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MODESTUM

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Earthquake response framework with IoT-based e-government services

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ABSTRACT

Earthquakes present a genuine threat to both lives and property, necessitating the minimization of their impact wherever possible. This is especially critical in countries like Iraq, which suffer from inadequate infrastructure. Consequently, this study developed a framework aimed at bolstering Iraq's current disaster management system to respond to earthquakes. The designation of this system stems from its integration of information and communication technology principles alongside the Internet of things (IoT). The framework's development was built based on related literature and data collected from websites related to disaster management, including the Ministry of Environment and the Ministry of Communication. The resultant framework was constructed utilizing unified modeling language diagrams, including both use-case and activity diagrams. This endeavor represents one of the few initiatives undertaken in the context of Iraq. Future research endeavors focusing on disaster planning in Iraq and similar contexts may utilize the findings of this study as a foundational resource.

Keywords: earthquake response framework, e-government, IoT, disaster management

INTRODUCTION

Safeguarding citizens and national resources from various threats, particularly natural disasters like earthquakes, stands as a paramount duty of any government (Ready, 2024). The devastating impact of earthquakes on both lives and property underscores the imperative for a systematic and proactive approach to disaster management. Preparation and planning before disaster strikes are essential. E-government emerges as the optimal avenue for delivering such services, leveraging the myriad advantages offered by cutting-edge applications in information and communication technologies (ICT), including the Internet of things (IoT) (Elneel et al., 2023). The motivation of this study is the disasters that affect Iraqi citizens. Iraqi citizens suffer from repeated disasters, including earthquakes, in addition to their suffering from a lack of readiness for disasters and the lack of applications in the Iraqi electronic government that provide services to citizens in the event of a disaster (Ibrahim & Mishra, 2021).

Prior research endeavors addressing smart earthquake predictions have explored various facets of integration but have typically emphasized different aspects. For example, the authors in (Fajardo & Oppus, 2010) focused on the use of smart devices in communication methods. However, the authors neglected other parts of the system, like the modification of the administrative side. Also, while the authors in (Mitchell et al., 2017) focused on the monitoring of climate by using the disaster management system (DMS), they did not mention the procedures that should be applied during and after a disaster. The primary aim of this study is to improve the efficacy of the DMS in addressing earthquake risks. This is to be achieved through the integration of ICT principles, particularly leveraging e-government and IoT technologies. The overarching objective is to furnish decision-makers with real-time data while simultaneously streamlining processes to conserve resources, time, and finances. Essentially, the research endeavors to automate the earthquake DMS and fortify its infrastructure to optimize outcomes. Accordingly, this study answers the following research questions (RQs):

RQ1. What are the prerequisites of the earthquake DMS before an earthquake occurs?

RQ2. What are the necessities of the earthquake DMS during an earthquake event?

RQ3. What are the essential requirements of the earthquake DMS following an earthquake occurrence?

Several studies have explored IoT protocols such as Modbus, DNP3, and IEEE C37.118 for SCADA and WAMS

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systems (Zabihi & Alavijeh, 2024), and MQTT/CoAP for lightweight, real-time communication (Papaioannou et al., 2025; Singh et al., 2025). Building on these, our study proposes to address challenges like latency, security, and interoperability (Alkhzaimi & Bakar, 2025; Bhide et al., 2025; Mohsin et al., 2025) using edge computing, encryption, and context-specific integration. The novelty of this study lies in its development of a comprehensive framework designed to enhance Iraq's DMS, specifically for earthquake response. This framework uniquely integrates ICT principles with IoT technologies, addressing the critical need for improved disaster management in a country with inadequate infrastructure. This innovative approach not only aims to minimize the impact of earthquakes on lives and property but also represents a significant advancement in leveraging modern technologies for disaster preparedness and response in Iraq.

To declare the research problems, we reviewed related literature and retrieved data from related websites in several ministries in Iraq. This study provides several contributions. This research develops an enhanced system of disaster management called smart disaster management system (SDMS). Based on ICT, especially the IoT and artificial intelligence (AI), this study provides a conceptual design for SDMS to define all the requirements of this system, as well as the activities of the system, to provide a clear vision for the developers to implement the system. This investigation visualizes all system participants as well as the activity of each participant by using the unified modeling language (UML) diagrams. The implementation of SDMS will increase citizen readiness for ICT and earthquakes because it will facilitate the use of system applications. Therefore, the SDMS will satisfy the end-user. We first discuss the research background. Then we discussed the research method. After that we will discuss the proposed framework. We then discuss the findings of this research and future research directions. Finally, we conclude this paper.

BACKGROUND

A disaster is defined as an occurrence that disrupts the normal state of life and inflicts considerable suffering on a community to the extent that it struggles to manage the situation. Disasters can be broadly categorized into two types: natural disasters and human-made disasters.

Disaster Management System

DMS is a technological system utilized to handle disaster-related data, amalgamating geographical and administrative information. This integration enables accessible and efficient utilization of data across all stages of disaster management (WHO, 2019). Disaster management unfolds in three key stages (Ibrahim & Mishra, 2021; Ready, 2024):

1. Before disaster: During this phase, the disaster management team assumes several responsibilities, including:
   a. Implement preventive measures, both administrative and executive, to safeguard lives and property and minimize losses.
   b. Review studies on disaster risk reduction and incorporate recommendations from these studies.
   c. Maintain vigilance to promptly and effectively respond to disasters.
   d. Raise awareness among citizens to foster a well-informed society, thereby reducing potential damage.
2. During disaster: This stage is characterized by chaos, making it crucial for the disaster management team to fulfill various duties, including:
   a. Furnishing decision-makers with real-time data regarding the disaster's impact on individuals and physical structures.
   b. Rescuing as many affected individuals as possible.
   c. Coordinating efforts with government bodies, civil society organizations, and trained citizens to optimize rescue operations.
   d. Directly engaging in rescue operations to aid injured or trapped individuals.
3. After disaster: In this phase, the disaster management team undertakes the following responsibilities:
   a. Establishing suitable shelters for citizens rendered homeless by the disaster.
   b. Supplying affected individuals with necessities like food and medicine.
   c. Offering material and emotional support to citizens who suffered losses during the disaster.

Smart Disaster Management System

The SDMS is defined as the DMS that underwent modification through the integration of ICT (Al-Obaithani et al., 2018). Leveraging ICT facilities, this system expedites information dissemination and minimizes decision-making errors during disasters. Its effectiveness stems from its capability to gather disaster-related information and execute real-time decision-making processes (Sakhardande et al., 2016). One of the significant ICT tools is the IoT, which holds considerable promise in disaster planning. IoT constitutes a network linking physical objects with actuators, sensors, software, and RFID devices, enabling interactions among themselves and humans to enhance people's lifestyles (Alzoubi et al., 2022). Alternatively, IoT may be defined as physical objects linked to the Internet, possessing the capability to identify other devices and engage in communication with them (Alzoubi et al., 2021).

During their examination of published research on DMSs, a dearth of emphasis on the technical dimensions of IoT technology was reported (Damaševičius et al., 2023). Accordingly, they proposed restructuring the administrative framework of the DMS by advocating for the integration of IoT's communication capabilities. This integration would link all components of the system, enabling seamless coordination (Damaševičius et al., 2023). Additionally, they recommended establishing a central control unit responsible for coordinating communication among all DMS units via IoT, thus consolidating command (Peng & Ke, 2023). The focus of the aforementioned group was on expeditious response to various aspects during disasters, including organizing traffic flow, ensuring the provision of ambulances and medical services, facilitating the arrival of rescue vehicles, fire trucks, and police cars, maintaining ongoing communication to warn citizens and provide updates on disaster developments, addressing urgent needs of citizens such as water, food, medicine, and electricity, and expediting the rehabilitation of damaged infrastructure and buildings (USGS, 2024).

