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Review

Applications of drone in disaster management: A scoping review

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ABSTRACT

The use of drones has rapidly evolved over the past decade involving a variety of fields ranging from agriculture, commercial and becoming increasingly used in disaster management or humanitarian aid. Unfortunately, the evidence of its use in mass disasters is still unclear and scarce. This article aims to evaluate the current drone feasibility projects and to discuss a number of challenges related to the deployment of drones in mass disasters in the hopes of empowering and inspiring possible future work. This research follows Arksey and O'Malley framework and updated by Joanna Briggs Institute Framework for Scoping Reviews methodology to summarise the results of 52 research papers over the past ten years, from 2009 to 2020, outlining the research trend of drone application in disaster. A literature search was performed in Medline, CINAHL, Scopus, individual journals, grey literature and google search with assessment based on their content and significance. Potential application of drones in disaster are broad. Based on articles identified, drone application in disasters are classified into four categories; (1) mapping or disaster management which has shown the highest contribution, (2) search and rescue, (3) transportation and (4) training. Although there is a significant increase in the number of publications on use of drone in disaster within the last five years, there is however limited discussion to address post-disaster healthcare situation especially with regards to disaster victim identification. It is evident that drone applications need to be further explored; to focus more on drone assistance to humans especially in victim identification. It is envisaged that with sufficient development, the application of drones appears to be promising and will improve their effectiveness especially in disaster management.

1. Introduction

Unmanned aerial vehicles (UAVs), more commonly referred to as drones, are small aircraft that fly autonomously. Originally developed for military purposes, they are now a major focus of research. Apart from unmanned aerial vehicles, drones are also referred to as UAS (Unmanned Aerial Systems), Remotely Piloted Vehicles (RPV), and Remotely Piloted Aircraft Systems (RPAS). The term "drone" is commonly known publicly, whereas the other terms, like UAVs, RPA, RPAS and UAS are official names given to the drone technology depending on the jurisdiction [1].

Previously, the term "drone" referred to an unmanned, radio-controlled military or target-towing aircraft. Nowadays, a drone is defined as an aircraft that flies without a pilot at the controls, but rather with the assistance of a ground operator or through automated flight with no human intervention. Drones are available for a variety of applications and can be used for crime scene surveillance [2], marine fauna detection [3], habitat destruction assessment [4], crop monitoring [5], and vegetation mapping [6]. Additionally, drone mapping has a wide range of applications in a variety of industries, including construction, agriculture, mining, and infrastructure inspection [7]. Recently, the application of drones to disaster or humanitarian relief has expanded to

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include search and rescue missions [8,9] disaster prevention [10] and disaster management [11,12].

Drones were initially designed as a simple device, but have grown in complexity as defined missions have become more complex. The diversity of drones is a primary factor in defining their operational capabilities, which are determined by their size, power, and application conditions [10]. Drones are classified into nine types, including fixed-wing, flapping-wing, rotary-wing, tilt-rotor, ducted fan, helicopter, ornithopter, and unconventional [7].

Disasters in any form are detrimental to the health and welfare of the affected population, but mass disasters disproportionately affect a large number of victims. Natural and man-made disasters are classified according to whether they are the result of an environmental, medical, industrial, or terrorist event [13]. Thus, when a disaster strikes, a rapid and effective response is critical to assisting the populace, reducing the number of victims, and mitigating the economic impact [14]. Regardless of the type of disasters or emergencies that occurred, disaster management is defined as a process or practise that includes mitigation, preparedness, response, and recovery [15].

Accurate data collection may be extremely difficult in an emergency situation due to the lack of coordinated actions by various agencies during a disaster [16]. Nonetheless, it has been suggested that in order to improve disaster management efficiency, new methodologies and technologies are required to conceptualise systems that incorporate a combination of telecommunication tools, remote sensing, and spatial/temporal-oriented databases [17].

Thus, the use of drones in a disaster has the following benefits: they reduce the time required to locate victims and the time required for subsequent intervention by searching a large area in a short period of time, in addition to providing critical information to rescuers about the route that needs to be taken during search and rescue operations [9]. Additionally, drones are capable of searching for alive victims buried beneath rubble using sensors such as noise sensing, binary sensing, vibration, and heat sensing [8]. These demonstrate the benefits of having drones on-site during disasters and the capability of drones as critical tools for acquiring aerial images.

To our knowledge, no comprehensive review has been conducted to assess the impact of drone applications in disaster situations. Earlier reviews concentrated on the construction [18], humanitarian [19,20], health [21], telemedicine [22], and public health [23] applications of drones. This scoping review was conducted to assess current drone feasibility projects and to identify recent advancements in drone technology that may expand the technology's current disaster applications. Thus, the primary research question that guides this review is "What are the current applications of drones in disaster management, specifically mass disaster?"

2. Method

A scoping review was conducted to synthesise evidence from a variety of study designs in order to clarify key concepts and identify gaps in the published literature, using the Arksey and O'Malley [24] and updated by Joanna Briggs Institute (JBI) Framework for Scoping Reviews. Framework for scoping reviews as a guide. Unlike systematic reviews, which focus exclusively on a single question and review objective, scoping reviews provide a broad overview of an unclear subject by mapping the available evidence from disparate sources. Because no comprehensive review of the research question has been conducted, the authors decided to conduct a scoping review to compile all available evidence on the subject before addressing more specific questions [25].

Arksey and O'Malley's framework is divided into five components: defining the research question, identifying relevant studies, selecting studies, charting the data, and collating, summarising, and reporting the results. The JBI framework or protocol is an extension of the previous framework, ensuring that a systematic approach is taken and that the process is transparent [25]. Additionally, this review adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA-ScR) guidelines (Fig. 1).

2.1. Search criteria

The review was framed around a PCC question (Population, Concept and Context) recommended for scoping reviews by the Joanna Briggs Institute [26] Table 1.

The study's search strategy identified relevant literature in the following databases: MEDLINE, CINAHL, and Scopus. Between January 2009 and December 2020, the databases were searched for the terms 'drone' OR 'unmanned aircraft system' OR 'unmanned aerial vehicle' OR'remotely piloted aircraft systems' OR'remotely piloted vehicles' AND 'disaster. Table 2 contains a summary of the search terms used. The initial date selected was when drones became commercially viable and gained popularity.

Additionally, similar search terms were used to locate any significant articles in the following journals: Forensic Science International, Journal of Forensic Sciences, Australian Journal of Forensic Sciences, International Journal of Legal Medicine, and Journal of Forensic and Legal Medicine. These journals were chosen because the majority of articles published were pertinent to this study. Furthermore, grey literature and Google searches were conducted.

