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Disruptive technologies and their use in disaster risk reduction and management

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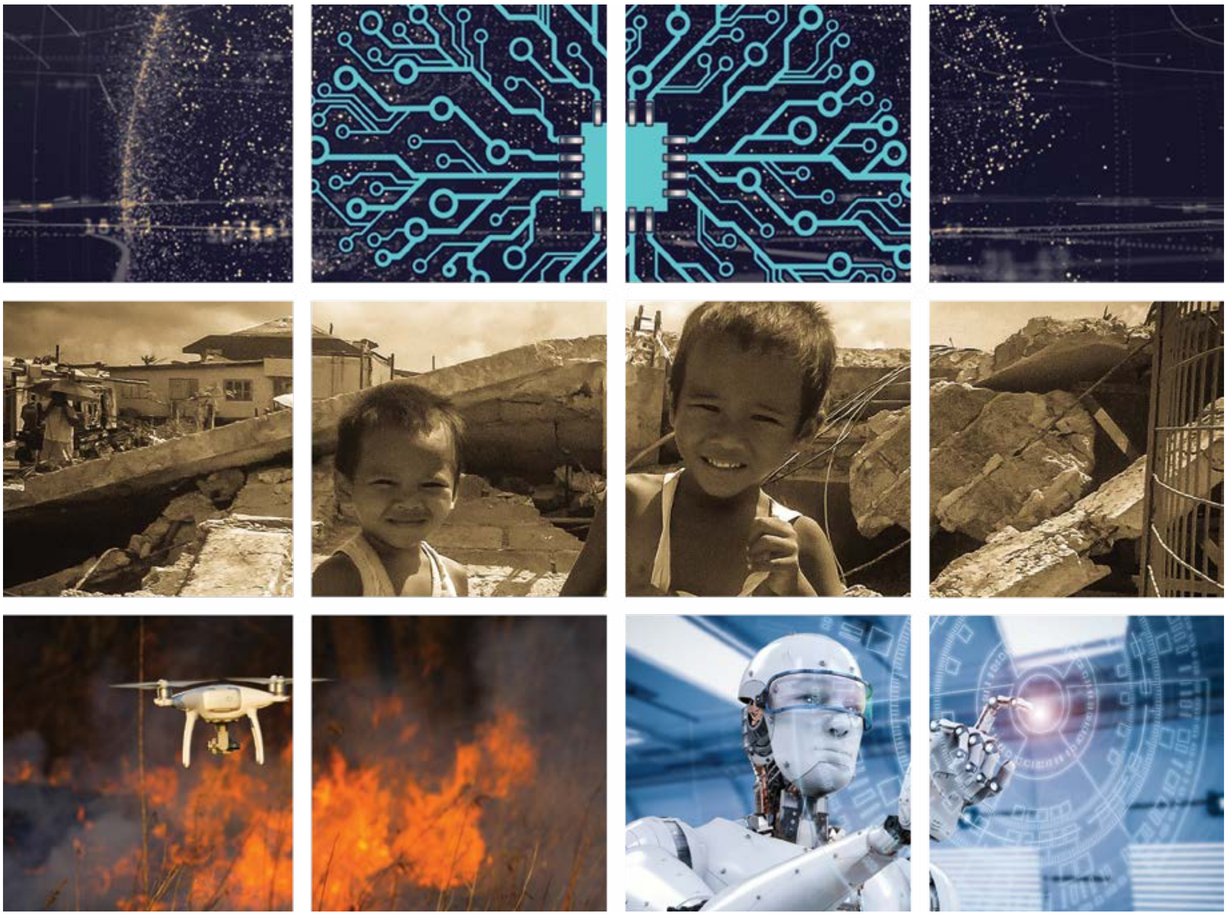

Disruptive technologies and their use in disaster risk reduction and management

The document was prepared by ITU expert Michael Minges, under the direction of the Least Developed Countries, Small Island Developing States and Emergency Telecommunications (LSE) Division of the ITU Telecommunication Development Bureau (BDT).

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Foreword

I am pleased to present this document on *Disruptive technologies and their use in disaster risk reduction and management*, published to coincide with the third ITU Global Forum on Emergency Telecommunications (GET-19), taking place from 6 to 8 March 2019 in Balaclava, Mauritius. The theme of GET-19 – *Innovating together to save lives: using technologies in disaster management* – is highly relevant given the devastating impacts that natural hazards have on people and economies across the globe. Each year over the past decade there were, on average, 354 disasters, 68 000 deaths, 210 million people affected and USD 153 billion in damages. However, there are signs that loss of life from major natural hazards are on the decline due to better disaster risk management.

This document discusses the use and opportunities of ICTs and disruptive technologies for disaster risk reduction and management. It responds to requests from ITU Member States to identify relevant technologies and facilitate the sharing of best practices. The document finds that technological advancement and innovation are creating new opportunities for enhancing disaster resiliency and risk reduction. Developments in disruptive technologies – such as artificial intelligence (AI), the Internet of Things (IoT) and Big Data – and innovations in such areas as robotics and drone technology are transforming many fields, including disaster risk reduction and management. The rapid spread of supporting digital infrastructure and devices, especially wireless broadband networks, smartphones and cloud computing, has created the foundation for the application of disruptive technologies for disaster management. Disruptive technologies can spread critical information more quickly, improve understanding of the causes of disasters, enhance early warning systems, assess damage in new ways and add to the knowledge base of the social behaviours and economic impacts after a crisis strikes. Situational awareness is improving with new tools providing the crisis community with a clearer understanding of the extent of damage and where to prioritize resources.

At the same time, the pace, scope and impact vary among the technologies. Use of drones and IoT is increasing, as experience is gained and costs fall. While social media are playing a greater role during disasters and the public is using digital technologies such as crowdsourcing map details to support disaster management, many uses of Big Data, robots and AI remain largely experimental. Large-scale impacts will require more time and investments in skills and research. Traditional technologies, though not considered disruptive, continue to play a critical role in disaster management, and are also benefitting from digitization. Satellite imagery and seismometers remain important methods for detecting, monitoring and accessing disasters, and text messaging has a wide reach when communicating with the public.

We set out important steps that governments, relief agencies, the private sector, the research community and assistance agencies can take to maximize benefits from the opportunities identified in this document, and we highlight the importance of regulation, training, scaling and building partnerships. These steps will help disruptive technologies achieve wider impact before, during, and after disasters with the potential to significantly reduce loss of life and hasten recovery efforts.

Executive Summary

Technological advancement and innovation have created new opportunities for enhancing disaster resiliency and risk reduction. Developments in disruptive technologies – such as artificial intelligence (AI), the Internet of Things (IoT), and Big Data – and innovations in such areas as robotics and drone technology are transforming many fields, including disaster risk reduction and management. The rapid spread of supporting digital infrastructure and devices – such as wireless broadband networks, smartphones and cloud computing – has created the foundation for the application of disruptive technologies for disaster management.

The first documented use of aerial drones was in 2005 after Hurricane Katrina in the United States of America. Because roads were blocked by trees, drones were deployed to search for survivors and assess river levels. Aerial drones are currently used for different disaster phases: preparedness, such as monitoring volcanic activity in order to determine when warnings should be issued; response, such as delivering equipment to locations where ground-based transportation has been disrupted; and recovery, such as photographing disaster areas for damage assessments. Underwater drones were used during the 2018 Hurricane Florence in the United States of America, measuring ocean heat fuelling the hurricane and transmitting data to the National Weather Service. The data filled in gaps left by satellite images, thus improving hurricane modelling. The data also enhanced forecasting the intensity and route of the hurricane, and sensors attached to the drones measured salinity levels to determine how much water from rain and rivers was mixing in the ocean.

An avalanche of data is being generated by sensors, closed-circuit television, smartphones, financial transactions and Internet activities, to name just a few. While many of these data are being mined by businesses for commercial purposes, Big Data analytics holds enormous potential for crisis management. Examples include the analysis of social media communications during a disaster to understand the types of data and creators, in order to have more impact and reduce false information. Another example is the use of financial transactions to monitor economic activity during and after a disaster, in order to improve targeting of support efforts.

The use of sensors for monitoring conditions that could trigger disasters dates back a number of years. Improvements in cloud computing, broadband wireless networks, the sensors themselves and data analysis have led to the emergence of powerful, integrated and real-time systems referred to as the Internet of Things (IoT). Disaster management is an ideal use case for IoT applications, since sensors can send alerts about a number of potentially dangerous situations. Tree sensors can detect if a fire has broken out by testing temperature, moisture and carbon dioxide levels. Ground sensors can detect earth movements, which might signal earthquakes. River levels can be monitored by sensors for possible flooding.

AI could have a tremendous impact for disaster management regarding quickening recovery and response times. Humanitarian groups are hoping to speed up map creation by using machine learning to extract objects such as buildings and roads from aerial images. Considerable research is currently being devoted to the use of AI for detecting and possibly one day predicting earthquakes.

Robots have become more sophisticated through integration with microprocessors and sensors. Their growing dexterity makes them suitable for disaster situations that are too dangerous for humans or rescue animals. Search-and-rescue robots were first used following the September 2011 terrorist attack in New York City to assess the wreckage of the demolished World Trade Center. Since then, more than 50 deployments of robots for disaster use have been reported. Breakthroughs are being achieved in Japan, where there is the possibility for commercialization of robots designed specifically for disasters.

One challenge during a rapidly evolving disaster is coordinating and verifying information among different stakeholders. The Blockchain distributed ledger system and chain of verified records could play a significant role in improving information control. In the United States of America, the Centers for Disease Control and Prevention is planning a pilot to test blockchain for more rapid and reliable collection of data during a crisis in order to reduce the spread of disease. This has relevance for disaster management since, similar to public health, agencies offering relief need to share trusted data quickly to collaborate effectively.

Social media are playing a greater role during disasters. Twitter has been widely used by the relief community in a number of disasters to coordinate response. Unlike text messages, users can follow tweeters; 'cards' can be included with links to photos, videos and other media; and hashtags help quickly receive or find tweets on a specific topic. The Facebook Crisis Response app allows users to mark themselves as safe, reassuring friends and family, provide or seek help, donate money, and receive information.

The public is using digital technologies to support disaster management. Crowdsourcing is helping to add vital details to maps of disaster areas. This enhances satellite imagery by providing greater granularity, making relief efforts more effective and targeted. It is also quicker and cheaper, especially since the crowd often does this on a volunteer basis, compared with traditional methods. Digital technologies provide another way of raising donations for disaster relief victims. More than USD 40 million was contributed via text messaging following the Haiti earthquake disaster in 2010. In India, Twitter was used to alert people to crowdfunding sites for those affected by floods. Some relief agencies have begun accepting donations in cryptocurrencies, such as Bitcoin. Mobile money is a safe way for relief organizations to transfer funds to those affected by disasters.

Traditional technologies, though not considered disruptive, continue to play a critical role in disaster management, and are also benefitting from digitization. Text messaging is used by many relief organizations, because of the ubiquity of mobile phones. Satellite-based emergency mapping has improved both in quality and response. New radar apertures can see through storm clouds, and satellite activations for disasters have risen. Radar radio waves continue to play a critical role for disaster monitoring, for example high-frequency ocean radar systems used for monitoring tsunami activity.

The document takes a closer look at the application of particular disruptive technologies through five case studies:

(a) In Vanuatu, aerial drones were used following Cyclone Pam for disaster assessment. Drones were felt to be an ideal solution for rapid and granular evaluation of the situation, particularly since cloud cover obscured satellite images. The imagery showed which houses were unrepairable compared with those that could be fixed, helping to guide funding and recovery efforts. Crops were surveyed for damage in order to determine how much food people would need from other sources. The imagery was input to an open source mapping platform for volunteers to upload and geo-tag images from social media to overlay on the map. There were challenges with connectivity, the weather conditions and data formats. Nevertheless, the experience provided valuable insights, with the drones providing the fastest method of mapping the damaged areas.

(b) Twitter was deployed by a number of different groups for a variety of purposes following severe flooding in Chennai, India, in 2015. Although emergency telephone numbers were established, they were overloaded, making social media such as Twitter a popular method for communication for those with Internet access. The Twitter live, real-time public platform was used by non-governmental organizations (NGOs), the public, government agencies and the media to share and exchange information. This resulted in unprecedented collaboration on the platform in responding to the crisis. Twitter India publicized three hashtags to be used during the flood, depending on the nature of the tweet, for citizen groups to help agencies on the ground. A variety of information was shared, including helpline phone numbers, updated train schedules, weather forecasts, relief efforts and safety tips. This helped to magnify critical messages, organize relief efforts, assist government agencies, warn the public and provide information in real time to citizens trapped in the floods.

(c) Researchers used Big Data techniques to explore financial transactions before, during and after Hurricane Odile struck the Mexican State of Baja California Sur in September 2014, to analyse its economic impact on those affected. The analysis identified which groups were most affected for targeting post-disaster assistance and how long it took to return to normal, and generated estimates of the economic impact. It would be attractive to develop an *ex ante* model so that the financial response to disasters could be analysed in real time to provide ongoing feedback loops to relief efforts.

(d) Japan is a pioneering centre for the use of robots in disasters. The Human–Robot Informatics Laboratory of Tohoku University has developed several types of robots for disaster response, including a snake-like robot with a camera that can crawl over obstacles, follow walls, and make turns in tight spaces. Research is ongoing to augment search-and-rescue dogs using cameras, Global Positioning System (GPS) and inertial measurement units, which are being designed to be small and light to fit on a dog pack. Damage to the Fukushima Daiichi Nuclear Power Plant in the 2011 earthquake triggered significant robot research due to radiation preventing humans from carrying out direct cleanup activities. One of the biggest challenges has been determining what happened to the fuel inside the core of the reactor. Various robots were used to penetrate the core, but without success. Finally, in 2017, a small robot designed to operate underwater with severe radiation exposure succeeded in locating the missing fuel inside the reactor core. Japanese manufacturer Honda is developing a disaster response robot that can walk, scale obstacles and climb ladders. If the prototype reaches fruition, it could have a major impact for rescue operations and clearing hazardous materials.

(e) Following the flooding of the Liboriana River, which triggered a devastating landslide in May 2015, causing more than 80 deaths, the Government of Colombia's National Unit for Disaster Risk Management took steps to mitigate future occurrences. It hired a company to implement an early warning system using IoT technology. Five solar powered sensors were installed along the Liboriana and two other rivers to monitor water levels and air temperature using ultrasound. The use of solar ensures the sensors continue to function in the event of an electricity outage. The system automatically sends a text message to village authorities if a risk is detected, and data are also stored in the cloud for others to access.

The volume of seismic data has increased dramatically, providing fuel for solutions to detect and locate earthquakes. Scientists have based detection on continuous seismic records, searching for repeating signals that provide information on upcoming earthquakes. Analysing many years of earthquake waveforms requires considerable computing power. A new approach uses AI to reduce waveform analysis processing. Based on convolutional neural network computer learning, the software is trained to analyse large waveform data sets, and distinguish between noise and true earthquake signals, while preserving location information. Compared with other methods, the convolutional neural network method is faster and retains location information with a high degree of accuracy.

These examples illustrate how disruptive technologies today are refining processes by spreading critical information more quickly, improving understanding of the causes of disasters, enhancing early warning systems, assessing damage quickly and adding to the knowledge base of the social behaviours and economic impacts after a crisis strikes.

Application of disruptive technologies to disaster management vary in pace, scope and impact. Social media platforms such as Facebook and Twitter have been applied in a number of events, and aerial drones and IoT are increasing in use as experience is gained and costs fall. Older technologies such as satellite imagery and seismometers are still the most important methods for detecting, monitoring and accessing disasters, and text messaging has the widest reach for communicating with the public. Big data, robots and AI remain largely experimental, and large-scale impacts will require more time and investments in skills and research.

Several recommendations have been identified that governments, relief agencies, the private sector and assistance agencies can take to maximize benefits offered by disruptive technologies:

(a) **Systemization and standardization** are needed to improve the application of technology interventions. Open standards will help to lower costs, ensure interoperability and enhance scaling. The standardization should also extend to the use of Big Data, which is currently often shrouded in opaqueness. Clear and transparent sharing protocols should be implemented, including application programming interfaces. For social media, standardized hashtags should be employed to reduce confusion among the public and magnify impacts.

(b) **Reach** of digital technologies must be factored into disaster management strategies. In respect to communications among stakeholders, this includes considering the purpose and audience. While Twitter has proven useful in crisis situations, particularly among the relief community, its penetration is relatively low among the general public. It should also be considered that some people may not want to use proprietary platforms for a number of reasons, and therefore relying on only one method may not reach all intended recipients.

(c) A **global repository** featuring information on how digital technologies are being applied for disaster management would raise awareness and understanding. Hundreds of applications of disruptive technology are underway around the world, but experiences are often buried in news articles and research reports. An information base would be useful for identifying digital interventions that have worked, who the implementers were, and other material to increase understanding about which technologies are relevant for different country circumstances and types of disasters.

(d) **Partnerships** with the private sector and academia will be critical for understanding and applying digital technologies for disaster prediction, detection, response and relief. Numerous uses of disruptive technologies are being developed by the private sector. In addition, the private sector controls significant amounts of personal information in Big Data sets, which are of immense use for the disaster community. Similarly, considerable relevant research is being undertaken by the academic community.

(e) **Scaling** disruptive technologies for crisis is essential to have widespread impact and lower deployment costs. To date, many interventions are still pilots or carried out in an ad hoc informal manner. Processes should exist to identify relevant use cases and scale them. Given the vast potential of disruptive technologies for disaster management under a huge variety of different circumstances, there is a need to nurture innovation. This is particularly relevant given the wide country contexts around the world, different types of disasters and crisis phases. Examples from the start-up world are relevant where incubators, labs, competitions, and venture capital are used to discover, mentor and scale up promising innovations.

