Mobilizing institutional capacities to adapt to climate change: local government collaboration networks for risk management in Mexico City

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State-centered and hierarchical government strategies based on technocratic top-down approaches have proved inadequate to address multiple interacting and cross-scale risks. In contrast, multilevel governance (MLG) provides a form of governance by networks that operate both in a horizontal arena with neighboring local governments, civil society organizations, and local communities, and in vertical settings, with higher-level governmental authorities and international organizations. In this paper, we examined the role and experience of local governments in a multilevel governance system for risk management in Mexico City. We sought to understand what collaborative resources local governments have to address multiple risks in Mexico City? How do they mobilize these resources in specific actions to address a risk, and how do they interact with different levels on diverse organizational scales? Our results show that resources for vertical and horizontal collaboration were key for local governments for coordination to address multiple risks. We found that collaboration was more common between local governments and with the subnational government. Also, the most common actions focused on forecasting and prevention, as well as preparedness and relief of multiple risks. We found evidence of successful elements of multilevel governance and identified the need for further research on the engagement and representation for non-governmental organizations and private actors in networks of risk management. The results from this study provide a better understanding of the arrangement of collaborative resources underlying local government actions under a state of urgency and scarcity, where action cannot wait for institutional change.

Climate change hazards pose challenges for sustainable adaptation in cities that experience rapid urbanization, high levels of inequality, and exposure to multiple and interconnected risks[1]. Climate adaptation in cities is mainly led by local governments, which have the responsibility of implementing climate action in coordination with the national and subnational governments and are the immediate government level in contact with vulnerable populations[2,3]. Effective local institutions require adequate institutional capacity to build consensus for climate action, enable coordination, and inform strategy setting[4]. Local governments need to be flexible in order to enable top-down and bottom-up action that can bring capacities together

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across different levels of government[1]. The institutional capacity of local governments for climate action can be hindered by the "tragedy of urgency"—constant pressure from immediate needs, daily demands or other pressing issues—[5], the lack of climate change awareness, and the low capacity to access and mobilize economic resources[6]. Asymmetries in institutional capacities of local governments also relate to political inequality[7] and the centralization of the political systems, preventing the state and local governments from sharing experiences and cooperating[8]. Nevertheless, the institutional capacity of local governments to respond to multiple risks can be strengthen by collaboration networks[9] and supported by multilevel governance (MLG)[10]. Both are an enabling condition for effective climate action, through: (a) enabling or strengthening cooperation and coordination between government levels and society; (b) improving the efficient use of scarce resources through shared responsibilities and learning; and (c) preventing policy gaps and contradictive policies[4,9,10]. MLG can also contribute to the decentralization of climate action through the devolution of power from central to local governments and increasing power sharing between the state and civil society[11]. Successful elements for the attention to disaster risks by MLG involve the protagonist role of local governments and their capacity to engage local communities and citizens and to interact constantly with higher-level authorities in implementation processes[10].

In this paper, we examined the experience of local governments in their role in a multilevel governance system for risk management. We aimed to understand how the local governments mobilize their collaborative resources to address multiple risks in Mexico City. We chose Mexico City as a case study, where the main risks that the city will experience due to climate change are associated with heat waves, droughts, flooding due to intense rainfall events, and landslides, in addition to non-climate risks, such as earthquakes[12–15]. To understand the available collaborative resources that local governments have and how these resources are mobilized to address multiple risks, we used a mixed-methods approach based on workshops with the 16 local governments (*alcaldías*) of Mexico City. We mapped the collaborative resources perceived by the government officials to address priority risks *(what collaborative resources do local governments have to address multiple risks in Mexico City?)*. Then we determined *how governments mobilize collaborative resources for specific actions to address a risk, and what the main similarities and differences are among them*. We used an Integrated Risk Management approach because it seeks to minimize human, economic, and physical losses, as well as reduce conditions of vulnerability to increase resilience and maintain the livelihoods of Mexico City dwellers[15]. Finally, we aimed to understand further how the local governments mobilize their collaborative resources by analyzing *how they interact with different levels on a jurisdictional scale (inter-governmental, local, regional and national governments) and other type of organizational scale (society)*[16], based on a network approach. Our results show that resources for vertical (with other government levels) and horizontal (with non-governmental actors and other local governments) collaboration were key for local governments to act, as local governments coordinated to address common risks. The lack of access to resources and a knowledge base regarding risks has been addressed through collaboration with non-governmental actors. In this study, we characterized the mobilization of collaborative resources as a key determinant of institutional capacity response under a multi-level governance approach. In doing so, we aimed to better understand the collaborative resources arrangement underlying local government actions under a state of urgency and scarcity, in which attention cannot wait for institutional change.

The Mexican federal system was originally structured in accordance with the classic model of U.S. federalism, including: (i) power at the federal level and bodies of power at the local level; (ii) a constitutional formula for the distribution of powers under the logic of dual federalism (with express powers of the federation and residual powers in favor of the federative or state entities); and (iii) a bicameral federal legislative branch. In this federal system, the state and local governments are elected independently from the federal government. However, the federal structure of the country exhibits a high degree of centralization that has part of its roots in the historical

struggles between federalists and centralists during the XIX century, and that was later consolidated during the XX century, and resulted in the subordination of the states and local governments to the federal or national government[17].

As such, local governments in Mexico are key elements for the administrative and political structure of Mexico to mitigate and adapt to climate change[18]. These governments have sovereignty and the capacity of self-determination in their territories as defined in the Mexican legal framework stated in the constitution. Some of the major responsibilities of the local governments in Mexico are the public administration of their territories, including public services provision to the population (i.e. potable water and sewage supply), and the determination of land uses (article 115 in the Constitución Política de Los Estados Unidos Mexicanos, 2021).

