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Investigating flood resilience perceptions and supporting collective decision-making through fuzzy cognitive mapping

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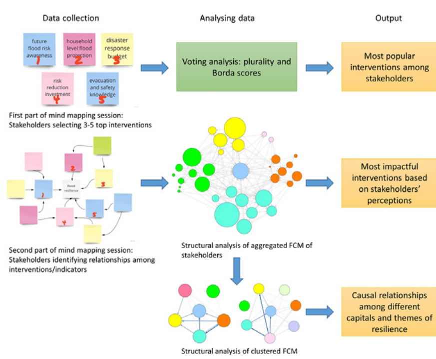
HIGHLIGHTS

- A combination of mind mapping and resilience measurement tool is applied.
- The methodology is used to support collective decision making for flood resilience.
- It encourages system-thinking and holistic approach in identifying resilience interventions.
- Raising awareness about flood resilience is as important as building flood protections.

GRAPHICAL ABSTRACT



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ABSTRACT

Improving flood resilience of communities requires a holistic understanding of risks and resilience options as well as the preferences and priorities of different stakeholders. Innovations in risk and resilience assessment have helped communities to identify gaps in their flood risk management strategy but selecting and implementing resilience solutions remains a big challenge for many decision-makers. In addition to traditional appraisals and cost-benefit assessments this also calls for a participatory process in which various stakeholders are encouraged to adopt a system-level approach in identifying interventions that can maximise a range of benefits and co-benefits. In this study, we investigate how a combination of modelling and measurement methods can help decision-makers with their flood resilience strategies. We apply a participatory system thinking approach combining Fuzzy Cognitive Mapping (FCM) with a flood resilience measurement framework called Flood Resilience Measurement for Communities (FRMC). We first investigate stakeholders' biases on flood resilience interventions, and then lead them through a system thinking exercise using FCM and FRMC to elicit mental models representing important aspects of flood resilience and their interrelation. These are then aggregated, representing the collective perceptions and knowledge of stakeholders, and used to identify the most beneficial resilience actions in terms of direct and indirect impacts on flood resilience. We apply this approach to the case of Lowestoft, a coastal town in England exposed to significant flood risk. Developed in close collaboration with the local authorities, the ambition is to support decision-making on flood resilience interventions. We find that this combination of methods enables system-level thinking and inclusive decision-making about flood resilience which can ultimately encourage transformative decisions on prioritization of actions and investments.

1. Introduction

In the face of climate change and its socio-economic impacts, decision making for future flood risk and resilience has been associated with many uncertainties and complexities. Climate change is increasing the likelihood of intense precipitation with longer durations and closer repetitions. The

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combination of heavy and intense rainfall with increasing sea level rise (also caused by climate change) and socio-economic developments is influencing risk patterns and exposures across the world; new places and communities are being hit by floods who have never experienced flooding before. While encountering such threats, increasing flood resilience of communities is becoming one of the main concerns of flood-prone cities and countries.

Flood resilience is a difficult concept, with a variety of definitions and interpretations. Most commonly it is considered as the capacity of communities (or businesses, governments, individuals) to reduce flood risks, be prepared for potential flood events, and be able to respond to and recover from flood impacts in a timely and efficient manner (Lavell et al., 2012; Zevenbergen et al., 2020; Hochrainer-Stigler et al., 2021). Increasing flood resilience of communities is, therefore, a holistic and multi-dimensional approach that includes not only structural protection measures (such as building dams, embankments, and floodwalls and barriers) but also non-structural measures such as land-use regulations, nature-based solutions, early warning systems, flood insurance, first aid training, evacuation and rescue plans, to improve the social, human, natural, and financial as well as physical capacities of communities. To support the understanding of various aspects of flood resilience and aid the prioritization of interventions and investments, several national and regional governments, as well as international aid agencies, have developed indicator-based tools and methods to measure the resilience of communities against flood or disaster risks. Such tools and methods tend to distil the complex concept of resilience into useful 'indicators' that cover various social, natural, political, physical, financial, and human capacities of societies, and thereby, provide decision-makers with rigorous and comprehensive evidence on where the challenges and weaknesses of flood resilience are (Cutter, 2016; Quinlan et al., 2016). Some of these tools have been widely used across the continents and various socio-economic contexts to support decision making, e.g., tools developed and implemented by ARUP, Asian Cities Climate Change Resilience Network, Zurich Flood Resilience Alliance, UN-Habitat, GOAL, and United Nations Office for Disaster Risk Reduction – a full review of these tools can be seen in Sharifi (2016), Asadzadeh et al. (2017), Saja et al. (2019), and Cai et al. (2018).

However, when it comes to decision-making (i.e., what action should be taken first and where the investments should go in what priority), there are still two aspects that are not covered by such tools: 1) the interdependencies and cause-effect relations among different resilience components e.g., how an increase or decrease of financial capacity of a community could cause a change in their physical, social, human or natural capacities, and 2) how interventions influence the different resilience components including identifying those co-benefits that apply across different components. These two aspects tend to be overlooked when conducting feasibility analysis or intervention options appraisal that only focus on the availability of resources and estimating expected cost-benefits of projects—see (Heath et al., 2020; Gawler and Tiwari, 2014; UN-Habitat, 2018; Keating and Hanger-Kopp, 2020). In addition, decisions and actions for flood resilience affect various groups of stakeholders from local councils to private businesses and civil societies, and those various groups often have different or sometimes contradictory perceptions, preferences, and priorities in how flood risk should be managed. In an effective and inclusive decision-making process, it is essential to include such heterogeneous perceptions when setting priorities for actions and investments. Therefore, one of the less explored questions in resilience studies is how to support a collective decision-making process that considers the potential co-benefits of resilience options and interdependencies among various components of resilience as well as stakeholders' various perceptions, preferences, and priorities.

In this study, we investigate how a combination of (a) mental modelling and (b) resilience measurement methods can support such a decision-making process. We apply Fuzzy Cognitive Mapping (FCM), i.e., a participatory mind mapping method, and Flood Resilience Measurement for Communities (FRMC), i.e., a resilience measurement framework and tool, to investigate a collective decision-making approach for enhancing flood resilience in the coastal town of Lowestoft in the UK. Using this methodology, we first collect stakeholders' priorities on flood resilience actions and interventions based on an intuitive and heuristic decision-making process and then lead them through a system thinking exercise, using FCM and FRMC, to elicit their deliberate and slow-thinking mental models (Kahneman, 2011) identifying the relations among different aspects of flood resilience. We utilize these mental models to 1) map and analyse the interdependencies and cause-effect relationships among different indicators of resilience, and 2) identify the most beneficial resilience actions in terms of their direct and indirect impacts on flood resilience, based on the collective perceptions and knowledge of stakeholders.

2. Background and context

The wide range of benefits of public participation in the process of decision-making has been demonstrated in various studies. Such benefits are mainly related to increasing legitimacy, acceptability, justice and equity of outcome decisions and actions, awareness of communities about problems and existing solutions, learning and empowerment, and therefore, improving willingness for community cooperation and individual behavioural change (Cattino and Reckien, 2021; Khatibi et al., 2021; Mehryar, 2019; Chu et al., 2016; Jeffers, 2020). All such benefits are crucial in the context of decision-making for climate change and related needs for societal transformation and resilience. Transformational projects that lack public participation in their design and implementation phases are reported to be more likely to fail due to a lack of consideration of local knowledge, perceptions, interest, and preferences (Fitton and Moncaster, 2018; Jeffers, 2020).

However, there are also studies showing that participatory approaches, under certain conditions, have led to perpetuating incremental measures and supporting the status quo (D'Alisa and Kallis, 2016; Wamsler et al., 2020). Various reasons have been discussed by scholars for such outcomes, including a tendency to opt for measures that fit existing resources and skills, lack of knowledge and awareness about the new solutions, and not involving various types of stakeholders (Maskrey et al., 2016; Wamsler et al., 2020). In this study, we argue that one of the challenges of participatory decision-making is the public bias towards short-term fixing solutions which may lead to selecting maladaptive and incremental measures rather than long-term transformative options. Societies are often influenced by their most recent experiences and observations, and therefore, are inclined to pick measures impacts of which have been observed in the short-term. Such cognitive biases can often lead a participatory decision-making process to a premature selection of existing measures and interventions that may overlook other potential alternatives with long-term more sustainable impacts. Applying a combination of FCM and FRMC, we aim to overcome such biases, and instead, introduce an approach for encouraging holistic and system-level thinking in the process of collective decision-making.