2.2. Study identification and selection

The selected literature was evaluated for its significance and relevance based on its content and publication type. Following that, the publication type was determined to ensure that only research articles and case reports published in the English language were included. Other types of manuscripts were excluded, including editorial notes, reviews, and conference abstracts. We excluded studies that (1) used external extension of hardware, such as a robot, (2) relied heavily on technical and network assistance, (3) were not written in English, and (4) were reviews, commentaries, editorials, unpublished manuscripts, or conference abstracts.

After identifying articles in the aforementioned databases, they were imported into EndNote X6 software (Thompson Reuters, Philadelphia, PA, USA), where duplicates were removed. The eligibility criteria were used to perform a preliminary screening of articles based on their titles and abstracts. The full text of articles was then accessed to determine which articles were eligible for inclusion in the review, as illustrated in Fig. 1 for the PRISMA-ScR selection process flow diagram. A data extraction form was used to extract study characteristics such as the author(s), the year of publication, the country of origin of the study, the research design, the population, the concept, and the context. To address the objectives, a narrative synthesis of the results was conducted.

3. Results

The initial search using the keywords identified 15,747 articles. A total of 15,600 articles were excluded due to title, abstract, and duplicate removal screening. The remaining 147 articles were evaluated for eligibility on a case-by-case basis. Finally, only 52 full-text articles met the criteria for inclusion. Fig. 1 depicts the study collection's comprehensive review process. The articles included in the scoping review are summarised in Table 3.

3.1. General characteristics of the included studies for the scoping review

The publications included ranged in date from 2009 to 2020. In 2009, only one study was published. Following a five-year period, two studies were conducted in 2014, three in 2015 and 2016, seven in 2017, six in 2018, sixteen in 2019, and fourteen in 2020. Around 49 of the 52 articles were published within the last five years, indicating that a surge

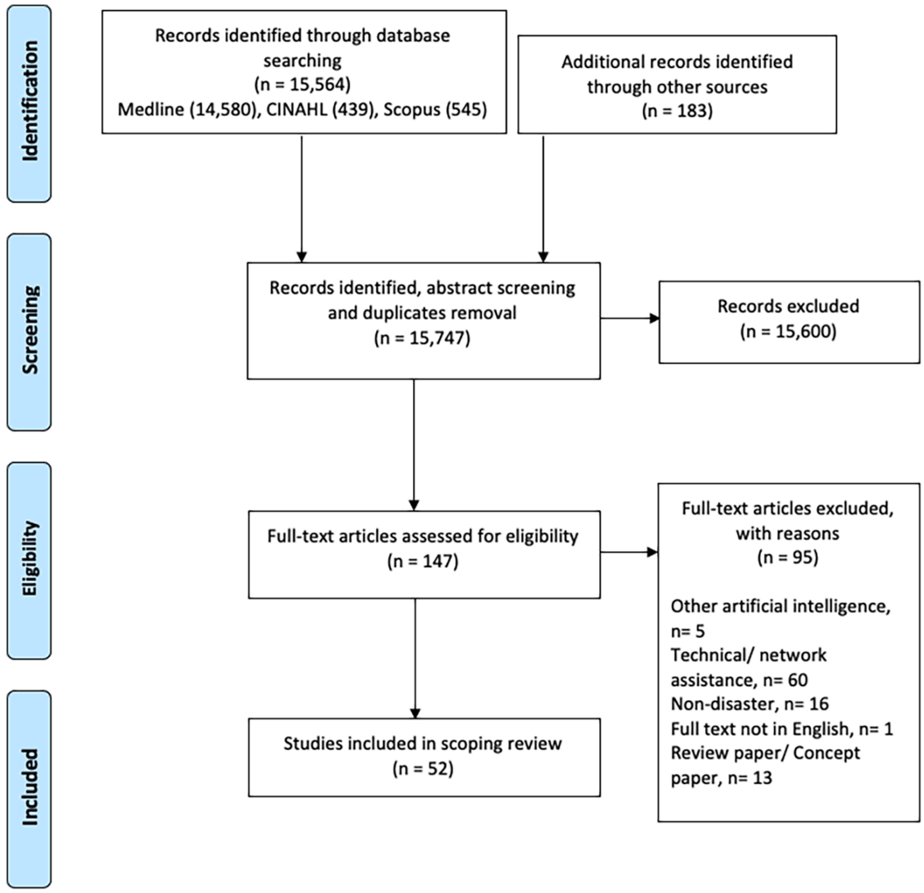

Fig. 1. PRISMA-ScR flowchart of the study collection.

Table 1
Search criteria based on a PCC question.

Population	Human, mannequin, images and video
Concept	All type of assessment; including questionnaire, observational study, case study and etc to evaluate the application of drones
Context	Natural or man-made disaster

Table 2
Summary of keyword terms.

	Keyword Terms
Drone related terms	Unmanned aerial vehicle (UAV) Unmanned aircraft system (UAS) Drone Remotely Piloted Aircraft Systems (RPAS) Remotely Piloted Vehicles (RPV)
Disaster related terms	Disaster Emergency Search and Rescue Mass Casualty Incidents (MCI)

in interest in drone applications in mass disasters began in 2015.

A total of 52 articles were reviewed, with the majority (7 of 52) conducted in the United States, as illustrated in Fig. 2. China came in second place with six articles, followed by Italy with five. This can be explained by the fact that these countries, particularly the United States, have experienced the highest number of weather-related disasters over the last two decades [27], including flooding, wildfires, hurricanes, tornadoes, and a variety of other disasters that cause significant economic and human-life losses.

The remaining papers were contributed by the United Kingdom (3), Japan (3), Indonesia (3), Taiwan (3), Korea (3), Canada (2), Sweden (2), Spain (2) and Greece (2), while Poland, Netherlands, Turkey, Russia, Belgium, Norway, India, Australia, Dominica, Saudi Arabia and Mexico contributed one paper each.

3.2. Types of disaster

As illustrated in Fig. 3, disasters can be classified as natural, man-made, simulated, search and rescue operations, and emergency aids. With a total of 22 studies (42%), the majority of studies focused on natural disasters, including landslides (8), hurricanes (5), earthquakes (3), flood (3), rockfall (1), forest fire (1), and volcano (1). The second highest contribution was 31%, which was used to fund other disaster-related activities such as search and rescue operations and emergency assistance. Twelve of the sixteen studies utilised drones for search and rescue, location, and rescue, while the remaining drones were used to transport emergency aid. Thirdly, with a total of 13 studies, is simulated disaster (25%). The simulated disaster involved a variety of hazards, including a crashed aeroplane, destroyed cars, and a flood disaster. Only one study (2%) focused on a man-made disaster, namely the Chernobyl radiological disaster, in which drones were launched outside contaminated areas to reduce operator risk during the radiation mapping process.