Local governments in Mexico have to develop, implement, and evaluate climate change policy at the local level[19]. Even though local governments can mainstream adaptation into their work, they still depend on the national and subnational governments for resources, capacities, and to scale-up local adaptation initiatives. Negative dependencies due to the lack of investment in capacity building by national and subnational governments can hinder climate action by local governments. Solorio (2021) identified the low levels of attention that the Mexico Government, through the National System on Climate Change (SINACC), pays to subnational and local concerns regarding climate action. Local governments in Mexico City face additional challenges than local governments in other states in Mexico because they exhibit some differences in their administrative capacity, particularly regarding budget allocation from the Mexico City Government (article 122 in the Constitución Política de los Estados Unidos Mexicanos, 2021). These constraining conditions that local governments face in Mexico City have also been acknowledged regarding climate change adaptation, which has been traditionally considered the responsibility of the Ministry of Environment of the Mexico City Government. In this context, inter-institutional coordination and communication is considered a key element to be improved to ensure a proper fit and alignment of climate change policies and strategies at various governmental levels and to reduce the current level of institutional fragmentation[13].

The attention that the Mexico City government pays to the vulnerability of multiple interconnected risks, together with the strengthening of adaptive capacity and resilience building, implies the consideration of policy and planning instruments that involve effective and innovative coordination between different jurisdictional (vertical) levels and network levels, or the government interacting with diverse sectors of society (horizontal). We mapped at least 16 policy, planning, management, financial, and participation instruments with direct attribution to Mexico City that can be leveraged to address the multiple and interconnected risks (Table 1). These instruments can be understood under a hybrid approach of planning adaptation, where there are benefits from the stability provided by regulations and institutional architecture, characteristic of a top-down approach, and from the flexibility that fosters the participation of diverse societal actors, provided by a bottom-up approach.

We chose Mexico City as a case study (Fig. 1), where the main risks that the city will experience due to climate change are associated with heat waves, droughts, flooding due to intense rainfall events, landslides, in addition to non-climate risks, such as earthquakes[12–15]. As of 2020, Mexico City had a population of 9,209,944, distributed in 1494.3 km^2, with a population density of 6163.3 inhabitants per km^2. There are 16 local governments or districts (*Alcaldías*): The Iztapalapa territorial district, with 1,835,486 inhabitants, is the most populated, followed by Gustavo A. Madero with 1,173,351 inhabitants, while the territorial districts with the lowest population are Cuajimalpa and Milpa Alta with 217,686 and 152,685 people respectively. The territorial districts of Iztacalco, Cuauhtémoc, Benito Juárez, and Iztapalapa have a density of more than 16,000 inhabitants per square kilometer[20].

It is expected that warming related to the Urban Heat Island effect (UHI) will be of a magnitude (2.5–4.5 °C) associated with climate scenarios of high emissions for the end of the century[21]. The temperature of Mexico

Table 1 | List of relevant policy, planning, management, financial and public participation instruments for Mexico City that manage and respond to multiple risks

Instrument type	Instrument	Reference
Policy	State Action Program for Climate Change (PECC) Programa de Acción Estatal de Cambio Climático (PECC)	[20]
Policy	Municipal Climate Change Program Programa Municipal de Cambio Climático	
Policy	Specific Program for Integral Risk Management and Civil Protection Programa Específico de Gestión Integral de Riesgos y Protección Civil	[21]
Policy	Mexico City Resilience Strategy Estrategia de Resiliencia de la CDMX	
Policy	Mexico City Civil Protection Program Programa de Protección Civil	
Policy	Mexico City Local Climate Action Strategy (2021–2050) Estrategia Local de Acción Climática (2021–2050)	(Ley de Mitigación y Adaptación al Cambio Climático y Desarrollo Sustentable de la Ciudad de México, 2021)
Policy	Mexico City Climate Action Program (2021–2030) Programa de Acción Climática de la Ciudad de México (2021–2030)	
Planning	Natural Protected Areas Management Program Programa de Manejo de Areas Naturales Protegidas (ANP)	(Ley General del Equilibrio Ecológico y la Protección al Ambiente, 2018)
Planning	Areas of Environmental Value Management Program Programa de Manejo de Areas de Valor Ambiental (AVA)	(Ley Ambiental de Protección a la Tierra en la Ciudad de México, 2023)
Planning	Community Conservation Area Plans Planes de Áreas Comunitarias para la Conservación (ACC)	
Planning	Mexico City Risk Atlas and risk atlas at at municipal scale Atlas de Riesgos de la CDMX y Atlas de Riesgos por Alcaldía	(Ley de Gestión Integral de Riesgos y Protección Civil de La Ciudad de México, 2019; Ley de Mitigación y Adaptación al Cambio Climático y Desarrollo Sustentable de la Ciudad de México, 2021)
Planning	Information systems: - Early Warning System /Sistema de Alerta Temprana - Digital Platform / Plataforma Digital - Climate Change Virtual Center /Centro Virtual de Cambio Climático	
Management	Construction Regulations for Mexico City Reglamento de Construcción de la CDMX	
Management	Regulation for agroecological production on conservation land in Mexico City Norma sobre producción agroecológica en suelo de conservación en CDMX	PROY-NACDMX-002-RNAT-2019
Auditing/financial	Disaster and Emergency Assistance Fund Fondo de Atención a Desastres y Emergencias (FADE)	[21]
Participation	Council for Integrated Risk Management and Civil Protection for each municipality Consejo de Gestión Integral de Riesgos y Protección Civil de cada Alcaldía	

Fig. 1 | Map of the 16 local governments of Mexico City. Created by the first author from public databases of the National Institute of Statistical and Geographical Information[36]. This image does not contain third party material.

City has already experienced a significant increase of 3° to 4 °C in the past 100 years. This increase relates to the UHI of the Mexico City Metropolitan Area (MCMA), associated with urbanization patterns and the loss of vegetation and surface water bodies. Newly urbanized regions increase the maximum temperature by the order of 1 °C per decade[12]. In addition to the gradual increase in temperature, heatwaves or warm spells (days with more than 30 °C) have doubled in the central, eastern, and northwestern parts of the city[12].