(f) **Training** is indispensable for the disaster community to understand how to properly and responsibly deploy new and emerging digital technologies in crisis settings. Manuals are needed for different technologies. For example, in the case of social media, this would cover hashtag guidelines, usage by public and relief organizations, coping with fake information, etc. Exchanges should be arranged for disaster management personnel to gain experience using new tools.

(g) **Legal ramifications** of technological research and interventions for disasters need to be understood. This is fairly straightforward in respect to specific regulations, such as registration and regulation of drones, but more nebulous regarding data protection and privacy. One relevant dilemma is whether the lack of data protection and privacy laws inhibits or encourages technologies that make heavy use of personal information. Further, while Big Data may eventually be forthcoming, in the event of a disaster it is needed immediately, so it is essential to have data access and sharing protocols in place beforehand. The disaster community has developed codes of conduct in certain areas that can help when laws are vague.

(h) **Adequate capacity** remains fundamental for properly planning and deploying relevant digital technologies. While digital technologies show great promise for all phases of disasters, on the ground, planning, management and operations are critical to their success. Disaster agencies do not need to be experts in digital technologies, but they do need to understand enough about them to develop proactive blueprints for deploying them. Disaster agencies might also consider creating a chief technologist post to better understand how to apply disruptive technologies.

Table of Contents

List of Tables, Figures and Boxes

Tables

Figures

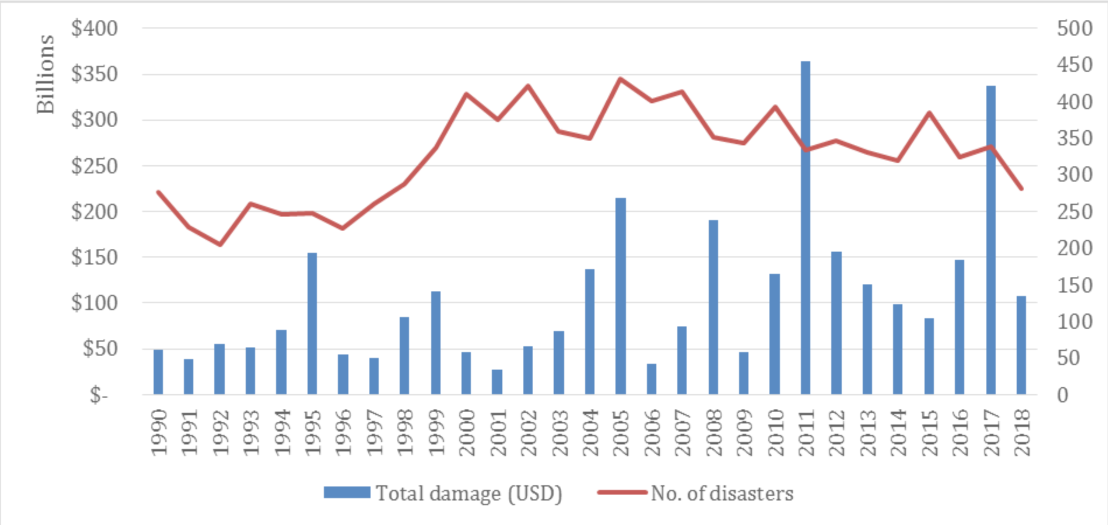
Boxes

1 Background

Technological advancements and innovation create new possibilities for supporting disaster resiliency and risk reduction actions. Developments in the area of AI, IoT, and fifth generation (5G) wireless network, Big Data, and innovations in such areas as robotics and drone technology are transforming many fields, including disaster risk reduction and management. IoT, Big Data and AI are key drivers behind the ongoing digital transformation, and will play an increasingly important role in all phases of disaster management and resiliency development. Examples include the use of AI to analyse seismometer data to make detection models about earthquakes, and the use of Big Data to identify communication patterns during disasters, through the analysis of social media.

Disasters have devastating effects on people's lives, as well as significant economic impact. From 2007 to 2017, the yearly average of the impact was 354 disasters, 68 000 deaths, 210 million people affected and USD 153 billion in damages (Centre for Research on the Epidemiology of Disasters (CRED), 2018). In 2017 alone, 122 countries were affected by disasters. There has been a marked increase reported in the cost of damage caused by disasters in the ten years up to the year 2000, in addition to a sustained increase in both the number and cost of disasters from 2000 to 2018 (Figure 1.1).

Figure 1.1: Annual disasters and economic impact



Source: EM-DAT: The Emergency Events Database – Université catholique de Louvain (UCL) – CRED, – www.emdat.be, Brussels, Belgium.

The 2030 Agenda for Sustainable Development has helped raise awareness of the importance of disaster and emergency management: of the 17 Sustainable Development Goals established by the United Nations, four of them (Goals 1, 2, 11 and 13) refer to the need of nations and communities to address the challenges related to natural hazards and disasters.

Member States have provided ITU with a clear mandate to ensure that all countries are able to take advantage of the opportunities brought by information and communication technologies (ICTs), including new technologies to address the challenges of disasters. The 2017 World Telecommunication Development Conference reiterated the need for ITU to identify relevant technologies and facilitate the sharing of best practices and applications, to allow countries to benefit from ICTs for disaster risk reduction and management.[1]

[1] ITU Resolution 34 (Rev. Buenos Aires, 2017). The role of telecommunications/information and communication technology in disaster preparedness, early warning, rescue, mitigation, relief and response. Available from www.itu.int/en/ITU-D/Conferences/WTDC/WTDC17/Documents/WTDC17_FinalReport_en.pdf (accessed 2 February 2019).

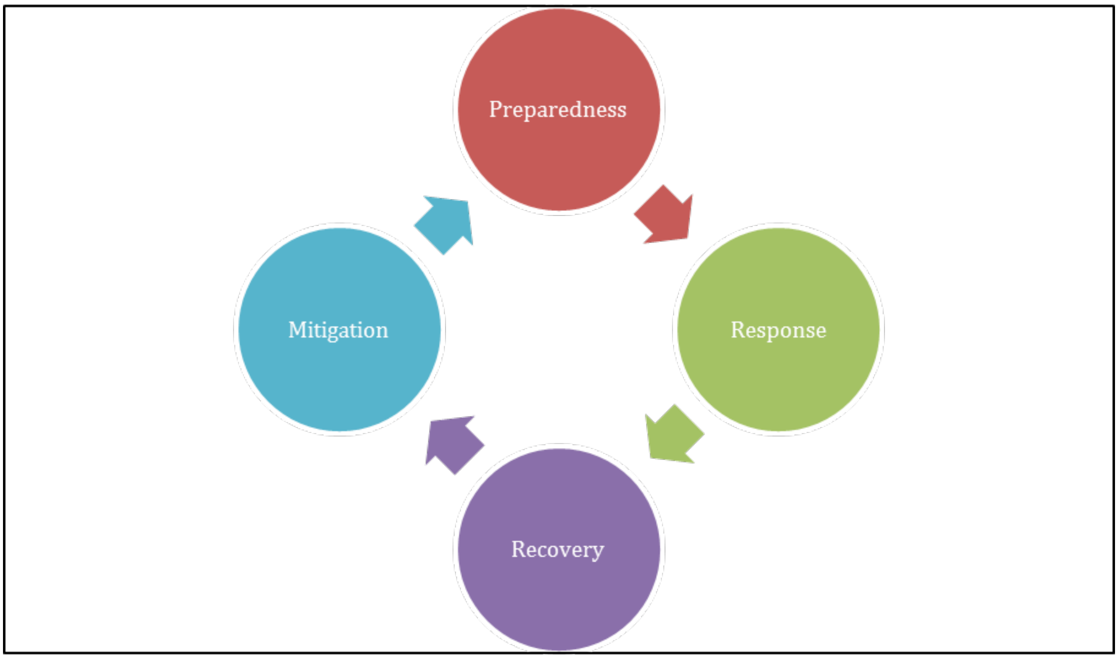
ITU has been dealing with the issue of emerging and disruptive technologies while designing and implementing projects and organizing events, including the annual AI for Good Global Summit.[2] The ITU Telecommunication Development Sector (ITU-D) Study Group 2 has a Question on the topic (Utilization of telecommunications/ICTs for disaster preparedness, mitigation and response) and ITU works in this area through its ITU-D programme on emergency telecommunications.

Introduction, scope, and purpose

This document discusses the use and opportunities of ICTs and disruptive technologies for disaster risk reduction and management. When the term disruptive technology was introduced more than two decades ago, it referred to new technologies having an impact on incumbent businesses with scope for major disruption (Christensen et al., 2015). Today, the term has taken on a wider lens by including the innovative application of new technologies across a range of domains, including disaster risk reduction and management.

The document looks at examples of the application of emerging technologies and their current and potential impact for managing and reducing the impact of disasters. The document covers emerging technologies and addresses existing and new solutions for disaster risk reduction and emergency management, and informed decision-making linked to the four phases of disaster management (Figure 1.2).

Figure 1.2: Disaster management phases



Source : ITU

The focus of this document is on disaster management in the case of natural hazards (geophysical, hydrological, meteorological and climatological) (Figure 1.3). It is intended to serve as a reference for ITU Members, the humanitarian community and others on the use and implementation of such solutions. It also seeks to contribute to raising awareness in terms of opportunities and challenges associated with the deployment and use of such technologies. The examples and case studies cover different regions, including both developed and developing countries, and different hazards.

[2] See https://aiforgood.itu.int/ accessed 2 February 2019).

Figure 1.3: Natural disaster subgroup

Source: CRED, Institute of Health and Society, and Université catholique de Louvain, 2016.

Some of the issues covered by the document include the complexity of digital innovations and their use in the context of disaster risk reduction and management in terms of impact, costs, policy and regulation, and skills. It also identifies different stakeholders involved in the use of the technologies.

2 Disruptive technologies for disaster risk reduction and management

This chapter offers an overview of disruptive technologies for disaster risk reduction and management. It identifies and defines key technologies, including references to research and projects.

The rapid spread of digital infrastructure and devices has created immense potential for the use of disruptive technologies for disaster management. Mobile broadband technologies are being rapidly extended, with an estimated 90 per cent of the world's population covered by at least a 3G signal by the end of 2018. Smartphones are proliferating; they can capture the geographic location of the user to help locate people affected by disasters. Furthermore, smartphones enable users to communicate in a richer way than basic mobile devices do, and use applications such as social media to rapidly exchange information during a crisis. Cloud computing enables storage of data generated by different sources and sharing among different groups (e.g. users, governments and NGOs). The monitoring sensors capture a variety of information, whether worn by users or embedded in the ground, providing real-time data streams and forming the basis of the Internet of Things (IoT). The spread and availability of these technologies vary among developed and developing nations and among high- and low-income regions, and this digital divide influences their suitability for different disaster management scenarios. Availability of the latest versions of technologies affects functionality and applicability. For example, 5G wireless networks are viewed as a key enabler of IoT,[3] but their deployment will initially occur in urban areas and predominantly in developed countries.

Classification of disruptive technologies varies. Some are universal and primarily concerned with the flow and analysis of communicating information generated by citizens, governments and sensors before, during and after a crisis (e.g. social media and Big Data). Others, such as drones and robots, are hardware aimed at specific interventions (though they also transmit essential data for analysis). Other digital technologies, while not necessarily considered disruptive, are critical, since they are

[3] See Ericsson, 5G and IoT: Ushering in a new era, available from www.ericsson.com/en/about-us/india/authored-articles/5g-and-iot-ushering-in-a-new-era (accessed 3 February 2019).

widely deployed and available, and arguably currently still have a greater impact (e.g. text messages and satellite images). Some technologies can be integrated with others to magnify the impact. That sometimes makes it difficult to clearly delineate them: for instance, AI is used in Big Data analytics as well as robotics (which sometimes includes the category of drones).

Box 2.1: 5G and disruptive technologies

The 5G wireless technology is viewed as a key enabler of several disruptive technologies applicable for disaster situations. IoT sensors generate vast amounts of data that need to be communicated rapidly. Drones are more effective if high definition images can be transmitted in real time, instead of having to wait until they return to their base. The 5G technology has higher capacity, is faster and has lower latency compared with previous generations, and thus can support disruptive technologies reaching their full functionality.

In early 2012, ITU embarked on a programme to develop IMT (International Mobile Telecommunication) for 2020 and beyond, setting the stage for 5G research activities that are emerging around the world. In September 2015, ITU finalized its vision of the 5G mobile broadband-connected society. This view of the horizon for the future of mobile technology will be instrumental in setting the agenda for the World Radiocommunication Conference 2019, where deliberations on additional spectrum for 5G are taking place. The whole process is planned to be completed in 2020, when detailed specifications for the new radio interfaces, based on input from the 3rd Generation Partnership Project (3GPP) and other stakeholders, will be submitted for approval within ITU. Meanwhile, other ITU standardization activities are addressing 5G enabling technologies, including extremely high-capacity optical networks that form the backbone of 5G (virtual networks, network function virtualization and network slicing), as well as strategies to assist machine learning in contributing to the efficiency of emerging 5G systems.

According to the Global Mobile Suppliers Association, almost a dozen countries had deployed 5G by January 2019, and operators in around 50 countries have announced plans to launch 5G before the end of 2022.

2.1 Mobile phones

As mobile phones have evolved in functionality, their impact for disaster relief has grown. From voice calls to text messages – and now location-based services, cameras and Internet access – mobile phones have a diverse set of features being leveraged by the public and disaster community in times of crisis. The wide spread of mobile phones – often with a higher penetration than television or radio in developing nations – today makes them the most universal communication device in the world.

Simple voice calls put the public in touch with friends, family and relief workers during times of crisis, with immeasurable lifesaving impacts. However, voice transmission lines are often overloaded during disasters. In this case, SMS (Short Message Service) text messaging, is more effective, since it uses a control rather than a voice channel for transmission. Text messages are asynchronous so, unlike a phone call, they are temporarily stored while waiting to be delivered.

SMS messages of up to 160 alphanumeric characters can be sent from one person to another or broadcast to a group of targeted recipients (i.e. Cell Broadcast[4]). Unlike other message-like applications, which require a computer or smartphone and Internet access, text messaging is a standard feature on all mobile phones, and thus its reach is immense. According to a 2016 study of mobile

[4] Available from www.cellbroadcastforum.org/whatisCB/index.html (accessed 3 February 2019).

phone users in 31 countries, 74 per cent used text messaging, the most popular mobile phone activity after making phone calls.[5]

SMS provides information quickly to those touched by disasters. Several studies have examined the impact of text messaging during disasters. Meier and Munro (2010) discuss the use of SMS following the major earthquake that struck Haiti in January 2010, destroying the capital Port-au-Prince. A short SMS code – 4636 – was created for people to text their locations, with volunteers using the information to create a live crisis map to support relief assistance. As the first widespread use of text messaging, invaluable lessons were learned, such as making the service 'opt-in', targeting messages to specific geographies and groups, setting up SMS platforms prior to the disaster, and minimizing use of short codes. These lessons have been codified in an SMS Code of Conduct for natural disasters (GSMA, 2013).

The advent of smartphones has created new opportunities for the public (i.e. crowd) to assist – knowingly or unknowingly – in helping to respond to disasters. Four roles have been identified (Poblet et al., 2014) (Figure 2.1):

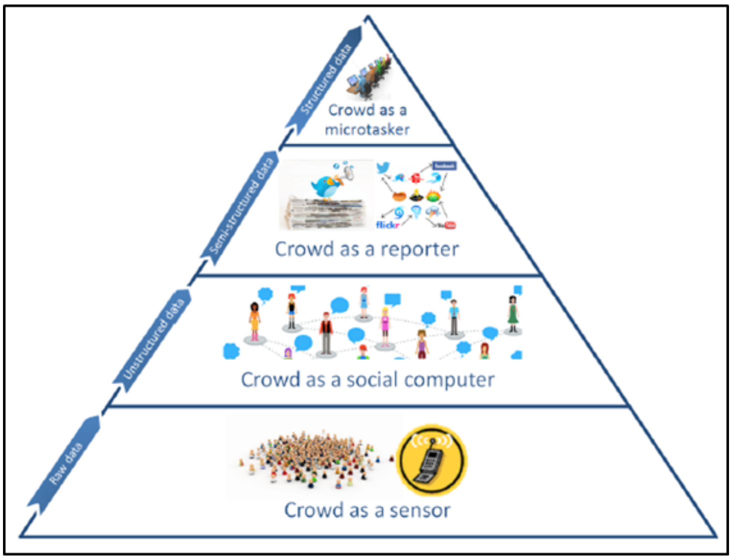
(a) Crowd as sensors: Mobile phones are continuously generating data from their internal sensors, including GPS, accelerometers, gyroscopes and magnetometers. The data are collected (opportunistic crowdsourcing) with little, if any, data processing by the user.

(b) Crowd as social computers: Users generate data by using apps such as those for social media. These data are collected by platforms (Big Data). Like the crowd as sensor, there is no direct effort to share the data by the user.

(c) Crowd as reporters: Users offer their own information on events (e.g. taking a photo of damage, tweeting about weather conditions, etc.). This user-generated content can include supplementary information (e.g. hashtags).

(d) Crowd as microtaskers: Users create content such as adding roads or buildings to satellite images. Here, users are active participants and often have specific skills.

Figure 2.1: Crowdsourcing roles based on user involvement and level of data processing



Source: Poblet et al. 2014.

[5] Deloitte. 2016. *Global mobile consumer trends*. https://www2.deloitte.com/content/dam/Deloitte/global/Documents/Technology-Media-Telecommunications/gx-deloitte-tmt-global-mobile-consumer-trends-report-first-edition.pdf

2.2 Drones

This section describes the use of drones, which are often referred to as vehicles that do not have a human occupant, and when drones operate without human intervention, they are sometimes classified as robots.