3.3. Application of drones

Drone application is another way to categorise and comprehend how drones are deployed. We demonstrated in these papers that there are four primary application areas at the moment: (1) mapping or damage assessment; (2) search and rescue; (3) transportation; and (4) training.

Table 3
Summary finding of eligible articles.

Author/ Year/ Country	Title	Study Design/ Population	Concept	Context
Greenwood et al. (2020) US [56]	Flying into the hurricane: A case study of UAV use in damage assessment during the 2017 hurricanes in Texas and Florida	Social media, direct observation, participant-observation and semi-directed interviews	- Able to assess damage depicting the post-hurricane condition of homes from image taken - Reflect the challenges when entering the field of disaster response, ranging from public perception to the creation of effective incorporation. - Still unclear where UAVs fit into the overall humanitarian cluster system. - No centralized system for tasking, compiling, and sharing humanitarian UAV data across aid agencies or NGOs.	Hurricanes in Texas and Florida
Luo et al. (2020) China [35]	Analyzing the formation mechanism of the Xuyong landslide, Sichuan province, China and emergency monitoring based on multiple remote sensing platform techniques	Observational study of 72 stereoscopic orthographic images of the landslide	- UAV manufactured by DJI and Pix4Dmapper to process the UAV images in post disaster assessment. - Accurately estimate the landslide and disaster information.	Xuyong landslide
Chang et al. (2020) Taiwan [36]	Application of unmanned aerial vehicle (UAV)- acquired topography for quantifying typhoon-driven landslide volume and its potential topographic impact on rivers in mountainous catchments	Observational study of high resolution aerial photographs of Laishe River from 2009 to 2015	- UAV used twice; January and November 2015. - Application used to analyse photos are Pix4Dmapper, DEMs and ArcGIS. - Emphasizes the feasibility of using UAVs to quantify the migration of landslide material and morphological changes in a mountainous river.	Typhoon and landslide
Yamazaki et al. (2020) Japan [67]	Audio processing based human detection at disaster sites with unmanned aerial vehicle	Experimental study	- UAV with 4 array microphone, integrated camera-based human detection system (PlayStation Eye), Raspberry Pi computer, loudspeaker, servomotor and small light-weight computer. - Able to confirm a clear human detection improvement using audio and images data but using images is difficult at higher altitudes.	Simulated disaster site
Tran et al. (2020) Korea [44]	Damage-map estimation using UAV images and deep learning algorithms for disaster management system	Observational study	- Phantom 4 Pro V2 UAV at 150 m incorporated with deep learning-based image segmentation algorithms. - Effective in extracting burnt areas from UAV images and able to estimate maps areas damaged by forest fires.	Forest fire
Schaefer et al. (2020) Dominica [46]	Low-cost UAV surveys of hurricane damage in Dominica: Automated processing with co-registration of pre-hurricane imagery for change analysis	Observational study	- 115 flights in 9 days using DJI Phantom 3 & 4. - UAV survey was rapid, accurate and cost-effective for disaster management applications.	Hurricane Maria
Jimenez-Jimenez et al. (2020) Mexico [30]	Rapid urban flood damage assessment using high resolution remote sensing data and an object-based approach	Observational study	- A hexacopter UAV equipped with a SONY camera and gyro-stabilised. 4 UAV flights at 120 m above ground. - Able to improve image classification of destroyed houses with high accuracy in short times compared to satellite images.	Flood caused by Tropical Storm Earl
Rottondi et al. (2020) Italy [31]	Scheduling of emergency tasks for multiservice UAVs in post-disaster scenarios	Experimental study	- UAVs equipped with video monitoring system, cellular communication interface and mounting frame for parcel carriage. - Better performance of multi-task UAVs than single-purpose UAV.	Simulated flood
Yakushiji et al. (2020) Japan [76]	Short-range transportation using unmanned aerial vehicles (UAVs) during disasters in Japan	Experimental study	- M1000 (Japanese UAV) UAV with maximum weight of 32 kg equipped with AED, rucksack, foodstuffs, self-injection set or insulin in the refrigerator in different flight times. - UAVs able to safely transport 17 kg of goods to the destination during disasters.	Simulated disaster
Zweglinski (2020) Poland [32]	The use of drones in disaster aerial needs reconnaissance and damage assessment-Three-dimensional modelling and orthophoto map study	Observational study of 16 disaster managers from 13 European countries	- 13 min of drone flights for the needs reconnaissance sessions and 15 min for the damage assessment sessions. - Improved the efficiency in terms of time and able to facilitate disaster managers with more precise damage assessment.	Simulation of flooding environment
Andreadakis et al. (2020) Greece [33]	Unmanned aerial systems-Aided post-flood peak discharge estimation in Ephemeral streams	Observational study	- Quadcopter DJI Phantom 4 Pro with DJI GO 4 Pro on an Apple iPad Pro - UAS aided data provided accurate results as traditional approach but more flexible	Flood hazard

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Table 3 (*continued*)