Regarding precipitation, Mexico City will face a progressive reduction in the mean annual precipitation and an increase in intense rainfall events. Mean precipitation is expected to decline on average by 7% in the 2050s, and by 10.4% by 2070. Reduced annual precipitation will trigger drought events and increase water scarcity, leading to heat strokes and a lack of water for human use[13]. Warmer conditions in the atmosphere can lead to intense precipitation or rainfall events. Mexico City has experienced an increase in the number of extreme rainfall events, crossing the precipitation threshold of 20 mm per day[12]. The distribution of extreme rainfall events has spread in the city, and nine out of 16 districts are considered to be at very high risk of flooding, representing 68% of Mexico City's population[14]. Extreme rainfall can also cause runoff and landslides due to the landscape (differential soil subsidence), unplanned urbanization, the absence of green open spaces, and the complete dependence on the extensive underground drainage system, particularly in the center, western, and southwestern areas of the city[13,22]. The climate risks will interact or will be exacerbated by other social-ecological risks affecting Mexico City, like those related to geophysical hazards, such as earthquakes and subsidence due to the overexploitation of the aquifer[15], and socio-political factors, such as protests due to social unrest.

Results

Collaborative resources (collaborative resources that local governments have to address multiple risks in Mexico City)

It is worth noting the central role that the Civil Protection Department had in all the local governments (RC1) and the Mexico City Ministry of Integrated Risk Management and Civil Protection. However, this may be explained by the fact that both types of government agencies were the ones that organized the workshops and summoned the workshop participants (Fig. 2). The risks prioritized in the workshops were earthquakes, flooding, wildfires, landslides, and those associated with social causes, such as protests and pilgrimages. To assess the local governments' capacities, we decided to focus on the three priority risks that were more frequently reported by the workshop's participants: earthquakes, flooding, and wildfires.

Actions (How governments mobilize the collaborative resources in specific actions to address a risk)

More than half of the Integrated Risk Management (IRM) actions corresponded to the preparedness-relief and prevention-prediction stages, and less than half to mitigation, risk identification, and recovery (Fig. 3). The actions of the preparedness-relief stage were aimed at carrying out drills and preparing brigades to respond to risks, mainly earthquakes. The prevention-prevision actions focused on preventing the adverse effects of floodings, wildfires, and earthquakes, such as investment in infrastructure or urban equipment to prevent flooding through the Municipal Infrastructure Contribution Fund (FAISM). Regarding the identification of risks, the workshop participants mentioned the existence of initiatives focused on the spatial identification of areas vulnerable to flooding. However, most of the local governments (69%, 11 local governments) indicated that they rely mainly on the Mexico City Risk Atlas or simply do not have enough information and responded directly to areas where the risk already materialized into a disaster. Recovery or reconstruction actions were mainly aimed to recover the function of the affected areas. It is worth noting that few local governments pointed out the scope of reconstruction after the 2017 earthquake.

Differences between the local governments

Even though 61% of the actions concentrated in the preparedness-relief and prevention-prevision stages, there were differences in the distribution of actions by risk between local governments (Fig. 3). For example, Azcapotzalco, Coyoacán, Cuauhtémoc, Cuajimalpa, Tláhuac and Venustiano Carranza showed a common pattern in relation to the distribution of IRM actions with a higher percentage of actions related to the preparedness-prevention stage. However, differences in the distribution of actions for the same risk stand out. Such was the case for actions to address flooding through forecasting and prevention (Cuajimalpa, Iztacalco and Venustiano Carranza), risk identification (Milpa Alta), risk mitigation (Gustavo A. Madero and Tlalpan), preparedness and relief (Álvaro Obregón and Coyoacán), and recovery and reconstruction (Xochimilco), or all of them equally distributed (Iztapalapa). It is important to mention that in the local governments where the workshops were conducted in person, more than one risk was explored in the timeline boards. This did not occur in the virtual workshops where only one risk was explored due to time constraints (Fig. 3).

Collaboration networks (How local governments interact with different levels on a jurisdictional scale -inter-governmental, local, regional and national governments- and another type of organizational scale -society-)

Results showed similar sizes (number of nodes and edges) regarding the collaboration networks of the local governments to address earthquakes and flooding; meanwhile, the wildfires collaboration network was smaller, both in the number of edges and nodes (Fig. 4).