Earthquake Background

Seismic tremors are normal risks that cause most passing compared to other occasions. Between 1998 and 2017, earthquakes resulted in nearly 750,000 fatalities worldwide, accounting for over half of all deaths attributed to natural disasters. Additionally, during this period, over 125 million individuals were impacted by earthquakes, experiencing injuries, displacement, homelessness, or evacuation during the initial emergency response phase of the disaster (WHO, 2018). Geophysicists can locate places where seismic tremors are certain, but no one can foresee when such a tremor will happen. The Earth's crust is made up of structural plates, all of which can move, causing seismic tremors (USGS, 2024). About 90% of the most devastating earthquakes are of tectonic origin, 3% are of volcanic origin, and 1% are due to underground landslides (USGS, 2024). Seismologists report more than 30,000 earthquakes each year, most of them weak in magnitude (Burton & Silva, 2016). Several factors aggravate earthquake consequences (Abdalzaher et al., 2023):

a. Population density: Since huge numbers of individuals live in earthquake-prone zones, more people are at greater risk. Seismic tremors affect eight out of the 10 most densely populated cities in the world. Most of the world's seismic tremors are on the Pacific Edge, followed by Asia, where two-thirds of the world's population lives.
b. Poorly developed and ineffective building construction means that buildings that cannot withstand the constraints of seismic tremors are more inclined to collapse. Poverty forces numerous individuals to live in stuffed, substandard, and hazardous places and accommodations. The destitute are affected more by seismic tremors than wealthy individuals are.

Related Literature

The literature reveals significant advancements in the integration of IoT and smart devices for earthquake detection and early warning systems. These innovations span from smartphone apps and wireless sensor networks (WSN) to comprehensive frameworks and real-time data processing techniques. The continuous development and pilot testing of these technologies underscore their potential to improve public safety and disaster response efficiency. These findings are discussed in the following paragraphs and summarized in **Table 1**.

1. Early warning systems for earthquakes: Alphonsa and Ravi (2016) emphasized the importance of sharing historical data for the success of earthquake prediction systems. They proposed an IoT-based early warning system using accelerometers to collect vibration data from different areas, which is processed by a PIC microcontroller. If the vibration exceeds a threshold, the system sends warning messages to people in danger zones and disaster response teams. Moreover, Zambrano et al. (2017) described an earthquake early warning system using a WSN, focusing on the time and spatial analysis of seismic data. Similarly, Wang et al. (2019) introduced a university emergency response system that aggregates data from multiple sources to improve decision-making during emergencies. Hadiana et al. (2020) presented a disaster preparedness architecture tailored for the Indonesian national board for disaster management, demonstrating its utility in enhancing disaster response efforts.
2. IoT-based earthquake detection and response: Won et al. (2020) introduced BLESeis, an IoT sensor designed for smart earthquake detection with 100% accuracy in classifying seismic events. Similarly, Sharma et al. (2021) proposed a disaster management framework utilizing interconnected IoT devices, examining their application across various disaster scenarios. Furthermore, Taale (2021) developed a full-stack design for an earthquake early warning platform using a dense network of sensors in consumer electronics. They introduced a neural network-based earthquake intensity prediction model. Additionally, Saini et al. (2022) leveraged IoT to collect sensor data, perform preprocessing, feature extraction, and classification using a random forest algorithm in the fog layer. Their model showed effectiveness in earthquake monitoring and prediction.
3. Technological innovations in earthquake detection: Fajardo and Oppus (2010) explored the integration of smart devices into communication methods within DMSs. They developed a smartphone app that recommends optimal paths for volunteers and rescue operations based on geographical regions. However, this system did not address administrative modifications within the disaster management framework. Lin et al. (2020) proposed a method to reduce earthquake impact by linking a base separation system to Japan's earthquake early warning system. This system improves vibration isolation without needing supplemental suspension or elasticity in base isolation. Chen et al. (2023) developed an integrated earthquake detection and warning system using sensors, Arduino, and transmission technology. This system includes additional hazard response mechanisms, such as activating exhaust fans when harmful gases are detected and alarms for rapid evacuation in case of fire.
4. Recent advances and pilot testing: Noor et al. (2023) employed a NodeMCU paired with a SW-420 vibration sensor for intelligent earthquake surveillance, utilizing the Blynk application for efficient notification and data visualization. Similarly, Pierleoni et al. (2023) proposed an IoT solution for earthquake early warning systems using the message queue-telemetry transport protocol, comparing it to standard system protocols. Moreover, Rathore et al. (2023) outlined the construction of an earthquake warning dissemination app that uses Firebase's cloud messaging system to provide early

Table 4. Related literature

Study	Focus	Findings
Fajardo and Oppus (2010)	Disaster management system	Recommendations for volunteers and rescues based on geographical regions.
Alphonsa and Ravi (2016)	Earthquake early warning system	An early warning system for earthquakes using the IoT was proposed.
Zambrano et al. (2017)	Earthquake early warning system using IoT	Details of the system's components, requirements, and design choices, emphasizing time and spatial analysis.
Wang et al. (2019)	A university emergency response system	A new approach to establishing campus emergency response protocols.
Hadiana et al. (2020)	A disaster preparedness architecture	A disaster management architecture.
Lin et al. (2020)	Earthquake impact reduction method	Linking a base separation system to Japan's earthquake early warning system.
Won et al. (2020)	IoT sensor smart earthquake detection	Sensor's ability to detect vibrations and accurately classify earthquakes.
Sharma et al. (2021)	A disaster management framework	A survey examines how the IoT can be applied to various disasters.
Taale (2021)	An earthquake early warning platform	A novel earthquake intensity prediction model based on a neural network structure.
Saini et al. (2022)	IoT to collect sensor data in the fog layer	Effectiveness of this model for earthquake monitoring and prediction.
Chen et al. (2023)	Detection and warning system	Integrating sensors, Arduino, and transmission technology.
Noor et al. (2023)	Earthquake surveillance	The NodeMCU is paired with a SW-420 vibration sensor.
Pierleoni et al. (2023)	Earthquake warning system	IoT solutions are utilized for waveform transmission from seismic nodes.
Rathore et al. (2023)	Earthquake warning system	Warning dissemination app.
Ahn et al. (2024)	Capabilities of IoT devices during earthquakes	The potential of IoT technology to improve public safety measures during seismic events.
Alkhzaimi and Bakar (2025)	Disaster management strategies in the UAE	IoT adoption can improve strategic value, timeliness, and effectiveness in flood response.
Bhide et al. (2025)	6G communication in industrial IoT applications	6G supports advanced automation and real-time decision-making, leading to safer and more efficient industrial processes.
Mohsin et al. (2025)	IoT-based emergency assistance services	A unified system approach is necessary for effective coordination and decision-making during emergencies.
Papaioannou et al. (2025)	IoT-enabled smart cities	Emphasizes the use of centralized control for resource management and emergency response, noting challenges in standardization, integration, and security.
Singh et al. (2025)	Use of IoT in cybersecurity and data science	Blockchain technology is proposed as a promising solution to enhance trust, authorization, authentication, and secure data sharing in IoT environments.
This study	Earthquake warning system	Integrating information and communication alongside IoT technologies.

alerts. This app also offers online earthquake safety suggestions. Finally, Ahn et al. (2024) investigated the rapid response capabilities of IoT devices during earthquakes, designing and pilot-testing an IoT-based service platform. This platform aims to ensure effectiveness and compliance with international standards, highlighting the potential of IoT technology to enhance public safety during seismic events (Ahn et al., 2024).

More recently, several reviewed papers collectively highlight the transformative potential of IoT across diverse domains, emphasizing its role in enhancing cybersecurity, urban management, industrial communication, emergency response, and disaster resilience. Singh et al. (2025) explore IoT's integration with blockchain and machine learning to address security, privacy, and interoperability challenges, proposing smart contracts like ACC for secure data sharing. Papaioannou et al. (2025) focus on scalable and secure HRMS frameworks for IoT-enabled smart cities, identifying gaps in real-time adaptability and integration of heterogeneous devices. Bhide et al. (2025) highlight how 6G and URLLC will revolutionize IoT through ultra-reliable, low-latency communication, enabling real-time automation in industries. Mohsin et al. (2025) emphasize IoT-based emergency systems that integrate cross-domain data for faster, coordinated responses, stressing the need for secure and scalable communication. Finally, Alkhzaimi and Bakar (2025) addresses flood resilience in the UAE by integrating TTF and TAM models with IoT for tailored disaster management solutions, improving strategic decision-making and resource allocation in arid regions.

