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Digital Solutions to Support Post-disaster Response and Recovery based on the Findings from Ground Zero after the 6th February 2023 Kahramanmaraş Earthquake Series

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Abstract: This paper presented the list of hazards of the response and recovery operations captured based on fact-finding mission performed in Malatya at the ground zero in the aftermath of the Kahramanmaras, Türkiye earthquake sequence happened on February 6, 2023. The study presents the findings of semi-structured interviews with four officials from Balıkesir Metropolitan Municipality allocated to Malatya for response and recovery with a team of approximately 200 people. As a result of these interviews and field observations, hazards that impacted the ground zero operations are categorised under three response and recovery activities: 1) planning, 2) logistics and supply, and 3) communication and information management. To mitigate these hazards and support ground-zero activities, a list of low-cost digital solutions is developed based on a literature review and expert validations with two experts. The outcomes of this study highlight an urgent need for developing a systematic framework for emergency response and relief supported by a set of low-cost digital solutions to improve coordination, communication, and information management.

6 Şubat 2023 Kahramanmaraş Depremlerinden Sonra Sıfır Noktası Bulgularına Dayalı Acil Durum Yönetimi ve Yardımını Destekleyecek Dijital Çözümler

Anahtar Kelimeler
Afet Yönetimi,
Deprem,
Dijital Çözümler

Öz: Bu makale, 6 Şubat 2023'te meydana gelen Kahramanmaraş, Türkiye deprem dizisinin ardından deprem bölgesine intikal eden afet yönetiminden sorumlu büyükşehir belediyelerinin yürüttüğü acil durum yönetimi ve yardımı aktivitelerini Malatya özelinde incelemiştir. Bu kapsamda çalışma, Malatya afet yönetimi merkezinde acil durum operasyonlarından sorumlu olarak bulunan Balıkesir Büyükşehir Belediyesine mensup yaklaşık iki yüz kişilik bir afet yönetimi ekibinden dört kişi ile yapılan mülakatların bulgularını sunmaktadır. Saha incelemeleri ve mülakatlar sonucunda, sahada yürütülen operasyonları engelleyen tehlikeler üç acil durum yönetimi ve yardımı başlığı altında listelenmiştir. Bu engel ve tehlikelerin önlenmesi ve acil durum yönetimi ve yardımı aktivitelerinin sahada daha etkin şekilde yürütülmesi için literatür taraması ve iki uzman görüşmeleri sonucunda orta çıkan ucuz maliyetli dijital çözümler listesi önerilmiştir. Bu çalışma, saha operasyonlarını düzenlemek, koordinasyonu, iletişimi ve bilgi paylaşımını arttırmak için sistematik acil durum yönetimi ve yardımı yaklaşıma ihtiyaç olduğunu ortaya çıkararak, saha operasyonlarının dijital araçlar ile desteklenmesi gerektiğinin altını çizmiştir.

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1. Introduction

Post-earthquake response and recovery is a significant element of disaster management and risk reduction which has different forms in different countries [1], [2]. The existing body for coordinating the disaster response and supporting prefectural and local authorities is crucial for a single point of decision-making [3] Federal Emergency Management Agency (FEMA) is the central disaster response agency in the USA responsible for preparing for, responding to, recovering from, and mitigating disasters. While these activities are coordinated by FEMA, they are conducted by the staff from federal, state, tribal and local government partners, as well as the private sector, non-governmental entities and the wider public to effectively deal with the adverse effects of disasters [4]. On the other hand, Japan, one of the countries in the world that experienced devastating earthquakes, has government-level strategies for mitigating adverse effects and recovery; and local authority-level (municipalities) action plans for carrying out other activities [5] [6]. However, the national government in Japan does not have a central agency, leading to a lack of coordination and overlapping or duplication of the effort needed in time and/or space [7] [6]. In Türkiye, Afet ve Acil Durum Yönetimi Başkanlığı (AFAD) reporting to the Ministry of Interior is the central agency responsible for designing precautionary measures and coordinating the disaster response through 81 provincial branches and 11 search and rescue units [8].