Regardless of their differences in size, the three collaboration networks exhibited similar characteristics regarding degree centralization but differences for density and cross-boundary exchange. Density in the three networks is relatively low, for example, the maximum number of potential
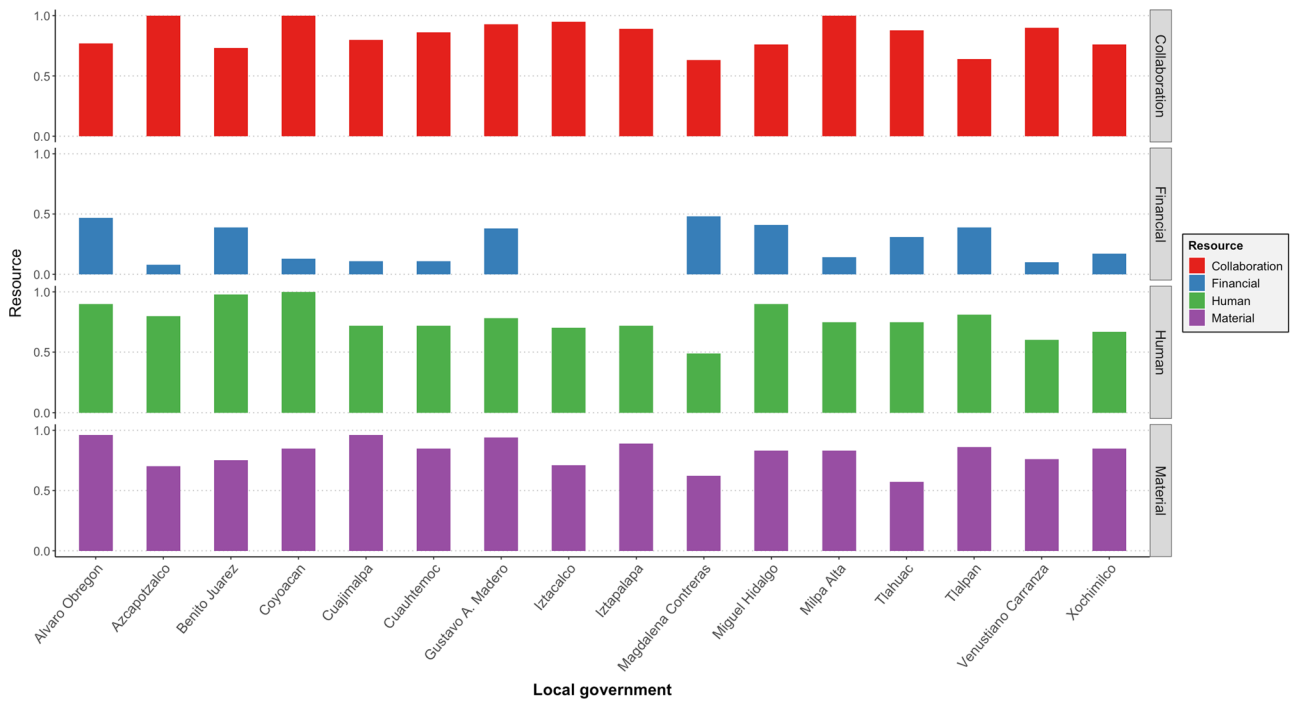
Fig. 2 | Distribution of material, human, financial and collaborative resources perceived by each of the 16 local governments to address risks in Mexico City. Collaboration: collaboration between departments within the local government RC1; with other local governments (RC2); with the state government (e.g., Mexico City Government) (RC3); with the national government (RC4); and (e) with non-governmental organizations (RC5).
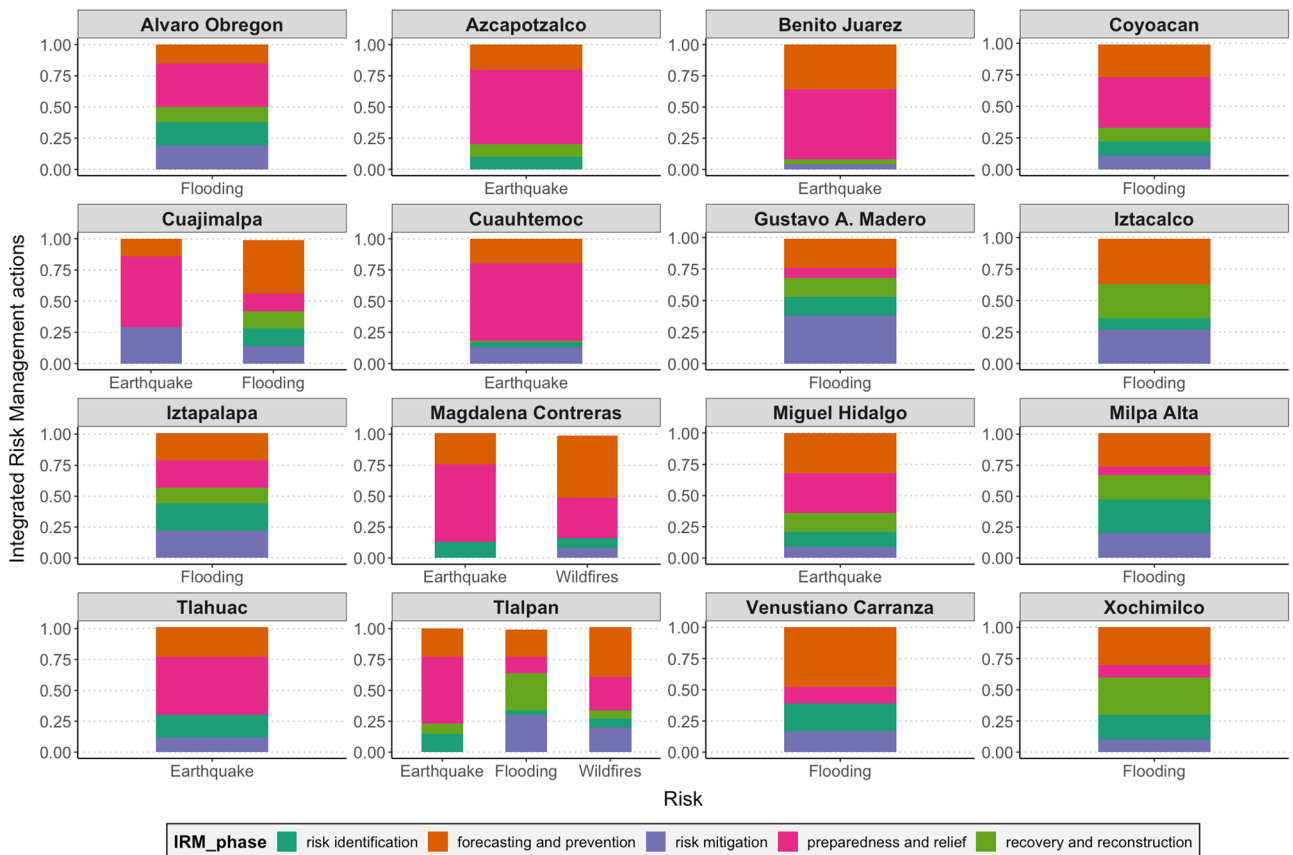

Fig. 3 | Distribution of Integrated Risk Management actions by each local government for the three risks identified. Each panel contains the distribution of each integrated risk management action per risk (represented by each color in the panels) per local government. The three risks represented in the graphs are earthquakes, flooding and wildfires.