2.2.1 Air

Unmanned air vehicles (UAVs) were initially developed for military use. They have since made their way into other uses, such as aerial photography and package delivery. UAVs are attractive, since they can fly places manned aircraft cannot. They can also fly at low altitudes, overcoming lack of visibility when there is cloud cover, and thus images from drones are higher resolution than satellite. The first documented use of drones was after Hurricane Katrina in the United States of America in 2005 (Meier, 2015). Because roads were blocked by trees, small drones were deployed to search for survivors and assess river levels.

Examples of UAV use for different disaster phases include:

(a) Preparedness such as filming volcanic activity in order to determine when warnings should be issued (Husain, 2018).

(b) Response such as delivering equipment to locations where networks have been affected by a disaster: For example, China has been using drones to deliver mobile gear to affected areas as well as a virtual tower functioning as a base station (China Telecommunications Corporation, 2018). Drones are already used to deliver blood in several countries, and this could be expanded to include other medical supplies and equipment needed during a disaster (Smyth, 2017). Another example is the use of drones to assist Australian firefighters at night. A Lockheed Martin Indago drone (Figure 2.2) streamed live video to operators on the ground, who used the images to determine fire location and intensity, and find people and property that were at risk. The drone helped save an estimated 100 homes, worth more than USD 50 million.[6]

(c) Assisting with recovery efforts by photographing disaster areas for damage assessments (section 3.1).

(d) The Pacific Drone Imagery Dashboard uses data from satellites and now drones for creating maps for disaster preparedness, response and recovery.[7]

In order to facilitate the use of drones for crisis, the United Nations International Children's Emergency Fund (UNICEF) collaborated with the Government of Malawi to create a drone corridor, allowing the private sector, academia and others to experiment with UAVs.

[6] See Firefighting Case Study, available from www.lockheedmartin.com/en-us/products/procerus-technologies/indago-unmanned-aerial-system/indago-firefighting-case-study.html (accessed 3 February 2019).

[7] See UAV Imagery For Disaster Response: Pacific Drone Imagery Dashboard (PACDID), available from www.hotosm.org/projects/uav-imagery-for-disaster-response-pacific-drone-imagery-dashboard-pacdid/ (accessed 3 February 2019).

Figure 2.2: Indago UAV

Source: Lockheed Martin, available from www.lockheedmartin.com/en-us/products/procerus-technologies/indago-unmanned-aerial-system.html (accessed 4 February 2019).

2.2.2 Underwater

Unmanned underwater vehicles (UUV) measure storm intensity and direction. One key difference between UUVs and airborne drones is that GPS does not work underwater, so UUVs are tethered, limiting their range (Meier, 2018b).

Six-foot long underwater drones are an example of UUV use (Figure 2.3)[8] that carry sensors to measure ocean heat, salinity and density (Niiler, 2018). They were used during Hurricane Florence in the United States of America in 2018. Sensors measured the ocean heat fuelling the hurricane, transmitting the data to the National Weather Service. The data fill in gaps left by satellite images, thus improving hurricane modelling. The data also enhance forecasting the intensity and route of the hurricane, and the sensors measure salinity levels, to determine how much water from rain and rivers is mixing into the ocean.

[8] Recent figures are not available, but in 2013 the glider cost USD 125 000–150 000, depending on the configuration. In comparison, a research vessel cost USD 35 000–100 000 per day. See Herkewitz (2013).

Figure 2.3: Slocum glider UUV

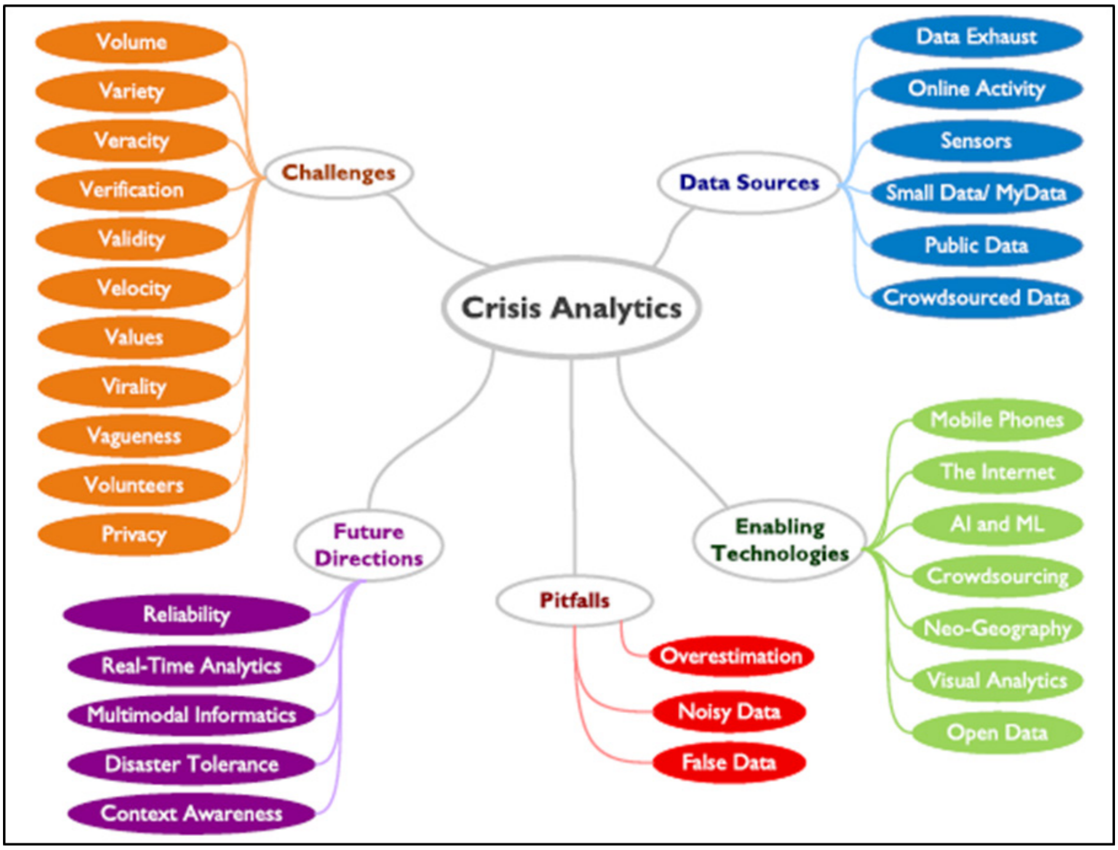
Source: Teledyne Marine, available from www.teledynemarine.com/slocum-glider (accessed 4 February 2019).

2.3 Big Data

Growing digitalization is creating an avalanche of data generated by sensors, closed circuit television, mobile phones, financial transactions and Internet activities, to name just a few. While the huge amount of data being generated is being mined by businesses for commercial purposes, Big Data analytics also hold enormous potential for disaster management. Examples include the analysis of social media communications during a disaster to understand the types of information and content creators, in order to have more impact and reduce false information. Another example is the use of financial transactions to monitor economic activity during and after a disaster, in order to improve targeting of support efforts (section 3.3). Cellphone data have been used to monitor the movement of the population during flooding (Telefónica, 2016). Big Data analytics are also used for analysing information generated by sensors in IoT implementations as well as data from drones and robots. Several disaster management-related projects have been deployed as part of the United Nations Big Data for Development initiative (Box 2.2).

Big Data and crisis analytics is a term used to refer to the analysis of large data sets for disasters. Due to advances in ICT and processing of large data sets, the ability to respond to disasters is at an inflection point (Qadir et al., 2016). Big data tools can today process large amounts of crisis-related data (e.g. user-generated, sensors) to support more effective disaster response. The role of Big Data and crisis analytics in different disaster phases and a detailed perspective of crisis data sources and technologies, challenges and pitfalls, as well as directions for future research, have been assembled in a framework consisting of five nodes relevant to data scientists working in the disaster area (Figure 2.4). *Data sources* identifies the various generators of information, such as online activity, sensors and so-called data exhaust (data triggered by users, through the use of cookies). *Enabling technologies* refers to software and hardware that enable capture, and process and analyse the data, including AI and machine learning. *Pitfalls* are the dangers of shortcomings in the data, such as false information or non-representativeness. There are numerous *challenges* posed by the data, ranging from managing the sheer volume to the rapid speed at which they are transmitted. Finally, *future directions* indicate where more research is needed, such as analysis of data in real time and how to protect the crisis analytics systems when deployed in an actual disaster.

Figure 2.4: Taxonomy of Big Data and crisis analytics



Source: Qadir et al., 2016.

One of the challenges of using Big Data is where to get it from. Mobile call data records can be a rich resource for tracking population movements during a crisis (*The Economist*, 2014). But call data records are held by mobile operators, who may not always be willing to share the data. This applies equally to data generated by social media, search engines and other platforms where the owner of the app considers it their data, and often have no formal sharing arrangement or only provide access to a limited subset. The mobile phone industry association GSMA is working to make some of the data collected by its members available through an IoT Big Data Ecosystem.[9] The United Nations Office for the Coordination of Humanitarian Affairs (OCHA) launched the Humanitarian Data Exchange, which has a portal featuring around 8 000 standardized data sets from over 1 000 sources, including several related to disasters.[10]

[9] See IoT Big Data, available from www.gsma.com/iot/iot-big-data/ (accessed 4 February 2019).

[10] Available from https://data.humdata.org (accessed 4 February 2019).

Box 2.2: United Nations Global Pulse: Big Data and Disaster Management initiatives and tools

Global Pulse is an initiative of the United Nations Secretary-General to investigate the role of Big Data for development. It has carried out several investigations related to disaster management and developed various initiatives.

Crowdsourcing taxonomies to assist disaster management efforts: Communication is a critical element in disaster management. A way to better listen to – and understand – what people say in social media is to use data analytics to extract information relevant to priority topics, the first step of which is to create taxonomies, or sets of keywords. However, building a detailed taxonomy in different languages – including local dialects, jargon and alphabets – can be labour-intensive and time-consuming. Language often represents a moving target, with trends and changes quickly altering the nature of relevant keywords and phrases. When such taxonomies are being used to seek information on time-critical issues such as disaster management, it is essential that they are constantly and accurately updated.

In an attempt to address this challenge, Pulse Lab Jakarta launched Translator Gator in 2016, a language game the Lab developed to create text mining dictionaries for recognizing sustainable development-related conversations in Indonesia. In 2017, the Lab released Translator Gator 2 to test whether crowdsourcing can be used to inform disaster management efforts. The aim of the project is to engage the 'wisdom of the crowd' to create taxonomies for disaster management for ten Association of South-East Asian Nations (ASEAN) countries and for Sri Lanka. The expected outcomes of the project are to (a) translate disaster keywords in multiple languages that can ultimately be used for computational research initiatives; (b) use social media to understand the behaviours of affected population before/during/after a disaster, and to improve communication with these communities; and (c) raise disaster-preparedness awareness in multiple countries.

Haze Gazer: A crisis analysis tool: Forest and peatland fires, which occur on an annual basis in Indonesia, affect the entire South-east Asia region, resulting in extensive environmental destruction and threatening livelihoods. To better support affected populations, the Government of Indonesia is looking for more timely and effective means of tracking and managing the impact of fire and haze events. In response, Pulse Lab Jakarta developed Haze Gazer, a crisis analysis and visualization tool that provides real-time situational information from various data sources to enhance disaster management efforts. The prototype enhances disaster management efforts by providing real-time insights on (a) the locations of fire and haze hotspots; (b) the strength of haze in population centres; (c) the locations of the most vulnerable cohorts of the population; and, most importantly, (d) the response strategies of affected populations, including movement patterns and in-situ behavioural changes.

Haze Gazer uses advanced data analytics and data science to mine open data, such as fire hotspot information from satellites and baseline information on population density and distribution, as well as citizen-generated data, including the national complaint system in Indonesia called LAPOR!, citizen journalism video uploads to an online news channel, and real-time Big Data such as text-, image- and video-oriented social media.

The tool is currently being tested and improved based on feedback from disaster management practitioners. Haze Gazer has the potential to enable Indonesia's local (BPBD) and national (BNPB) disaster management authorities to target their interventions and to align their efforts with those of affected populations to increase community resilience.

Monitoring social response before and after disasters with data analytics: Building on the Haze Gazer platform, CycloMon is an analytics and visualization platform developed to assist governments in supporting communities to prepare for and respond to the impact of tropical cyclones. The platform was developed to monitor social response before, during and after cyclones across 14 countries in the Pacific region. CycloMon's basic function is to collect, analyse and visualize information from weather satellites on the path of a cyclone, as well as insights from social media on the preparations and impact of the cyclone on communities. The platform contains three modes to help cyclone monitoring: (a) Normal Mode: to monitor citizens' preparedness to cyclones across 14 countries in the Pacific region; (b) Emergency Mode: to present social media signals from a country affected by a cyclone, along with information on the cyclone itself; and (c) Country-Specific Mode: to provide more detailed historical insights on disaster preparedness and impact from text-, image- and video-based feeds.

Using mobile phone activity for disaster management during floods: In this study, mobile phone activity data were combined with remote sensing data to understand how people communicated during severe flooding in the Mexican State of Tabasco in 2009, in order to explore ways that mobile data could be used to improve disaster response. The results of the study showed that the patterns of mobile phone activity in affected locations during and after the floods could be used as indicators of (a) flooding impact on infrastructure and population, and (b) public awareness of the disaster. These early results demonstrated the value of a public–private partnership in using mobile data to accurately indicate flooding impacts in Tabasco, thus improving early warning and crisis management.

Source: United Nations Global Pulse (https://www.unglobalpulse.org/projects).

2.4 Internet of Things

The use of sensors for monitoring the conditions that could trigger disasters is not new. Developments in cloud computing, broadband wireless networks, the sensors themselves and data analysis have led to the emergence of powerful, integrated and real-time systems referred to as the Internet of Things (IoT). Disaster management is an ideal case for IoT applications, since sensors can send alerts about a number of potentially dangerous situations. Tree sensors can detect if a fire has broken out by testing temperature, moisture and carbon dioxide levels. Ground sensors can detect earth movements that might signal earthquakes. River levels can be monitored by sensors for possible flooding (section 3.5).

One approach to IoT is the integration of sensor data with a range of other information for a multi-faceted understanding of and response to disasters. After serious landslides in April 2010 that killed more than 50 people in Rio de Janeiro, Brazil, and left thousands homeless, a City Hall Operations Centre was built in collaboration with IBM (Centre for Public Impact, 2016). The centre operates non-stop monitoring of various data streams generated in the city, such as security cameras, rain gauges, traffic signal data, the electricity grid, traffic controls, GPS-equipped public transit vehicles and social media feeds. IBM weather forecasting software uses the data and can predict emergencies up to two days in advance.[11] Social media, radio and television broadcasts and text messaging are used to inform the public when an emergency occurs, and sirens are used in high-risk areas, alerting people to evacuate.

[11] IOT In Disaster Management: Saving Lives With Early Warning, available from https://10innovations.alumniportal.com/internet-of-things/iot-in-disaster-management-saving-lives-with-early-warning.html (accessed 4 February 2019).

2.5 Artificial intelligence

Software algorithms are increasingly generating valuable insights about a variety of phenomena. This allows computers to imitate human intelligence, hence the term artificial intelligence (AI). Examples of AI are already operational, such as voice and facial recognition, and commercialized by products such as the IBM Watson computer system, which integrates AI into the analysis of Big Data (Box 2.3).[12] Watson has been applied to disaster scenarios by having it analyse weather and census data to help organizations prepare for a crisis and optimally allocate resources (IBM, 2012).

AI could have tremendous impact for disaster management, from potentially predicting earthquakes to quickening recovery and response times. Humanitarian groups are hoping to speed up map creation by using machine learning in computer software to extract objects such as buildings and roads from aerial images.[13] Considerable research effort is currently being devoted to the use of AI for detecting and maybe one day predicting earthquakes (see section 3.6). AI does not need to be costly, as shown in research by the Tanzania Meteorological Agency on weather and climate monitoring (Kikwasi, 2016). The Agency used the PHP programming language to execute equations regarding meteorological observations, with the software refining its calculations to make better predictions. The cloud-based system features a user-friendly web-based interface, and utilizes the free open source MySQL database management software.

Box 2.3: Artificial intelligence and machine learning in emergency situations

Artificial intelligence (AI) and machine learning have advanced to the state where they are highly proficient in making predictions and in identification and classification.

1. **Processing information:** AI is used for image recognition of satellite photos to identify damaged buildings, flooding, impassable roads, etc. Multiple data streams can be combined with unreliable data removed and heat maps generated. For example, DigitalGlobe (https://www.digitalglobe.com) provides open source software for disaster response that learns how to recognize buildings on satellite photos. Following the Nepal earthquakes in 2015, humanitarian and relief groups used pre- and post-disaster imagery and utilized crowdsourced data analysis and machine learning to identify locations affected by the quakes that had not yet been assessed or received aid.
2. **Emergency calls:** During a crisis, call centres are often overwhelmed. In addition to voice calls, emergencies are increasingly reported by text messages and social media. AI and machine learning are being applied to cope with the volume and different types of calls. In the United States of America, Watson, developed by IBM, is being used for speech-to-text recognition at emergency call centres (IBM, 2017). The text is input to analytical software that guides operators on how to respond to the call.
3. **Social media analysis:** Real-time information from Facebook, Twitter, Instagram and YouTube can be analysed and validated by AI to filter and classify information and make predictive analysis. Artificial Intelligence for Disaster Response (AIDR) was created to process the large number of tweets generated during a crisis.[1] AIDR uses machine learning to automatically process tweets in real time. The software collects tweets based on hashtags and keywords, and then uses AI to further classify them by topic. The open software is free for those who work in crisis response.

[1] Available from http://aidr.qcri.org (accessed 4 February 2019).

[12] Available from www.ibm.com/watson/about/index.html (accessed 4 February 2019).

[13] See Integrating Machine Learning into the Tasking Manager: Notes on a Direction, available from www.hotosm.org/updates/integrating-machine-learning-into-the-tasking-manager (accessed 4 February 2019).