Author/ Year/ Country	Title	Study Design/ Population	Concept	Context
			in terms of resources and timing where the study reach can be remotely revisited.	
Liu & You (2020) China [71]	Drone transports medical supplies to Puerto Rico based on shortest path	Observational study	- 7 types of drones and 3 types of medical packages distributed using Dijkstra algorithm. - Improves the efficiency of rescue and distributes rescue materials effectively.	Hurricane
Yeh & Chuang (2020) Taiwan [40]	Morphological analysis of landslides in extreme topography by UAS-SfM: Data acquisition, 3D models and change detection	Observational study	- DJI Phantom 4 Pro and Phantom 4 RTK operated manually. - UAV-SfM is a suitable method to analyse detailed morphological information of landslide with extreme topography with low cost.	Landslide
Sugita et al. (2020) Japan [52]	Quick and low-cost high resolution remote sensing using UAV and aircraft to address initial stage of disaster response	Experimental study	- DJI Phantom 4 Pro for UAV and Nikon D810 on the helicopter. - Good quality for information gathering in the initial stage of disaster response in much lower cost.	Disaster simulation
Al-Kaff et al. (2019) Spain [59]	An appearance-based tracking algorithm for aerial search and rescue purposes	Experimental study using static and dynamic human bodies	- Allows the tracking and identification of multiple people with invariance to the scale, translation and rotation of the point of view with respect to the target objects in remarkably challenging aerial sequences.	Simulated wilderness search and rescue
Bogle (2019) US [74]	The case for drone-assisted emergency response to cardiac arrest: An optimized state wide deployment approach	Experimental study	- Small autonomous drones carrying AED. - Improve survival outcomes, decreased the tome of defibrillator arrival and cost effective.	Emergency response to cardiac arrest simulation
Lygouras et al. (2019) Greece [62]	Unsupervised human detection with an embedded vision system on a fully autonomous UAV for search and rescue operations	Experimental study	- 1 rescue UAV embedded with Nvidia Jetson TX1 for the real-time swimmer detection. - Precisely detecting and rescuing open water swimmers in peril and executing time-crucial life-saving operations.	Search and rescue in open water sea
Connor et al. (2019) UK [50]	Radiological mapping of post-disaster nuclear environments using fixed-wing unmanned aerial systems: A study from Chornobyl	Observational study	- Custom made UAS weight of 8.5 kg and equipped with supporting sensors including radiation sensor, barometric altitude and airspeed indicator. Hand-launched and recovered by parachute. - Minimised risk of the operators during radiation mapping investigations as UASs can be launched outside of contaminated regions.	Radiological disaster
Nimilan et al. (2019) India [75]	Drone-aid: An aerial medical assistance	Experimental study	- X-shaped frame quadcopter equipped with ECG sensor, AED, temperature sensor and respiratory sensor.- Aid in analysing patient's condition before arrival of ambulance and to deliver medical drugs and blood samples during emergencies.	Emergency response during disaster simulation
Al-Naji et al. (2019) Australia [61]	Life signs detector using a drone in disaster zones	Experimental study using human subjects and one full-body male mannequin	- GoPro Hero 4 was attached to drone with gimbal to reduce vibrations and stabilise the footage. - Videos captured at an altitude of 4–8 m from the subject. - Videos from drone able to detect 100% the presence or absence of life signs from humans and mannequin at different poses - A good tool for search and rescue operations.	Disaster simulation
Alotaibi et al. (2019) Saudi Arabia [64]	LSAR: Multi-UAV collaboration for search and rescue missions	Experimental study	- A team of multiple UAVs connected through a cloud server running the LSAR algorithm. - UAV aircraft running the LSAR algorithm has highest percentage and require the least amount of time to rescue a survivor.	Disaster simulation
Nex et al. (2019) Netherlands [53]	Towards real-time building damage mapping with low-cost UAV solutions	Experimental study	- DJI Mavic Pro connected to remote control, smartphone and laptop via USB and wi-fi. - Building damage maps can be generated in near real-time using low-cost and commercial UAVS even though reduces the productivity of flight but better images quality.	Building damage in search and rescue simulation
Watson et al. (2019) US [37]	UAV-Derived Himalayan Topography: Hazard assessments and comparison with global DEM products	Observational study of high mountain Himalaya	- DJI Phantom 4 Pro + with a 20 megapixel camera was manually flown from April and May 2018.	Landslide and flood related hazard

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Table 3 (*continued*)

Author/ Year/ Country	Title	Study Design/ Population	Concept	Context
			- Fine-resolution topography from UAV DEMs is acquired for monitoring purposes and for real-time decision making but time required to obtain approval is too long.	
McRae et al. (2019) US [58]	Using an unmanned aircraft system (drone) to conduct a complex high altitude search and rescue operation: A case study	Case study	- DJI Mavic Pro drone - Drones help to reduce response time and maintain the safety of responders at high altitude and difficult areas in search and rescue operations.	Search and rescue
Meshcheryakov et al. (2019) Rusia [63]	An application of swarm of quadcopters for searching operations	Experimental study	- UAV embedded with telemetry system, video transmission system, GPS, depth camera sensor, YOLO algorithms as detection system. - Significant advantage using UAV over helicopter or a chain of people.	Search and rescue simulation
Marfai et al. (2019) Indonesia [47]	An Evaluation of tsunami hazard modelling in Gunungkidul coastal area using UAV photogrammetry and GIS Case Study: Drini coastal area	Case study	- Fixed wing aircraft with a Bixler airframe equipped with Canon PowerShot A2500 pocket camera with a resolution of 16 Mpix. - Evaluation of hazard maps and assembly points using UAV lead to more effective, low cost, accurate and less time-consuming on the evacuation process.	Tsunami inundation model
Kim et al. (2019) Korea [38]	Applicability assessment of UAV mapping for disaster damage investigation in Korea	Observational study	- DJI's Inspire2 & FireFly6 mounted with camera and gimbal at the flight attitude of 100 ~ 200 m. - Alternative approach to support or replace the labor-intensive disaster site survey that needs to investigate the disaster site more quickly and accurate.	Landslides, river floods and reservoir collapse
Baeck et al. (2019) Belgium [56]	Drone based near real-time human detection with geographic localization	Experimental study using mannequins	- Fixed wing drone; senseFly eBee platform) with an optical camera at 100 m altitude. - Able to detect human dummies, and translate the pixel coordinate to real world coordinates near real time and allows search and rescue teams to operate more efficiently.	Search and rescue
Hung et al. (2019) Taiwan [41]	Multi-Temporal high-resolution landslide monitoring based on UAS photogrammetry and UAS lidar geoinformation	Observational study	- Integrates UAS, field geomatic survey, terrestrial laser scanner and UAS Lidar. More than 10 UAS flight missions since 2015 - Provide geoinformatics dataset of hazardous area and for hazard mitigation and planning.	Landslide
Ulfa & Sartohadi (2019) Indonesia [42]	The role of small format aerial photographs for first response in landslide event	Comparison study between first responder and aerial photographs	- DJI Phantom 4 and Agisoft Photoscan Software - The aerial photograph is effective for landslide first response which time is more efficient compared to first responder information in terms of situation analysis and evacuation process.	Landslide
Clark et al. (2018) Canada [66]	What role can unmanned aerial vehicles play in emergency response in the Arctic: A case study from Canada	- Semi structured interviews (n = 18) - Participants: SAR responders, elders & emergency management officials	- DJI Phantom 3, DJI Phantom 4 and iPhones for UAV video feeds and image capturing in time of flight 17 - UAVs were demonstrated to have potential benefits for hazard monitoring but not for SAR or medical response due to legal restrictions, weather margins, and local capacity. - There are numerous limitations to the use of consumer UAVs by Arctic communities.	Search and rescue
Hashemi-Beni et al. (2018) US [34]	Challenges and opportunities for UAV-based digital elevation model (DEM) generation for flood-risk management: A case of Princeville, North Calorina	Case study	- Trimble UX5 fixed-wing aircraft embedded with Sony a5100 camera flying at 100 m above ground level at 80kph of speed to mapping and flood assessment. - Proven to be highly useful for mapping and flood assessment applications. - However, failed image matching in low altitude image sets due to inflexibility of UAV data.	Flood disaster
Duo et al. (2018) Italy [45]	Local-scale post-event assessments with GPS and UAV-based quick response surveys: A pilot case from the Emilia-Romagna (Italy) coast	Pilot case study	- DJI Phantom Vision 2 + was conducted manually, back and forth across the beach. - - Effective for erosion and flooding assessments by providing detailed, continuous 2-D (and 3-D) information,	Coastal storm