Fig. 4 | Collaboration networks per priority extreme event. The nodes in the three networks represent local governments (blue node), subnational government or Mexico City Government (purple node), national government or Mexico Government (orange node) and non-governmental organizations (green node). Each panel represents a risk: earthquakes, flooding, or wildfires.
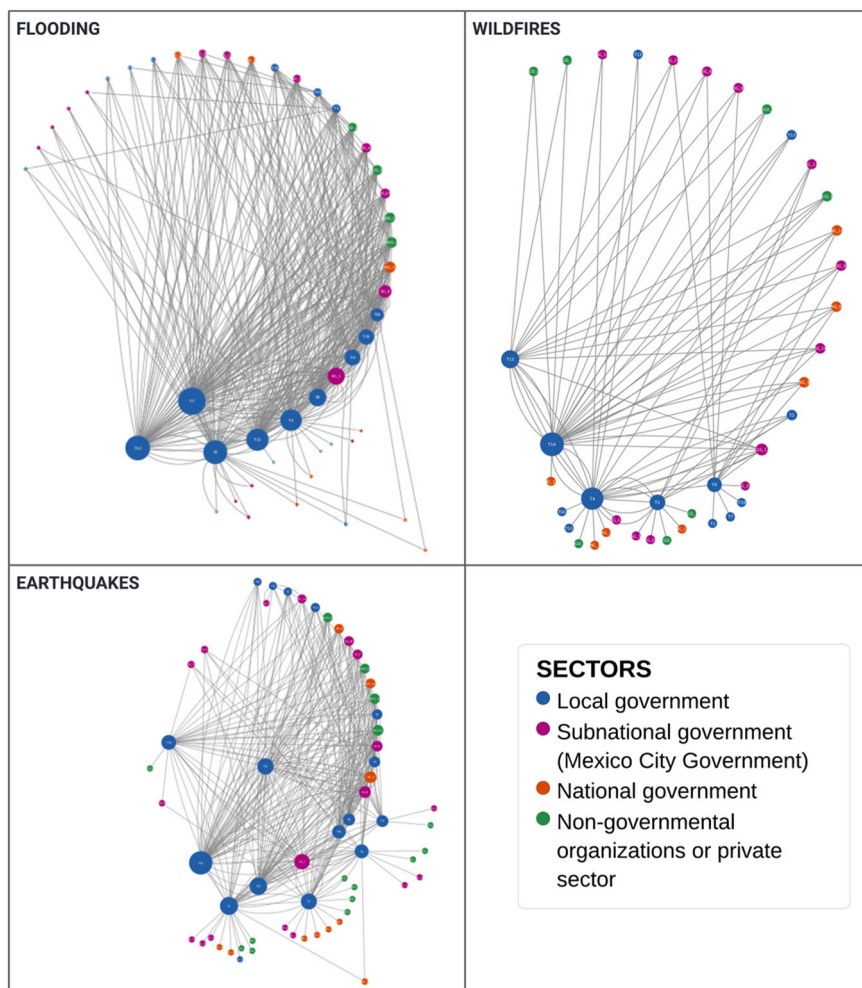
edges of the earthquake network could be 1770 given 60 nodes; in contrast, there are 320 edges. This meant that there was a low connectedness in the networks and the most connected nodes were the egos of the network, which are the local governments. The higher centrality of the local governments (blue node size in Fig. 4) can be partially explained because the integrated networks were built with the egonets of each local government. That is, the workshops' participants were local government officials and there were no participants from the subnational and national government, or from non-governmental organizations. The cross-boundary exchange appeared to be mainly in local and sub-national governments, and to a lesser extent with non-governmental organizations and the national government (Table 2).

The organizations (nodes) with the higher centrality in each priority risk network are shown in Table 3. The earthquake and flooding networks shared similar results regarding the more connected organizations. In both networks, the local governments were from both the central area (e.g., Cuauhtémoc, Coyoacán, Iztapalapa) and the outer or more peripheral area of Mexico City (e.g., Álvaro Obregón and Tlalpan). Also, the earthquake and flooding networks shared similarities regarding higher jurisdictional levels, which mainly have key responsibilities for disaster response both at subnational (e.g., Risk Management and Civil Protection) and national (e.g., National Center for Disaster Prevention), with some differences (e.g., Ministry of Energy). In contrast, the five more central local governments in the wildfire network were in more peripheral areas of Mexico City and have the larger areas of vegetated areas under a conservation status. Meanwhile, this network had subnational and national government agencies for disaster response, but also regarding environment, mobility, and human rights. The composition of the more central non-governmental organizations was

similar in the three priority risk networks, with a predominance of academic institutions and neighborhood committees.

Discussion

Regarding the experience of local governments in their role in a multilevel governance system for risk management in Mexico City, the highest cross-boundary exchange with local governments indicated strong horizontal collaboration between local governments, particularly for dealing with wildfires between governments from the peripheral area of Mexico City (Tables 2 and 3). Also, neighborhood committees and research centers were the most common non-governmental organization that local governments collaborated with to address the three priority risks. Regarding vertical collaboration, the Risk Management and Civil Protection Ministry of Mexico City and the Ministry of Defense were the most connected subnational and national governmental agencies in the three priority risks networks. The wildfire network provided additional elements to understand the diversity of collaboration by including subnational and national governmental agencies focused on environment, mobility, and human rights. The local governments with higher centrality in this network have natural protected areas and indigenous communities in their territories, and three of them had a lower income (less than 6%) of the total budget transferred from the Mexico City Government[23]. The diversity in the vertical and horizontal collaboration in the wildfire network indicated the need for the local governments to access a wide set of resources under financial scarcity conditions. Also, the highest values of the local governments in the cross-boundary exchange metric and the horizontal and vertical collaboration, particularly for the wildfire network, may indicate the existence of successful