RESEARCH METHOD

To systematically analyze and code the amassed data, we adhered to the guidelines outlined by Miles and Huberman (1994) and Alzoubi and Gill (2021), which encompass four key stages: data collection, data reduction, data display, and conclusion drawing.

Data Collection

We collected data from all available online documents from various ministries in Iraq, spanning disaster management and the ICT sector. Our data search centered around three focal points: the existing ICT infrastructure, the disaster procedures implemented in Iraq, and the requirements of the SDMS. The researchers collected data mainly from the Iraqi Ministry of Environment website (https://moen.gov.iq/), which is responsible for disaster management. The types of disasters

Table 2. Differences between SDMS and the current system

Feature	CS	SDMS
Continuous monitoring using WSN	No	Yes
Real-time data	No	Yes
Using AI in decision making	No	Yes
Using ICT in alarming	No	Yes
Using IoT in detect location and statistics	No	Yes
Using IoT in remote control of power sources	No	Yes

Note. CS: Current system

faced by Iraqi citizens and the strategies employed for disaster management were extracted. Moreover, concerns about citizens' lack of preparedness and insufficient knowledge of handling disasters were also summarized. A general direction by the ministry and people was on the utilization of modern scientific methods and ICT in disaster management.

The second source of data collected was from the Iraqi Ministry of Communications website (https://moc.gov.iq). This was important for an initial evaluation of what telecommunication infrastructure is available, the future ministry plan, and the potential for adopting the latest ICT technologies. The initial collection of data shows the state of information technology and the Internet infrastructure in Iraq, revealing deficiencies in telecommunications infrastructure and the limited availability of wired Internet services, particularly in rural areas. Additionally, the absence of electronic payment services and insufficient utilization of smartphones and computers to address electronic illiteracy among citizens further hindered the effectiveness of e-government initiatives. These factors collectively contribute to the limited reliability of the e-government project and the low willingness of Iraqi citizens to embrace its services. It is important to highlight that all the data obtained from these websites was in Arabic. The first and third researchers undertook the translation process, leveraging their proficiency in both Arabic and English.

Data Analysis

Here, we explore the data reduction, data display, and conclusion drawing, as per (Miles & Huberman, 1994). In this phase, the data underwent thorough examination to pinpoint key issues, concepts, and themes relevant to the RQs (Miles & Huberman, 1994). This iterative process involved scrutinizing the data within and across case data sets. A coding scheme was devised to categorize and index the text concerning various aspects such as procedures, tools, ICT, IoT devices, and other requirements pertinent to the presence of disaster plans. This scheme enabled systematic organization and analysis of the data, facilitating the identification of recurring patterns and themes essential for the research objectives.

During the data display phase, the collected data was organized, condensed, and presented in a more coherent and accessible format compared to its original scattered state (Miles & Huberman, 1994). This process involved the creation of several UML diagrams illustrating the proposed framework. These diagrams served to visually represent the structure and components of the framework, enhancing clarity and comprehension of the data. In the final phase, the focus shifted to concluding, accomplished by presenting detailed insights into the requirements of the three stages: before disaster, during disaster, and after disaster. This conclusive step synthesized the findings, offering a comprehensive understanding of the essential elements needed at each phase of the disaster management process. According to the data analyzed, the differences between the currently used DMS in Iraq and the proposed SDMS in this study are summarized in **Table 2**.

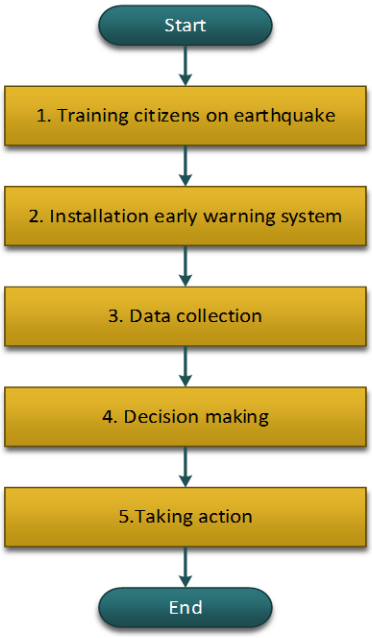

Figure 1. Main activities to take before earthquake (Source: Authors' own elaboration)

EARTHQUAKE RESPONSE FRAMEWORK

Following the analysis stage, the subsequent phase is the design of the system framework. This framework serves to elucidate the system's characteristics and dimensions by analyzing its three dimensions (Chen et al., 2023; Damaševičius et al., 2023): definition, abstraction, and implementation. Additionally, it delineates the components of the SDMS and the interrelationships within the system.

The UML was employed to visually represent the framework, aiding software developers as UML serves as a standard in software development (Gogolla et al., 2007). Consequently, the conceptual design of the SDMS was crafted using UML diagrams. The conceptual design of the SDMS encompasses three distinct scenarios, each accompanied by a corresponding UML diagram representing stages before, during, and after earthquakes. Within each stage, two activity diagrams were utilized: one outlining the main activity and another detailing a specific activity. Additionally, use-case diagrams were applied to delineate scenarios within each stage.

Before Earthquake Stage

This stage is pre-disaster stage and includes all the physical and psychological preparations needed in case an earthquake strikes. The main activities to be done before the disaster stage are shown in **Figure 1**, which includes the requirements, participants, and detailed activities of this stage.

The DMS requires a foundational infrastructure comprising personal computers, sensors, networks, data centers, databases (DB), and the Internet connectivity. Smart devices featuring GPS software are integral for location tracking and communication purposes. An alarming system, integrated with AI software, serves as an early warning mechanism to alert authorities and citizens to potential disasters. Additionally, a dedicated training center equipped with necessary resources is essential for training citizens and disaster response teams in disaster preparedness and response protocols. Adequate provisions of food, medicines, and equipment are indispensable for use during and after a disaster to sustain affected individuals and support relief efforts.

Objectives

The objectives at this stage are as follows:

1. Implementing various WSN to detect diverse types of disasters, interconnected with a data center equipped with AI software endowed with decision-making capabilities. This system will serve as an early warning mechanism for detecting anomalies.
2. Educating citizens on first aid techniques, rescuing procedures, and evacuation methods to leverage these skills effectively during disasters.
3. Equipping and training emergency response teams, maintaining readiness for disaster response.
4. Identifying evacuation zones for citizens and formulating evacuation plans. Additionally, establishing emergency shelters, delineating access routes, and stockpiling essential supplies, including food, medicine, and equipment necessary for any emergency scenario.
5. Utilizing historical data to forecast casualty rates for each type of disaster and preparing the requisite resources for their treatment.
6. Establishing a comprehensive DB containing individuals' medical histories to identify those with chronic illnesses. Additionally, identifying individuals with special needs, elderly populations, and people with disabilities and mapping their residences will facilitate their rescue during disasters.

People involved

Three groups of people are involved in the response to the earthquake: the disaster team, the supporting team, and volunteers.

1. Disaster management team
   a. Team leader: Responsible for declaring a state of emergency during a disaster and issuing instructions to the disaster management team, support personnel, and volunteers. This individual, often a governor or city mayor, oversees disaster management from its onset until resolution.
   b. Team members: Experienced in handling various types of disasters, these individuals possess the skills necessary to train volunteers and manage emergencies. They maintain readiness for disaster response at all times.
2. Supporting personnel
   a. Police officers: Skilled in first aid and emergency response, police officers play a crucial role in disaster management by safeguarding critical facilities and addressing emergencies.
   b. Firefighters: Tasked with extinguishing fires, firefighters rescue individuals trapped in collapsed structures. They also administer first aid.
   c. Paramedics: Provide initial medical treatment to injured individuals and facilitate the transfer of critical cases to hospitals during disasters.
   d. Transporters: Evacuate affected individuals to safe areas and administer first aid as needed to preserve lives during disasters.
3. Volunteers: Civilians trained in first aid by disaster management teams and volunteers play a vital role in disaster response efforts by aiding rescue operations and minimizing casualties.