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Table 3 (*continued*)

Author/ Year/ Country	Title	Study Design/ Population	Concept	Context
			with less time spent in the field in comparison with traditional RTK GPS surveys and other approaches.	
Jain et al (2018) Canada [77]	Comparison of unmanned aerial vehicle technology-Assisted triage versus standard practice in triaging casualties by paramedic students in a mass-casualty incident scenario	Randomized comparison study with 40 paramedic students and UAV	- Tornado H920 UAV with a remote loud speaker system and infrared camera. - No increase in time on scene by using UAV but demonstrated the accurate, safe and feasible use of UAV at mass casualty's incident.	Simulated motor vehicle collision (mass-casualty)
Li & Tang (2018) China [54]	Building damage extraction triggered by earthquake using the UAV imagery	Observational study	- UAV images able to extract the building damage accurately and timely.	Post- Earthquake
Wang et al. (2018) China [49]	Near real-time georeference of unmanned aerial vehicle images for post-earthquake response	Observational study	- Fixed wing UAV equipped with a Sony camera at flight height of 250 m. - UAV images are achieved georeferenced in rapid manner which is of great value in disaster emergency application.	Earthquake
Fernandez-Pacheco et al. (2017) Spain [78]	Drones at the service for training on mass casualty incident	Observational study; mixed method	- Drones are a great resource for training and preparing of EMS workers	Simulation of mass casualty incident
Claesson et al. (2017) Sweden [73]	Time to delivery of an automated external defibrillator (AED) using a drone for simulated out of hospital cardiac arrests vs emergency medical services (EMS)	Experimental study	- 8 rotor drone (weight 5.7 kg) equipped with GPS, camera and autopilot system to dispatch an AED weighing 763 g within 10 km radius in 18 time of flight - Drone arrived earlier than the EMS in all simulated cases over short distances in good weather.	Emergency scenario
Bejiga et al. (2017) Italy [69]	A convolutional neural network approach for assisting avalanche search and rescue operations with UAV imagery	Observational study	- 2 datasets: 1. Frames from different videos of ski areas captured by UAVs available on the web. 2. Video recorded on a mountain close using a GoPro camera mounted on a hexacopter. - Detection performance increases with an increase in resolution.	Avalanche search and rescue
Karaca et al. (2017) Turkey [59]	The potential use of unmanned aircraft systems (drones) in mountain search and rescue operations	Randomized simulation study to compare classical line search and drone-snowmobile technique in terms of first human contact time	- DJI Phantom 3 Pro was used with image quality of 1080p. - Drone search technique able to search, locate and rescue victim faster compared to classical line technique.	Mountain search and rescue
Van Tilburg (2017) US [9]	First report of using portable unmanned aircraft systems (drones) for search and rescue	Case study	- Phantom 3 4 K quadcopter UAS and SAR Bot with thermal imager. - UAS able to confirm a fatality and send a rescuer with right item and augmented ground searching and acquired images of difficult areas.	Search and rescue
Lin et al. (2017) China [39]	Landslide identification and information extraction based on optical and multispectral UAV remote sensing imagery	Observational study	- UAV remote sensing system consists of fixed-wing UAV platform, ground station control system, flight control system and remote sensor. - Prove the feasibility and effectiveness of applying the fixed wing UAV system to rapid identification and extraction of landslide information.	Landslide
Tarigan et al. (2017) Indonesia [48]	Mapping a volcano hazard area of Mount Sinabung using drone: Preliminary Results	Observational study	- Lightweight camera was mounted on drones with gimbal to produce stable shooting. - Photo mosaic and 3D map obtained from drone images could be used to access the volcanic disaster effectively and efficiently.	Volcano hazard
Sun et al. (2016) China [1]	A camera-based target detection and positioning UAV system for search and rescue (SAR) purposes	Experimental study	- UAV system consists of Talon UAV (weight = 3.8 kg), navigation system, GoPro Hero 4, Odroid XU4 and oCam for target identification and mapping in 8 flight test - Performance of the post-target identification is better than real-time onboard target identification, due to the higher resolution of the image source. - Provided an efficient real-time supplementary tool for the all-in-one rescue mission.	Simulated crashed airplane and broken cars
Claesson et al. (2016) Sweden [72]	Unmanned aerial vehicles (drones) in-out of hospital cardiac arrest	Experimental study	- 2 different eight-rotor class 2 UAV's with two latches holding the AED were used in 13 test flights.	Emergency case scenario

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Table 3 (*continued*)

Author/ Year/ Country	Title	Study Design/ Population	Concept	Context
			- Delivery of AED: 1. AED was dropped from the UAV using a parachute technique from high altitude 2. AED was dropped from the UAV at an altitude of 3–4 m with a remote release system 3. landed on the UAV sites - Both drones arrived before EMS in urban and rural areas. The safest ways to deliver an AED to the bystander in rural areas by latch-release from low altitude or landing the drone on flat ground.	
Kim et al. (2016) Korea [55]	Data management framework of drone-based 3D model reconstruction of disaster Site	Observational study	- Drone is equipped with various sensors, stereo-vision camera and gimbal to develop depth map of the disaster site. - Drone image date successfully developed the 3D model to reconstruct the disaster site effectively.	Simulation disaster
Abrahamsen (2015) Norway [65]	A remotely piloted aircraft system in major incident management: Concept and pilot, feasibility study	Mixed methods- direct observation using audio and video recordings, informal interviews, participant observation and researcher's field notes	- RPAS with sensors, video camera, avalanche beacon, laser, release hook & searchlight. - Scenario 1 (Mass casualty accident): Possible to determine type of accident, number of vehicles involved and damage assessment. - Scenario 2 (Mountain rescue): Possible to observe rescue climbers planning and evacuation of the skier. - Scenario 3 (Unknown number of skiers buried in an avalanche): Managed to locate the buried subject and rescuers were sent to the location. - Scenario 4 (Ice fisherman through thin ice in a lake): RPAS was used as a tool carrier, successfully transport and drop the equipment within reach of a person lying on the ice. - Scenario 5 (Aerial search for casualties under different lighting conditions): Able to detect human body-sized silhouettes and warm objects at night via infrared camera.	Mass casualty traffic accident & search and rescue simulation
Boccardo et al. (2015) Italy [29]	UAV deployment exercise for mapping purposes: Evaluation of emergency response applications	Experimental study	- Fixed-wing and rotor platforms were used to evaluate the fitness for mapping purposes in an emergency context and possible limitations. - Multi-rotor platforms are more flexible, suitable for surveying small areas or isolated buildings while fixed-wing UAVs to mapping large areas such as floods and wildfires.	Flood disaster simulation
Giordan et al. (2015) Italy [43]	Brief Communication: The use of an unmanned aerial vehicle in a rockfall emergency scenario	Case study	- Six-rotor multicopter Carnboncore 950 equipped with a GoPro Hero 3 digital video-camera and Nikon AW 100. - Data was processed with Photoscan software and VirtualDub. - Drone act as a rapid and low cost solution where the survey results from disaster site have to be available in a rapid and straight- forward. - Able to obtain information on the unstable area, by taking a large number of photos and videos from several points and different angles of view.	Rockfall emergency
Mardell et al. (2014) UK [70]	A comparison of image inspection modes for a visual search and rescue task	- N = 18 (none had received training in SAR) - Image presentation and questionnaire	- 1 drone is used to collect images at three different speeds: 60,90 and 120 mph in SVP (serial visual presentation) and moving mode. - Better target detection in SVP compared to moving mode but consist of high number of incorrectly identified targets. - Lower speed has better target identification in both modes.	Search and rescue simulation
Adams et al. (2014) US [51]		Images and videos of two severely damaged residential buildings		Post-Tornado