Table 2 | Density, degree centralization and cross-boundary exchange for the priority risks

SNA metric	Earthquake	Flooding	Wildfires
Local governments in the network	16	16	13
Number of nodes	60	48	39
Number of edges	320	369	93
Density	0.11	0.16	0.09
Degree centralization	0.38	0.52	0.40
Cross-boundary exchange			
National government	8%	7%	9%
Subnational government (Mexico City Government)	20%	20%	18%
Local governments	62%	62%	66%
Non-governmental organizations	10%	11%	8%

elements of multilevel governance[10]. That is, it underscores the protagonist role of local governments: Most of them had the higher centrality in the priority risks networks (see large blue nodes in Fig. 4), the ability to involve local communities (particularly neighborhood committees and other NGOs, see Table 3), and the capacity to interact constantly with higher-level authorities (particularly with the subnational Mexico City government according the cross-boundary exchange results in Table 2). However, further research is needed to better understand the potential routes for the local governments to collaborate with other types of non-governmental or private organizations for addressing multiple risks. The engagement of non-governmental organizations and actors is key due to the potential role of environmental groups and other socio-political constituencies, that can integrate the needs and demands of the most vulnerable segments population and provide support for stronger climate policies by means of a higher level of environmental community activism[24]. There is also the need to further understand degree of democratic legitimacy of risk management in the multilevel governance system for risk management. That is, to understand the extent to which citizens have an effective say in risk management by local governments[11].

Additional empirical evidence could assist in understanding how institutional capacity as an enabling condition for adaptation can be mobilized into climate action[25]. In this regard, the results here suggest that the IRM actions associated with preparedness-relief (e.g., drills) and prevention-prevision (e.g., investment in public infrastructure through federal funds) were more important for local governments. This indicated the existence, at the local level, of a well-structured and organized system of capacities related to relief during flood events and earthquake management. For example, in the case of floods, many government agents identified actions aimed at mitigating flood risk (e.g., periodic drainage in collaboration with the Mexico City Water System), preparing the population (e.g., communication campaigns), and prevention (e.g., investment in public infrastructure, with contributions from federal funding). These actions represented the specific capacities of each local government to provide relief during flooding events. There were also few actions associated with the recovery and reconstruction stage after earthquakes, and when these were mentioned, they were mainly related to recover the function of the affected areas. Also, in six workshops, reference was made to the 2017 earthquake, the most recent large earthquake that occurred in Mexico City; however, participants did not specify the scope of reconstruction in subsequent years. This may be due to the approach that the Mexico City Government has in coordinating these activities, which may not depend directly on the local governments.

Another IRM action with fewer examples was risk identification. The participants pointed out various initiatives in their municipalities for the identification of vulnerable areas to risks such as flooding. However, local governments did not focus on risk identification by themselves. Instead, they relied on the Mexico City Risk Atlas or on the collaboration with

Table 3 | Top key organizations in the priority risks networks by type of organization

SNA metric	Earthquake	Flooding	Wildfires
Local government	1) Tláhuac 2) Miguel Hidalgo 3) Coyoacán 4) Xochimilco 5) Cuauhtémoc	1) Venustiano Carranza 2) Coyoacán 3) Álvaro Obregón 4) Iztapalapa 5) Tlalpan	1) Milpa Alta 2) Tlalpan 3) Xochimilco 4) Magdalena Contreras 5) Gustavo A. Madero
Subnational government (Mexico City Government Ministry of...)	1) Risk Management and Civil Protection 2) Citizen Security 3) Infrastructure and Services 4) Health 5) Interior	1) Risk Management and Civil Protection 2) Citizen Security 3) Health 4) Infrastructure and Services 5) Interior	1) Risk Management and Civil Protection 2) Citizen Security 3) Mobility 4) Environment 5) Infrastructure and Services
National government (Ministry of....)	1) Defense 2) Internal Affairs 3) Navy 4) National Center for Disaster Prevention 5) Energy	1) Defense 2) Navy 3) Internal Affairs 4) National Center for Disaster Prevention 5) National Guard	1) Defense 2) National Commission on Human Rights 3) National Forestry Commission 4) Environment and Natural Resources 5) National Agrarian Registry
Non-governmental organization	1) National Autonomous University of Mexico 2) Neighborhood committees 3) Metropolitan Autonomous University 4) National Polytechnic Institute 5) Civil Engineers Association	1) National Autonomous University of Mexico 2) Neighborhood committees 3) National Polytechnic Institute 4) Metropolitan Autonomous University 5) Civil Associations	1) Neighborhood committees 2) National Autonomous University of Mexico 3) National Polytechnic Institute 4) Metropolitan Autonomous University 5) Supercívicos

Fig. 5 | Timeline of the participatory workshops' execution. The timelines describe the period where the in-person workshops (dark green) and the virtual workshops (light green) took place, from 2019 to 2020.

research institutions and local universities. Nonetheless, some local governments (e.g., Iztapalapa) referred to the use of participatory mapping with local communities and organizations for planning at a neighborhood scale. As for risk mitigation, it was mentioned by only 15% of the local governments. This result may reflect the lack of capacities at the local government level to plan for the reduction of the adverse effects of multiple risks. Although some of the IRM actions coincided with previous findings[9], particularly the importance of coordination and cooperation networks, there are still several challenges acknowledged by the participants regarding the participation of non-governmental organizations, besides research centers and neighborhood committees previously mentioned in Table 3, and the ability to generate their own data for risk identification. Further research may benefit from the implementation of the same workshops, but with representatives from the subnational and national government and from non-governmental sectors.