Activities

The activities before a disaster are depicted diagrammatically in **Figure 2**. Disaster preparedness, the initial phase, involves ongoing research to enhance disaster management and mitigate risks. Citizens undergo training in first aid and evacuation procedures, while disaster management teams, supporters, and volunteers simulate various disaster scenarios for effective management. Evacuation areas are routinely inspected to ensure readiness. Suppose the WSN deployed across various locations transmits data to the data center regarding oscillations. Upon comparison with the historical data stored in the DB, it reveals that the received data is anomalous and aligns with earthquake patterns. Consequently, an automatic alarm message is dispatched to the team leader. Upon reviewing the details within the alarm message, the team leader determines whether the situation indicates a minor or a significant earthquake. Subsequently, the team leader notifies the relevant support team to make the necessary preparations.

1. The first step entails installing a WSN comprising sensors, a DB, a network, and PCs. Sensors, strategically placed based on geographic location and potential disaster threats, transmit data to the data center. Each sensor's data includes an ID for location detection and a value indicating normal or abnormal conditions.
2. The WSN transmits its data to the data center. Each data point received from the sensors comprises two variables. The first variable denotes the sensor ID, which is crucial for pinpointing the sensor's location and identifying the affected area. The second part of the sensor data encompasses the sensor value, scrutinized by the system to discern normalcy or abnormality, thereby determining the presence of a potential disaster risk. **Figure 3** illustrates the message transfer among various stages of the SDMS, elucidating the system's intelligence and functionality.
3. The data center, equipped with a DB storing historical disaster data, continually compares incoming sensor data. If anomalies are detected, an alarm message is

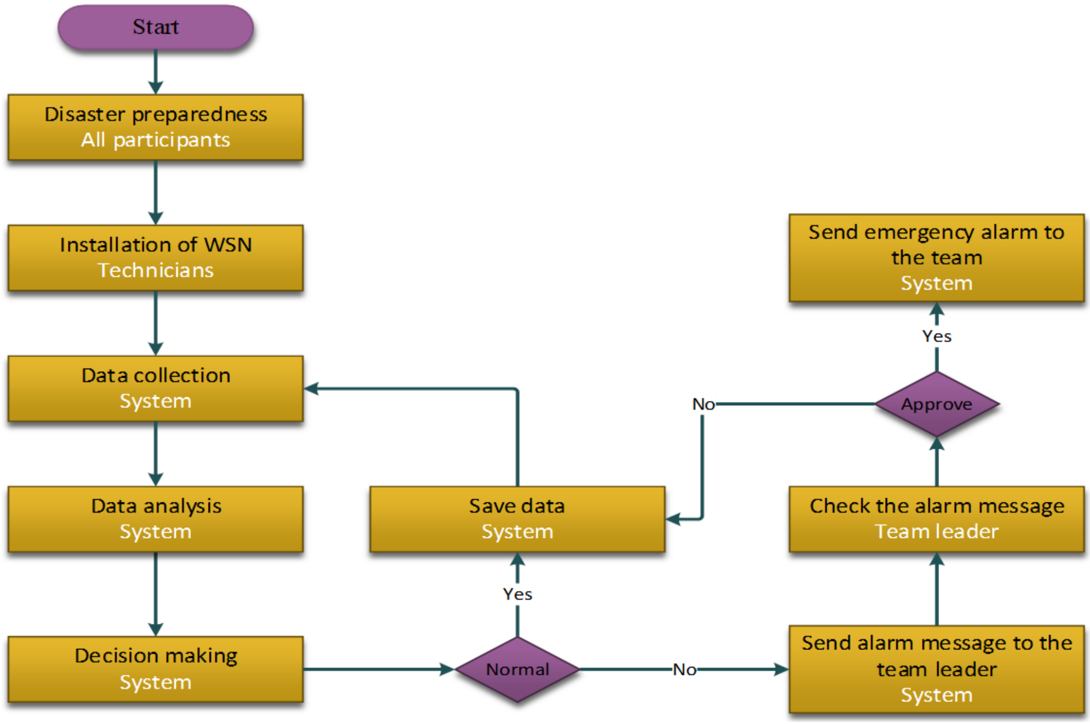

Figure 2. Flowchart of detailed activities to take before earthquake (white text indicates who is performing the operation) (Source: Authors' own elaboration)

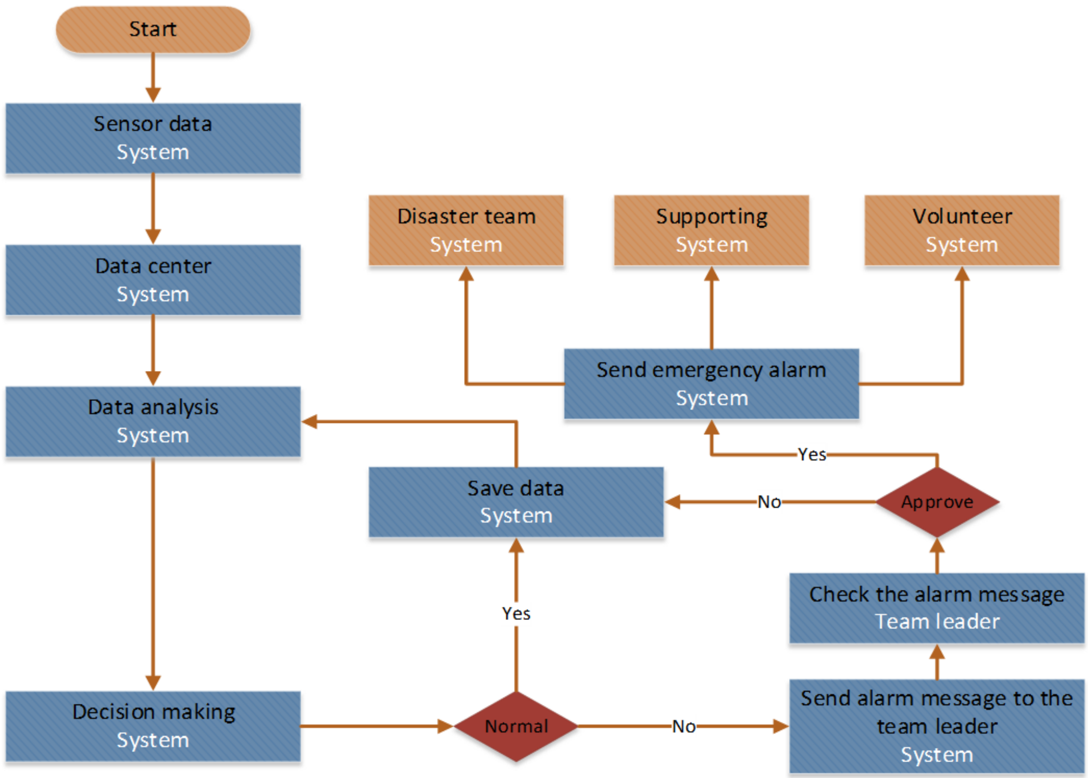

Figure 3. SDMS message transfer (Source: Authors' own elaboration)

relayed to the team leader; otherwise, normal data is logged. The team leader evaluates the severity of received alerts and activates emergency protocols if warranted, prompting disaster response, support, and civilian volunteer teams to enter emergency mode. Otherwise, standby mode is maintained.

Use case diagram for key actions before earthquake

Use case diagrams were employed to depict the roles, processes, and data flow within the system for the stage preceding a disaster. **Figure 4** presents a diagram illustrating this stage in the proposed SDMS.