4. **Predictive analytics:** AI is being used to analyse past data to predict what is likely to happen in the event of a disaster. Optima Predict software processes information from emergency response systems to optimize ambulance routes (Young, 2017). The data can be integrated with online dashboards so that emergency personnel can respond in real time.

Source: Adapted from Sugandha Lahoti (2018).

2.6 Robots

Although industrial robots have been around for some time, robots have become more sophisticated through integration with microprocessors and sensors. The growing dexterity of robots makes them suitable in disaster situations that are too dangerous for humans or rescue animals. Search-and-rescue robots were reportedly first used following the September 2011 terrorist attack in New York City to assess the wreckage of the demolished World Trade Center (Feuilherade, 2017). Since then, more than 50 deployments of robots for disaster use have been reported.

Breakthroughs are being achieved in Japan, where there is the possibility for commercialization of robots designed specifically for disasters (section 3.4).

2.7 Blockchain

One challenge during a rapidly evolving disaster is coordinating and verifying information among different stakeholders. For example, the United Nations found that, in the wake of the 2010 Haitian earthquake, assistance efforts were hampered by too many data sources among the some 20 relief groups (Rohr, 2017). The Blockchain distributed ledger system and chain of verified records could play a significant role in ameliorating information control.

In the United States of America Centers for Disease Control and Prevention is planning a pilot test of blockchain for a more rapid and reliable collection of data during a crisis, in order to reduce the spread of disease (Orcutt, 2017). This has relevance for disaster management, since similar to public health, agencies offering relief (e.g. government, assistance agencies, telecom operators, food suppliers, transporters, health workers and the public) need to share trusted data quickly to collaborate effectively (IBM Academy of Technology, 2018).

Another way blockchain technology is already indirectly used for disaster relief is for fundraising activities that accept cryptocurrencies (Harmes, 2018). Several organizations – including Direct Relief, Humanity Road and Save the Children – currently accept cryptocurrencies such as Bitcoin in their fundraising activities.

2.8 Social media

2.8.1 Twitter

Twitter is a messaging service where users can post 140 character[14] messages or tweets. Users must register for the service and, in the case of smartphones, download an app. Unlike text messages, registered users can follow other users' tweets. So-called 'cards' can be included with links to photos, videos and other media that get around the character limit. Another feature of Twitter is that hashtags

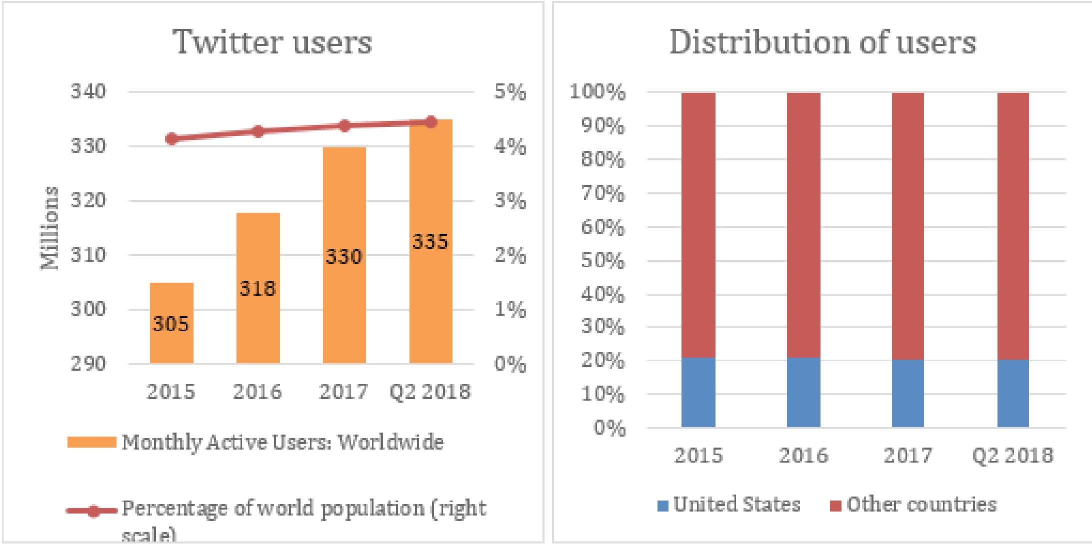
[14] As of November 2017, Twitter has increased the character count of Tweets in certain languages to make it easier to share what is happening.

can be added using # to quickly receive or find tweets on a specific topic. For example, the keyword #hurricane locates all tweets containing the keyword hurricane. The drawback is that multiple hashtags can be created by different organizations during a disaster, making it difficult to know which one to use.

Twitter Lite is a stripped-down version of the application that is useful for many in developing nations who only have access to slower-speed mobile networks (e.g. 2G/3G), which uses less data, thus saving prepaid bundle usage. It is available for Android smartphones in more than 45 countries (Shah, 2018).

Usage of Twitter is not as high as other communication technologies, and recent growth has been somewhat stagnant. There were 335 million users around the world in June 2018 (Figure 2.5), some 4.4 per cent of the world's population.[15] This limits its suitability for reaching a large number of users during a disaster, particularly given the low penetration of Twitter outside large urban areas in developing nations.

Figure 2.5: Global Twitter users



Source: Twitter.

Twitter has implemented the Alerts feature, aimed at use of the service during disasters.[16] Alerts are sent instantly as either tweets or converted to regular text messages. The Alerts service was launched following the experience of the Lifeline project in Japan,[17] and major public safety organizations in Japan are participating, including the Tokyo Metropolitan Government and Fire Department, and the Osaka Police. Organizations in other countries include the City of Seoul in the Republic of Korea; the Rio de Janeiro Operations Centre in Brazil; and the City of Sydney, the Red Cross, the Department of Health, and fire and police departments from several municipalities in Australia.

Studies (Baek, 2016; Kongthon et al., 2012; Takahashi et al., 2015) have looked at the role of Twitter during disasters, primarily flooding, hurricanes and typhoons. Most of these studies deploy Big Data analysis to examine the type of tweets and what they are used for, rather than their effectiveness during the disaster. Therefore, the goal is primarily to investigate how Twitter is used to improve planning and achieve more effective disaster communications. This includes understanding who are the most influential tweeters (i.e. biggest number of followers or retweets) or categorization of tweets.

[15] See Selected Company Metrics and Financials, available from https://investor.twitterinc.com/static-files/b66a0b83-5dad-4a45-a89f-d7d4034c5287 (accessed 4 February 2019).

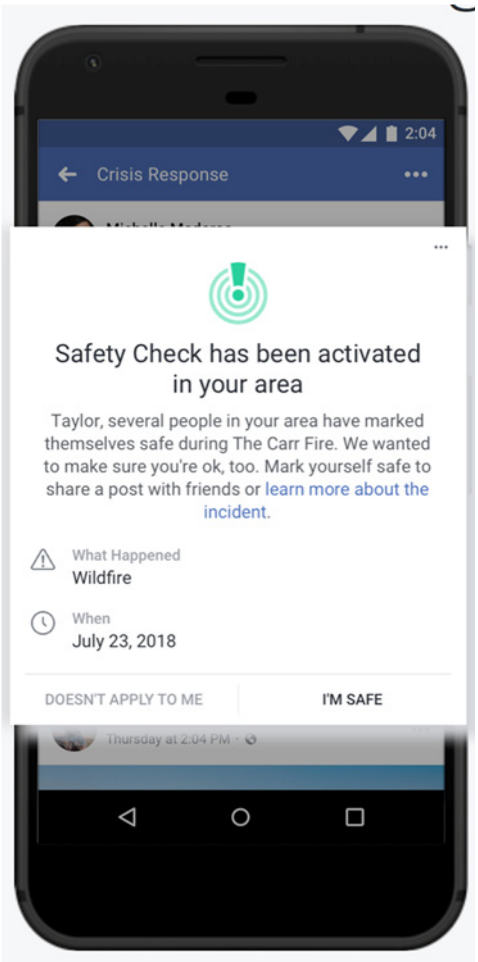
[16] See How to use Twitter Alerts, available from https://help.twitter.com/en/managing-your-account/how-to-use-twitter-alerts (accessed 4 February 2019).

[17] See Twitter Alerts: New countries and features, available from https://blog.twitter.com/official/en_us/a/2013/twitter-alerts-new-countries-and-features.html (accessed 4 February 2019).

2.8.2 Facebook

Like Twitter, Facebook also has features specific to crises. Its Crisis Response app allows users to mark themselves as safe (Safety Check), reassuring friends and family; provide or seek help; donate money; and receive information.[18] Additionally, other features of the application – such as Groups, Pages, Events and Fundraisers – can be useful during a crisis.[19]

Figure 2.6: Facebook Safety Check

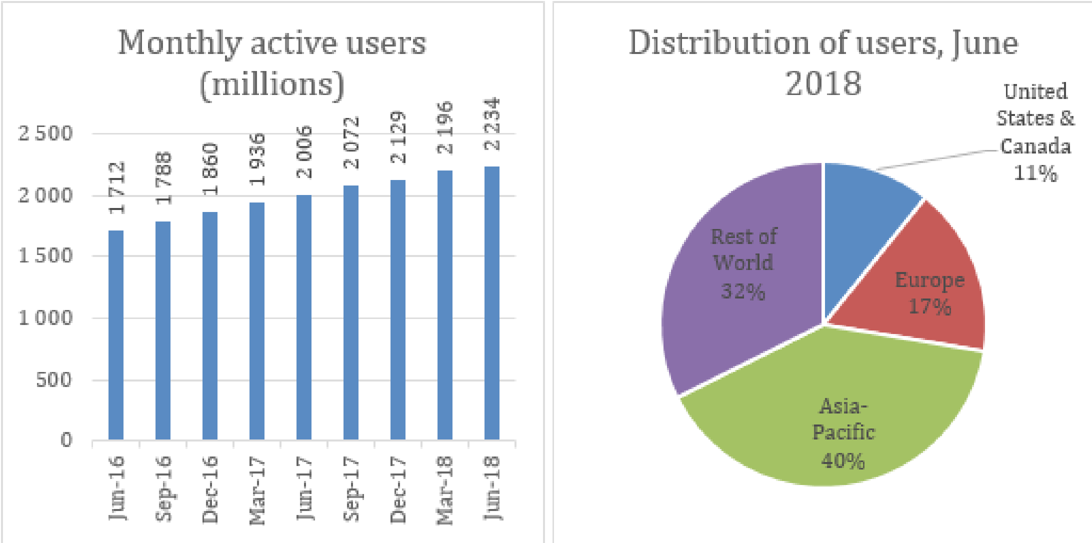


Source: https://www.facebook.com/about/crisisresponse/

Facebook is relevant for disaster relief, given that it is the largest social media platform in the world, with 2.2 billion users in June 2018 (Figure 2.7), equivalent to 30 per cent of the world's population.

18 See www.facebook.com/about/crisisresponse/, (accessed 4 February 2019).
19 See www.facebook.com/disaster/posts/after-hurricane-florence-made-landfall-yesterday-morning-the-facebook-community-/10156736515514936/ (accessed 4 February 2019).

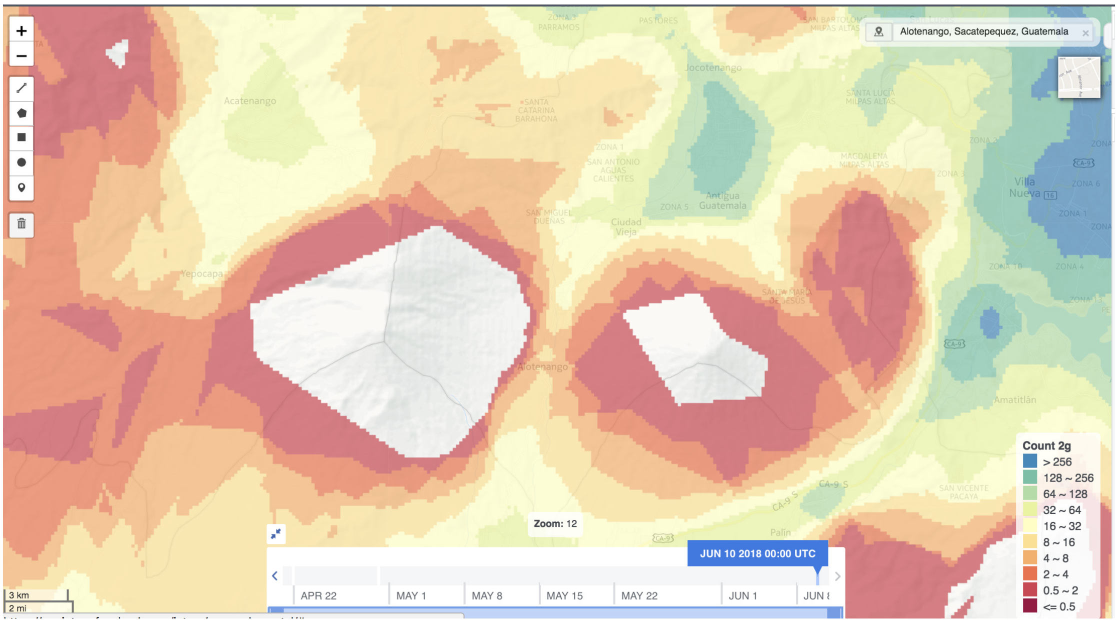
Figure 2.7: Number and distribution of Facebook users



Source: Facebook.

Facebook has a Disaster Maps tool showing where users are located, moving to and whether they are using the Safety Check feature. The Disaster Maps tool has been used by relief organizations to identify where Internet connectivity required restoration in Puerto Rico following Hurricane Maria, and where respiratory masks were needed during the Southern California Wildfires (Maas et al., 2018). The maps are particularly useful for examining mobile cellular network coverage, cellphone battery charging and population movement during a disaster. For example, the maps were used to show 2G network coverage after a volcanic eruption in Alotenango, Guatemala (Figure 2.8).

Figure 2.8: 2G network coverage following volcanic eruption in Guatemala



Note: The map depicts big drops in cellphone use (red and orange areas) and complete blank spots reflecting a sharp drop in network use in the areas surrounding the site of the eruption.
Source: Facebook (https://research.fb.com/new-data-tools-for-relief-organizations-network-coverage-power-and-displacement/).

One challenge is that the maps are reflective of people who use the app and have location services turned on. People who do not use Facebook are not included. Facebook will work with UNICEF, the

World Food Programme and the Red Cross to find solutions for adjusting the data to be more representative.[20]

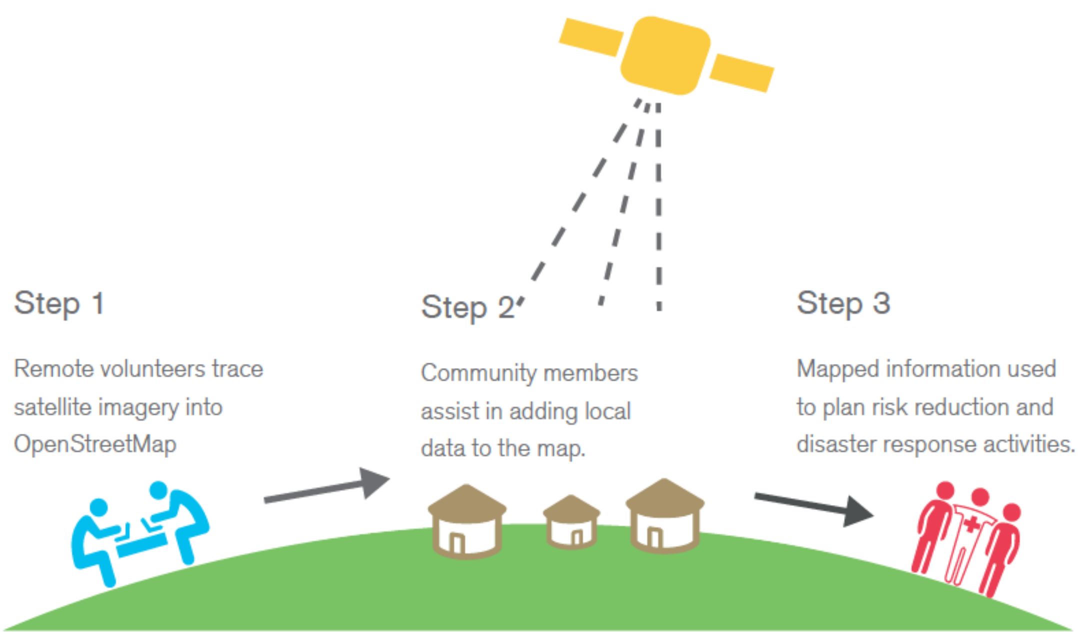
2.9 Crowdsourcing and crowdfunding

The public is increasingly using digital technologies to support disaster management. This includes crowdsourcing (e.g. adding content to disaster maps) and crowdfunding (raising money for disaster victims using text messaging and crowdfunding platforms).

Crowdsourcing is used to add vital details to maps of disaster areas. This enhances satellite imagery by providing greater granularity, making relief efforts more effective and targeted. It is also quicker and cheaper, especially since the crowd often does this on a volunteer basis compared with traditional methods (Becker and Bendett, 2015).

Missing Maps is a project launched in 2014 and spearheaded by the American Red Cross, the British Red Cross, Médecins Sans Frontières–UK, and the Humanitarian OpenStreetMap Team (American Red Cross, 2015). It uses volunteers to add information to maps in order to better serve those affected by a crisis and get assistance to them more rapidly. In the first stage, volunteers edit satellite imagery to add details (Figure 2.9). More than 2 500 people have provided assistance, making 3.7 million edits and locating 4.5 million people on the map. The next stage involves working with local communities to add details about roads and buildings. The last stage includes data validation and inputting project-specific information to generate maps for different disaster programmes.

Figure 2.9: Putting communities on a map



Source: American Red Cross (2015).