On February 6, 2023, two very large earthquakes of magnitude (Mw) 7.8 and 7.5 occurred nine hours apart on different fault lines in the southern region of Türkiye and northern Syria [9], [10]. The first earthquake occurred at 04:17 Türkiye local time and its epicentre was Pazarcık (Kahramanmaraş) which was about 35 km distant to the northwest of Gaziantep (see Figure 1). The second major earthquake occurred at 13:45 Türkiye local time and its epicentre was Elbistan (Kahramamaraş) [9]. The two earthquakes and associated aftershocks caused widespread damage in 11 out of 81 provinces of Türkiye in the south of the country which are Adana, Adıyaman, Diyarbakır, Elazığ, Gaziantep, Hatay, Kahramanmaraş, Kilis, Malatya, Osmaniye and Şanlıurfa [11]. The most severe damage occurred in Hatay, Kahramanmaraş, Gaziantep, Malatya and Adıyaman provinces, which are home to around 6.45 million people (around 7.4 percent of the country's population) [12]. The affected people were both evacuated to other cities in Türkiye and accommodated in temporary shelters (see Figure 2).

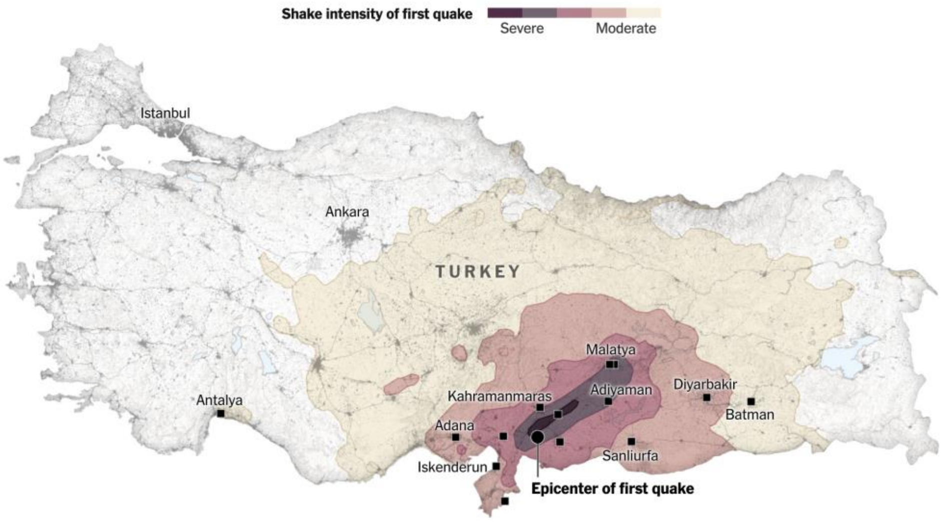

Figure 1. Epicentre and shake intensity of 6th February Kahramanmaraş-Pazarcık ((Mw) 7.8) earthquake [46]

As presented in Figure 1, widespread coverage of the earthquake area with high-intensity ground shaking, the characteristics of the built environment, and the geography and the human ecology combined with the damage and social disruption made the emergency response difficult. The extent of the damage to the main highways and the volume of the debris in the streets created major traffic congestion and blocked access for emergency and rescue vehicles [13]. Disruption of communication systems and IT infrastructure made search and rescue and emergency response challenging and water shortages due to the significant damage to the utility infrastructure impeded the relief and rehabilitation activities.

This study aims to (i) identify the challenges of response and recovery activities from ground zero in the aftermath of the 6th February Kahramanmaraş earthquake series, and accordingly (ii) propose a set of low-cost digital solutions to address the challenges related to response and recovery activities. In April 2023, a fact-finding mission was performed in Malatya, one of the most affected cities during the earthquake as shown in Figure 1. Hence, officials and staff from Balıkesir Metropolitan Municipality (BMM), which is a city from the Aegean coast of Türkiye, were allocated to Malatya for performing post-disaster response and recovery. The BMM team carried out post-disaster activities such as restoration of essential services and debris removal, but not emergency response actions such as search and rescue, thereby, challenges of emergency response were not captured in this study. The fact-finding mission in Malatya took four days (between 12 to 15 April 2023) and included field observations and semi-structured interviews with four officials from the municipalities of Balıkesir and Malatya which are explained in Section 4. The challenges that BMM staff faced and the proposed digital solution to address these challenges are presented in Section 5. The conclusions are drawn, and recommendations are provided in Section 6.