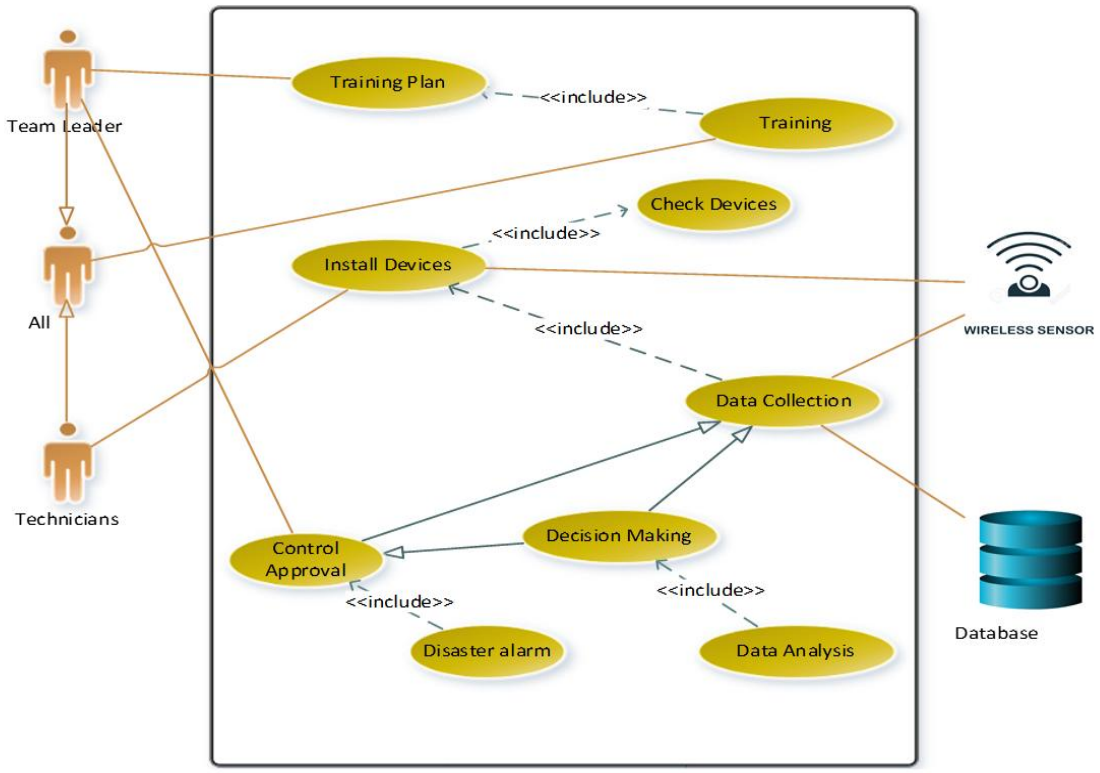

Figure 4. Use case diagram of main actions before earthquake (Source: Authors' own elaboration)

1. The team leader is tasked with outlining the training program, scheduling sessions, determining participants, and identifying necessary materials.
2. All members of the SDMS team, including the team leader, participate in the training program to ensure readiness for handling disasters.
3. Technicians oversee the installation of system hardware, network connections, and conduct routine checks to ensure proper functionality.
4. Sensors commence transmitting data to the data center to monitor the area for anomalies.
5. The data center receives and analyzes incoming data; if abnormal patterns are detected, the system compares them with historical data stored in the DB.
6. Upon identifying potential danger, an alarm message is relayed to the team leader.
7. The team leader assesses the risk level based on data received from the data center.
8. If the situation is manageable, specialists are dispatched to address the situation, and a report is logged into the DB for archival purposes.
9. In cases of high-risk levels, the team leader declares an emergency, initiating the system's second phase.

During Earthquake Stage

This stage represents the most critical and perilous phase for the SDMS. Here, events unfold in real-time, demanding that the earthquake management team possess thorough training and proper equipment to effectively address the situation. Efficient management during this stage is pivotal in minimizing loss of life and property. Incorporating ICTs into the DMS will notably enhance the system's efficiency. Utilizing GPS and IoT enables the real-time transmission of information, while remote control over various devices becomes a crucial element in the successful management and control of earthquakes at this stage. The scenario for how this phase unfolds is discussed in the following sections.

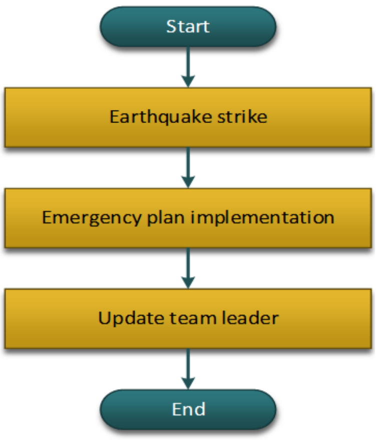

Figure 5. Main activities to take during an earthquake (Source: Authors' own elaboration)

The main activities during the earthquake stage are shown in **Figure 5**. The resources required encompass a range of modern technologies and equipment. These include cell phones, smart devices, PCs, satellite channels, and the Internet service to facilitate communication and coordination. Transportation assets such as buses, ambulances, fire vehicles, police cars, fire-fighting aircraft, rescue boats, lifeboats, loaders, and lorries are essential for swift mobilization and evacuation efforts.

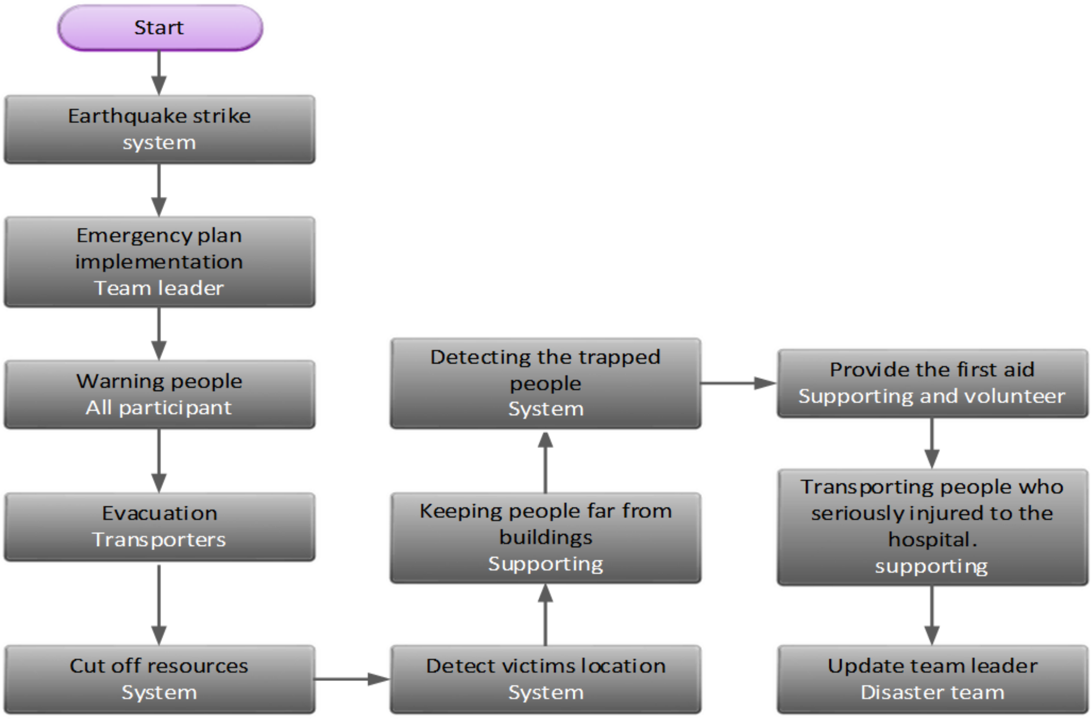

Figure 6. Detailed activities to take during an earthquake (Source: Authors' own elaboration)

Additionally, sensors, RFIDs, and wireless communication devices play a crucial role in gathering and transmitting vital data during emergencies. Moreover, electric generators, water suction pumps, masks, respirators, and fire extinguishers are indispensable tools for mitigating hazards and ensuring the safety of responders and affected individuals.

Objectives

The objectives of this stage apply broadly to various types of disasters; however, we will focus on earthquakes. These objectives encompass:

1. Alerting people about the impending disaster through diverse communication channels such as SMS, social media, emails, TV broadcasts, and public announcement systems.
2. Safely evacuating individuals to designated safe zones equipped with essential supplies like food, water, and medicine.
3. Shutting off electricity, gas, and water sources either through automated smart controllers or manual intervention to prevent potential hazards.
4. Administering first aid by trained paramedics or civilian volunteers to provide immediate medical assistance to affected individuals, alleviating the burden on hospitals.
5. Transporting critically injured individuals to hospitals for advanced medical treatment beyond the scope of on-site first aid, aiming to preserve lives.
6. Conducting search and rescue operations to extricate individuals trapped in debris, with firefighters and civilian volunteers working diligently to ensure no one is left behind.
7. Prioritizing swift rescue efforts to minimize the duration of individuals being trapped.
8. Implementing measures to keep people away from buildings susceptible to collapse due to aftershocks or subsequent tremors from earthquakes.

