conclusion

On the basis of reflexive, iterative and inclusive methodological practice, forensic approaches may serve in foregrounding the structural causes of risk that drive risk accumulation, especially for vulnerable populations. As the systemic risk concept becomes further institutionalised within disaster risk reduction policy and practice, the FORIN body of work can serve to address some of the conceptual and methodological challenges bound up with the concept. When carefully designed and implemented, such investigations can serve to interrogate the fundamental value of any given system and its spatial and temporal bounds, harness cross-disciplinary expertise and, in so doing, provide a more grounded, deliberated understanding of the complex drivers of risk. Future research and broader engagement with the systemic risk concept should consider the further refinement of methods such as causal mapping deployed within such investigations, in particular around participant selection and facilitation. Such engagement should consider how their strengths centring around the generation of mental models and cross-disciplinary deliberation can be fully harnessed, and their weaknesses arising from the potential to reproduce linear understandings of cause and effect mitigated. Opportunities for documenting and sharing experience in this regard should also be promoted.

CRediT authorship contribution statement

Ronan McDermott: Conceptualization, Methodology, Validation, Writing – original draft, Visualization. **Arabella Fraser:** Conceptualization, Validation, Investigation, Writing – review & editing, Supervision, Funding acquisition. **Jon Ensor:** Validation, Investigation, Writing – review & editing, Supervision. **Hamed Seddighi:** Validation, Writing – review & editing.

Declaration of Competing Interest

The authors declare no competing interest.

Data availability

The data that has been used is confidential.

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