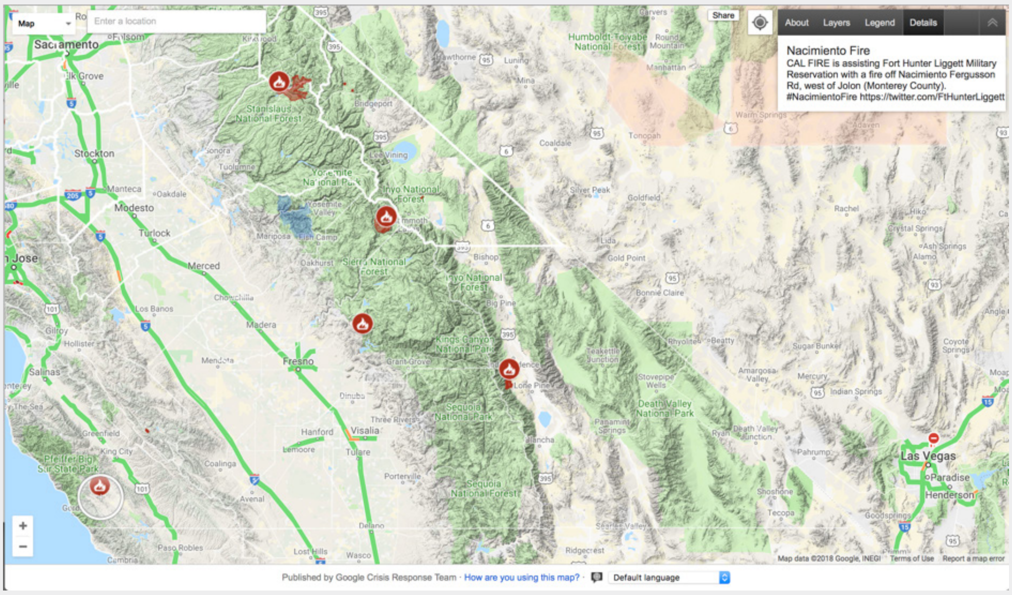
Digital technologies provide another way of raising donations for disaster relief victims. More than USD 40 million was contributed via text messaging following the Haiti earthquake disaster in 2010 (Smith, 2012). In India, Twitter was used to alert people to crowdfunding sites for those affected by floods (section 3.2). Some relief agencies have begun accepting donations in cryptocurrencies such

[20] See Facebook Disaster Maps, available from https://research.fb.com/facebook-disaster-maps-methodology/ (accessed 4 February 2019).

as Bitcoin. Mobile money has been increasing financial inclusion in many countries and is a useful way for friends, family and relief organizations to transfer funds to those affected by disasters (CSR Asia, 2014). Following the 2010 Haiti earthquake, the Bill and Melinda Gates Foundation and the United States Agency for International Development (USAID) offered a reward to the first company to launch mobile money in the country, in order to reduce security issues involved with distributing cash (Sossouvi, 2012).

Box 2.4: Google Crisis Map

Google has created a Crisis Map (google.org/crisismap) for users to help locate critical emergency information. The maps feature satellite imagery and relevant information such as the weather, flood zones, evacuation routes, shelters and power outages. Users can zoom in on specific events such as wildfires, as shown in the map below. Crisis Map mainly shows the situation in the United States of America, drawing on data from the United States National Hurricane Center and weather.com. Users can request to add layers.



Source: Google (https://google.org/crisismap/us-wildfires).

2.10 Others

Traditional technologies, though not considered disruptive, continue to play a critical role in disaster management, and are also benefitting from digitization. Radio and television broadcasting, which now exists in digital versions, remains vital for informing the public about preparedness and response procedures. However, they must operate in the event of a disaster, which can be an issue, especially for television, since it generally requires a reliable electrical source.[21] In many least developed countries (LDCs), the spread of mobile communications has resulted in cellphones being more prevalent in households than radios or televisions (Table 2.1). Therefore, cellphones may be more relevant for communicating with the public during a crisis, provided they can be charged.

[21] Radio is more resilient and digital shortwave is being promoted as a good communication solution during disasters (Digital Radio Mondiale, 2014).

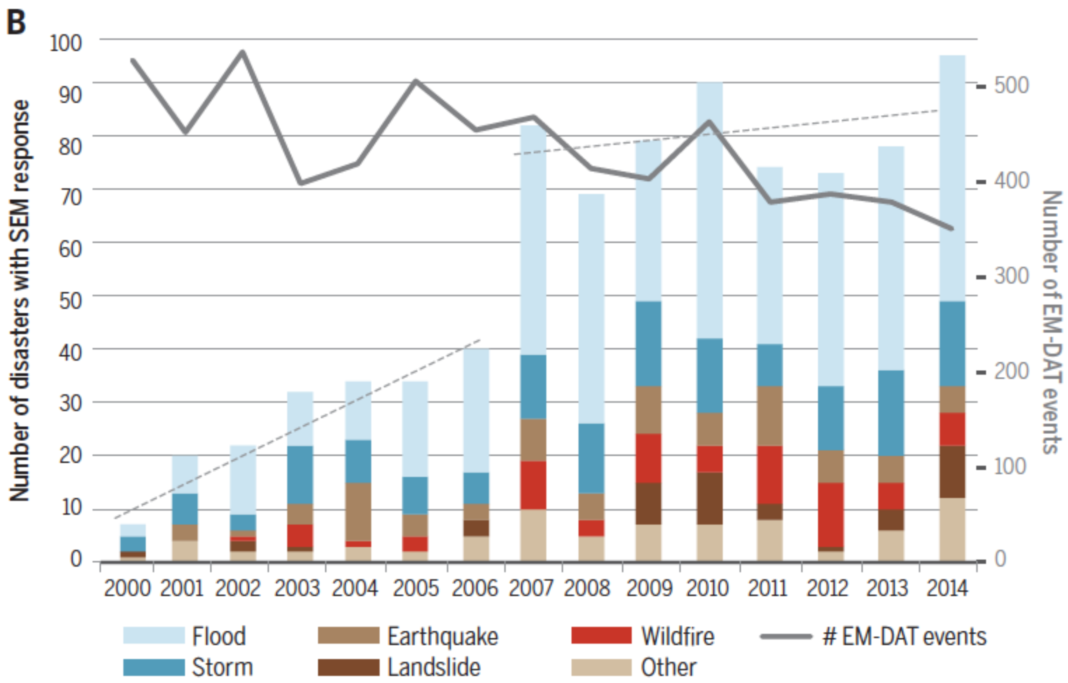
Table 2.1: Radio, television and mobile phone (% of households), selected LDCs

		Total national (urban and rural)			Rural		
Country	Year	Radio	Television	Mobile	Radio	Television	Mobile
Bangladesh	2014	3.5	43.5	88.5	3.6	33.0	86.7
Haiti	2016-17	48.0	30.7	75.9	37.3	11.5	66.5
Lao P.D.R.	2017	...	79.3	90.1	...	72.2	86.6
Madagascar	2016	48.9	17.1	34.0	46.6	12.1	29.1
Timor-Leste	2016	24.5	40.2	84.3	21.6	27.8	80.5
Yemen	2013	39.9	66.8	80.0	39.4	54.5	74.0

Source: Demographic and Health Surveys (https://dhsprogram.com).

Satellite-based emergency mapping (SEM) has improved both in quality and response (Voigt et al., 2016). New radar apertures can see through storm clouds, and coordination between the satellite and relief communities has improved tremendously. Satellite activations for disasters have risen from 7 in 2000 to 123 in 2014 (Figure 2.10). Challenges remain with the time required to convert satellite images to maps and to reprogram satellite positions.

Figure 2.10: Number of disasters with satellite response



Note: EM-DAT refers to the global database on natural and technological disasters maintained by the Centre for Research on the Epidemiology of Disasters (CRED).

Source: Voigt et al. 2016.

Radar radio waves continue to play a critical role for disaster monitoring. One example is high-frequency ocean radar systems used for monitoring tsunami activity. The radar monitors the ocean surface in real time, measuring its velocity, and computer software suggests the probability of a tsunami (International Oceanographic Commission/United Nations Educational, Scientific and Cultural Organization, 2018).

3 Case studies

This section highlights the use of disruptive technologies for disaster management in several countries.

3.1 Drones for disaster damage assessment in Vanuatu

Cyclone Pam struck the South Pacific archipelago nation of Vanuatu on 13–14 March 2015. It was one of the worst disasters to hit Vanuatu, destroying thousands of buildings and leaving around 75 000 people homeless. Relief efforts were quickly organized, with a strong need for assessment of the areas affected. Drones were felt to be an ideal solution for rapid and granular evaluation of the situation, particularly since cloud cover obscured satellite images. The World Bank contracted two drone teams from Australia and New Zealand[22] as the first project of using UAVs for disaster resilience (Bonte-Grapentin et al., 2017). The drone activities were supervised by the Humanitarian UAV Network (UAViators).[23] The Civil Aviation Authority of Vanuatu reviewed the drone use for compliance with regulations and provided usage guidelines (Niel, 2017).

Some 200 flights were flown and the imagery taken from the drones allowed relief workers to determine which houses were unrepairable compared with those that could be fixed, helping to guide funding and recovery efforts. Drones are an improvement from airplane or satellite imagery, which cannot provide as much detailed information. Because drones can collect imagery at different angles, walls and other parts of buildings can be assessed. Agriculture is evaluated by measuring how many crops have been destroyed and consequently how much food people will need from other sources. Wells are examined to see if they are still working.

The imagery collected is owned by the Government of Vanuatu and published on Mapbox, an open source mapping platform (Figure 3.1).[24] This is shared with the Humanitarian OpenStreetMap Team (Leson, 2015) and Micromappers[25] to draw roads and buildings and evaluate damage to individual structures. Volunteers uploaded and geo-tagged images from social media to overlay on the map (Irin, 2015).

The higher resolution of damages available with drone photography provides a more accurate figure of the cost of rebuilding compared with traditional methods. The drones also identify the most seriously affected communities so that assistance can be prioritized.

There were challenges surrounding connectivity, the weather conditions and data formats. Nevertheless, the experience provided valuable insights, with the drones providing the fastest method of mapping the damaged areas (Meier and Soesilo, 2015).

[22] The team from Australia used two Indago quadcopters (https://www.lockheedmartin.com/en-us/products/procerus-technologies/indago-unmanned-aerial-system.html), while the team from New Zealand used three Alliance hexacopters.

[23] Available from http://uaviators.org (accessed 4 February 2019).

[24] Available from www.mapbox.com (accessed 4 February 2019).

[25] See MicroMaps of Cyclone Pam – Vanuatu – April 2015, available from https://micromappers.wordpress.com/maps/ (accessed 4 February 2019).

Figure 3.1: Mapbox of Cyclone Pam damage

Note: Red structures are heavily damaged, blue structures moderately damaged, and yellow structures undamaged.

Source: Matt Irwin, Mapping Cyclone Pam's destruction with drones.

3.2 Twitter during the Chennai flood, India

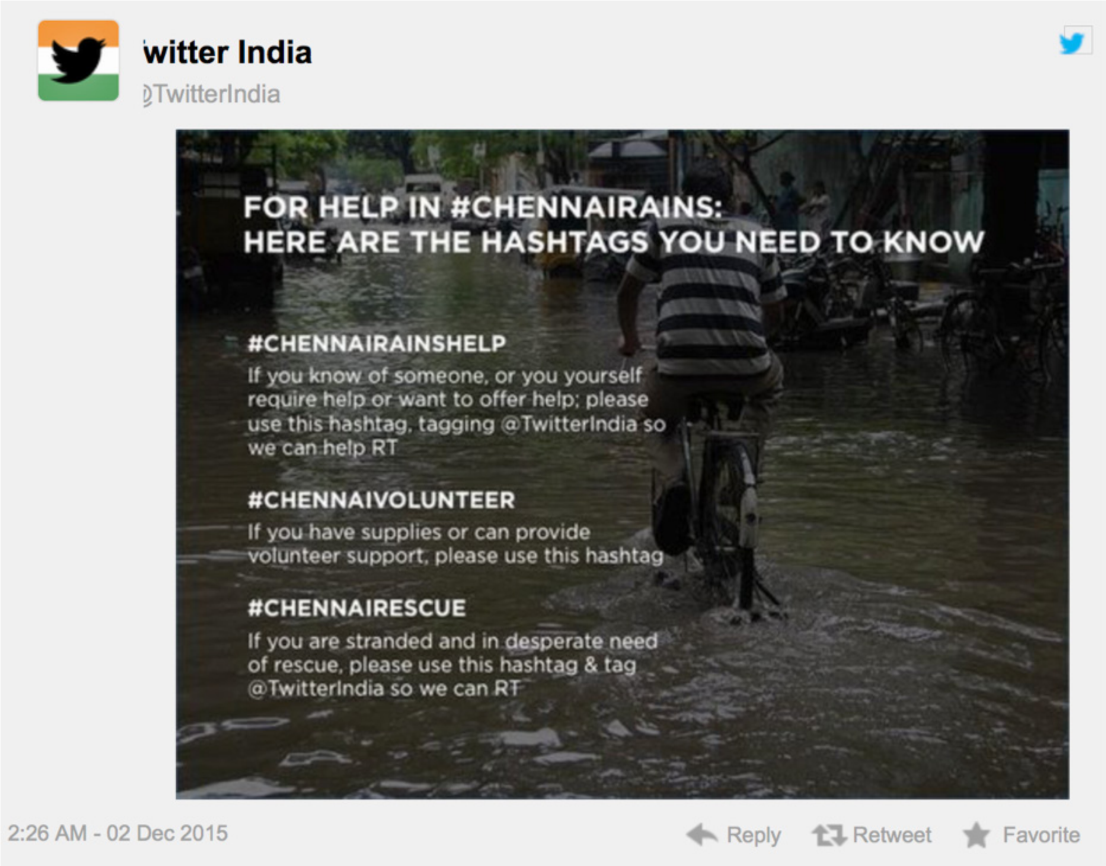
Monsoons regularly affect Southern India during the months of October to December. However, in 2015 the amount of rainfall was 90 per cent above normal, attributed to the El Niño effect. It was the worst rainfall in 100 years, causing severe flooding, which was magnified as a result of sprawling urban development and inadequate drainage systems. It was estimated that more than 500 people died and 1.8 million people were displaced during the several weeks of flooding (Nair et al., 2017). Although emergency telephone numbers were established, they were overloaded, making it difficult to get through, making social media such as Facebook and Twitter a popular method for communication for those with Internet access.

Twitter was deployed by a number of different groups for a variety of different purposes. The Twitter live, real-time public platform was used by NGOs, the public, government agencies and the media to share and exchange information. This resulted in unprecedented collaboration on the platform in responding to the crisis.

Twitter India publicized three hashtags to be used during the flood, depending on the nature of the tweet: #ChennaiRainsHelp, #ChennaiRescue and #ChennaiVolunteer for citizen groups to help agencies on the ground (Figure 3.2). A variety of information was shared, including helpline phone numbers, updated train schedules, weather forecasts, relief efforts and safety tips.[26] This helped to magnify critical messages, organize relief efforts, assist government agencies, warn the public and provide information in real time to citizens trapped in the floods.

[26] For examples of the Tweets, see First Post (2015).

Figure 3.2: Twitter India hashtags for the Chennai floods



Twitter also triggered use of other applications to assist with the crisis. For example, after a suggestion from another Twitter user, a Google spreadsheet was created that crowdsourced information about shelter, weather and other useful tips used by the public, police and the government. In turn, through suggestions on Twitter, the spreadsheet was turned into a website (chennairains.org) (Lal, 2017).

Twitter was also used to raise money on crowdfunding sites. For example, hashtag #rebuildingchennai was used to alert people of funding drives on platforms such as BitGiving and Ketto (Figure 3.3).[27]

[27] Available from https://twitter.com/hashtag/rebuildingchennai and https://chennaifloods.ketto.org (both accessed 5 February 2019).

Figure 3.3: Twitter link to crowdfunding for Chennai floods

Twitter India organized a workshop in July 2016 on lessons learned from the experience and how to have greater impact in the future. Other organizations also organized meetings post-crisis to discuss how use of Twitter could be improved, such as optimal use of hashtags, deploying media cards, dealing with misinformation, etc. (Kaul, 2016).

Researchers studied the use of Twitter during the flood using Big Data software to categorize tweets and analyse the most influential tweeters based on the number sent, retweets and number of followers (Nair et al., 2017). The results of the research are aimed at understanding the role of Twitter for planning and managing future relief measures. The research based its analysis on the #Chennaiflood hashtag, which was not one of the tags publicized by Twitter India. This affects the completeness of the findings, pointing to the need for standardized hashtags for social media response during a disaster. It is also notable that Twitter was popular due to the flood occurring in mainly urban areas, where there is a higher level of ICT penetration and social media use. It is not clear there would be the same impact in rural zones.

3.3 Financial big data for Hurricane Odile, Mexico[28]

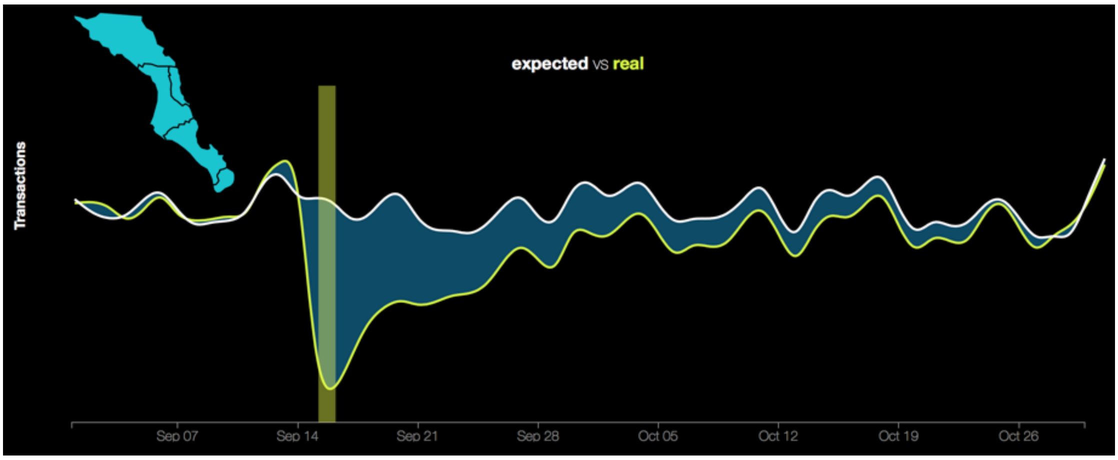
Hurricane Odile struck the Mexican State of Baja California Sur 15–17 September 2014. It was one of the strongest hurricanes ever to hit the area, and caused widespread damage.