(continued on next page)

Table 3 (*continued*)

Author/ Year/ Country	Title	Study Design/ Population	Concept	Context
	High resolution imagery collection for post-disaster studies utilizing unmanned aircraft systems (UAS)		- Custom UAS (UAV, ground control station and sensors) equipped with digital camera and Go Pro Hero 2 HD for video imagery. - High resolution of the UAS based imagery is suitable for identification of damage at affected buildings.	
Tatham (2009) UK [28]	An investigation into the suitability of the use of unmanned aerial vehicle system (UAVS) to support the initial needs assessment process in rapid onset humanitarian disasters	Case study	- Aerosonde UAV embedded with visual and IR cameras. - UAV provide a cost-effective, operating in less favourable weather conditions and can be brought into operation faster than fixed wing light aircraft and helicopter.	2005 Pakistan earthquake

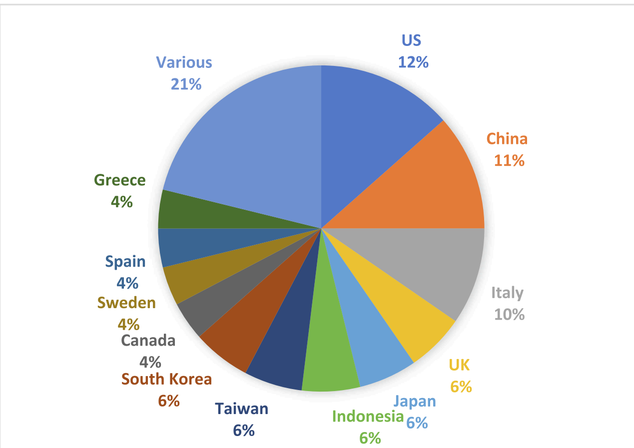

Fig. 2. Countries of authors' affiliation.

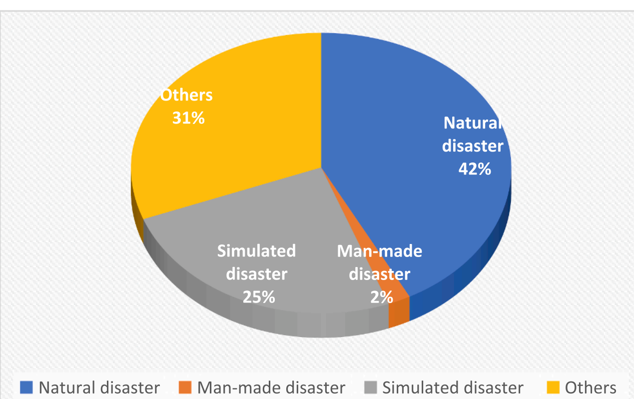

Fig. 3. Disaster classification.

3.3.1. Mapping or disaster management

Drone mapping has significant application in a variety of industries, including construction, agriculture, mining, and infrastructure inspection. Drones are extremely useful in the context of disaster management for monitoring, mapping, and damage assessment. As a result, the majority of the studies presented are in this promising application area. Tatham's initial study [28] examined the use of drones to aid in initial disaster assessment. The author used the 2005 Pakistan earthquake as a case study because it exemplifies a large-scale, rapid-onset disaster that impacted a large geographic area. In comparison to a fixed wing light aircraft or helicopter, the author discovered that drones were more cost effective, faster, and suitable for use in extreme weather conditions.

Drones have been extensively used in the aftermath of floods [29–34], landslide [35–42], rockfall [43], forest fire [44], hurricanes [45,46], tsunami [47], volcano [48], earthquake [49], and even the Chernobyl radiological disaster [50]. Drones appeared to provide significant value in disaster management when compared to conventional methods in terms of cost and efficiency in these studies. For example, drones are more efficient than first responder information [42], delivering high-quality images in less time than satellite images [48,51] and GPS survey [45]. Drones were also effective in assessing erosion and flooding, as they provided detailed and continuous 2D and 3D data with minimal time spent on-site [45]. Additionally, drones have proven to be more adaptable in terms of resources and timing, allowing for remote revisiting of the study site [33]. Furthermore, drones are capable of sharing information more efficiently during the initial stages of a disaster with the development of a drone aerial photo sharing web system [52].

Drones have also been used to assess building damage in difficult-to-access areas [51,53,54]. Apart from mapping and damage assessment, drone images have been used to create 3D models of the disaster site using the Unity Engine software [55]. Drone mapping has been implemented by Baeck, Lewyckyj, Beusen, Horsten, and Pauly [56], which included flight planning, GNSS-RTK surveying, aerial photo acquisition, keypoint extraction, 3D point cloud extraction and image matching, and finally DEM and *ortho*-image generation. A Digital Elevation Model (DEM) created via drone-based photogrammetry is the optimal 3D model for evacuation planning [48]. DEM-drone outperformed DEM-RBI (national topographic map RBI map) in terms of spatial and temporal resolution, making it an excellent source of data for disaster management [47]. Despite reports on the effectiveness of drone use, several reports discuss the technology's challenges or disadvantages. Tatham [28] reported that, while drones have proven to be extremely useful for mapping and flood assessment applications, they are limited in their ability to collect low altitude image data. Light Detection and Ranging (LiDAR) data were used to evaluate the quality and accuracy of drone-based DEMs in their work. While LiDAR is the preferred method for creating 3D models, DEMs are widely used for flood modelling and mapping. Unfortunately, image matching at low altitude was unsuccessful due to the inflexibility of the drone-derived DEM in light of the application's demanding requirements. There was no centralised system for assigning, compiling, and sharing humanitarian drone data across aid agencies or non-governmental organisations, resulting in a lack of clarity regarding drone use in disasters and public perception during the 2017 hurricanes in Texas and Florida, USA [57]. Approval from authorities was also a challenge for Watson, Kargel, and Tiruwa [37], with helicopter flights receiving approval faster and with fewer permission requirements, despite their limited ability to access remote sites in comparison to drones. All of these factors could result in ineffective disaster management through the use of drones.