FCM is a participatory semi-quantitative modelling method that allows structuring and representing participants' perceptions and knowledge and including various perspectives in one model—also known as cognitive models (Kosko, 1986; Özesmi and Özesmi, 2004; Jetter and Kok, 2014). The individual and aggregated FCMs provide visual and communicable expression of how individuals in a community conceive of and frame a particular problem or issue, and its key functions and processes (Gray et al., 2019). In an individual interview or workshop setting, participants develop maps consisting of nodes (representing concepts, variables, indicators, or components of a system in question) and weighted, directed connections among the nodes. An important aspect of FCM is that it represents the causal relationships as participants provide quantification for connections based on their perception of the cause-and-effect relationships among concepts—i.e., how interrelated concepts affect one another and provide feedback (Singh and Chudasama, 2017). The values of connections between the concepts are within the range -1 and $+1$. Positive values describe directly proportional relationships, meaning an increase (decrease) in one concept will cause an increase (decrease) in the interconnected concept, whereas negative values indicate an inversely proportional relationship between concepts (Carvalho, 2013).

FCM is now increasingly being employed in environmental and social-ecological decision-making contexts due to its ability to 1) capture stakeholders' knowledge, perceptions, and beliefs for evidence-based decision-making, and 2) model complex and hard-to-model qualitative and subjective concepts and their causal relationships (Singh and Chudasama, 2021; Gray et al., 2019). The aggregated model developed via FCM are often used in four ways to support decision-making: first, FCMs are used as a knowledge co-production method that aggregate knowledge and perceptions of local stakeholders in one model and provide a holistic representation of the system or challenge under consideration (Olazabal et al., 2018; Mehryar et al., 2017; Singh and Chudasama, 2021). This is particularly useful in modelling data-scarce or subjective parts of a system (Reckien, 2014; Singh and Chudasama, 2021). Such models can then be used to simulate the possible impact of various policies on the system/challenge (Gray et al., 2019; Singh and Chudasama, 2021). Some studies take the advantage of cause-and-effect networks developed by such models to analyse the potential trade-offs, benefits, and co-benefits of adaptation actions (Coletta et al., 2021; Furman et al., 2021; Martín et al., 2020; Giordano et al., 2020). Second, FCMs are used to collect and compare different groups of stakeholders' perspectives on a common issue, allowing contrasting views to be explicitly highlighted and negotiated in the process (Lavin et al., 2018; Arroyo-Lambaer et al., 2021; Shahvi et al., 2021; Santoro et al., 2019). Uncovering such differences in mental models of stakeholders can help identify avenues to overcome barriers and improve collaboration for effective decision making. Third, some studies analyse FCMs of different groups of stakeholders to identify the socio-psychological and environmental factors causing similar or different perceptions and beliefs, and eventually, lead into different actions (Gray et al., 2015; Bardenhagen et al., 2020). Fourth, since mental models are subject to change due to learning and environmental changes, some studies use FCM to assess how people's mental models change or how an intervention may influence people's mindset about a problem. Due to the subjectivity of the outcome of participatory FCMs (i.e., FCMs developed based on human knowledge and perceptions), there has been a tendency to use this technique to support collective decision-making, raising awareness, sharing knowledge, and comparing different perceptions of a common problem, rather than providing decision-makers with objective evidence.

The FRMC framework and tool, developed by Zurich Flood Resilience Alliance, is one of the most widely applied disaster resilience measurement approaches in the world, informing community-led action in nearly 300 communities globally (https://floodresilience.net/frmc_story/). This tool applies an indicator-based approach for assessing the resilience of communities prone to flood risks (Keating et al., 2017; Campbell et al., 2019). The underlying aim of the development and application of these tools is to support local decision-makers (e.g., local authorities, managers, NGOs, and civil society representatives) in identifying both flood resilience challenges and weaknesses, and areas with an urgent need for resilience interventions.

FRMC is founded on a holistic and integrated conceptualization of community resilience capacity as comprising of human, social, natural, physical, and financial capitals, and 44 indicators of resilience used for measuring these five capitals' capacities i.e., shown in Fig. 1 (Mehryar and Surminski, 2021). The *financial* capital is mainly about the financial resources, such as national budget and funding, insurance, and individual savings, that communities have access to, and which can be used in the risk reduction, preparedness and response and recovery phases of flood risk management. The *human* capital relates to the knowledge and awareness of community members about local flood risks and what they can do to protect themselves and their assets when a flood happens. The *natural* capital is about the natural resources that also work as flood risk prevention and protection such as plants and trees alongside the riverbanks which slow runoff and stabilize banks. The *physical* capital includes all the physical measures that support communities' risk protection and reduction such as flood walls and property-level protection measures. Finally, *social* capital is about the social networks, including community participation and collaboration in flood-related activities. Each of these capitals compromises a set of indicators which in total create 44 'indicators of flood resilience' (Fig. 1 – more details: https://floodresilience.net/frmc/). The methodology used in FRMC (Campbell et al., 2019; Laurien et al., 2020; Hochrainer-Stigler et al., 2021) brings together quantitative and qualitative data from secondary data sources, focus group discussion, key informant interviews and household surveys to evaluate and grade the 44 indicators. These indicators can then be categorized and analysed using different 'lenses', that is by combining the indicators based on, for example, the five capitals of resilience (i.e., social, human, physical, financial, natural capitals), the five stages of the DRM cycle (i.e., prospective risk reduction, corrective risk reduction, preparedness, response and recovery), or seven themes (i.e., governance, social norms, natural environment, assets, livelihoods, life & health, and lifelines). A full description of these lenses can be found in supplementary 1. Such categories provide local decision-makers with different ways of looking at resilience problems and challenges and finding solutions. The FRMC tool has been applied in 11 countries and 118 communities in the first phase of the Alliance program (2013–2017) and is being conducted in a further 20 countries including the United Kingdom in the second phase of the program (2018 until now).

Following these applications, FRMC has been reported by the local users to be helpful in supporting evidence-based decision-making by identifying the weaknesses and strengths of flood resilience. However, it has also been raised by many local users that when it comes to making decisions about what actions should be taken first and where investments and resources should take place, one would need to a) prioritize the areas needing attention the most, and b) assess the potential impact of each intervention on various indicators of resilience. These call for a better understanding of the interlinkages and interdependencies of resilience indicators as such indicators are not in silos. Instead, improvement or deterioration of some of these indicators may positively or negatively impact other indicators. Therefore, when deciding about the resilience interventions, a network of interacting indicators should be considered, which is currently missed in the FRMC processes.

3. Application of methods to the case study

In this study, we employ a combination of FCM methodology and FRMC framework to understand where stakeholders' current bias is, lead them through a systems-thinking exercise, and model the flood resilience system using the collective wisdom and shared knowledge of stakeholders. This model is then used to identify the level of agreement among stakeholders on the most important parts of flood resilience that need to be improved. In this approach, the FCM method supports collecting mental models and transferring those into a semi-quantitative model and FRMC provides a holistic and multi-dimensional framework of flood resilience which is used to structure the input and output of FCMs and encourage system-thinking among the participants.

Located on the east coast of England, Lowestoft's population is exposed to tidal, pluvial, and fluvial flood risks. In 2013, Lowestoft suffered its most recent tidal storm surge, in which 158 homes and 233 commercial properties were flooded, and the town's A-roads, rail network and key infrastructure were significantly disrupted for weeks. Lowestoft has also faced a surface water flood in 2015 in which 33 properties were flooded, and another, lesser tidal surge in 2017. As climate change continues to drive an increase in both sea level and severe weather events, a wider geographic area and more people and businesses are expected to be exposed to the three types of flood risks.