Researchers from BBVA Data and Analytics[29] and United Nation Global Pulse[30] used Big Data techniques to explore the relationship between financial transactions in the state (bank card payments and ATM cash withdrawals) before, during and after Odile, to analyse its economic impact on those affected. This analysis can improve understanding about which groups are most affected for targeting post-disaster assistance, how long it takes to return to normal, and how to generate estimates of the economic impact.

The study used data generated by more than 100 000 users of banking services in the state who carry out around 25 000 point-of-sale and ATM cash withdrawals a day. The data were anonymized and aggregated in conformance with Mexico laws. The data set supports analysis of the amounts and times when transactions were made; the type of store where the purchase was made; and purchaser demographics such as gender, age and residence postal code.

The hurricane impact is noticeable from the financial transactions. The day before the hurricane, there was a shift in the types of transactions, with spending on food and gas increasing. The day of the hurricane, transactions dropped dramatically, partly attributed to the blackout that occurred (Figure 3.4). Recovery time was modelled as the number of days for transactions to return to 90 per cent of their normal level. While on average this was about two weeks, there were significant differences, from less than two days to over a month in areas most seriously affected by the storm. Following the storm, there were more ATM cash transactions than point-of-sale due to the large number of shops that remained closed. Lower-income groups recovered faster (in terms of ATM transactions returning to the normal level), likely because they had less financial capacity to stockpile goods prior to the storm and because they spent less than wealthier groups to begin with. The data also showed that women had longer recovery times than men.

Figure 3.4: Expected versus real banking transactions in Baja California Sur, September—October 2014



Source: BBVA, available from www.bbvadata.com/odile/ (accessed 5 February 2019).

The researchers point to a number of uses for the analysis, including more precise targeting of supplies or cash transfers to areas most economically affected by the disaster. Insights from transaction data

[28] This case is adapted from: Martinez, Elena Alfaro et al. 2016.

[29] BBVA is a Spanish bank with a subsidiary in Mexico (Bancomer). Available from www.bbvadata.com (accessed 5 February 2019).

[30] Global Pulse is an initiative of the United Nations Secretary-General on the use of Big Data for development. Available from www.unglobalpulse.org/about-new (accessed 5 February 2019).

could also be incorporated into current mechanisms for estimating economic losses. The data could also be used to enhance inventory decisions in the future to reduce depletion of essential items. It would also be attractive to develop an *ex ante* model of the study so that financial response to disasters could be analysed in real time to provide ongoing feedback loops to relief efforts.

One limiting factor of the model is that findings are dependent on the level of financial inclusion for monitoring transactions. Although the study found that half the Mexico population had bank accounts, a 2017 survey shows the level to be lower, at 35 per cent, barely half the world average (Table 3.1). The percentage of people with bank accounts rises with income levels. Therefore, unless provision is made for the unbanked (or those using mobile money), analysis of financial transactions during and after disasters will be unrepresentative of those likely to need the most support.

Table 3.1: Account ownership by income group, 2017

	Financial institution account (% age 15+)	Mobile money account (% age 15+)
Mexico	35	6
World	67	4
Low income	24	18
Lower middle income	56	5
Upper middle income	73	3
High income	94	..

Source: World Bank Global Financial Inclusion database.

3.4 Disaster robots in Japan

Japan is a pioneering centre for the use of robots in disasters. The Human–Robot Informatics Laboratory of Tohoku University[31] is active in developing several types of robots for disaster response:

(a) Active Scope Camera is a snake-like robot covered by small vibrating filaments, allowing the robot to crawl over obstacles, follow walls and make turns in tight spaces. Its design makes it useful for searching through rubble to find survivors, such as in a train wreck, and it can also detect sounds, such as people trapped in collapsed houses.

(b) Quince is a mobile robot equipped with four sets of tracked wheels, some of which can move up and down to allow the robot to negotiate obstacles. It carries cameras, as well as infrared and carbon dioxide sensors, for detecting the presence of survivors trapped under rubble.

(c) Kenaf can explore a damaged building, underground facility or unstable ground after a disaster. Kenaf enters a hole of approximately 60 cm in diameter, and is operated via wireless communication to obtain images, sounds and 3D shapes.

(d) Search-and-rescue dogs are used for finding victims in disaster sites. However, in Japan, search-and-rescue dogs are not used for real rescue missions due to the inability to track the animal in real time. Research is ongoing to record and visualize the dog's activities using cameras, GPS and inertial measurement units, which are being designed to be small and light in order to fit on a dog pack.

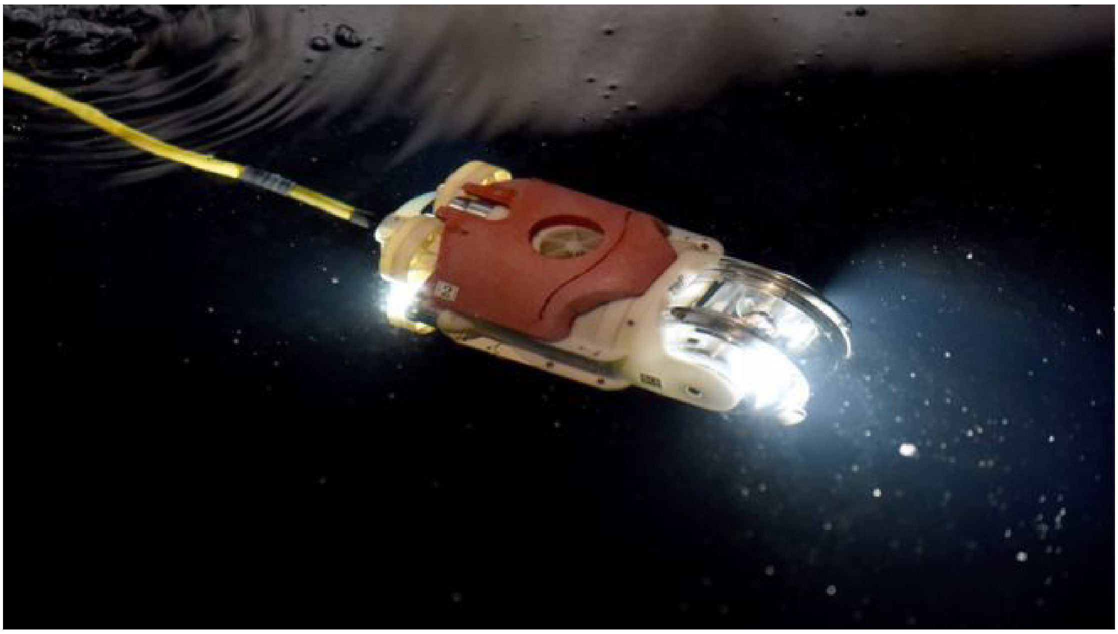
Damage to the Fukushima Daiichi Nuclear Power Plant in the 2011 earthquake triggered significant robot research, due to radiation preventing humans from carrying out direct clean-up activities.

[31] See Rescue Systems, available from www.rm.is.tohoku.ac.jp/rescue+systems/ (accessed 5 February 2019).

In 2013, the Government of Japan established the International Research Institute for Nuclear Decommissioning, including the mandate of developing robots. The institute consists of a consortium of public utilities and private companies – such as Hitachi, Mitsubishi and Toshiba – which has developed around 20 robots. There is a research and development centre near the plant where robot operators practice on giant 3D models of the reactors as well as and on life-size copies.

One of the biggest challenges has been how to determine what happened to the fuel inside the core of the reactor. Various robots have been used to penetrate the core but without success. Finally, in 2017, a small robot dubbed 'Little Sunfish' (Figure 3.5) – equipped with five propellers, video cameras, an array of sensors and designed to operate underwater under severe radiation exposure – succeeded in locating the missing fuel inside the reactor core (Beiser, 2018).

Figure 3.5: Little sunfish robot



Source: BBC (https://www.bbc.com/news/in-pictures-40298569).

Japanese manufacturer Honda has a robotics division known for development of the ASIMO humanoid robot.[32] It is now developing a disaster response robot, E2-DR (Figure 3.6) (Ackerman, 2017). The robot can walk, climb over obstacles, and climb ladders and stairs. E2-DR features cameras, 3D sensors and hand grippers. There are currently some limitations, including a battery life of one and a half hours, and a limit of 20 minutes in wet weather. If the prototype reaches fruition, it could have a major impact for rescue operations and clearing hazardous materials.

[32] See Honda Robotics, available from https://global.honda/innovation/robotics.html (accessed 4 February 2019).

Figure 3.6: Honda E2-DR robot

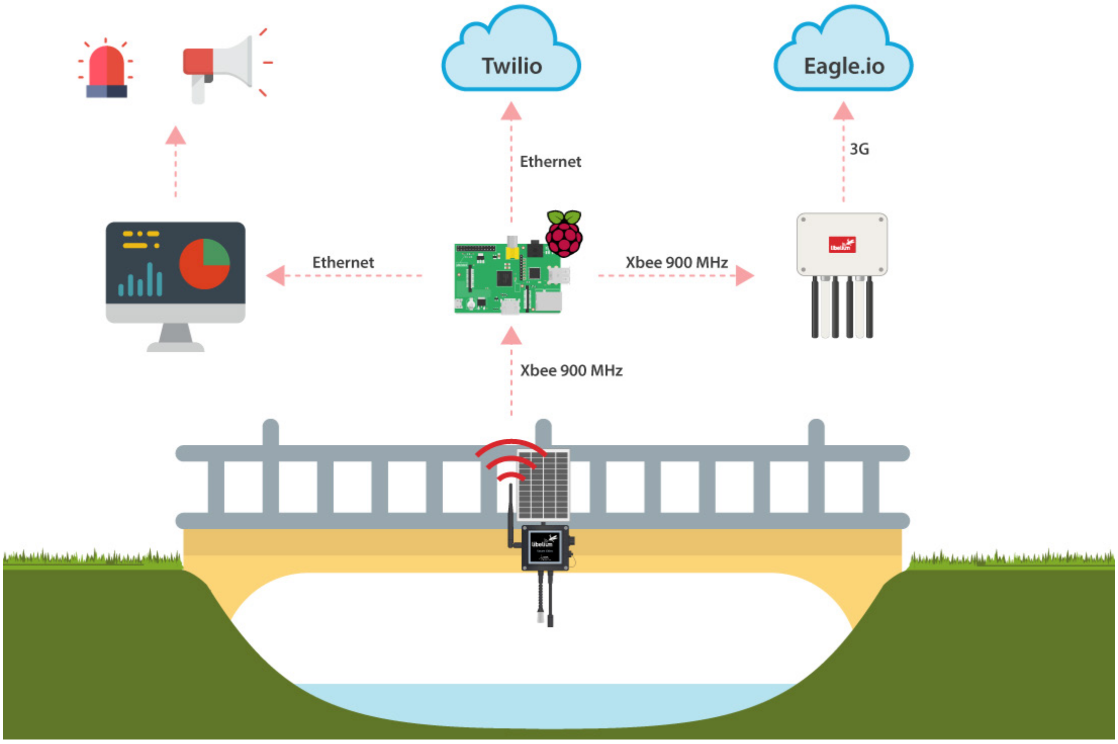
Source: Institute of Electrical and Electronics Engineers (IEEE) (Ackerman, 2017).

3.5 Internet of Things for river flooding control in Colombia

One example of an IoT deployment is the village of Salgar, Colombia (Libelium, 2017). Following the flooding of the Liboriana River, which triggered a devastating landslide in May 2015, causing more than 80 deaths, the Colombia Government National Unit for Disaster Risk Management (http://portal.gestiondelriesgo.gov.co) took steps to mitigate future occurrences. It hired a Colombia-based company to implement an early warning system using IoT technology. Five solar-powered sensors were installed along the Liboriana and two other rivers to monitor water levels and air temperature using ultrasound. The use of solar ensures the sensors continue to function in the event of an electricity outage. The price of each sensor is EUR 5 200 (www.the-iot-marketplace.com/smart-water-iot-vertical-kit). Sirens were installed in the municipality and flood hazard zones. Communications among the sensors were a challenge, due to the hilly terrain and patchy 3G coverage. Consequently, a 900 MHz mesh network was installed, allowing the sensors to transmit data to the control centre in the village for local authorities to monitor and decide whether to activate the early warning system. Data are also stored in the cloud on the eagle.io remote sensor site for others to access[33]. The system software automatically sends a text message to village authorities if a risk is detected. When required, the sirens are activated and blinking lights are displayed indicating the river level. The system is scalable, so more sensors and monitoring points can be added. The Government of Colombia spent COP 410 million (USD 130 000) to deploy the system (Federman, 2016).

[33] https://eagle.io/

Figure 3.7: IoT system for river monitoring in Salgar, Colombia



Source: Libelium 2017.

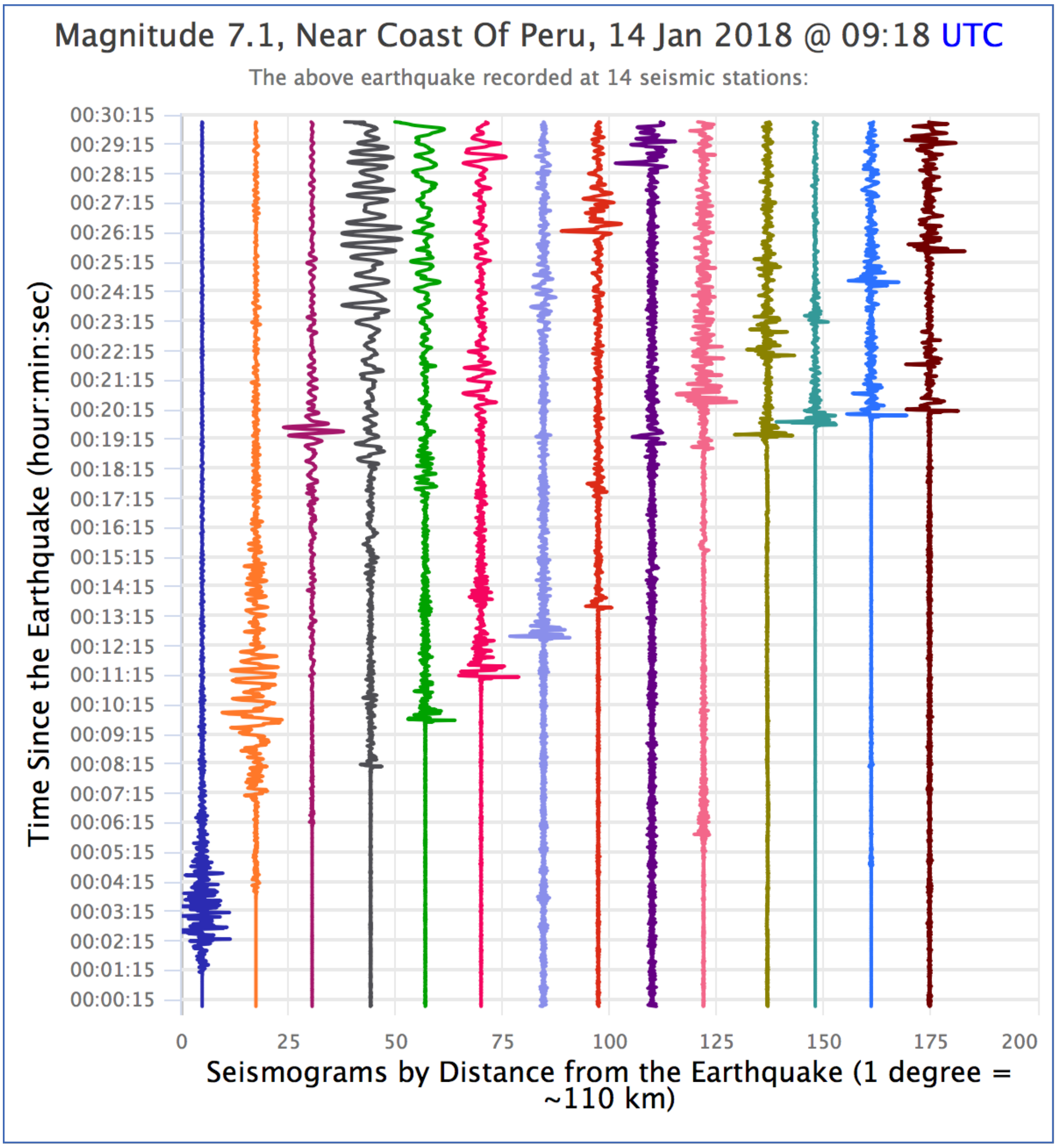
Colombian researchers have investigated the event to better understand the dynamics and how to reduce risks and loss of life from extreme rainfall events in the future, given the frequency of flash floods and torrential rainfalls, which occur regularly in the country (Velásquez et al., 2018). A model has been constructed of the hydrological and meteorological conditions in order to develop applications to improve risk management. Reflectivity images captured from the C-Band radar Early Warning System of Medellín, about 60 km away, were used to classify the precipitation fields and estimate the amount of rainfall and the cause of the landslide. Future research is planned in Colombia to determine if satellite images can provide the same granularity in areas where there is no radar.