People involved

In earthquake scenarios, two primary teams are mobilized: the disaster management team and the supporting team. The disaster management team comprises the team leader and designated members trained to handle crisis effectively. Meanwhile, the supporting team encompasses various professionals, potentially including police officers, firefighters, pilots for firefighting aircraft, divers specializing in underwater rescue operations, paramedics, transporters facilitating evacuation, and additional volunteers contributing to relief efforts.

Activities

The operational procedures during the earthquake stage are delineated into three distinct scenarios tailored to Iraq's prevalent disaster types. **Figure 6** summarizes the activities during earthquakes.

1. Upon detection of seismic activity, the team leader disseminates an alert message to all team members, support teams, and civilian volunteers, initiating the earthquake disaster protocol.
2. The initial phase of the earthquake protocol involves widespread dissemination of earthquake alerts through various communication channels such as SMS, social media, television, and radio, prompting individuals to seek refuge in designated safe zones.

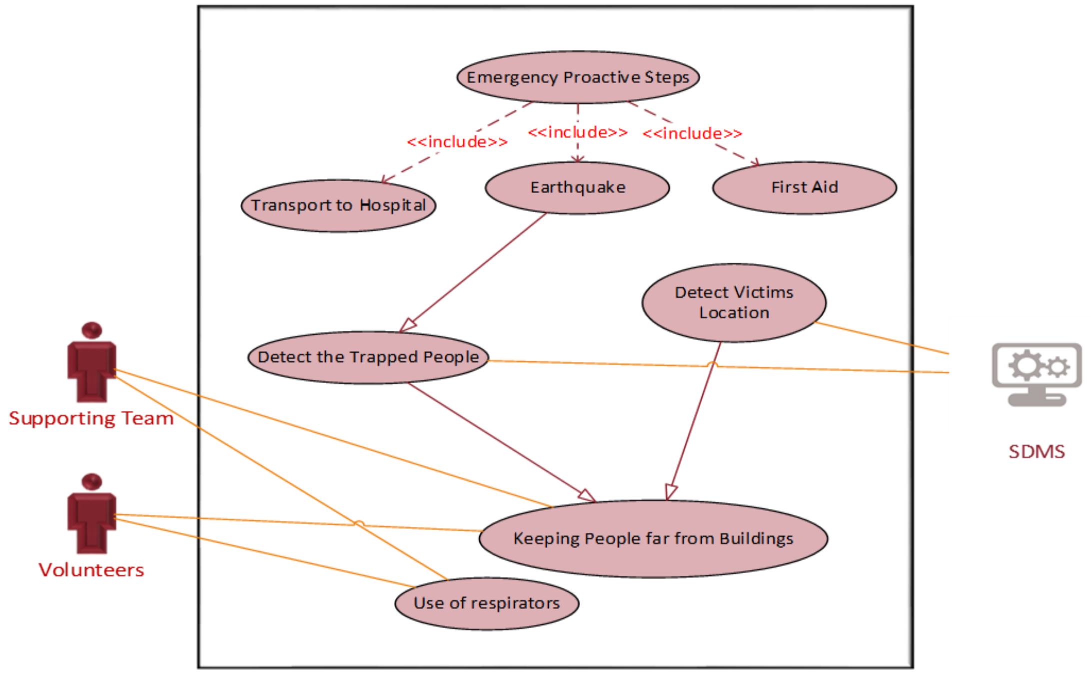

Figure 7. Use case diagram of main actions during an earthquake (Ibrahim, 2020)

3. Utilize RFID technology to pinpoint the whereabouts of elderly and disabled individuals for prompt rescue operations.
4. Execute evacuation procedures to relocate individuals to pre-designated safe areas established during the disaster preparedness phase.
5. Implement measures to deactivate electricity, gas, and water utilities to mitigate potential hazards. vi. Employ RFID technology to identify and rescue individuals trapped in debris.
6. Enforce safety protocols to keep individuals at a safe distance from structures susceptible to collapse during aftershocks. viii. Administer first aid to individuals with minor injuries promptly.
7. Facilitate the transportation of individuals with severe injuries to hospitals for advanced medical care.
8. Maintain regular communication with the team leader to relay real-time updates on the disaster situation and ground conditions.

In an earthquake scenario, the team leader initiates the disaster plan upon receiving an imminent earthquake alarm, prompting the team, including supporting members and volunteers, to activate their trained response protocols. Their immediate actions involve alerting the public through various communication channels and directing them to evacuate buildings, seeking open areas to minimize potential injuries from collapsing structures. Simultaneously, transport teams, aided by traffic authorities, facilitate the safe evacuation of individuals to designated secure zones or pre-prepared areas. Furthermore, the team employs IoT controllers to swiftly disconnect electricity, gas, and water sources, mitigating potential secondary damages. Using radiofrequency identification devices, rescue teams pinpoint individuals at risk of being trapped under debris, collaborating with firefighters and law enforcement to swiftly extract and aid them. Helicopters, coordinated by police and military personnel, assist in reaching individuals trapped under rubble, while loaders and trucks expedite debris removal from collapsed buildings. Paramedics, alongside civilian volunteers, administer initial medical assistance to individuals with minor injuries, alleviating strain on hospital resources, while ambulances prioritize transporting critically injured individuals to medical facilities. Throughout the operation, team members maintain direct communication with the leader, providing real-time updates and adhering to directives. Subsequently, the team transitions to the post-disaster phase to address recovery efforts.

Use case diagram for key actions during earthquake

The use case diagrams delineating actions during the earthquake stage were crafted based on developer guidelines to elucidate the roles, processes, and data flow within the system. These diagrams elucidate the specific protocols for addressing earthquake disasters. **Figure 7** illustrates the use case diagram during the disaster stage of SDMS.

1. The team leader assumes responsibility for declaring the disaster and authorizing the implementation of the emergency plan.
2. All SDMS teams initiate the dissemination of disaster warnings to the populace.
3. Supporting team transporters facilitates the evacuation of individuals to designated safe zones.
4. The supporting team, in coordination with the system, executes the shutdown of electricity, gas, and water utilities to mitigate further damage.
5. Volunteer teams administer initial aid to non-critical injury cases.
6. Ambulances dispatched by the supporting team transport critical cases to medical facilities for urgent care.

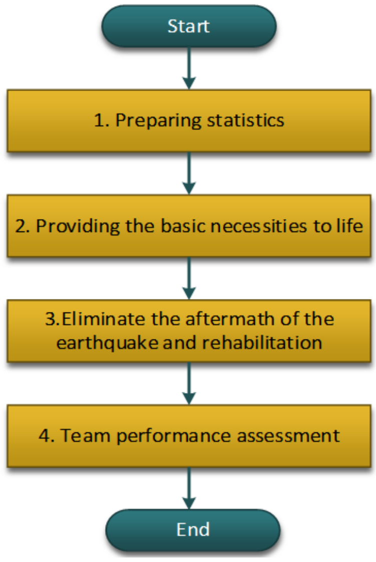

Figure 8. Main activities to take after an earthquake (Source: Authors' own elaboration)

After Earthquake Stage

This is the last stage in the SDMS, at the end of which the system will go back to standby mode. During this stage, the disaster management team, supporting team, and civilian volunteers have different duties in a different scenario. The main activities, requirements, and participants of the after-disaster stage are shown diagrammatically in **Figure 8**. The requirements encompass various essentials for disaster management: Cell phones, smart devices, PCs, DB, the Internet service, RFID, and statistical software facilitate communication and data management. Tents, food, clean water, and medicine ensure basic sustenance and healthcare provision. Trucks, ambulances, police cars, generators, and water treatment plants support transportation, emergency response, and infrastructure maintenance. Building materials are essential for reconstruction and repair efforts in the aftermath of disasters.

Objectives

The objectives for post-disaster management are as follows:

1. To maintain standby status for 72 hours post-earthquake to address potential secondary threats like epidemics or disease outbreaks, managed by the disaster management team, supporting teams, and civilian volunteers.
2. To compile statistics on survivors, injuries, missing persons, fatalities, and financial losses using RFID technology, managed by statistics experts.
3. To supply necessities like tents, food, water, and medicine to survivors and those at evacuation sites, facilitated by transporters and civilian volunteers.
4. To ensure adequate housing, electricity, and communication means for affected individuals, organized during the preparation stage by the disaster team.
5. To safeguard damaged buildings, archaeological sites, and government structures against theft, carried out by police officers. To mitigate the aftermath by rehabilitating affected areas, undertaken by the rehabilitation team.
6. To restore infrastructure, including water, electricity, gas, buildings, and basic services like the Internet and communications, managed by the rehabilitation team.
7. To evaluate the performance of disaster management teams, supporters, and civilian volunteers, overseen by the leader of the disaster management team.