The earthquake and flooding networks can be used to illustrate the role and relevance of vertical collaboration, mainly led by a top-down approach. That means that those networks exhibited the articulation between local governments with the subnational (Mexico City Government) and national government. In this case, the Mexico City government plays a key role in supporting the development of regulatory frameworks and creating the conditions for local governments to protect vulnerable groups and areas, such as the provision of financial support[26]. The low level of cross-boundary exchange between the local governments and the national government (Table 2) may indicate the barriers posed by jurisdictional boundaries[11] and the low relevance of the development of local institutional capacities in the national agenda for climate action[8]. Nevertheless, vertical coordination is key to address some of the main challenges to a top-down approach, including the restrictions to up-scale local initiatives and the generation of negative dependencies in local governments due to the lack of investment in capacity building[2]. For example, Cid and Lerner[6] explored how intergovernmental coordination can reduce the gap of local governments to access climate finance in Mexico.

The wildfire network can be used to illustrate the relevance of horizontal collaboration, from a bottom-up approach, to address multiple risks, including those exacerbated or generated by climate change. The horizontal collaboration is illustrated by the integration of diverse sectors, both governmental and non-governmental, beyond the ones traditionally associated to risk management (Table 3). However, the low levels of cross-boundary exchange between the local governments (Table 2) denote the need to develop bottom-up processes with more active local level participation[11]. Potential responses to address cross-scales problems, such as the ones posed by multiple interconnected risks in Mexico City, can involve the interaction between management systems located at adjacent levels and co-management strategies, involving a series of agreements based on varying degrees of power and responsibility sharing between governments and local communities[16].

State-centered and hierarchical government strategies based on technocratic top-down approaches have proved inadequate to address multiple interacting and cross-scale risks. Under these approaches, unilateral local government strategies are ineffective to tackle complex cross-jurisdictional problems such as climate change and disaster risks[10]. In contrast, multilevel governance (MLG) provides a form of governance by networks that operate both in a horizontal arena with neighboring local governments, civil society organizations, and local communities, and in vertical settings, with higher-level governmental authorities and international organizations[10,27].

In this study, we analyzed the experience of local governments in their role in a multilevel governance system for risk management in Mexico City. We found that collaboration was more common between local governments and with the subnational government (Mexico City Government). We determined that the collaboration networks to address earthquakes and flooding were similar regarding their size and composition, mainly with government agencies with key responsibilities for disaster response. In contrast, we characterized a more diverse network to address wildfires in Mexico, with government agencies and non-governmental organizations focused on disaster management, environment, mobility, and human rights. The diversity in the vertical and horizontal collaboration in the wildfire network indicated the need for the local governments to access a wide set of resources under conditions of financial scarcity. We found evidence of successful elements of multilevel governance, following[10] and identified the need for further research on the engagement and representation for non-governmental organizations and private actors in the priority risk networks. Regarding the mobilization of resources into Integrated Risk Management actions, we found evidence of actions focused on both prevention and response, with potential needs to strengthen the recovery and risk identification actions, due to the reliance on the subnational government (Mexico City Government) and on research centers. The results from this study provide a better understanding of the arrangement of collaborative resources underlying local government actions under a state of urgency and scarcity, where disasters will increase under climate change and action is needed immediately. Further research should focus on the construction of networks from the experience of subnational and non-governmental organizations on a metropolitan scale, to address alternative arrangements of cross-boundary exchange and collaboration on a metropolitan scale.

Methods
Data elicitation
We used a mixed-methods approach based on participatory workshops with the 16 local governments (*alcaldías*), involving 221 government officials, from 119 government agencies, in a 13-month period (between 2019 and 2020). The first six workshops were in-person at the local government facilities (October 2019 to March 2020). Due to the COVID-19 lock-out restrictions, the subsequent ten workshops were virtual (Fig. 5).

The workshops were organized by the Ministry of Integrated Risk Management and Civil Protection of Mexico City (SGIRPC by its Spanish acronym) with the collaboration of the National Laboratory of Sustainability Science (LANCIS by its Spanish acronym) in the Institute of Ecology at the National Autonomous University of Mexico (UNAM). The SGIRPC coordinated the dates and sites for the workshops with the Civil Protection Agencies of each local government; however, they were only observers and did not contribute to the workshops' data collection and analysis. The participants were informed of the data usage and collection processes and provided their informed consent to participate. All personal identifiers of the participants were eliminated in the analysis. The results of the workshops were systematized and analyzed by the team in LANCIS, published by the SGIRPC[28], and shared with the local governments.

The in-person workshops comprised the integration of groups from diverse areas (i.e., Civil Protection, Urban Development, Citizen Participation, etc.) with a facilitator for each group. The workshop dynamic of the groups was divided into three sections. First, we elaborated the construction of a resource matrix, were the participants described on cards the human, financial, material, and collaborative resources of their respective area. The resources matrix also included the three main risks perceived as priority to address in their boroughs. Subsequently, a timeline was built to understand how they mobilized the resources previously described into actions given a particular extreme event (i.e., flood, earthquake, etc.). Finally, a map of the borough was used to understand the perceptions of the participants of the

Fig. 6 | Description of analysis of the collaborative resources of local governments in Mexico City. The panes are distributed by three columns: phase, methods and outputs; and four stages in the research process: participatory workshops, construction of the collaborative resource matrix, mapping of the integrated risk management actions, and the collaborative network analysis.

spatial distribution of extreme events and the distribution of the actions previously described to address them. The general design of the workshops had to be adjusted to fit a virtual environment, where the construction of the resource matrix was built mainly through on-line surveys, and the timeline and mapping were conducted in live virtual workshops using QGIS software and Zoom.

The data from the workshops was elicited and assessed in three main phases: (1) construction of the collaborative resource matrix for risk management of the local government, (2) mapping of risk management actions implemented by the local governments, and (3) assessment of the collaboration resources that local governments mobilize to address priority risks (Fig. 6).