Lowestoft is also one of the most deprived communities in the UK. The decline of key industries in the late 20th century in Lowestoft has left a legacy of vacant post-industrial lands and social-economic challenges, largely due to a loss of employment opportunities and resulting in low property and land value. One of the main barriers to the economic regeneration of Lowestoft is the high risk of flooding threatening this coastal town and impacting business confidence and inbound investments. To address these growing risks, the local government has defined a project and received £43 million in July 2020 for building tidal flood walls and barriers in Lowestoft. This project was going to start in May 2021 (after the completion of this study) and was expected to protect over 1500 homes and businesses in Lowestoft (more details: https://www.lowestoftfrmp.org.uk/). Prior to

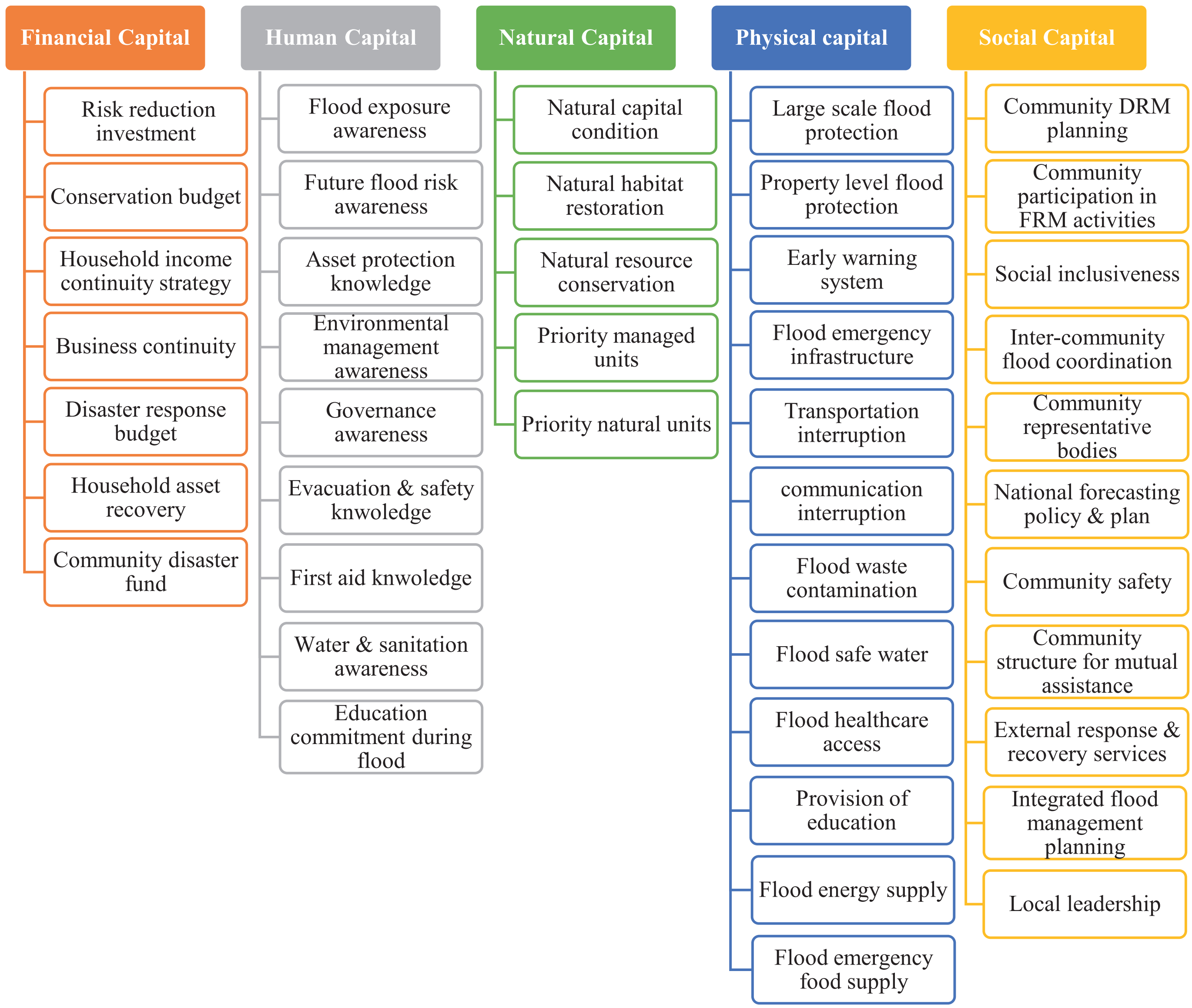

Fig. 1. 5 capitals and 44 indicators of resilience used for measuring community flood resilience in FRMC. Source: https://floodresilience.net/frmc/

the allocation of government funding the local campaigns and political discussions in Lowestoft have helped to raise awareness among citizens and local actors about structural flood risk management options.

Despite the signs of progress in building tidal flood walls, it has been well-recognized by the Lowestoft local authority that large-scale flood protections will never completely remove flood risk and may even create a false sense of security, as it tends to stop other complementary risk reduction and adaptation activities from going ahead. Considering the concept of residual risk, including the potential failure or breach of flood defences, the Lowestoft local authority aims to continue working with holistic resilience efforts, including those that increase social, human, natural, physical, and financial capacities of communities in preparing for and responding to flood events. In October 2019, the Lowestoft local authority (i.e., East Suffolk Council) started its collaboration with the Zurich Flood Resilience Alliance in implementing FRMC and measuring community flood resilience in Lowestoft to provide a baseline for evaluating impacts of future flood risk management projects. FRMC was, therefore, used to provide the local authority with a holistic assessment of flood resilience situation in Lowestoft. FCM has also been applied in combination with FRMC as a complementary tool to support participatory and collective decision-making based on evidence provided by FRMC.

Data collection for FCM was done in parallel with the FRMC engagement activities and therefore benefited from the FRMC discussions and the awareness they raised around flood resilience indicators and interventions in Lowestoft.

3.1. Stakeholder engagement and knowledge elicitation

FCM sessions were conducted together with the focus group discussions and key informant interviews organized for collecting data for the FRMC tool. Three focus group discussions and seven individual key-informant interviews were conducted with local stakeholders who were involved in or have knowledge on flood risk and resilience in Lowestoft. Participants, selected in a stakeholder mapping session with the local authority and a local humanitarian organization in Lowestoft, included representatives from the three main group of stakeholders who are influencing or being influenced by flood-related decisions and actions in this coastal town: 1) government (e.g., environment agency, and local and regional councils), 2) businesses (e.g., large, small, and medium size business owners), and 3) citizens (e.g., from health, water and community related associations who have information about vulnerable and flood-prone households). The sampling of stakeholders was done in a way to involve stakeholders

Table 1
Data collection activities for FRMC and FCM at each session. FGD: Focus Group Discussion, KII: Key Informant Interview.

	FRMC activities (1st part of each session)	FCM activities (2nd part of each session)
Session 1	FGD with business team (2 h)	5 individual mind maps (45–60 min)
Session 2	FGD with community representatives (2 h)	7 individual mind maps (45–60 min)
Session 3	FGD with members of government (2 h)	4 individual mind maps (45–60 min)
Sessions 4–10	KII with individual stakeholders (45 min)	7 individual mind maps (45–60 min)

from different sectors and backgrounds (e.g., early warning system, education, first-aid training, as well as risk finance and environmental management) with different types of expertise such that diverse knowledge and insight could be provided. Demographic information of participants can be seen in supplementary 2.

In the first part of the focus group discussions and key-informant interviews, the participants were introduced to the concept and definition of flood resilience, five capitals, and 44 indicators of the FRMC framework. Then a set of questions allocated to each group/interviewee were used to trigger discussion and information sharing, through which data for the 44 indicators of the FRMC tool was collected (source: https://floodresilience.net/frmc/). This part helped participants to familiarize themselves with various aspects of flood resilience, thereby encouraging a holistic and system-thinking view of flood resilience before the FCM session. In fact, the comprehensiveness and broadness of FRMC indicators minimised the anchoring effect that pre-defined concepts may have in developing FCMs vs open question approach (Tepes and Neumann, 2020). It also helped the research team to overcome issues related to ambiguity in perception or misinterpretation of the indicators by participants.

The second part of the focus group discussions and key-informant interviews was allocated to developing stakeholders' FCM. While all seven key informants took part in the FCM part, in the focus group discussions we only managed to develop mind maps with those who stayed until the end of the sessions (see Table 1 for the number of mind maps per each session). In total, we developed 23 mind maps via semi-structured individual interviews with the help of trained facilitators.