People involved

After an earthquake, various individuals play crucial roles. The DMS team is led by a designated team leader who oversees the coordination of operations. Along with the leader, team members are tasked with executing specific responsibilities during the crisis. Supporting personnel, including police officers, paramedics, statistics experts, technicians, construction workers, and transporters, contribute their expertise to the response efforts. Additionally, volunteers from the community are instrumental in helping and support where needed.

Activities

Following the earthquake, the activities during the post-disaster stage are outlined based on the main activity diagram illustrated in **Figure 9**.

1. Upon receiving continuous feedback, the team leader officially declares the end of the disaster. However, it's essential for the disaster management team, supporting team, and civilian volunteers to remain on standby for 72 hours after the post-announcement to address any potential subsequent issues.
2. The team leader directs statistics experts to compile detailed reports on survivors, injuries, missing persons, fatalities, and financial damages using RFID technology for accurate data collection.
3. The Disaster Management Team establishes temporary camps for survivors in evacuation areas until full rehabilitation of housing and infrastructure is achieved.
4. Provisions, including food, water, medicine, electricity, and communication services, are supplied to survivors by the DMS team. Police officers are tasked with safeguarding damaged buildings, archaeological sites, and government facilities to prevent looting and further damage.
5. The rehabilitation team initiates efforts to mitigate the aftermath of the disaster by restoring vital infrastructure such as water, electricity, and gas, as well as rehabilitating housing and basic services like the Internet and communications.

The maintenance procedure for the SDMS encompasses several key steps. Firstly, all system devices, including sensors, DBs, network devices, and PCs, undergo regular maintenance to ensure optimal functionality. In the event of damage caused by a disaster, affected equipment is promptly replaced. Sensors are reinstalled in their designated locations as part of the restoration process. A comprehensive inspection of the entire system is conducted to verify proper operation and address any

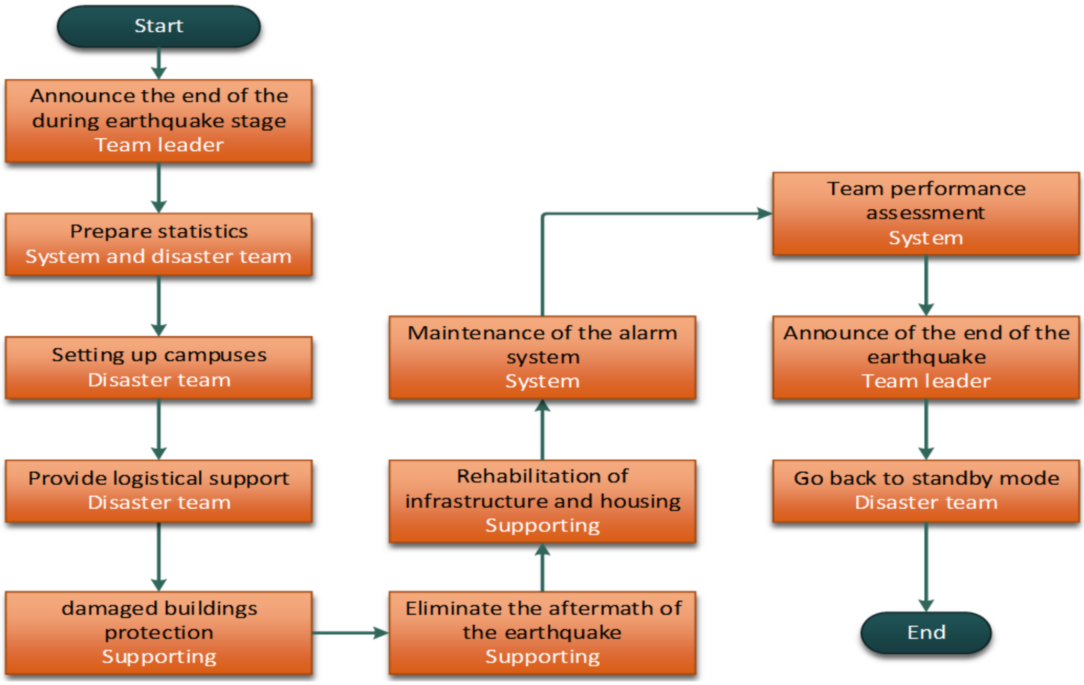

Figure 9. Detailed activities to take after an earthquake (Source: Authors' own elaboration)

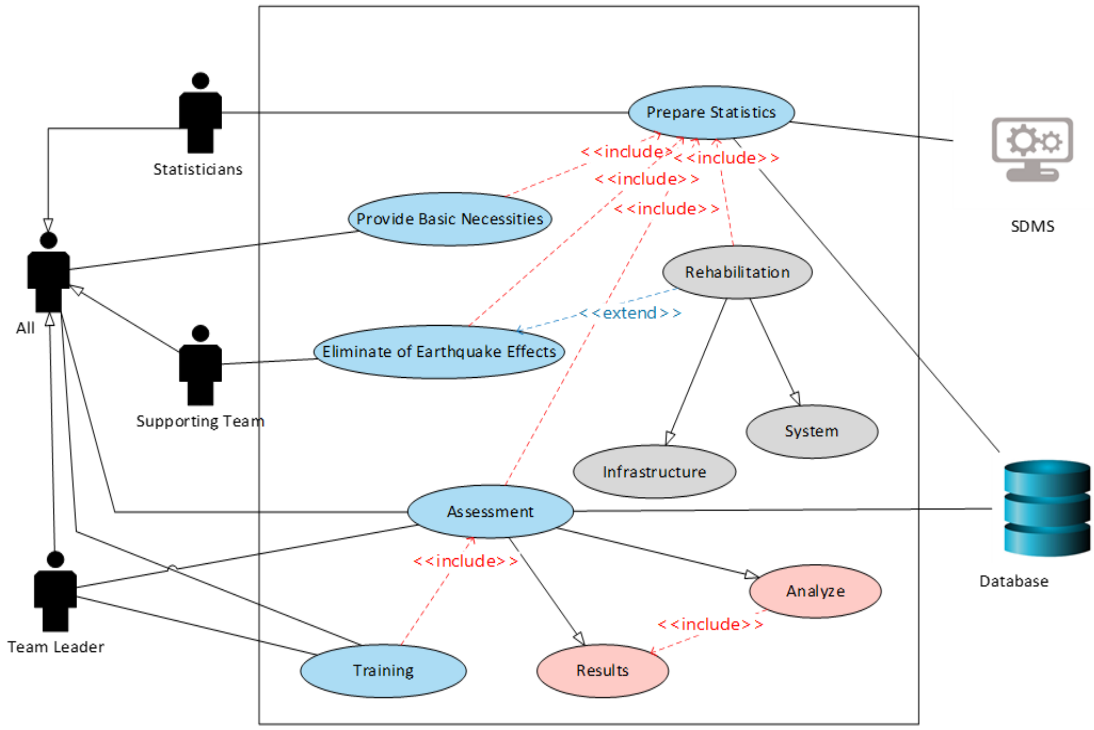

Figure 10. Use case diagram of main actions after earthquake (Ibrahim, 2020)

issues. A lifecycle table is maintained for all devices to schedule timely replacements and ensure continuous functionality. Regular checks are conducted on all system components to verify their proper operation and functionality. Furthermore, the team leader assesses the performance of the disaster management team, its supporters, and civilian volunteers, evaluating the success rate of the entire disaster management process. Upon completion of the assessment, the team leader officially declares the end of the disaster and instructs the disaster team to return to standby mode.

Use case diagram for key actions after earthquake

The use case diagram for the after-earthquake stage, depicted in **Figure 10**, outlines key actions and roles within the SDMS.

1. Statisticians, supported by the SDMS, conduct a thorough statistical analysis to determine the number of survivors, injured, missing, and deceased individuals, along with assessing material losses and infrastructure damage.