3.6 Artificial intelligence for earthquake detection and prediction

The volume of seismic data has increased exponentially, providing fuel for solutions to reliably detect and locate earthquakes. Scientists have based detection on continuous seismic records, searching for repeating signals that provide information on upcoming earthquakes. Recent advances in AI provide the potential to detect earthquakes and perhaps even predict them.

Seismometers detect vibration in the Earth, recording the waves on a graph (waveforms) (Figure 3.8). The distances the vibrations take to reach control stations were traditionally used to locate earthquakes through triangulation. Newer techniques use computer software to analyse waveforms combined with other events to more precisely locate the epicentre of an earthquake (Richards et al., 2006). This approach requires an extended time-series of waveforms that are analysed using cross-correlation and multi-event location software.

Figure 3.8: Seismogram plot



Source: Incorporated Research Institutions for Seismology (http://ds.iris.edu/gsv/tsplotForID.phtml?evid=10604800&useCache=1&epo=0&caller=map)

Analysing many years of earthquake waveforms requires considerable computing power. One way to reduce the processing time is to select a subset of relevant waveforms (template matching). A new technique referred to as Fingerprint And Similarity Thresholding (FAST), reduces the processing involved with matching templates by selecting features (fingerprints) from waveforms. The drawback with these methods is that location information is lost.

A new approach uses AI to reduce waveform analysis processing while retaining location information. Developed by a team of researchers at Harvard University and the Massachusetts Institute of Technology, ConvNetQuake implements AI based on convolutional neural network computer learning (Perol et al., 2018). The software is trained to analyse large waveform data sets and distinguish between noise and true earthquake signals. Instead of matching waveforms to historical data, the software filters them, eliminating the need for a library of matching templates. One important feature of ConvNetQuake is that it preserves location information.

The software was tested in Oklahoma in the United States of America, where earthquakes have become more frequent due to increased fracking and injection of underground wastewater. ConvNetQuake detected many more earthquakes of lower magnitude than traditional techniques. Compared with other methods, ConvNetQuake is faster and retains location information with a high degree of accuracy (Table 3.2). The main drawback is the amount of upfront time for the software to 'learn' (around one and a half hours). ConvNetQuake has the potential for very rapid earthquake detection and location, critical for earthquake early warning.

Table 3.2: Comparison of performance of earthquake detection methods

Table 1. Performances of three detection methods, excluding the overhead runtimes (1.5 hours of offline training for ConvNetQuake and 47 min of feature extraction and database generation for FAST). Autocorrelation and FAST results are as reported by Yoon *et al.* (*11*). The computational runtimes are for the analysis of 1 week of continuous waveform data. NA, not applicable.

	Autocorrelation	**FAST**	**ConvNetQuake (this study)**
Precision	100%	88.1%	94.8%
Recall	77.5%	80.1%	100%
Event location accuracy	NA	NA	74.6%
Reported runtime	9 days, 13 hours	48 min	1 min, 1 s

Table 3.2: Comparison of performance of earthquake detection methods describes the performances of three detection methods, excluding the overhead runtimes (1.5 hours of offline training for ConvNetQuake and 47 minutes of feature extraction and database generation for Fingerprint And Similarity Thresholding (FAST)), and explains that the computational runtimes are for the analysis of 1 week of continuous waveform data. ConvNetQuake shows a precision of 94.8%, recall of 100% and event location accuracy of 74.6%.

Source: ConvNetQuake

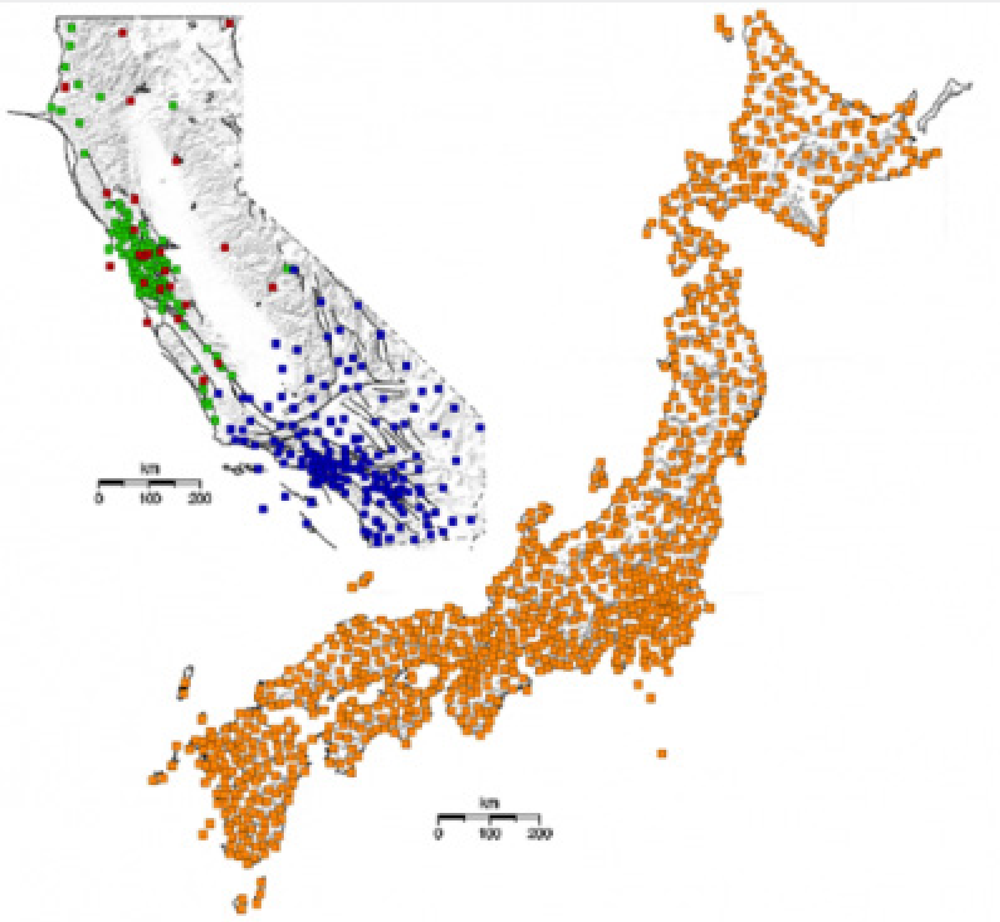
While there is ongoing progress in earthquake detection, there is debate about whether prediction is possible. Scientists at Los Alamos National Laboratory in the United States of America are using machine learning to experiment with prediction methods (Rouet-Leduc et al., 2017). They modelled tectonic plates using steel beams. Movement of the beams generates waveforms analysed by computer software with a self-learning algorithm. The software eventually predicted when the beams would rupture. The technique is now being applied to real data, which is proving challenging, due to the large amount of extraneous ambient noise.

Box 3.1: Using ground sensor technology to detect earthquakes

One technique used in earthquake early warning systems is a network of specialized ground sensors similar to IoT. Seismic sensors are deployed in earthquake-prone areas. Data are transmitted from the sensors to a central site, where the information is processed for signals that might indicate an earthquake is likely. This method takes longer to detect earthquakes than a single station, but is more accurate and has greater resiliency.

The California Integrated Seismic Network ShakeAlert system uses network sensors for earthquake detection, with warning times of a few seconds to tens of seconds. One challenge is the cost of installing more sensors to create a more accurate and faster network. Japan has almost nationwide coverage, whereas in California there are still a lot of blind zones (Figure 3.9). The Japan network K-NET (Kyoshin network) consists of more than 1 000 seismographs uniformly distributed every 20 km. Data are transmitted to the National Research Institute for Earth Science and Disaster Resilience, and made available to the public over a website (www.kyoshin.bosai.go.jp).

Figure 3.9: Earthquake sensor density in California and Japan



Source: ShakeAlert (https://www.shakealert.org/faq/#whateew).

4 Challenges, relevance and sustainability

Disruptive technologies have the potential to significantly transform disaster preparation, response, recovery and mitigation. Some technologies, such as drones and IoT, are increasingly utilized in disaster situations, while others are still being piloted. Wider application depends both on overcoming a number of challenges and the relevance of sustainability in different contexts.

4.1 Challenges

The use of disruptive technologies in disaster settings faces a number of challenges limiting their impact:

(a) **Skills:** While some of the technologies require few skills and their use can be learned quickly, a high level of competence is required to successfully deploy others. Drones and robots require skilled human technicians to deploy, operate and maintain. Big Data analytics require advanced software, powerful computers and data science expertise, and involve significant testing and modelling, and investment in research. Many of these skill sets and supporting resources are in short supply in developing countries.

(b) **Data deluge:** Growing access to ICTs and the increasing application of sensors are generating massive volumes of data. Such Big Data has immense relevance for disaster management. However, the growing amount of data poses challenges for data management, analysis and verification. As one expert puts it: “The overflow of information generated during disasters can be as paralyzing to humanitarian response as the lack of information. This flash flood of information is often referred to as Big Data, or Big Crisis Data. Making sense of Big Crisis Data is proving to be an impossible challenge for traditional humanitarian organizations” (www.digital-humanitarians.com)

(c) **False information:** While real-time information dissemination can save lives, the rapidity by which the data flow makes it difficult to verify, and the consequences of false information can be deadly. There are a number of levels on which information can be false, with negative consequences for disaster preparedness and response. First, the public tends to exaggerate under extreme stress (Qadir et al., 2016). A study on social media use relating to the Boston Marathon bombing in 2013 analysed 8 million unique tweets, finding that only 20 per cent relayed accurate information; the remaining tweets either consisted of fake content or rumours (29 per cent) or general comments and opinions (51 per cent) (Meier, 2013). A second way that information is false is through bias, particularly with exclusive reliance on Big Data. The Google Flu Tracker overestimated the size of the 2013 influenza pandemic by half, forecasting twice the amount of flu-related doctor visits (Butler, 2013). Some of the factors distorting Big Data include intentional or unintentional false crowdsourced data and how well they represent the actual population.

(d) **Legal ramifications:** Disruptive technologies pose a number of regulatory and legal challenges. Drones often need to be registered and abide by civil air regulations, particularly in crowded urban areas. Some jurisdictions ban the use of drones, due to security concerns. Around 60 relief organizations have developed a code of conduct related to legal and other issues concerning drone use in humanitarian work (Box 4.1). The increasing use of Big Data for crisis analysis poses challenges for data protection and privacy, and even more so when the data are shared cross-border, raising issues for international research collaboration.

(e) **Scale:** Few disruptive technologies have scaled in the sense of widespread application with out-of-the-box open solutions and a supporting ecosystem. As a result, it is difficult and costly to select appropriate solutions.

(f) **Costs:** Investment for implementing digital solutions for disaster management can be high. While costs of hardware such as UAVs and sensors are continuously declining, the cost of operating, integrating and analysing the information they generate are high. Similarly, while Big Data itself costs little to generate, its analysis requires specialized software and hardware and data science expertise. Few disruptive digital solutions have achieved the scale necessary to achieve a dramatic reduction in costs.

(g) **Ownership:** This revolves around several areas. One is the ability for governments and other national organizations involved in disaster relief to own relevant disruptive technology equipment. As noted, though dropping in costs, the price of equipment such as drones remains costly for many developing countries. While drones are often deployed by experienced teams, the delay between them arriving on site and a country already having the equipment could be significant. Another aspect relates to the data ownership. Data are generated by different disruptive technologies. Policies need to be in place regarding ownership of data generated during disasters, including appropriate data protection and privacy regulations. A third aspect of ownership relates to governments directing their own strategy for use of disruptive technology for disaster management or relying on others to do so. While a lack of resources may stipulate the latter option, in the long run, sustainability dictates that governments themselves are best placed to know how best to utilize disruptive technologies under different contextual environments. This is becoming particularly important for coordination purposes, given the variety of technology tools in the hands of different groups.

(h) **Readiness:** Countries vary in their capabilities to properly absorb digital technologies for disaster situations. Within countries, there are differences in access to ICTs as well as applications. This may make it problematic for some disruptive technologies to achieve wide impact. For example, an analysis of citizens impacted by 2014 floods in Malaysia found that mobile phones and SMS were used most often during the flood (Aisha et al., 2015). Facebook was the most popularly used social media application, compared with Instagram or Twitter. WhatsApp was the mobile messaging application used most often. There was also a significant age difference: younger users were more likely to use social media, and there was a notable inverse relationship between age and the use of social media. No analysis was done of differences in use by gender, although it is notable that the majority of surveys used for the study were completed by female flood victims (63 per cent of respondents).

Box 4.1: Humanitarian UAV Code of Conduct

Work on the Humanitarian UAV Code of Conduct began in 2014. It was led by the Humanitarian UAV Network (UAViators), with more than 60 organizations contributing including relief agencies such as OCHA, UNICEF, the Office of the United Nations High Commissioner for Refugees, the United Nations Disaster Assessment and Coordination, the International Organization for Migration, the World Food Programme and the American Red Cross. The code has 15 guidelines, reproduced below.

1. Prioritize safety above all other concerns: Humanitarian benefits should clearly outweigh risks to persons or properties.
2. Identify the most appropriate solution: Only operate UAVs when more effective means are not available and when humanitarian purposes are clear, such as the assessment of needs and the response thereto. UAV missions should be informed by humanitarian professionals and experts in UAV operations with direct knowledge of the local context.
3. Respect the humanitarian principles of humanity, neutrality, impartiality and independence: Prioritize UAV missions based on needs and vulnerabilities, make sure actions are not, and are not perceived as being, politically or economically influenced; do not discriminate or make distinctions on the basis of nationality, race, gender, religious belief, class or political opinions.

4. Do no harm: Assess and mitigate potential unintended consequences that UAV operations may have on affected communities and humanitarian action.
5. Operate with relevant permissions: UAV operations must be in compliance with relevant international and domestic law, and applicable regulatory frameworks including customs, aviation, liability and insurance, telecoms, data protection and others. Where national laws do not exist, operators shall adhere to the International Civil Aviation Organization Remotely Piloted Aircraft Systems Circular 328-AN/190, with the approval of national authorities.
6. Engage with communities: Community engagement is important and obligatory. Developing trust and engaging local communities encourage active partnership, build local capacities and leadership, and enhance the impact of your mission. Information should continuously be provided to communities regarding the intent and use of UAVs. Refer to Humanitarian UAV Community Engagement Guidelines.
7. Be responsible: Contingency plans should always be in place for unintended consequences. UAV teams must take responsibility for and resolve any issues involving harm to people and property, including liability.
8. Coordinate to increase effectiveness: Seek out and liaise with relevant local and international actors and authorities. UAV teams must not interfere with and always seek to complement formal humanitarian coordination mechanisms or operations.
9. Consider environmental implications: Operating UAVs should not pose undue risk to the natural environment and wildlife. UAV operators must take responsibility for any negative environmental impact their mission causes
10. Be conflict sensitive: All interventions in conflict zones become part of conflict dynamics and can result in very serious unintended consequences, including the loss of life. Extraordinary caution must be used in deploying UAVs in conflict zones. Refer to Humanitarian UAV Conflict Zones Guidelines.
11. Collect, use, manage and store data responsibly: Collect, store, share and discard data ethically using a needs-based approach, applying informed consent where possible and employing mitigation measures where it is not. The potential for information to put individuals or communities at risk if shared or lost must be assessed, and measures taken to mitigate that risk (e.g. limit or cease collection or sharing). Refer to Humanitarian UAV Data Ethics Guidelines.
12. Develop effective partnerships in preparation for and in response to crises: Work with groups that offer complementary skill sets (humanitarian action, UAV operations, local context, data analysis, communications) during, and preferably in advance of, crises. Refer to Humanitarian UAV Effective Partnerships Guidelines.
13. Be transparent: Share flight activities as widely as possible, ideally publicly, as appropriate to the context. Convey lessons or issues to communities, relevant authorities and coordinating bodies as early as possible.
14. Contribute to learning: Carry out and share any evaluations and after action reviews to inform the betterment of UAV use for humanitarian action.
15. Be open and collaborative: Coordination is a multistakeholder process. This means that lessons learned and best practices on the use and coordination of UAVs in humanitarian settings must remain open and transparent, along with any related workshops, trainings and simulations.

In addition to the code of conduct, four guidelines have also been developed on Data Protection, Community Engagement, Effective Partnerships and Conflict Sensitivity. A best practices guide has also been drafted based on experiences in the field.

Source: Humanitarian UAV Code of Conduct.

4.2 Relevance and sustainability

The use case for disruptive technologies can be examined across a spectrum of different factors, such as location, complexity and cost. Characteristics of the technologies in the case study settings above are reviewed in order to understand the relevance and sustainability of different technologies under different conditions (Table 4.1).

In terms of *location*, any of the technologies could, theoretically, be applied in rural as well as urban areas, and are equally relevant in both. However, rural areas face several stumbling blocks. Communications is one, since almost all of the technologies require high-speed networks to function at their best, and rural areas tend to lag in fast broadband. While most technologies will still be usable, they will not operate to full capacity. In the case of Colombia, the lack of 3G coverage led to the deployment of a proprietary communication network, while in Vanuatu, real-time drone assessment was hampered by a lack of mobile broadband wireless coverage. In India, flooding occurred mainly in urban areas, where there is good cellphone coverage. It is unclear whether the use of Twitter would have been as effective in rural areas with lower levels of coverage and smartphone penetration. The case on Big Data will be affected by the lower level of financial inclusion in rural areas if applied to other developing nations. The use of robots still remains largely experimental, and there was little evidence of them being applied in rural areas at any scale. The data used for the AI case came from monitoring Earth movements in largely rural areas, although the computation took place in urban universities.

Technologies varied in what *phase* of disasters they fit in. The IoT case was used for preparedness through monitoring hydrological conditions. Like the AI example, the Big Data case was an *ex post* research study. In an unfolding disaster, it would likely be useful for the recovery phase to identify communities that required financial assistance. In the case of AI, if it proves practical for real-time monitoring, it could enhance mitigation and possibly preparedness by having a better understanding of the conditions under which earthquakes occur. The robot example was used during the recovery phase to locate radioactive fluids, although a more generalized use would also suggest robot relevance for response. The use of drones in Vanuatu involved both response by filming damage as well as recovery by informing relief workers about possible prioritization of assistance. Twitter was primarily used to inform the public and coordinate communications among the relief agencies during the response and recovery phases.