Figure 2. AFAD emergency shelter camps in Malatya

2. Literature Review

A Disaster Management Framework (DMF) enables effective recovery support to disaster-impacted regions by providing a flexible structure that enables different agencies to operate in a unified and collaborative manner. Most DMFs usually have four key components that are defined as follows [14] :

1. *Prevention* is related to mitigation consisting of creating capabilities to reduce loss of life and property by lessening the impact of disasters.
2. *Preparedness* is developing knowledge and capacities to effectively anticipate, respond to and recover from the impacts of disasters. It can include early warning systems, contingency planning, stockpiling of equipment and supplies, and creating coordination mechanisms.
3. *Response* is disaster relief including actions taken during or immediately after a disaster to protect lives and property, reduce health impacts, ensure public safety, meet the basic subsistence needs of the people affected and control secondary earthquake hazards. Typically, it includes rapid damage assessment, search and rescue, emergency medical care, restoration of essential services, firefighting, communication, crisis decision-making, evacuation, protection of lives and property, provision of emergency shelters for the people affected, and debris removal.
4. *Recovery* aims to restore communities affected by a disaster. It involves not only reconstructing and restoring physical infrastructure damaged during an earthquake but also rebuilding the economic strength and social stability of a community, dealing with the disruption that the disaster caused and mitigating future hazards.

DMFs are often supported by national-level risk assessments that typically consider a broad range of earthquake impacts including water, transport and energy utility infrastructures alongside enabling services such as information and communication technology (ICT) to identify vulnerable locations and services. [15], [16]DMFs can also be employed for identifying suitable recovery strategies for restoring the infrastructure services in a prioritised manner [17] and to ensure their resilience to further disasters.[18]. Several studies have compared the DMFs of various countries such as Chile and Ecuador [19], Bucharest, Mexico and Turkey[20], Japan and India [21] and Indonesia [22]. For the task in hand, the development of disaster management in Türkiye can be divided into five periods [3][23] :

- *1923 to 1944* the focus was on immediate response,
- *1944 to 1958* the focus changed to disaster reduction,
- *1959 to 1999* saw the foundation of a dedicated ministry through law No.7269 on precautions to be taken due to disasters affecting public life and assistance to be provided,
- *1999 to 2009* was the turning point for disaster management and coordination in the aftermath of the 1999 Marmara Earthquake with regulations established on construction in disaster areas and buildings in earthquake-prone areas including materials regulation and fire prevention (2007),
- *Post-2009* was the period when institutional roles were redefined and organised into AFAD as part of law No. 5902 passed in the Turkish Parliament; followed by the setting up of a disaster insurance law (2012) and an update to the 2007 construction regulations (2018) to use high-quality concrete reinforced with steel bars in earthquake-prone areas.

While national frameworks are often quite distinct, focussing on different aspects, it was reported that legal, policy, planning and organisational aspects form the key foundations for a systematic and coordinated response to disasters. The need for a structured DMF was arguably established by the United Nations (UN) World Conference on Natural Disaster Reduction in 1994, which came to be known as the Yokohama Strategy. This strategy highlighted the close links between risk, disaster reduction, sustainable development, environmental protection and poverty alleviation. A decade later, the Hyogo Framework [24] was introduced that focused on disaster response and recovery and was composed of three strategic goals, several guiding principles, five priorities for actions and considerations for implementation and follow-up. Succeeding this, the Sendai Framework [25] was developed as a multilateral framework focusing on disaster preparedness and prevention, including priorities dealing with governance to technical issues. It acts as an umbrella strategic framework that sets out recommendations for national and local-level efforts by understanding the disaster risk, enhancing disaster preparedness, strengthening disaster risk governance, and appraising investments in disaster risk reduction. Whilst these frameworks and strategies provide a basis for designing a structured response to earthquakes, there are several challenges at the ground zero that impede response and recovery. Communities are seldom able to cope with the emergency when a disaster occurs, almost immediately losing the ability to judge, respond, and adapt to the situation [26]. Information flow and cooperation between multiple agencies and personnel during the response can also be challenging. Other challenges include overcoming barriers to medical delivery and implementation [27], and the shortage of trained people and resources for rescue operations [28]. Finally, having proper information about building structures, escape routes, and indoor-outdoor connections is crucial for effective response strategies [29]. To this end, several Building Information Modelling (BIM) applications are developed to be used in different phases of earthquake disaster management. The BIM–GIS integrated applications combines the the micro-level internal structure of individual building simulation with the macroscopic landscape and layout of the entire urban area. For instance, BIM-based simulations and 3D spatial environmental demonstrations effectively simulate disaster scenarios for disaster forecasting and generate early warning in disaster prevention and mitigation; and BIM–GIS integrated risk management system helps positioning of the disaster and the corresponding 3D demonstration for disaster detection and warning and evacuation and rescue [30]. In post disaster recovery, BIM is used for post-earthquake building condition assessment that includes earthquake damage simulations and infrastructure reconstruction costs; for example FEMA P-58 that is a BIM-based framework used for performing post-disaster reconstruction/refurbishment expenditure estimation [31]. BIM-based augmented reality (AR) applications also assist in identifying key infrastructure and utility systems to prioritise resource allocation and restoration efforts to ensure the rapid recovery of essential services [32] .