2. Support teams and volunteers provide essential supplies such as food, water, and medicine, and establish suitable living arrangements for survivors.
3. Construction workers, aided by volunteers, undertake the crucial task of debris removal in the earthquake-affected area. In their support role, construction workers focus on rehabilitating infrastructure and housing to restore functionality and living conditions.
4. Technicians play a vital role in SDMS rehabilitation, conducting meticulous inspections of system components to ensure optimal functionality and performance.
5. Upon completion of the rehabilitation efforts, the team leader evaluates the performance of the risk management team, supporters, and volunteers, analyzing response times and strategies for future earthquake management. A comprehensive report is archived in the DB for training and reference purposes.
6. The team leader officially declares the end of the disaster and instructs the team to return to standby mode, ready to respond to any future emergencies.

DISCUSSION

This study is structured around three main RQs aimed at understanding the prerequisites, necessities, and essential requirements of the earthquake SDMS at different stages: before, during, and after an earthquake event. These RQs were addressed in before. In the subsequent sections, we delve into the findings gleaned from this study, reflecting on its limitations and outlining future research avenues within the realm of earthquake SDMS.

Findings Summary

While numerous studies have advanced IoT-based earthquake detection and early warning systems, as summarized in **Table 1**, most of these frameworks are either highly localized prototypes, focus solely on sensor performance, or are designed for countries with robust digital and emergency infrastructures. What distinguishes the current study is its tailored design for Iraq, a region with limited disaster management capacity and infrastructural challenges. Unlike prior models, this framework integrates ICT principles with IoT infrastructure into a cohesive, scalable system aimed at national-level coordination. It goes beyond technical detection by incorporating institutional response pathways, data integration mechanisms, and public communication protocols, all adapted to the Iraqi context. This dual focus on technological capability and administrative readiness, especially in an under-resourced environment, represents a meaningful advancement over existing literature and fills a critical gap not addressed by earlier solutions.

As it was previously mentioned, the main goal of the DMS is not to eliminate the disaster permanently because this is not possible. However, the goal of a DMS is to minimize the impact of a disaster. This was approved by all the literature. The weakness of the existing DMSs is not related to the technical side only; it is also related to the administrative side. That is, the success of the DMS needs to make a change in the administrative structure of this system and make all units of the system linked to one administration and receive orders from only one leader. In addition to linking all units of the system with each other using ICT, increasing the readiness of citizens towards disasters as well as increasing their ICT knowledge will contribute to reducing the effect of the earthquake (Abdalzaher et al., 2023). One of the most prominent challenges facing the implementation of the DMS is the high cost of the components of this system; therefore, research in this field relies on conceptual design when trying to apply new ideas.

The UML was used to visualize the SDMS framework; this visualization will help developers in software development because UML can be used as a software-developing standard. The conceptual design of the SDMS consists of three different scenarios: before an earthquake, during an earthquake, and after an earthquake. This framework will serve as a guideline for developers to develop similar systems. It can assist developers in designing and developing the proposed system by elucidating all system activities, data transmission methods, and the roles of each individual within the system. By enhancing the earthquake DMS, citizens' preparedness in utilizing e-government applications will increase, fostering a knowledge-based society equipped to confront disaster risks and consequently minimizing the extent of losses caused by such disasters.

Several papers highlight a range of IoT communication protocols and their applications across different domains. Zabihi and Alavijeh (2024) discuss industrial protocols like Modbus, DNP3, and IEEE C37.118 in SCADA and WAMS systems, enabling real-time monitoring and control. Singh et al. (2025) and Papaioannou et al. (2025) emphasize MQTT and CoAP for lightweight, efficient communication in constrained IoT environments, with MQTT being widely adopted for inter-node and cloud interactions. Bhide et al. (2025) highlight URLLC in 6G networks as a key enabler for ultra-reliable, low-latency IoT applications. In contrast, Alkhzaimi and Bakar (2025) focus on conceptual IoT integration in disaster management without detailing specific protocols.

It's also important to note that IoT communication comes with several challenges. These challenges are related to security, latency, data loss, interoperability, and system integration. Zabihi and Alavijeh (2024) emphasize edge computing to reduce latency and data loss, while stressing cybersecurity vulnerabilities and recommending encryption and standards for secure interoperability. Similarly, Singh et al. (2025) and Papaioannou et al. (2025) identify centralized systems as single points of failure and note the strain of massive IoT data volumes on storage and processing. Bhide et al. (2025) highlight URLLC in 6G as a solution for low-latency IoT communication. Mohsin et al. (2025) underscores secure, real-time cross-domain data sharing for emergency response, while Alkhzaimi and Bakar (2025) notes adoption barriers and the need for context-specific IoT integration. Accordingly, an effective IoT-based solution must be secure and privacy-preserving, low-latency and reliable, interoperable and scalable, as well as human-centered and context-aware. By addressing these key attributes through insights drawn from current research, including the use of encryption, decentralized architectures, edge computing, standardized protocols, and user-focused design, governments can develop DMSs that are not only technologically robust but also adaptable to local conditions and stakeholder needs.

Research Limitations and Future Directions

This study is primarily limited to the Iraqi context, focusing on the challenges posed by low ICT readiness among citizens and limited adoption of e-government applications, as well as the broader infrastructural and resource constraints facing the country. While the framework was designed to address these specific issues, the findings may not be immediately generalizable to countries with more advanced digital ecosystems. However, the framework holds strong potential for adaptation in other low-resource or post-conflict settings that face similar systemic challenges, such as fragile governance, infrastructure gaps, or public mistrust in digital services. Its modular structure, emphasis on ICT integration, and flexibility in sensor and communication technologies make it adaptable to regions with varying technological capacities. For instance, with minor modifications, the model can be implemented in countries across the MENA region, Sub-Saharan Africa, or parts of Southeast Asia where disaster management capabilities remain underdeveloped. Future research should explore cross-regional applications and pilot deployments to test and refine the framework's scalability, usability, and contextual fit across diverse environments.

Another potential future research direction for earthquake SDMS systems is the implementation of such systems in real-world scenarios. This entails deploying the earthquake SDMS in regions prone to seismic activity and integrating it into existing disaster management frameworks. By implementing the earthquake SDMS, researchers and disaster management authorities can assess its practical effectiveness in mitigating the impact of earthquakes and facilitating response efforts. Additionally, testing the earthquake SDMS in simulated disaster scenarios can provide valuable insights into its functionality and usability. Another important avenue for future research involves evaluating the performance of disaster response teams when utilizing the earthquake SDMS. This evaluation can involve assessing factors such as response time, coordination among team members, and overall effectiveness in managing earthquake-related crises. Furthermore, expanding the scope of testing to include a diverse range of countries and regions can help identify potential challenges and opportunities for improving the earthquake SDMS's applicability on a global scale. Moreover, future research efforts could focus on preparing scenarios for other types of disasters, such as hurricanes, floods, and wildfires, to enhance the versatility and utility of SDMS systems beyond earthquake-specific scenarios. By addressing these research directions, stakeholders can advance the development and implementation of earthquake SDMS systems to better prepare for and respond to seismic events and other natural disasters.

CONCLUSIONS

Earthquakes pose significant challenges to communities worldwide, necessitating effective management strategies to mitigate their impact and enhance preparedness and response capabilities. This study aims to investigate the potential of ICT, particularly the IoT, in bolstering earthquake management strategies, with a specific focus on Iraq as a case study. Through an extensive review of existing literature and data collection from disaster-related ministries, a comprehensive framework for earthquake management, termed the SDMS, has been developed. The SDMS integrates cutting-edge ICT technologies like IoT and AI to enhance preparedness and response capabilities. The framework comprises a meticulously crafted conceptual design, delineating key stages of earthquake management: before, during, and after the event. Detailed UML diagrams illustrate the roles, activities, and interactions within the system, providing a clear visual representation.

The insights derived from this study have broader implications for disaster management beyond the immediate context of Iraq. The SDMS framework can catalyze future research endeavors in disaster management, serving as a foundation for exploring and validating innovative approaches across diverse contexts and disaster scenarios. Future research efforts can focus on refining and adapting the SDMS framework to address other types of natural disasters, such as flooding and fire emergencies, thereby advancing resilience and mitigating the impact of disasters worldwide.

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Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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