Participants were provided with the 44 indicators of flood resilience printed on cards, colour-coded by the five capitals. At the beginning of the FCM part, participants were asked to pick 3 to 5 flood resilience indicators which (they believed) would have a high impact on flood resilience and rank them from the most to the least important (in terms of their impact on flood resilience). This ranking was later used to identify the most popular actions/measures among the stakeholders.

The selected 3–5 cards were then stuck on a sheet and direct connections between the cards and 'flood resilience' (as the core concept) were drawn. Then, participants were asked to complete the map using the following questions[1]:

1. How much does each of these indicators impact flood resilience compared to each other?

   a. Assign a value between 1 and 5 indicating the lowest to highest impacts to each connection. Connections can receive similar values.[2]
2. What actions should be taken (i.e., what other indicators need to be improved) to improve the situation of selected indicators?

   a. Actions can be either selected from the FRMC indicator cards or created as a new card.
   b. Identify all possible relationships among the existing and new indicators in the map.
3. For those indicators that receive more than one input assign a value between 1 and 5 (indicating the lowest to the highest impacts) to represent the comparative impact of indicators on each other.

   a. Increasing impact receive positive value and decreasing impact receive negative values.

This way, the interviewees were encouraged to identify 1) the relevant flood resilience aspects that they believed need to be improved and 2) actions or interventions required for improving those aspects, which, therefore, lead to indirect impacts on flood resilience. Question 2 helped to identify indicators having an indirect impact on flood resilience and questions 1 and 3 elicited the causal links among indicators and relative weights of the connections. Each interview took between 45 and 60 min.

Interviewees were asked to explain their interpretation of all indicators they selected, and these were added to the maps in case they were different from the pre-defined definition of those indicators. This helped to make sure that interviewees' perceptions about the pre-defined indicators are well understood and reflected in the aggregated FCM. Documented definitions were later used to support homogenizing individual maps (Section 3.2).

3.2. Constructing adjacency matrix

All the visual maps were then coded into square adjacency matrices separately, where the indicators/nodes were listed on the vertical and horizontal axes on a spreadsheet. The values of connections assigned by participants were normalized between -1 and $+1$ and then coded into the related cells of the adjacency matrices.

While adding to the adjacency matrix, the concepts collected and drawn during the interviews should be homogenized. This is to evaluate the new indicators added by participants to the list of pre-defined indicators and find a common terminology for similar concepts described with different wording (e.g., 'disaster response fund' and 'flood response budget'). It helps to reduce the number of concepts in the combined FCM and unify the understanding of concepts and connections across the individual maps (Olazabal et al., 2018). Most of the interviews were followed with a quick (15–30 min) phone interview with interviewees to clarify and validate the digital and homogenized version of their maps.

The individual homogenized maps are then aggregated into a single map. The process adopted here for aggregating individual FCMs was simple matrix addition in which the values of connections that appear in more than one map is the mean value. However, in contrast to the traditional approach, we provided information on Standard Deviation (SD), Coefficient of Variations (CV), and the number of times each connection was repeated across the individual maps, in addition to the mean value. Averaging values across the relationships—which is commonly done in standard FCMs (Özesmi and Özesmi, 2004)—is useful to represent one median picture of various perceptions existing in a society. Nevertheless, this can cause relationship values cancelling each other out, resulting in a homogeneous FCM that does not show the heterogeneity of perceptions and preferences (Mehryar et al., 2019; de Jong and Kok, 2021). Such heterogeneity is particularly important in FCMs meant to support collective decision making. Therefore, we suggest considering information on SD, CV, and count of maps in which relationships are mentioned, as well as the mean values, to provide a better understanding of the level of consensus on the topics discussed and analysed.

[1] A step-by-step visual guide on developing maps used by the facilitators together with a sample of a complete FCM can be seen in supplementary 3.

[2] The difference between this and previous grading is that, unlike the first grading, here participants can allocate same value to more than one connection (i.e., for indicators they believe have equal impact on flood resilience) or non-sequential values (e.g., 5 to three connections and 1 to one connection, representing a large gap between the impacts of the former and latter indicators on flood resilience).

The aggregated FCM was then analysed using 'FCMapper' (http://www.fcmappers.net/), a spreadsheet-based analytical tool facilitating structural analysis of FCMs, and visualized using 'Visione' (http://visone.info/), a network-analysis software (Wildenberg et al., 2010).

3.3. Structural analysis of maps

First, we analysed the indicators' rankings collected at the beginning of FCM sessions via using the voting methods and second, we analysed the structure of combined FCM using graph and network analysis methods including indegree, outdegree, and centrality degree. The former analysis results show the most popular (or highly ranked) resilience indicators that need to be improved (i.e., the most urgent intervention based on the perception of stakeholders), and the latter show the most impactful resilience indicators in terms of their impacts on other resilience indicators based on collective perceptions of stakeholders. Comparing the results of these two analyses, therefore, reveals to what extent the most popular resilience indicators are also the most impactful ones, according to participants' perceptions. Finally, we clustered the 40 indicators into the "5 capitals" and "7 themes" categories (explained in Section 2) and analysed the causal relationships among different capitals and themes of flood resilience in Lowestoft (Fig. 2).

3.3.1. Voting methods

We calculated the final aggregated rank of indicators selected and ranked at the beginning of the mind mapping session using the plurality and Borda count rules (Pacuit, 2019).

Plurality score: In plurality voting, the winner is the option that has the highest number of votes, and the rest of the options can be ranked based on the number of votes they receive. Here we calculated plurality based on the number of times each indicator was selected as the initial 3–5 important indicators across the individual maps.

Borda score: In the Borda voting method, however, each voter provides a ranking of the options. Then, the Borda count determines the winner by giving each candidate some points as follows. If there are n options, the option ranked first receives $n-1$ points, the option ranked second receives $n-2$ points, …, options ranked second to last and last receive 1 and 0 points, respectively. By aggregating all the scores from all the voting cards, the Borda score of option A, denoted by BS(A), is calculated as follows (where #U denotes the number of elements in the set U and i is a voter):

$$BS(A) = (N-1) \times \#\{i \mid i\ ranks\ A\ first\} + (n-2) \times \#\{i \mid i\ ranks\ A\ second\} + \ldots + 1 \times \#\{i \mid i\ ranks\ second\ to\ last\} + 0 \times \#\{i \mid i\ ranks\ A\ last\}$$

Therefore, the Borda count elects broadly acceptable options, rather than those preferred by a majority (Lippman, 2017). Here we calculated the Borda score of all indicators selected as the initial 3–5 important indicators by participants considering the ranks assigned to them.