The adoption of low-cost digital solutions has accelerated by Small and Medium Enterprises (SMEs) in various industries such as manufacturing [33], construction [34]and logistics [35]. Studies in the literature highlighted that these solutions generated a significant improvement in operational efficiency [36] and digital transformation maturity of SMEs [37]. Digital solutions can significantly contribute to providing effective and rapid earthquake response and recovery. For instance, early warning systems like ShakeMaps and TriNet have been reported to be efficient [38]. They can be augmented with remote sensing technologies such as GIS and GPS, and Unmanned Aerial Vehicles (UAVs) for rapid damage assessments, aiding in the distribution of relief materials and response teams to the affected areas [39], particularly for densely populated cities. Wireless communication links using satellites, two-way radios, the Internet of Things (IoT), big data and mobile technologies have been widely applied to support response and recovery operations [40] and often form the backbone for communication services due to their adaptability [41]. Telehealth services have shown promising results for delivering healthcare during disasters [42]. Moreover, social media has significantly coordinated response and recovery efforts during recent earthquakes [43]. However, there is a gap in the literature that shows how low-cost digital solutions can be used in disaster management and improve the efficiency of ground-zero activities. Additionally, the research gaps in DMFs persist in areas such as cross-sectoral collaboration, community engagement, and dynamic risk assessment. Traditional approaches often lack real-time data integration and communication. Digital solutions can bridge these gaps by enabling data-driven decision-making to resource allocations and enhancing early warning systems. To this end, this study frames the role of digital solutions in supporting post-earthquake response and recovery activities for improved coordination, communication, and information management.

3. Fact-finding from Ground Zero after 6th February 2023, Kahramanmaraş Earthquake Series

This study adopts case study research [44] to address two research objectives: 1) identify challenges that impede post-disaster response and recovery and 2) propose a set of digital solutions to address these challenges. To achieve these objectives, a fact-finding mission was conducted in Malatya to (see Figure 3): 1) identify challenges of response and recovery operations from ground zero, 2) validate the identified challenges, and 3) propose a set of digital solutions to address these challenges.

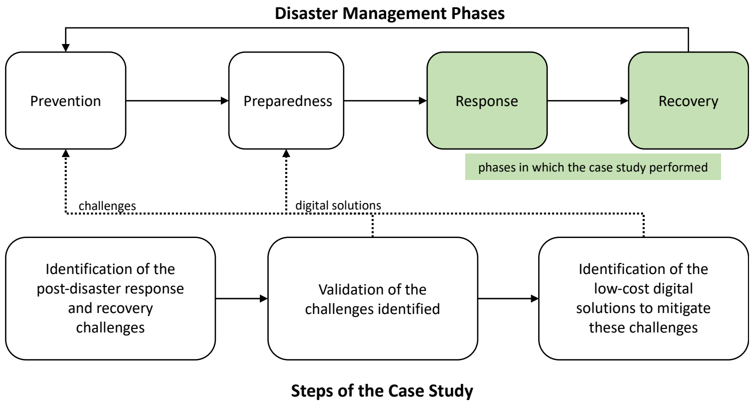

Figure 3. Disaster management phases and research steps

A response and recovery team from BMM was accommodated in a coordination centre in Malatya for 150 to 200 BMM staff with equipment, vehicles and inventory including food and water supplies for distribution to the affected (see Figure 4). A part of the team was replaced with newcomers every two weeks for reinforcement. A shopping mall in Balıkesir was identified as the strategic point for people to drop off the relief materials that were transferred regularly to Malatya every alternative day. The team was responsible only for the post-earthquake response and recovery operations as presented in green in Figure 3 including receiving requests for relief materials, planning deliveries based on urgent needs and route optimisation, and carrying out daily deliveries. They were not responsible for emergency response actions such as search and rescue; hence, these emergency actions were not analysed in this study to identify their challenges.