Multi-rotor platforms offer greater flexibility and are better suited to surveying small areas or isolated buildings, whereas fixed-wing drones are better suited to mapping large areas such as floods and wildfires [29]. In a matter of minutes, a very high resolution orthophoto from both platforms is available, significantly speeding up post-event analysis. Orthophotos are created from drone image data sets using the Photoscan software, which is used for 3D reconstruction. They are then used for emergency mapping activities, such as identifying the most affected areas and assessing damage to critical infrastructure. Additionally, Photoscan software was used to process images from drone surveys in rockfall scenarios, along with VirtualDub software for video editing [43]. The orthophoto images created by Luo et al. [35] were also effective in landslide disasters, but the images were processed using Pix4Dmapper. The authors proposed that multiple remote sensing platforms, including satellite images, drone photogrammetry, and ground-based radar, should be used before and after disasters to study the various phases of landslides in order to prevent future disasters and ensure the safety of emergency response. Chang et al. [36], proposed similar configurations, in which drone-acquired DEMs were combined with airborne LiDAR (satellite images) to assess topography changes before and after a typhoon and to quantify changes in landslide volume. Additionally, the LiDAR sensor can be mounted on a drone as a geomatics technology tool [41]. Schaefer et al. [46], pioneered the use of a built-in Python script to automate the extraction of structure from drone images and the generation of orthophotographs, enabling image comparison and change detection between pre- and post-hurricane surveys.

Drone efficiency in disaster scenarios can be increased by using a multi-purpose drone that performs better than a single-purpose drone, but the drone's equipment and mission plan must be carefully planned to avoid the drone's trajectories colliding [31]. Advanced photogrammetric techniques and deep learning algorithms were combined to produce rapid results with an accurate map of building damage, which aided first responders in their rescue efforts [53]. Drone-SfM technology has been shown to be effective at rapidly creating high-quality digital surface models of landforms on a shoestring budget [40]. The authors tested two types of drones and discovered that Real Time Kinetic (RTK) drones can significantly improve the accuracy of three-dimensional (3D) models. Additionally, the rapid georeferencing algorithm has been well developed, which is advantageous in disaster-related applications where thousands of drone images can be processed in a short period of time [49].

One study extended image processing to create orthophotos from Photoscan to the DroneDeploy platform, incorporating image segmentation algorithms based on deep learning to identify burnt areas [44]. The novel approach demonstrated its efficacy in extracting burnt areas and has the potential to contribute to the estimation of maps depicting the areas damaged by forest fires. In the context of radiological mapping, a customised drone was introduced that could be launched manually and recovered using a parachute attached to the aircraft's tail [50]. Additionally, the system included supporting sensors such as a radiation sensor, barometric altitude indicator, and airspeed indicator. The drone's raw gamma-ray data was converted to cesium equivalent dose-rate (CED) data that was equivalent to the ground-based team's data. This study established that radiation mapping investigations can be conducted safely outside of contaminated areas.

3.3.2. Search and rescue

The use of drones for search and rescue has increased in recent years, as has the capability of rescue operations. Numerous researchers have examined this area in a variety of contexts. Van Tilburg [9] presented the first case report involving the use of drones, in which drones were used in a slot canyon to confirm a fatality in steep terrain. According to the report, drones assisted ground search efforts by acquiring images of areas that were difficult or impossible to search. McRae, Gay, Nielsen, and Hunt [58] presented another case study in which commercial drones were used at high altitudes to locate a missing climber. The use of drones significantly speeds up the rescue process without endangering the rescuers. Additionally, a prospective randomised simulation study was conducted to compare rescuers and drone technique for locating and reaching the victim in a snow-covered environment [59]. They concluded that drones were able to search for and locate the victim over a larger area in less time than rescuers.

Later studies established the effectiveness of drones for search, locate, and rescue missions in incredibly difficult aerial sequences [56,60,61]. Multi-Object Tracking algorithms based on colour and depth data collected from onboard sensors were introduced to provide useful information in incredibly difficult aerial sequences for the detection of victims [60]. The human detection method was enhanced by combining deep learning and photogrammetric algorithms and positioning them on DEM and orthomosaic images using geographical coordinates. As a result of this strategy, Search and Rescue (SAR) teams were able to operate more efficiently in difficult-to-reach areas. A novel method of detecting victims has been proposed in which drone data can detect cardiopulmonary motion caused by the victims' periodic chest movement [61]. The system successfully detects signs of life in a variety of poses with a 100% accuracy, indicating that it has potential as a future tool for SAR operations.

The technology has also been a great tool to detect victims at open sea [62]. Drone technology combined with the Global Navigation Satellite System (GNSS), real-time computer vision, and deep learning techniques may enable drones to provide accurate assistance to first responders in a short period of time. A new technique that employs a swarm of drones rather than a single drone has been demonstrated to be effective in searching for missing persons over a large area, reducing costs and time while increasing or maintaining the quality of SAR operations [63]. The use of a team of drones in SAR missions has the potential to save the greatest number of people in the shortest amount of time [64]. Additionally, the authors proposed a novel technique called the layered search and rescue (LSAR) algorithm, which increases the percentage of rescuers as the number of drones increases.

Despite the disruption potential discussed previously, drones have been used at high altitude and in difficult-to-access areas, reducing response and evacuation times while maintaining responder safety, and even locating buried subjects [65]. Simulated exercises were also conducted to evaluate the feasibility and concept of using a Remotely Piloted Aircraft (RPA) system equipped with a variety of sensors, including a video camera, an avalanche beacon, and a tool carrier for equipment such as a laser, a release hook, and a searchlight. The author concluded that RPA is feasible and capable of assisting in situation assessment and decision-making during major incidents.

Nonetheless, there are numerous drawbacks to using drones for SAR, including legal constraints, weather conditions, and local community capacity [66]. It was challenging to detect persons at high altitude using images alone, but this was solved by mounting an array microphone on a drone to detect human voice and YOLO v3, a deep-learning-based algorithm for detecting humans from images [67]. Due to the higher image resolution, post-image processing performs better at detecting and identifying the target than real-time processing does [68–70]. Through several simulated search and rescue missions, a successful all-in-one camera-based target detection and positioning system capable of on-board, real-time, and post-target identification, as well as aerial image collection for further mapping applications, was developed [68]. The system is composed of a drone, a communication system, an automatic antenna tracker, cameras, an on-board processing board called an Odroid, and a gimbal. By integrating pre- and post-processing methods, the detection performance also increases as the image resolution increases [69]. This is because more detailed information is available at a higher resolution than at a lower resolution.