The *costs* of the interventions varied and were affected by donations and whether wider expenses were considered. In the drone case, the equipment and expertise were provided by assistance agencies. Twitter is relatively low-cost, primarily incurring user data communication charges. The Big Data example was a research project carried out by data scientists at a bank and a United Nations agency. In a real-world setting, it is not clear whether there would have been a cost to obtain the data and the price of hiring data scientists to analyse them. To obtain the cost of the robot, the previous prototypes and expenses on simulating the real-world scenario must be factored in. Going forward, it is not yet clear what crisis-specific robots would cost. The cost of the IoT intervention was covered by the Government of Colombia, and amounted to just over USD 100 000. The AI example required powerful computers to carry out the analysis. Considering wider and stronger impacts, then, the costs of deploying mobile broadband to uncovered areas should be considered. Drones, Twitter and IoT have higher functionality if mobile broadband coverage is available.

Complexity of the interventions is affected by the expertise required to develop and use those interventions and the degree of functionality required. The robot and AI examples required a high level of expertise, and were based on years of previous research and development. The Big Data example was undertaken by data scientists. The drone case involved experienced operators, though it is likely the skills can be transferred fairly easily. Similarly, while the IoT case required technical knowledge, the skills involved could also be transferred. Twitter was the least complex.

There was a range of *stakeholders* in the cases analysed. It is notable that, in two of the three cases where hardware solutions were implemented (robots and AI), government was involved as a funding source and the private sector as implementer. In the case of drones, the intervention was implemented by a collection of assistance partners. Twitter was the only case where there was direct public use in addition to government and relief agencies. The case of Big Data and AI were both research projects involving the former banks and the United Nations, and for the latter academics. The variety of stakeholders identifies the different parties that need to be involved to realize the potential of disruptive technology: governments, international agencies, NGOs, the private sector, the public and researchers.

All of the technologies raise *legal* issues with privacy and data protection common to almost all of them, with robots possibly posing more of an ethical than legal issue. The degree of possible legal considerations depends on the laws in each country. Drones often need to be registered and comply with airspace regulations, and the information they observe and collect would be subject to privacy and possibly data protection statutes in some jurisdictions. Likewise, Twitter, Big Data, AI and IoT might be regulated in some markets to comply with privacy and data protection laws. IoT might have to comply with national environmental laws regarding sensor locations and visual pollution.

Table 4.1: Disruptive technology classification (based on case studies)

	Drones	Social Media	Big Data	Robots	AI	IoT
Urban	Dependent on regulations	Likely relatively high	Likely high	High	High	Yes
Rural	High except may not have supporting infrastructure for full functionality (e.g., 3G/4G mobile coverage)	Possibly low (depending on spread of ICT)	Possibly low (depending on level of financial inclusion)	Few examples	High	Subject to 3G coverage or installing communications system
Disaster phase	Response, recovery	Mitigation, preparedness	Recovery	Recovery	Preparedness	Preparedness
Costs	Medium	Low	Low	High	High	Low to medium
Complexity	Medium to high (qualified drone operators, establishing and interpreting data streams)	Low to disseminate; high to analyse and interpret	High (to analyse and interpret data)	Medium to high (to manipulate robot, interpret data and maintain the system)	High	Medium
Stakeholders	World Bank, NGOs, United Nations	Public, NGOs, government	Banks, UN	Government, private sector	Academia	Government, private sector
Regulatory issues	Air space regulation, data protection and privacy	Some countries have Internet filtering	Data protection and privacy	Ethics	Ethics, data protection	Data privacy and protection, environmental considerations

Source: Based on case studies in this document.

5 Conclusions and recommendations

Disruptive technologies are affecting disaster management, although the pace, scope and impact vary among the technologies. While social media platforms such as Facebook and Twitter have been applied in a number of emergency events, Big Data, robots and AI remain largely experimental. Large-scale impacts will require more time and investment in skills and research.

Despite this, drones and IoT are increasing in application, as experience is gained and costs fall. Older technologies such as satellite imagery and seismometers are still the most important methods for detecting, monitoring and accessing disasters, and text messaging has the widest reach for communicating with the public.

While there is evidence that AI can accurately predict some types of disasters before they happen, the application of disruptive technologies today has a more incremental effect. These technologies are refining processes by spreading critical information more quickly, improving understanding of the causes of disasters, enhancing early warning systems, assessing damage quickly, and adding to the knowledge base of the social behaviours and economic impacts after a crisis strikes. Disruptive technologies are improving situational awareness by providing the crisis community with a clearer understanding of the extent of damage and where to prioritize resources.

This section summarizes findings from the examples of disruptive technology use and makes several recommendations, and steps are identified that governments, relief agencies, the private sector and assistance agencies can take to maximize benefits from the opportunities highlighted in the document.

Systemization and standardization are needed to improve the application of technology interventions. In terms of text messaging, it is recognized that use of a few well-publicized short code numbers is to be encouraged and that, similarly for social media, standardized hashtags should be employed (Government of the Philippines, 2014). This will reduce confusion among the public and magnify impacts. Open standards will help to lower costs and ensure interoperability of different technologies. The Common Alerting Protocol aims to standardize national and international disaster information to enhance interoperability.[34] The mobile industry has a standard for machine-to-machine communications using fourth generation wireless technology (LTE-M) to support IoT.[35] IEEE has been working on IoT and issued a draft standard on an architectural framework.[36] The ITU Telecommunication Standardization Bureau also has a Study Group carrying out work on IoT.[37] The standardization should also extend to the use of Big Data, which is currently often shrouded in opaqueness. Clear and transparent sharing protocols should be implemented, including application programming interfaces.

Reach of digital technologies must be factored in to disaster management strategies. In respect to communications among stakeholders, this includes considering the purpose and audience. While Twitter has proved useful in crisis situations, particularly among the relief community, its penetration is relatively low among the general public. It should also be considered that some people may not want to use proprietary platforms, for a number of reasons, and therefore relying only on one method may not reach all intended recipients. Research such as the case of financial Big Data described above faces a challenge, given low levels of financial inclusion in some countries and also the need to incorporate all types of financial accounts (e.g. both traditional bank accounts as well as mobile money).

A **global repository** featuring information on how digital technologies are being applied for disaster management would raise awareness and understanding. Hundreds of applications of disruptive technology are underway around the world, but experiences are often buried in news articles and research reports. While this document highlights some examples, it is the tip of the iceberg. An

34 See Sahana Alerting and Messaging Broker (SAMBRO), available from http://eden.sahanafoundation.org/wiki/Deployments/SAMBRO (accessed 6 February 2019).

35 See Long Term Evolution for Machines: LTE-M, available from www.gsma.com/iot/mobile-iot-technology-lte-m/ (accessed 6 February 2019).

36 See Internet of Things, available from https://standards.ieee.org/initiatives/iot/index.html (accessed 6 February 2019).

37 Available from www.itu.int/en/ITU-T/studygroups/2017-2020/20/Pages/default.aspx (accessed 6 February 2019).

information base would be useful for identifying digital interventions that have worked, who the implementers were and other material, in order to increase understanding about which technologies are relevant for different country circumstances and types of disasters. Some disruptive technologies portals exist,[38] but these tend to be cross-sector, whereas what is suggested here would be specifically about their application for disaster management.

Partnerships with the private sector and academia will be critical for understanding and applying digital technologies for disaster prediction, detection, response and relief. Numerous uses of disruptive technologies are being developed by the private sector. In addition, the private sector controls significant amounts of personal information in Big Data sets that are of immense use for the disaster community. Similarly, considerable relevant research is being undertaken by the academic community. Ties between the disaster community, private sector and academia need to be strengthened.

Scaling disruptive technologies for crisis is essential to have widespread impact and be reasonably affordable. To date, many interventions are still pilots or carried out in an ad hoc, informal manner. Processes should exist to identify relevant use cases and scale them. This can lower costs and bring their utility to a wider audience. Given the vast potential of disruptive technologies for disaster management under a huge variety of different circumstances, there is a need to nurture innovation. This is particularly relevant given the wide country contexts around the world, different types of disasters and crisis phases. Examples from the start-up world are relevant where incubators, labs, competitions and venture capital are used to discover, mentor and scale up promising innovations. One example is the IBM Call for Code challenge, inviting developers to create new applications to help better prepare for disasters (IBM, 2018)). The company has pledged USD 30 million to help coders scale their ideas, and includes support from the Linux Foundation. One app that has been developed under this scheme uses weather data and supply chain information to alert supermarkets, pharmacies and other stores to increase supplies. Another example is One Concern, a California start-up founded by Stanford University alumni that uses machine learning to predict the impact of earthquakes, flooding and forest fires, and thus improve situational awareness.[39]

Training is indispensable for the disaster community to understand how to properly deploy new and emerging digital technologies in crisis settings. Manuals are needed for different technologies. For example, in the case of social media, this would cover hashtag guidelines, usage by public and relief organizations, coping with fake information, etc. Training materials would ideally supplement existing documents for text messaging (GSMA, 2013) and UAVs.[40] One Concern – a start-up that uses AI to better manage earthquakes, flooding and other disasters – provides a training module featuring simulated disaster scenarios to train emergency relief personnel how to use the software (Shueh, 2016).

Legal ramifications of technological research and interventions for disasters need to be understood. This is fairly straightforward in respect to specific regulations, such as registration and regulation of drones, but more nebulous regarding data protection and privacy. One relevant dilemma is whether the lack of data protection and privacy laws inhibit or encourage technologies that make heavy use of personal information. While the financial Big Data described above abided by Mexican laws in anonymizing and aggregating personal data so individuals could not be identified, it also pointed out that significant relevant information was lost in the process. On the other hand, the case of the Ebola epidemic in West Africa is telling[41], as mobile operators refused to share call data records due to possible legal exposure, because of a lack of clarity regarding data privacy (*The Economist*, 2014). Further, while Big Data may eventually be forthcoming, in the event of a disaster it is needed immediately, so it essential to have data access and sharing protocols in place beforehand (National

[38] See AI Repository, available from www.itu.int/en/ITU-T/AI/Pages/ai-repository.aspx (accessed 6 February 2019).
[39] Available from www.oneconcern.com (accessed 6 February 2019).
[40] The Code of Conduct for UAVs was entirely volunteer-driven with no funding. Available from https://uavcode.org (accessed 6 February 2019).
[41] See https://www.itu.int/en/ITU-D/Emergency-Telecommunications/Pages/Publications.aspx for reports on CDR analysis in Guinea, Liberia, and Sierra Leone.

Security Telecommunications Advisory Committee, 2016). The disaster community has developed codes of conduct in certain areas, including data protection, that can help when laws are vague, such as blurring images of people when filmed by drones.[42]

Adequate capacity remains fundamental for properly planning and deploying relevant digital technologies. While digital technologies show great promise for all phases of disasters, on-the-ground planning, management and operations are critical to their success (Teutsch, 2010). Disaster agencies do not need to be experts in digital technologies, but they do need to understand enough about them to develop proactive blueprints for deploying them. Disaster agencies might also consider creating a chief technologist post to better understand how to apply disruptive technologies.

[42] See Humanitarian UAV Code of Conduct, available from https://uavcode.org/further-guidance/131-2/ (accessed 6 February 2019).

Abbreviations

5G	Fifth Generation
AI	Artificial Intelligence
AIDR	Artificial Intelligence for Disaster Response
BDT	Telecommunication Development Bureau
CRED	Centre for Research on the Epidemiology of Disasters
GPS	Global Positioning System
ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
LDC	Least Developed Country
LSE	Least Developed Countries, Small Island Developing States and Emergency Telecommunications Division (ITU)
NGO	Non-Governmental Organization
OCHA	United Nations Office for the Coordination of Humanitarian Affairs
SMS	Short Message Service
UAV	Unmanned Air Vehicle
UNICEF	United Nations International Children's Emergency Fund
USD	United States Dollar
UUV	Unmanned Underwater Vehicle

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International Telecommunication Union (ITU)
Telecommunication Development Bureau (BDT)
Office of the Director
Place des Nations
CH-1211 Geneva 20 – Switzerland
Email: bdtdirector@itu.int
Tel.: +41 22 730 5035/5435
Fax: +41 22 730 5484

Deputy to the Director and Director，Administration and Operations Coordination Department (DDR)
Email: bdtdeputydir@itu.int
Tel.: +41 22 730 5784
Fax: +41 22 730 5484

Infrastructure Enabling Environmnent and e-Applications Department (IEE)
Email: bdtiee@itu.int
Tel.: +41 22 730 5421
Fax: +41 22 730 5484

Innovation and Partnership Department (IP)
Email: bdtip@itu.int
Tel.: +41 22 730 5900
Fax: +41 22 730 5484

Project Support and Knowledge Management Department (PKM)
Email: bdtpkm@itu.int
Tel.: +41 22 730 5447
Fax: +41 22 730 5484

Africa

Ethiopia
International Telecommunication Union (ITU)
Regional Office
P.O. Box 60 005
Gambia Rd., Leghar ETC Building
3rd floor
Addis Ababa – Ethiopia

Email: itu-addis@itu.int
Tel.: +251 11 551 4977
Tel.: +251 11 551 4855
Tel.: +251 11 551 8328
Fax: +251 11 551 7299

Cameroon
Union internationale des télécommunications (UIT)
Bureau de zone
Immeuble CAMPOST, 3e étage
Boulevard du 20 mai
Boîte postale 11017
Yaoundé – Cameroun

Email: itu-yaounde@itu.int
Tel.: + 237 22 22 9292
Tel.: + 237 22 22 9291
Fax: + 237 22 22 9297

Senegal
Union internationale des télécommunications (UIT)
Bureau de zone
19, Rue Parchappe x Amadou
Assane Ndoye
Immeuble Fayçal, 4e étage
B.P. 50202 Dakar RP
Dakar – Sénégal

Email: itu-dakar@itu.int
Tel.: +221 33 849 7720
Fax: +221 33 822 8013

Zimbabwe
International Telecommunication Union (ITU)
Area Office
TelOne Centre for Learning
Corner Samora Machel and
Hampton Road
P.O. Box BE 792 Belvedere
Harare – Zimbabwe

Email: itu-harare@itu.int
Tel.: +263 4 77 5939
Tel.: +263 4 77 5941
Fax: +263 4 77 1257

Americas

Brazil
União Internacional de Telecomunicações (UIT)
Regional Office
SAUS Quadra 06, Bloco "E"
11° andar, Ala Sul
Ed. Luis Eduardo Magalhães (Anatel)
70070-940 Brasilia, DF – Brazil

Email: itubrasilia@itu.int
Tel.: +55 61 2312 2730-1
Tel.: +55 61 2312 2733-5
Fax: +55 61 2312 2738

Barbados
International Telecommunication Union (ITU)
Area Office
United Nations House
Marine Gardens
Hastings, Christ Church
P.O. Box 1047
Bridgetown – Barbados

Email: itubridgetown@itu.int
Tel.: +1 246 431 0343/4
Fax: +1 246 437 7403

Chile
Unión Internacional de Telecomunicaciones (UIT)
Oficina de Representación de Área
Merced 753, Piso 4
Casilla 50484, Plaza de Armas
Santiago de Chile – Chile

Email: itusantiago@itu.int
Tel.: +56 2 632 6134/6147
Fax: +56 2 632 6154

Honduras
Unión Internacional de Telecomunicaciones (UIT)
Oficina de Representación de Área
Colonia Palmira, Avenida Brasil
Ed. COMTELCA/UIT, 4.º piso
P.O. Box 976
Tegucigalpa – Honduras

Email: itutegucigalpa@itu.int
Tel.: +504 22 201 074
Fax: +504 22 201 075

Arab States

Egypt
International Telecommunication Union (ITU)
Regional Office
Smart Village, Building B 147, 3rd floor
Km 28 Cairo – Alexandria Desert Road
Giza Governorate
Cairo – Egypt

Email: itucairo@itu.int
Tel.: +202 3537 1777
Fax: +202 3537 1888

Asia and the Pacific

Thailand
International Telecommunication Union (ITU)
Regional Office
Thailand Post Training Center, 5th floor,
111 Chaengwattana Road, Laksi
Bangkok 10210 – Thailand

Mailing address
P.O. Box 178, Laksi Post Office
Laksi, Bangkok 10210 – Thailand

Email: itubangkok@itu.int
Tel.: +66 2 575 0055
Fax: +66 2 575 3507

Indonesia
International Telecommunication Union (ITU)
Area Office
Sapta Pesona Building, 13th floor
Jl. Merdan Merdeka Barat No. 17
Jakarta 10001 – Indonesia

Mailing address:
c/o UNDP – P.O. Box 2338
Jakarta 10001 – Indonesia

Email: itujakarta@itu.int
Tel.: +62 21 381 3572
Tel.: +62 21 380 2322
Tel.: +62 21 380 2324
Fax: +62 21 389 05521

CIS countries

Russian Federation
International Telecommunication Union (ITU)
Regional Office
4, Building 1
Sergiy Radonezhsky Str.
Moscow 105120
Russian Federation

Mailing address:
P.O. Box 25 – Moscow 105120
Russian Federation

Email: itumoskow@itu.int
Tel.: +7 495 926 6070
Fax: +7 495 926 6073

Europe

Switzerland
International Telecommunication Union (ITU)
Telecommunication Development Bureau (BDT)
Europe Unit (EUR)
Place des Nations
CH-1211 Geneva 20 – Switzerland
Switzerland
Email: eurregion@itu.int
Tel.: +41 22 730 5111

International Telecommunication Union
Telecommunication Development Bureau
Place des Nations
CH-1211 Geneva 20
Switzerland

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