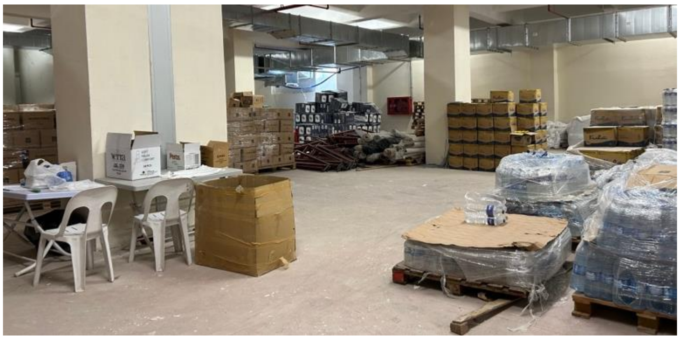

Figure 4. BMM coordination centre's inventory in Malatya

For challenge identification, data was collected from two sources: 1) semi-structured interviews with four officials, including three officials from BMM and the General Secretary of Malatya Municipality and 2) field observations from ground zero in Malatya. Three BMM officials, who have different managerial roles and were responsible for different response and recovery operations in Malatya, and the General Secretary of Malatya Municipality (a high-level manager), were selected as interviewees, thereby ensuring the development of a comprehensive set of challenges (see Table 1 for details). The first interviewee, who is an architect in BMM, was working as the coordinator of a response and recovery team with 150 to 200 BMM staff and was responsible for coordinating daily and longer-term response and recovery operations in Malatya. The second interviewee is a health and social services expert who was working as the coordinator of rehabilitation to plan and support the performance of mental and social health services in Malatya. The third interviewee was the mayor of Balıkesir who was responsible for arranging the logistics of the resources and relief materials between the two cities such as the logistics of the municipality staff and delivery of the necessary equipment (see Table 1). The last interviewee was the General Secretary of the Malatya Municipality who was responsible for local organisation and decision-making capacity though outside technical assistance i.e., external response and recovery teams coming from other city municipalities across Türkiye.

The interviews and field observations lasted four days i.e., between the dates of 12 to 15 April 2023 at ground zero in Malatya. In the first day of fact-finding mission (on 12th April), a quick trip across Malatya was completed with the coordinators of the team and the rehabilitation staff to understand the impact of the earthquake not only on the physical infrastructure but also the economic strength and social stability of the community in Malatya. Moreover, planning and coordinating the daily response and recovery operations were analysed in detail. Data was collected about receiving requests for relief materials, planning deliveries based on urgent needs and route optimisation and carrying out daily deliveries. In the second day (on 13th April), response and recovery activities planned for the long-term such as debris removal and inspection of damaged infrastructure were analysed, and emergency shelter and container camps were visited to understand dealing with the disruption that earthquakes caused in community life and meeting the recovery-related needs of the people affected. In the third day (on 14th April), mayor of the Balıkesir was interviewed to understand the management of bringing outside technical support to Malatya. In the last day (on 15th April), the General Secretary of Malatya was interviewed for analysing post-earthquake local organisation and decision-making capacity while receiving external technical, financial and resource support. Moreover, review and validation of the challenges identified based on the interviews and observations conducted with BMM staff was completed. The list of digital solutions is generated through multiple expert validations (see Figure 3 and Table 1). Expert opinions were gathered from two academics who are experienced in digital transformation and disaster risk management two identify the digital solutions to address the post-earthquake response and recovery challenges identified from ground zero.

Table 1. Background of the participants and their contribution to the study

Case study steps participants involved in	Designation of the participant	Role of the participant at ground zero	Contribution of the participant in fact-finding
Identification of the challenges	Mayor of BMM	Head of response and recovery team in Malatya	- Identifying challenges related to managing response and recovery resources between two cities i.e., Balıkesir and Malatya (e.g., planning the logistics of the municipality staff and delivery of the necessary equipment)
	Architect and head of city history/aesthetics in BMM	Coordinator of the response and recovery team in Malatya	- Identifying challenges related to planning and coordinating the daily and long-term response and recovery operations (e.g., debris removal, inspection of damaged infrastructure, population displacement and temporary housing, delivery of relief materials)
	BMM staff in health and social services	Coordinator of the rehabilitation services in Malatya	- Identifying challenges related to planning and performance of mental and social health services at ground zero (e.g., organising special social activities to cope with trauma, setting up school and educational activities for the children affected)
Validation of the identified challenges	General Secretary of Malatya Municipality	Local coordinator of disaster management in Malatya	- Identifying challenges related to strengthening local organisation and decision-making capacity through coordination of the local and external resources. - Validation of the identified challenges
Identification of new digital solutions	Academic	Expert in digital transformation	- Identifying digital solutions to address these challenges
	Academic and consultant	Expert in disaster risk management and digitalisation	- Validation of the identified digital solutions based on the challenges