Collaborative resource matrix

The construction of the collaborative resource matrix consisted of identifying the resources that local governments perceived they already have and mobilize to address risks. The original data entailed human, material, financial, and collaborative resources, following[29]. However, in this paper we only assess the collaborative resources, which entailed those coordination or cooperation relationships between the local government, with different levels in jurisdictional (inter-governmental, local, regional and national governments) and network (society) scales[16]. The collaborative resources were determined for each department in each local government and organized in five main categories, depending on if they collaborate: (a) between departments within the local government (RC1), (b) with other local

governments (RC2), (c) with the state government (e.g., Mexico City Government) (RC3), (d) with the national government (RC4), and (e) with non-governmental organizations (RC5). For every local government, the collaborative resources for each department comprised the presence or absence of each resource category (RC1-RC5), and its corresponding description. For example, in one workshop the RC3 resources of the Civil Protection Department included the ministries of Risk Management and Civil Protection, Water and Sanitation, Infrastructure and Services, the Fire Department, and the Rescue and Medical Emergencies Squad of the Mexico City Government. The value of each local government per each collaborative resource category was estimated as the average for all departments within that local government.

The mapping of risk management actions involved the characterization of the actions in a structured board inspired by the work of Withycombe-Keeler et al.[30]. The board consisted of a timeline in which participants collectively determined the sequence of actions that were implemented to address a risk, previously prioritized in the resource matrix.

Integrated risk management analysis

The actions were coded following a thematic analysis with MAXQDA 2022[31], based on an Integrated Risk Management cycle approach in five main categories: 1) risk identification; 2) forecasting and prevention; 3) mitigation; 4) preparedness and relief; and, 5) recovery and reconstruction, based on an Integrated Risk Management (IRM) approach[32]. Then the frequencies of the actions were estimated for each category and the results were transformed to an interval scale in order to allow for comparison, by means of a min-max normalization[33]. The IRM categories of actions are described below:

– *Risk identification* focuses on the factors that contribute to the generation of risks; actions of this phase include the identification of areas of social marginalization, urban growth, urban and environmental impact, and irregular human settlements.
– *Forecasting and prevention* comprise the actions and mechanisms carried out prior to the occurrence of an extreme event, to reduce or prevent it and its impact. The elaboration of risk maps to inform the planning of the city and early warning systems are examples of forecasting and prevention actions.
– The *mitigation* phase includes actions carried out to reduce the vulnerability of the population and key infrastructure. Preventive and corrective maintenance of infrastructure, technical training, and relocation of infrastructure are examples of actions aimed at mitigating risks.
– *Preparedness and relief* contain two phases in one. Preparedness actions maintain an adequate response capacity when a risk materializes into a disaster and reduce the damage and losses caused to the population. Among them are drills and permanent training of brigade and community members, emergency squads, public agents, and the population in general. Relief refers to the immediate response to a disaster and includes the period from the moment the risk causes damage and losses, until the rehabilitation of systems and services. Actions in this phase include the establishment of a coordination station, the delimitation of affected areas, the provision of relief to the population, and the establishment of shelters.
– The *recovery and reconstruction* phase focuses on gradually reestablishing and improving the conditions of the sites affected by a disaster. Actions in this stage include the recovery of communication routes, the reconstruction or rehabilitation of infrastructure and equipment, the creation of temporary jobs, and the coordination of inter-institutional actions.

The IRM phases and actions are conceived as part of a cycle. Hence, it was expected that the recovery and reconstruction phase would inform the actions to be carried out in the risk identification, prevention, mitigation, and preparedness phases. As a result, this would promote continuous learning and more robust Integrated Risk Management systems[15].

Social network analysis

The assessment of the collaboration resources followed a Social Network Analysis (SNA) approach[27] to examine the experience of local governments in their role in a multi-level governance system for risk management in Mexico City. The nodes of the system came from the collaborative resource matrix and the ties came both from the collaborative resource matrix and the IRM actions mapping. The ties of the network included elements of horizontal (e.g., between local governments) or vertical coordination (e.g., between federal, state or local government structures). We built the *ego-centered network or egonet* of each local government, which was then integrated with all the remaining egonets into a single network per priority risk, which resulted in three networks. An egonet is a network, or part of it, that involves a particular node we are focusing on, which we call egos or index nodes (in our case the local governments are the egos). This network consists of ego, the nodes ego refers to be connected to (also referred as ego's alters), and usually the ties between ego's alters[34].

Each priority risk network was assessed in terms of its density, degree centralization, and cross-boundary exchange with *Cytoscape*[35]. The density was used to analyze the connectedness of the network, and also as a proxy for the potential for collaborative processes within the network. The lower the network density -closer to 0- the more potential for the existence of sub-groups and potentially less collaboration between such subgroups; in contrast, the higher the density -closer to 1- the more homogeneous the network will be[27]. Degree centralization indicates the existence of dominant organizations (nodes) that may hold the most information or quickly connect with the broader network, and act as a crucial channel for information or resources flow[32]. Regarding the degree centralization, because of the relative concentration of observed edges, value 1 represents a network with all nodes connected only to a single node (with a star like structure), and 0 when they are all equally connected. Cross-boundary exchange is a measure of network heterogeneity, where a low cross-boundary exchange -closer to 0- indicates a relatively high tie density within groups and potentially less collaboration between groups. It is estimated by the number of ties connecting actors with different affiliations divided by the total number of connections in the network and expressed as a percentage[27]. We assessed the cross-boundary exchange between node types, which were defined as different levels in a jurisdictional scale (local, subnational and national government agencies) and another type of organizational scale (governments and non-governmental organizations).

Reporting summary

Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability

Available information is in the following repository: https://github.com/AbrilCid/NJPCLIMATACTION-00135.git.

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Competing interests

The authors declare no competing interests.

Additional information

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