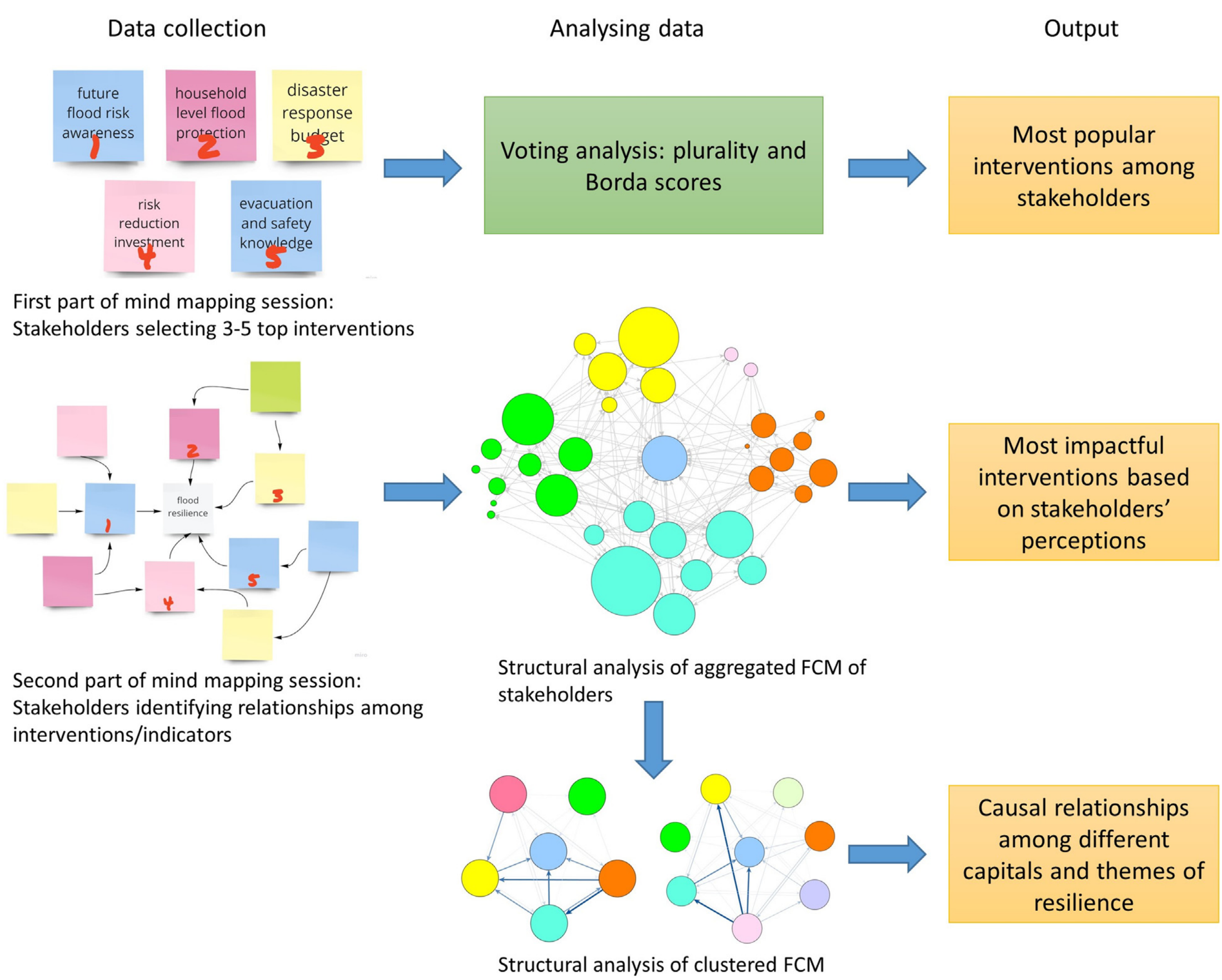

Fig. 2. Process of data collection, data analysis and outcome per each part of data collected in the mind mapping session.

3.3.2. Network analysis methods

Indegree, outdegree, and centrality degree: The 'indegree' shows the summation of weights of links entering the node while the 'outdegree' represents the summation of weights of the links exiting the node. The indegree and outdegree indicate the extent to which a node is impacted by and has impacted other nodes, respectively. In our analysis, higher outdegree suggests a higher level of impact of one indicator on other resilience indicators, meaning improving quality and capacity of that indicator causes a high increase in quality or capacities of other resilience indicators (both in terms of the number of indicators being impacted and the level of impact on those indicators). Likewise, higher indegree suggests a high level of impact that one indicator receives from other resilience indicators. The 'centrality' is the sum of indegree and outdegree, representing a measure of the relative importance of the nodes in FCM analysis. The greater the centrality, the greater is the potential for that node to affect change in the whole map/system. Therefore, centrality C(V) is:

$$C(V) = \sum(id(V) + od(v))$$

where id(V) and od(V) are indegree and outdegree of node V.

3.3.3. Clustering nodes and analysing relationships among different categories of resilience indicators

Finally, we applied a cluster analysis of aggregated FCM to provide insights on the causal relationships among different sub-groups of resilience indicators defined in the FRMC framework (i.e., 5 capitals and 7 themes) based on the knowledge co-produced by stakeholders. To do this, nodes with the same attribute (e.g., same capital or theme) were merged in three separate maps. To merge the links among the same category nodes, the weights of the same directional links were summed using the links merge functionality in the Visone software. This way the merged maps represent the total impact of the clusters of nodes with the same attribute. For example, the merged capital map shows what is the accumulative impact of financial capital on social, physical, or human capital, thereby one can compare the relative impact of the 5 capitals on each other and on resilience based on the aggregated knowledge and perception of stakeholders involved.

4. Results

The combined FCM has 40 nodes, representing 40 homogenized indicators selected by the interviewees, and 161 connections among the nodes (see Table 2 for the list of selected indicators). 35 out of 40 indicators were picked from the FRMC pre-defined indicator-set and 5 were added by interviewees i.e., 'risk communication and engagement' ($n = 19$), 'identifying the socio-spatially vulnerable areas' ($n = 3$), 'avoiding construction in high-risk areas' ($n = 4$), 'national flood protection policies' ($n = 6$), and 'robust drainage system' ($n = 1$)—n shows the number of maps including each indicator. Although there were similar indicators for some of these, it became clear through the clarification discussions with the interviewees that more specific indicators are needed to represent the exact nature of some of the indicators or interventions discussed.

Due to the nature of indicators (i.e., representing various capacities of communities that contribute to building or enhancing flood resilience), most of the relationships received positive values, meaning an increase in quality or quantity of the indicators lead to an increase in flood resilience, or in quality or quantity of other indicators. Among the 23 maps developed, we only found one negative relationship in one map, i.e., large scale flood protection ➔ avoiding construction in high-risk areas, meaning that 'large scale flood protection' has a negative impact of regulating and prohibiting construction in high-risk areas.[3] The rest of the relationships received positive values.

[3] This participant argued that building flood walls and barriers in Lowestoft may cause a false sense of security that encourages construction in areas which may look safe now but can become exposed to flood risks in future due to the impacts of climate change.

4.1. The most popular and impactful indicators

Table 2 shows the Plurality and Borda scores representing the popularity of flood resilience indicators that need to be improved based on the perception of stakeholders. Indicators selected the most across the individual maps are "large scale flood protection" (selected by 91% of participants), and 'risk reduction investment' and 'early warning system' (both selected by 78% of participants). Borda count scores also represent similar results; 'large scale flood protection' has a significantly higher score than other indicators followed by 'risk reduction investment' and 'early warning system' as the second and third most popular options. This means that there is a large consensus among the participants that 1) building coastal flood barriers, 2) increasing government budget for risk reduction activities, and 3) improving outreach and speed of early warning systems are among the most important and urgent interventions for enhancing flood resilience in Lowestoft. The high percentage of participants voting for these three indicators shows a large agreement among stakeholders regardless of their expertise and level of familiarity with such measures in Lowestoft.

On the other hand, outdegree values of the aggregated FCM represent the level of impact each indicator has on other resilience indicators (based on aggregated knowledge and perception of stakeholders). Therefore, a high outdegree value of indicator A shows 1) a high number of other resilience indicators positively impacted by improving indicator A, and/or 2) a strong impact that improving indicator A has on any number of other resilience indicators.

In contrast to the plurality and Borda scores, the highest outdegree score appears to be for 'risk communication and engagement', followed by 'risk reduction investment' and 'future risk awareness' (see Table 2). This means that based on the aggregated perception of stakeholders increasing risk communication and engagement activities as well as improving the distribution of risk reduction funding and raising awareness on future flood risk have the largest impact on other indicators of resilience, and therefore, are the indicators perceived to be most impactful in terms of increasing overall resilience. This is particularly interesting because 'risk communication & engagement' is rated the 25th and 26th in the Plurality and Borda scores. Such difference indicates that although stakeholders did not perceive 'risk communication and engagement' as an intervention having an immediate and direct impact on increasing flood resilience (like building flood walls and installing property level protections), digging into their mental models shows that they believe it has strong *indirect* impact through strengthening other parameters of flood resilience. For example, based on stakeholders' understanding/perception, the 'risk communication and engagement' indicator has a strong impact ($W = 0.7–0.9$) on 15 indicators including 'flood exposure awareness', 'future flood risk awareness', 'water and sanitation awareness', 'community disaster risk management planning', 'evaluation and safety knowledge', 'business continuity strategy', and 'asset protection knowledge' all of which have a strong impact on community flood resilience. Therefore, based on these FCM maps, increasing risk communication and engagement may influence flood resilience in many different ways, shapes and forms.