5. Post-earthquake Response and Recovery Challenges and Digital Solutions to address them

The challenges from ground zero (see Table 2) are associated with four response and recovery activities in which the BMM team was involved. These activities are:

1. *Planning* deals with establishing the policies and procedures for post-disaster recovery activities (e.g., allocating equipment and vehicles, provisions for emergency shelters and container camps, and trained personnel).
2. *Logistics and supply* are related to ensuring a well-organised supply service supported by resources, storage and transport facilities for post-disaster recovery.
3. *Communication and information management* deal with supporting other emergency response activities through essential communication equipment and information management protocols.

Table 2. Fact findings on response and recovery reported from ground zero

Activities	Challenges reported from observations and interviews
Planning	- Poor clarity in policies and procedures for emergency response that includes search and rescue, evacuation/migration, emergency relief and psychological support for the affected. - Infrequent updates to the action plan for response and relief. - Unavailability of equipment, vehicles and information to support search and rescue (e.g., lack of heat sensors for spotting people trapped under the rubbles, inaccurate imagery data/maps).

	- Lack of a planned/standardized approach for rehabilitating the affected people (e.g., people were allowed to setup make-shift tents close to their damaged houses which were usually away from the designated area) - Loss in workforce due to the poor planning for the temporary accommodation (e.g., upon completion of the infrastructure of the tent camps, had to be disassembled and transferred to be reinstalled in container camps). - Lack of long-term planning for switching back to 'normal' life (e.g., debris removal, disassembly of temporary accommodations, initiatives to motivate stranded people to return back to Malatya, and funding for traders/businesses to resume their work).
Logistics and supply	- Lack of local personnel to assist the external response team allocated to the city results in delays. - Not able to allocate the team quickly when an urgent request comes. - Poor visibility on the progress of ongoing response and relief activities. - Poor intersectoral coordination between different response and relief teams. - Poor visibility across the relief material supply chain to match demand with stocks in inventory (e.g., collecting order requests and relief materials in Balıkesir while storing and distributing in Malatya).
Communication and information management	- Lack of structured communication protocol that results in ineffective resource allocation and duplication of tasks (i.e. currently no single contact point (e.g., personnel or centre) for receiving the requests from the ground zero). - Lack of an information management protocol (e.g., currently using WhatsApp for receiving requests, and exchanging information between the team members as a reactive communication measure). - Lack of essential communication equipment for information flow (e.g. radios and satellite phones). - Not able to understand where the urgent request coming from i.e., which part of the city. - Poor visibility on the incident area i.e., don't know where the response team/personnel is.

To this end, 20 digital solutions are proposed in Table 3 based on the digital solutions identified from the literature [33]–[35] and the challenges captured from ground zero (see Table 2). The applicability of the set of digital solutions for response and recovery is validated by engaging with two relevant experts through a workshop. The first expert has experience in digital transformation, digital solution design and development and information systems. The second expert is working in disaster risk management and mitigation, and infrastructure resilience to shock events. Based on the expert opinions, the proposed set of digital solutions is deemed suitable for assisting the activities across four areas namely planning, logistics and supply, and communication and information management (see Table 3).

Table 3. Digital solutions to support post-disaster response and recovery

Activities	Digital solutions
Planning	1. Geocoded early warning and monitoring (e.g. ground vibration sensing, remote-sensing) 2. Operations planning (e.g. emergency activities planning) 3. Human resource planning (e.g. allocating/scheduling support teams, time/shift management) 4. Digitised personnel training (e.g. standard operation procedures for search and rescue, evacuation/migration, emergency relief and psychological support) 5. Change control (Document change control, Policy/Procedure change control) 6. Digitised setup instructions (e.g. Work instructions, Guidelines, Setup instructions, Setup checklists, machine/vehicle setup support) 7. Tool/Equipment selection assistance (e.g. selection guidelines, checklists) 8. Layout planning (e.g. coordination centre planning, temporary accommodation design) 9. Pre-completion support for handover (e.g. structural impact assessment, financial support schemes) 10. Geocoded hazard mapping and disaster risk estimation
Logistics and supply	11. Geocoded prediction for recovery in disaster areas/zones based on parameters such as population, intensity of damage, demographic information, etc. 12. Supply chain monitoring (e.g. supplier lead time monitoring, Supplier sustainability tracking, Supplier performance data capture, record keeping, reporting) 13. Order tracking (e.g. order status tracking, order location tracking) 14. Progress monitoring (e.g. emergency activity tracking, maintenance activity tracking) 15. Disruption monitoring (e.g. supplier delay impact monitoring and analysis) 16. Capacity monitoring (e.g. workload monitoring, uptime monitoring, availability assessment, bottleneck monitoring) 17. Scheduling support (e.g. order prioritisation, scheduling for temporary accommodation)
Communication and information management	18. Inventory tracking (e.g. stock management, stock level monitoring) 19. Tracking and assignment of tools/equipment (e.g. GPS-based equipment/vehicle tracking) 20. Issue/query tracking (e.g. issue/query reporting, flagging of problems)

6. Discussion and Conclusion

Earthquakes are events that have long-term impacts on the natural, economic, and social fabric of a nation. Countries have developed and adopted various disaster management frameworks to aid the prevention, mitigation, preparedness, response and recovery in the event of such disasters. This study captured the response and recovery challenges at ground zero in Malatya in the aftermath of Kahramanmaras, Türkiye earthquake sequence that happened on February 6, 2023.

Field observations and semi-structured interviews with the four officials from municipalities of Balıkesir and Malatya highlighted four hazard areas that impeded the response and recovery operations:

1) *Planning* related hazards include the absence of an institutional framework at the regional/local level, lack of a structured disaster response and recovery plan i.e. organisational structure, information, lack of an early warning system, etc.
2) *Logistics and supply* related deficiencies exist in shortage of resources i.e. financial, equipment, human, absence of standardised medical teams, inefficient resource allocation of existing resources, and
3) *Communication and information management* related challenges include lack of a central and single decision-making point at the scene which led to poor intersectoral coordination, ineffective communication i.e. challenges in communication protocols, lack of knowledge about Malatya and on-site experience in the city, etc.

The fact-finding mission including data collection via interviews with BMM's response and recovery team and observations from ground showed that outside technical, financial and resource support help strengthen local organizational and decision-making capacity. However, the challenges presented in Table 2 highlight disaster management's complexity and multifaceted nature, requiring comprehensive strategies and approaches to address them effectively. It is observed that there was a poor formal process for response and recovery, which needs to be clearly articulated and addressed through a comprehensive disaster management framework. The absence of such an institutional framework at the regional/local levels led to conflicts between the external teams that came from different 10+ municipalities to support ground zero activities in Malatya. Such a framework not only explicitly and individually describe local and central formal processes but also should capture the role of technology and digital solution as enablers to assist in response and recovery efforts. While the knowledge generated on the hazards is related to earthquake response and recovery, these can be applicable to any ground-zero scenarios of different disasters (e.g., floods, wildfires).

This study highlights the need for developing a systematic framework that sets the structure of response and recovery including procedures and descriptions, roles and responsibilities at the local and central authority levels. Such a framework has significant potential to eliminate the duplication of efforts and excessive usage of resources. The processes defined this framework need to be supported through a set of digital solutions which are low-cost, portable, sustainable, durable, etc. Implementation of these low-cost solutions in other industries showed a significant improvement in operational efficiencies such as timesaving, waste reduction etc. [36]. The set of 20 digital solutions scoped within this study (see Table 2) can operationalise the framework by supporting ground-zero activities and creating long-term value for disaster management. While this study scopes low-cost digital solutions for response and recovery, there are ongoing developments by AFAD for deploying radio systems to provide instant access to people affected, drone technologies in search and rescue, early warning systems engaging with gas, electricity and water suppliers, satellite technologies for disaster response, sensor and robotic-based digital solutions for disaster management and information systems for effective data exchange between stakeholders, and simulation and game-based training systems to support search and rescue operations [45].

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