4.2. Different stages of flood risk management cycle

Fig. 3 shows the numbers, level of impacts, and popularity of indicators in the aggregated FCM per various stages of the Flood Risk Management (FRM) cycle, i.e., prospective risk reduction, corrective risk reduction, preparedness, response, and recovery. In disaster risk management, *prospective risk reduction* includes activities that address and seek to avoid the development of new or increased risks in future, e.g., land-use planning, sustainable drainage system, and community risk awareness, while *corrective risk reduction* measures seek to remove or reduce existing disaster risks, e.g., relocation of exposed populations or retrofitting of critical infrastructure (UNDRR, 2016). *Preparedness* includes actions carried out before an event to provide capacities needed to effectively manage flood emergencies, e.g., forecasting and early warning systems. *Response* and *recovery*, on the other hand, include activities that should be taken in the short or long-term after an event to manage the

Table 2
Plurality scores, Borda scores, indegree, outdegree, and centrality of nodes in aggregated FCM. The top three rates in each column are shown in bold and underlined. Colour scale is also used to show the order of rates from high to low. The five indicators highlighted in yellow are those added by interviewees and not included in FRMC set of indicators. The last six indicators are selected in response to the second question only (as indicators indirectly impacting flood resilience), and therefore, are not included in the plurality and Borda scores.

Concepts	Plurality scores	Borda count scores	Outdegree	Indegree	Centrality
large scale flood protection	**21**	**831**	1.17	3.59	4.76
risk reduction investment	**18**	**687**	**9.74**	3.39	**13.13**
early warning system	**18**	**684**	5.70	**5.12**	10.82
future flood risk awareness	14	629	**8.36**	4.95	**13.31**
community disaster risk management planning	14	625	3.22	4.20	7.42
disaster response budget	13	597	5.67	0.60	6.27
flood emergency infrastructure	14	518	0.79	**5.00**	5.79
evacuation and safety knowledge	5	492	3.18	4.67	7.85
business continuity strategy	13	483	2.96	3.30	6.26
national forecasting policy and plan	11	458	6.35	3.10	9.45
flood exposure awareness	12	448	5.47	4.10	9.57
household level flood protection	12	426	0.29	3.50	3.79
community local leadership	7	409	4.45	3.50	7.95
inter-community flood coordination	11	407	2.40	1.90	4.30
post-flood access to food/water/energy	10	373	0.54	**5.20**	5.74
community participation in flood-related activities	2	369	2.88	3.50	6.38
state of natural environment	9	337	0.61	3.80	4.41
community structure for mutual assistance	6	293	1.83	1.80	3.63
asset protection knowledge	9	254	0.41	1.40	1.81
flood response and recovery service	6	224	2.56	3.50	6.06
post-flood transportation interruption	6	219	0.43	0.00	0.43
community safety	5	183	0.42	2.50	2.92
flood healthcare access	5	183	0.42	0.70	1.12
household asset recovery	5	183	0.46	0.00	0.46
post-flood waste contamination	5	176	0.10	0.00	0.10
risk communication & community engagement	4	152	**13.02**	3.70	**16.72**
post-flood communication interruption	2	146	1.40	0.90	2.30
environmental management awareness	3	108	0.37	0.00	0.37
governance awareness	3	107	5.53	1.80	7.33
first aid knowledge	2	74	0.60	0.00	0.60
household income continuity	2	70	0.10	0.00	0.10
avoiding construction in high-risk areas	1	39	1.80	1.90	3.70
water and sanitation awareness	1	37	1.60	2.70	4.30
social inclusiveness	1	27	2.00	0.00	2.00
identifying the social-spatially vulnerable areas	0	0	1.60	4.30	5.90
community representative body	0	0	4.00	0.90	4.90
flood awareness activities	0	0	4.40	0.00	4.40
community disaster response fund	0	0	2.80	0.50	3.30
national flood protection policies	0	0	1.40	0.00	1.40
robust drainage system	0	0	0.00	0.70	0.70

adverse conditions brought on by flood and reconstruct the damaged parts of communities. Post-flood access to flood healthcare and first aid, for example, support the response stage while business credit and insurance contribute to recovering from the impacts of flood events.

The aggregated FCM categorized in the FRM cycle shows two resilience indicators that are at the same time 1) highly popular (i.e., those with highest Borda score) and 2) highly impactful (i.e., those with the highest outdegree value) in their FRM categories. These are 'future flood risk awareness' for prospective risk reduction, and 'risk reduction investment' for corrective risk reduction. This means that there is a general agreement among the local stakeholders that increasing awareness around the level and location of future flood risks as well as increasing and properly allocating budget for various kinds of risk reduction activities (e.g., property-level protection, nature-based solutions, managed retreat, etc.) are the most important actions that should be taken for flood risk reduction in Lowestoft. Communication of flood risks and what people need to do to protect themselves against future flood risks appeared to be the most impactful indicator in the preparedness stage but has not been among the top-ranked action item by stakeholders, probably because of the indirect and long-term impact of 'risk communication & engagement' on flood resilience compared to other indicators/actions – see Section 4.1.

Response and recovery stages do not have any popular or impactful indicators. This is probably because, as has been discussed by stakeholders in the focus group discussions, a lot has already been done for response and recovery phases in Lowestoft, including planning for evacuation and rescue and preparing response services and equipment. Yet, what has been given

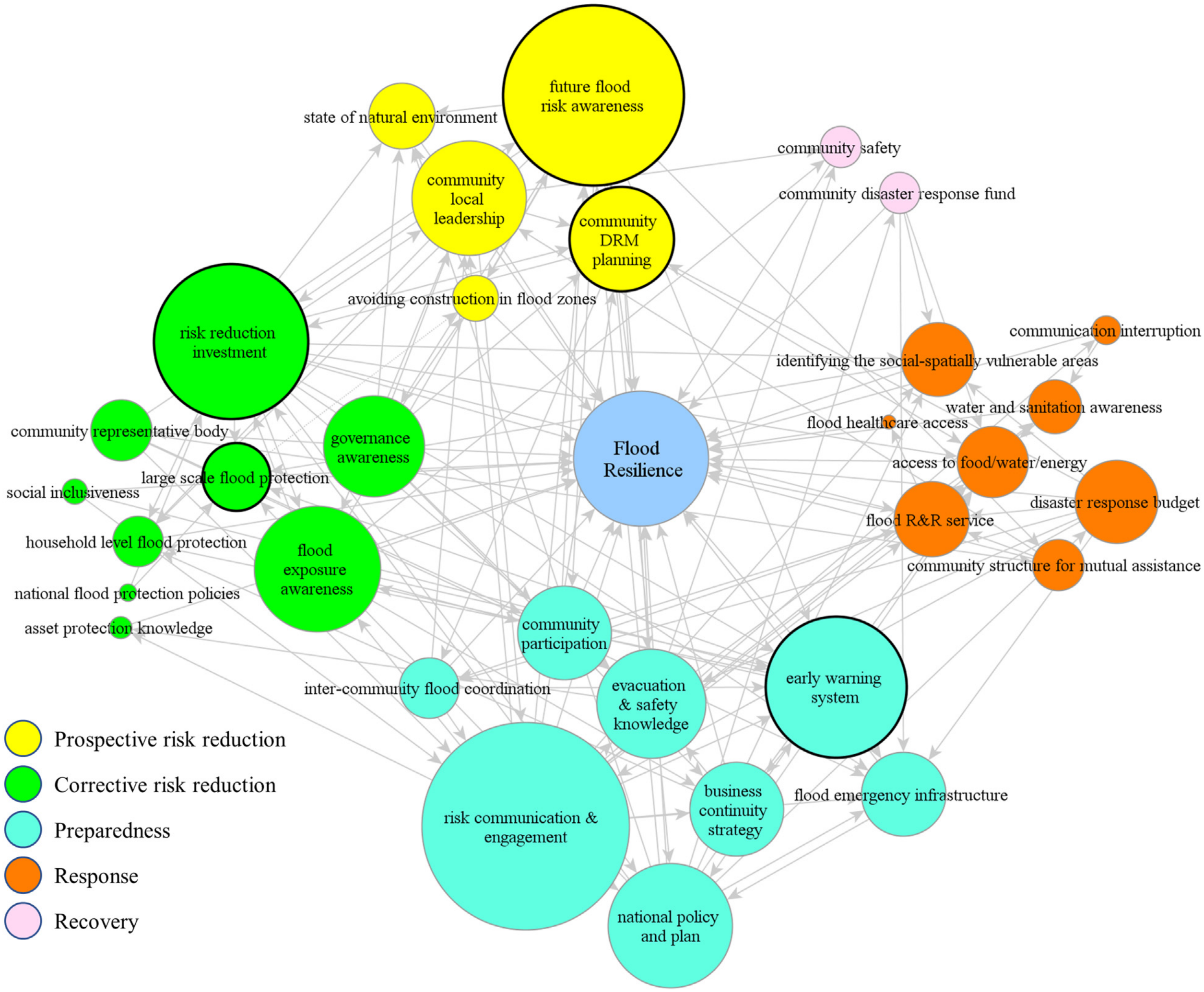

Fig. 3. Visual representation of the aggregated FCM. Size of nodes indicate the outdegree or importance of each node in terms of its impact on other indicators. Nodes with thick border represent the 5 indicators with highest Borda score, i.e., the 5 most popular areas requiring resilience action - Nodes with output centrality degree lower than 1 are removed from this map to increase the readability of the map.

insufficient attention is proactive and ex-ante activities to reduce the predicted flood risks and protect the population exposed to such risks. In addition, response and recovery activities are often intended to cope with impacts, fix things that were affected, and get back to pre-event normal as quickly as possible. They are, therefore, targeted at specific problems with short-term fixing impacts, which does not offer long-term systematic benefits. Pre-event risk reduction and prevention activities, on the other hand, are more systems-focused by their nature. They are done with more time, thought, and consultation, and therefore, they tend to have multiple benefits for pre- and post-event. Likewise, our analysis shows that the most impactful indicators perceived by stakeholders are from the prospective and corrective risk reduction, and preparedness stages. Although the response section has a similar number of indicators to risk reduction and preparedness, the accumulated impacts of response and recovery indicators on other indicators and on overall resilience are significantly lower than risk reduction and preparedness activities. This confirms the multi-beneficial aspect of pre-event risk reduction and preparedness compared to the post-event response and recovery actions. For example, activities meant to reduce risk and protect population and assets such as improving flood walls and barriers, and resilience-building measures could also protect essential buildings and services such as health centres and water/energy/food providers to provide service and assistance in flood response and recovery phases. In addition, an effective early warning system, risk management communication, and evacuation and safety education before flood events can significantly reduce the burden on flood response and recovery services and increase the quality and efficiency of such services.

It has also been noticed that 'large scale flood protection' is well-recognized by stakeholders as an important intervention for improving flood resilience yet does not appear to have many co-benefits for other resilience indicators. Whereas 'risk communication and engagement' from the preparedness stage seem to have large benefits for other resilience indicators but was not selected by a majority of stakeholders as a priority intervention or resilience indicators that should be improved. It should be noted that none of these measures should be ignored in favour of other measures. Instead, it should be recognized that measures with immediate and quick impact on reducing flood risks (such as physical protection measures) are more likely to come up first as a solution in the mental models of decision-makers. However, actions and interventions with an indirect impact on flood resilience (such as activities to communicate and raise awareness on locations and level of flood risks) may cause as much if not larger impact on flood resilience, and therefore, should be equally considered in prioritizing resilience actions.

4.3. Level of consensus among stakeholders

Among the 161 connections (representing relationships among the map's nodes) identified in the combined FCM, 37 are between an indicator and 'flood resilience' i.e., the core of the map (indicator-core relations), and

124 are among the indicators (indicator-indicator relations). While the former shows the perception of stakeholders on the *direct* impact of indicators on resilience, the latter represents their perception of impacts of indicators on each other that eventually cause an *indirect* impact on flood resilience. Similar to the nodes' frequency, analysis of the connections' frequency across the individual maps shows the most frequent connections are 'large scale flood protection ➔ flood resilience' ($n = 21$), 'risk reduction investment ➔ flood resilience' ($n = 18$), and 'early warning system ➔ flood resilience' (n = 18). Additionally, we observe that the frequency of connections mentioned across individual maps is significantly higher in the indicators-core (mean = 12.91) than indicator-indicator (mean = 2.15) relations (see supplementary material 4). This indicates that while there is a large consensus among the participants on the indicators directly impacting flood resilience (the core node) their perceptions of the indicators indirectly affecting flood resilience seem to be scattered and unfocused. This may suggest a similar conclusion made by Olazabal et al. (2018) that in a complex and multi-dimensional problem, different stakeholders provide different pieces of knowledge based on their expertise and experiences. For example, in the case of Lowestoft, there is a large agreement on what needs to be done to reduce flood risk (i.e., large scale flood protection, risk reduction investment, and early warning system). Yet, there are various views on which of the five capitals can indirectly and in the long run improve flood resilience, depending on the field expertise and experiences of the stakeholders. Therefore, it is critical to include diverse stakeholders and combine different sources of knowledge to produce a comprehensive system knowledge closer to reality.

Regarding the SD and CV of relationships, we did not observe any significantly different or contradictory values given by interviewees for each relationship. The CV of relationships range from 0 to 0.79, and among the relationships that are repeated in 2 or more maps, 77 out of 81 (95%) relations have CV lower than 0.5. This shows a relatively high agreement among the values of relationships given by stakeholders in more than one map.

4.4. Causal relationships among different clusters of flood resilience

Fig. 4 shows the causal relationships among different clusters of flood resilience discussed in Sections 2 and 3.3.3, i.e., 'capitals' and 'themes' of resilience.

The causal relationships among the clusters of 5-capitals (financial, physical, social, human, and natural) show the strongest cause-effect relation from human to social capital, and that among the five capitals, social capital has the strongest impact on flood resilience followed by physical and human capitals, respectively. This means that, according to the stakeholders' collective knowledge and perception, human indicators such as awareness about flood risk and knowledge of flood risk management and governance have the strongest impact on the social indicators such as people participating in flood-related activities, national and community-level policies and plans, and coordination and mutual assistance at the time of flood events (see supplementary 4 for the full list of indicators per capital). Note that the weights of the connections between clusters are dependent on a combination of 1) the number of indicators selected by stakeholders per each cluster, and 2) the weight of aggregated connections among the clusters. The low causal relation of financial capital on other capitals and flood resilience is, for example, due to the low number of indicators in this category (financial capital = 3, physical = 12, social = 10, human = 8, and natural = 1 – note that indicators are selected by stakeholders, thus, the difference in the number of indicators per capital is due to the difference in perceived available options for improving flood resilience per capital). Thus, while the 'risk reduction investment' and 'disaster response budget' are among the most important individual indicators, the aggregated impact of financial capital is lower than other capitals that contain more indicators. This shows that capitals with more options (i.e., indicators) to change resilience of communities can be more impactful and have higher capacity to change than those with fewer options. As shown in Fig. 4, human capital has the largest outdegree among the five capitals meaning it has the highest impact on enhancing other capitals as well as flood resilience in Lowestoft. Among the human capital indicators, those related to awareness, education, and information-sharing come up as the main drivers and enablers of many other resilience indicators. In fact, it has been manifested in climate and disaster risk management that improving climate service and communication to improve human capacities in managing flood risks are among the main enablers of climate resilience (Daniels et al., 2020; Nkiaka et al., 2019). However, when it comes to decision-making the direct and indirect impacts of such activities on flood resilience becomes hard to measure, which therefore, prioritize other actions and interventions with the most tangible and measurable outcome—e.g., flood barriers which protect X number of houses and businesses.

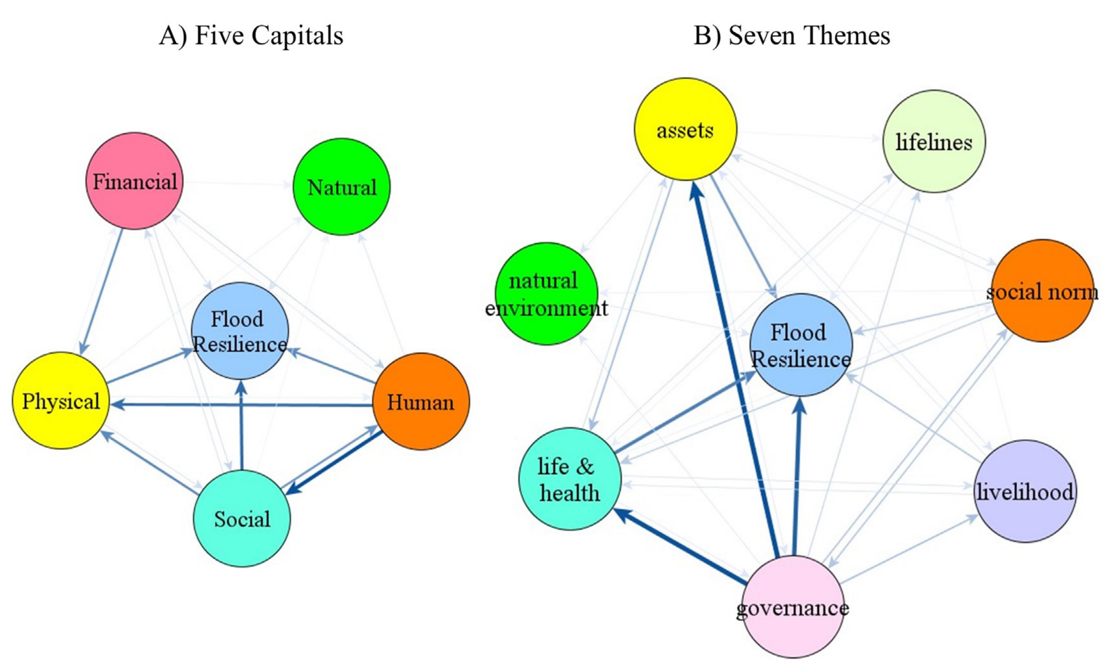

Fig. 4. The causal relationships among clusters of 'Capitals' and 'Themes'.

These results underpin why system thinking and a holistic view are so important in decision-making for flood resilience. Despite the general perception that lack of financial resources is often the main obstacle for taking adaptation and resilience actions, such analysis shows that providing enough financial support may not necessarily lead to taking resilience actions if required human and social systems are not in place to encourage resilience decision-making. This system thinking is particularly important as human, social, and natural capital are often neglected, while activities to improve financial and physical capitals, which are essential but might not be enough in building community resilience against floods, are favoured.

Another observation is the weak relationships among the natural capital other capitals/resilience. It has been admitted by the stakeholders that Lowestoft is dealing with a lack of natural resources, and therefore, a lack of nature-based solutions for FRM. This is basically due to the massive built-environment development in Lowestoft, which does not leave much space for the natural environment to be preserved or extended. Therefore, according to the perceptions of stakeholders, applying nature-based solutions in Lowestoft does not depend on other indicators/capitals such as financial investments in natural measures or increasing human capacities such as awareness and education around the role of natural capital. This, particularly, suggests that further investigation is needed as to how and to what extent natural capital can be improved and used for flood risk management in Lowestoft. This is an example of where internal knowledge of stakeholders may not provide sufficient information to solve the problem, and therefore, external knowledge, expertise and best practices are required to assist the decision-making process.

In the thematic clusters, we also observe strong causal relationships from the governance theme (including FRM planning, risk communication, awareness activities, response coordination, and allocated budget for FRM) to 1) flood resilience (core concept), 2) assets (such as buildings and their contents, land, and infrastructure), and 3) life & health (Fig. 4.b). This is mainly because of the strong impacts of risk communication, awareness activities, and risk policies and plans (i.e., formal and informal organizations and institutions and their operations that create governance) on increasing activities that protect assets (e.g., property-level protection measures), life (e.g., evacuation and safety), and health (e.g., first aid assistance).

5. Discussion and conclusion

In this paper, we combine a participatory mind mapping method, i.e., FCM, with a flood resilience measurement framework, i.e., FRMC. With this methodology, we encourage a system-thinking exercise during the participatory process and develop a collective mental model using the perceptions and knowledge of local stakeholders. This model has been used to identify 1) the causal relationships among various aspects/indicators of flood resilience, and 2) the level of agreement among different stakeholders on what action should be taken first and where investments should go for building/improving flood resilience in Lowestoft, UK.

This study demonstrates a new way of applying the FCM method for supporting decision-making. While commonly used for knowledge coproduction and understanding perceptions of local stakeholders, in this study, by combining FCM and FRMC, a new holistic approach in problem-solving as well as collective and inclusive decision-making based on system-thinking is tested. This can be particularly useful in decision-making for complex, multi-dimensional and multi-stakeholder issues such as climate-related disasters.

Combining FCM and FRMC also shows benefits for resilience measurement activities. While resilience measurement tools developed by international aid agencies often set out to encourage a holistic view of resilience by introducing various types of indicators, such indicators are often measured and analysed in silos. By applying FCM in combination with FRMC we propose a system model which represents the interdependencies and interlinkages among resilience indicators based on the best available local knowledge. In addition, resilience measurement tools are currently being used mainly for sharing knowledge and raising awareness on resilience challenges and weaknesses and have less focus on supporting decision-making for and implementation of resilience actions (Mehryar et al., 2022). This is mainly because deciding what measures should be implemented when and where does require the identification of gaps, weaknesses, and challenges but also an understanding of the local priorities for investing resources and of the benefits and co-benefits of each intervention option. In this study, we demonstrate how applying a participatory system mapping method such as FCM can support prioritization and identification of co-benefits by utilizing knowledge and perceptions of local stakeholders to identify potential impacts of interventions, and therefore, formulate priorities.

Our analysis helps identify intervention areas and their potential for increasing flood resilience based on local perceptions and priorities. Funding and implementing *large-scale flood protection* measures (e.g., building floodwalls and barriers) are often perceived as the most urgent action. However, interventions aiming at *increasing knowledge and awareness* of the Lowestoft population about current and future flood risks and flood risk management activities are perceived to be the most impactful, particularly, in terms of increasing the social, financial, and physical capacities of the community. We, therefore, argue that enhancing/building resilience requires consideration of actions with direct and indirect impact on flood risk protection and prevention. While building large-scale physical flood protections will have immediate benefits for the population at flood risk, reducing and preventing flood risks (or keeping people away from flood risk areas) can be supported by many different approaches in the long term. The benefits of softer approaches can be seen in e.g., improved policies, regulations, and incentive mechanisms to prohibit building in risk zones, and greater awareness and education about flood risk areas and flood protection/resilience measures.

This study also highlights the fact that there is often a tendency among decision-makers to focus on measures that provide immediate protection over those that have long-term and indirect impacts. Applying FCM in combination with FRMC in the case of flood resilience in Lowestoft helps us to expand the mental models of stakeholders towards including various (social, physical, human, natural and financial) aspects of flood resilience and interrelationships among such aspects when identifying and prioritizing actions and interventions. In our case study this approach has helped the local authority to understand the priorities and preferences of local stakeholders and to identify the direct and indirect impacts of different interventions based on stakeholders' perceptions. Our analysis of clustered FCM shows the importance of the flood governance system (e.g., FRM planning, risk communication, awareness activities, response coordination, and allocated budget for FRM) as well as social and human capitals indicators (i.e., relating to the plans, policies and human awareness and knowledge) as the focal points that could trigger a change in overall flood resilience in Lowestoft.

The methodology explored in this paper supports place-based and context-specific decision-making by using local knowledge and perception based on the experiences of different stakeholders. However, it should be noted that using participatory methods such as FCM is not suitable for quantifying the real impacts of interventions in a cost-benefit evaluation manner. Rather it is used to understand and expand stakeholders' mental models about the core problem, incorporate their insight and perception informed by their experiences in working with flood risk and resilience. The advantages of such approaches are, therefore, twofold: 1) to support participants in a participatory decision-making process to include a system-level and interconnected view of flood resilience in their decision-making, and 2) to consider various preferences, priorities, and interests of local stakeholders in the process of prioritizing and implementing resilience interventions. Future studies are, however, needed to explore ways through which subjective and qualitative knowledge of stakeholders can be combined with quantitative data (e.g., cost-benefit data) in computational models trying to evaluate potential impacts of interventions and compare different scenarios. In addition, further studies are needed to 1) analyse and compare mental models of different groups of stakeholders in terms of their attributions (e.g., expertise or group discussions), or compare mental models of stakeholders before and after the discussion sessions to assess the impact of resilience discussions and knowledge sharing on stakeholders' perceptions of resilience decisions and actions, and 2) re-evaluation of the result with stakeholders.

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CRediT authorship contribution statement

Sara Mehryar: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Software; Visualization; Writing - original draft; Writing. **Swenja Surminski**: Conceptualization; Funding acquisition; Methodology; Project administration; Resources; Supervision; Writing - review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Sara Mehryar and Swenja Surminski reports financial support was provided by Z Zurich foundation.

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