3.3.3. Transportation

For many years, researchers have been interested in the transportation of medical or emergency supplies to a disaster-affected region or during an emergency situation [71]. Three studies examined the transportation of medical supplies in an emergency situation, and one examined the transportation of medical supplies during a disaster. Three methods for delivering defibrillators safely and more quickly at the emergency scene have been developed in comparison to emergency medical services (EMS) [72]. They proposed that the most secure method of delivering a defibrillator is via latch-release from a low altitude or by landing on flat ground. Claesson et al. [73] extended the work and concluded that drones arrived sooner than EMS in all simulated cases involving short distances and favourable weather. The study took place in a restricted airspace with significant delays in EMS response times and a densely populated area.

In addition, drones have been shown to significantly improve the survival rate and cost effectiveness of emergency cardiac arrest response [74]. Besides, drones can be used to assess a patient's condition prior to the arrival of an ambulance and to deliver medical supplies and blood samples during emergencies. Several studies have documented the transportation of goods to their destinations via drones during disasters [75,76]. Their studies demonstrated the successful transport of disaster medical assistance team equipment, AED, insulin, and emergency food weighing up to 17 kg using a rope suspension method under the manual supervision and control of a pilot. According to the authors, drones are one of the most promising disaster mitigation and intervention strategies available at the moment.

3.3.4. Training

Not only have drones been used in disaster mapping and search and rescue operations, but they can also be an excellent resource for training and preparing EMS personnel in Mass-Casualty Incidents (MCI) research [77]. Fernandez-Pacheco [78] conducted a simulation study to compare participants' self-perception of their ability to visualise aerial views before and after the MCI simulation. A questionnaire was administered to a total of 35 participants prior to and following the MCI simulation involving 40 victims. They concluded that drone use is more straightforward and cost-effective in open-air situations involving a large number of victims and large open spaces. Additionally, participants' self-perception improved following the MCI simulation, either individually or in groups.

4. Discussion

4.1. Strength of the study

To our knowledge, this is the first comprehensive scoping review of drone applications in disaster situations. Existing review articles have not discussed disasters specifically and are based on a broad search without using a structured method for literature review, which may result in the omission of relevant research articles. On the other hand, this scoping review was capable of screening all publicly accessible resources worldwide. Although a systematic review cannot be conducted at the moment due to the scarcity of experimental studies in the context of disasters, the lack of standardisation of disaster drones, the lack of local enforcement and regulations regarding drone use, as well as a lack of knowledge and awareness, this review followed a structured methodology that included the type of disaster, the application of drones, drone interventions, and research. Thus, this article may be the most in-depth examination of drone applications in disasters.

4.2. Knowledge gaps

This article demonstrates several shortcomings and a significant knowledge gap in prior research on drone applications in disasters. Our review reaffirms the scientific community's interest in disaster relief aided by drones. The following constraints and challenges must be addressed for future development. Studies that rely on simulations overestimate the drone's performance in comparison to its performance in real-world disasters. When applied to real-world disasters, researchers' obstacles should be considered. Additionally, there is no evidence in the literature for Disaster Victim Identification (DVI), indicating that it is worth studying. It would be worthwhile to consider additional parameters associated with drone applications. Additionally, drone flight policies and regulations vary by region, and no standard drone procedures, characteristics, or properties of drones have been established. Standardized and enhanced regulation of drone deployment and integration into governmental and non-governmental regions will improve short- and long-term analytical capabilities for damage minimization. Additionally, drones' appropriate and correct properties can be advantageously exploited in certain circumstances, enhancing their capability for disaster response.

One of the challenges that must be highlighted is the presence of prohibited areas where drones cannot be deployed. The design of drone routes within no-fly zones is a critical area of research. A permanent agreement between nations should be implemented to facilitate and secure the deployment of humanitarian assistance. A discussion with the appropriate aviation authorities to expedite the emergency response permit process should also be encouraged. A lack of photogrammetry quality and a lengthy processing time have also been reported. To overcome these constraints, both a video and a photo camera can be used to set up a possible solution or manual. Additionally, photogrammetrists must be prepared, well-trained, and have pre-planned procedures for handling imagery acquired during a disaster, in order to maximise the photogrammetry's quality. Without a doubt, faster processing times and more accurate data could be obtained in a timely manner. Adverse weather conditions such as low visibility, torrential rains, and strong winds can also be a significant challenge. The majority of the literature examined drones in typical weather conditions. As a result, flight operations may be delayed in the event of a true disaster. To address this issue, researchers are advised to conduct their research with adverse weather conditions in mind, and waterproofing electronic components may be implemented, particularly during rainy weather. Proper training for SAR teams on the use of drones should be managed in the context of SAR operations. Given the limitations of the drone's specification, such as battery life, the SAR team should be well versed in proper drone operation. Prior to the SAR mission, planning and developing a search strategy is critical to minimising risk to the SAR teams and maximising victim rescue time. Finally, low awareness and a negative perception of the importance of drones in disaster response among the local community, particularly in rural areas, must be addressed, as this could result in response delays due to the local community's lack of cooperation.

This review reveals a significant increase in the number of publications over the last five years, implying a significant increase in the knowledge, awareness, and popularity of drone application in disaster situations. However, much of the existing literature is experimental, introducing bias into drone performance due to the absence of real-world disasters. Additionally, this study demonstrates that mapping or disaster management played a significant role in disaster drone research. Additionally, the majority of studies revealed that the technical capabilities of drones or such innovation are driven by computer and software engineering or computer science, which improved the drone's performance. Healthcare and health-related applications received scant attention, as the majority of studies concentrated on the transportation of medical equipment or emergency supplies. However, data on the use of drones in the post-disaster period, particularly for health-related applications such as disaster victim identification, are scarce. While several studies have demonstrated the use of drones to detect decomposed bodies using animal model experiments, data on their use in real-world DVI involving human victims remains scarce. Additionally, there have been some unsubstantiated claims about the use of drone technology to search for missing people and bodies. There has been a lapse in proper investigation into the search and recovery of deceased victims in large-scale disasters. As a result, additional research is necessary to address this issue. Drone systems, with sufficient development, could be used in a variety of applications. The use of a more comprehensive measure across studies has been identified as a critical component of increasing the effectiveness of drones and their interventions, particularly in disaster situations.

5. Conclusion and future recommendations

There is currently insufficient evidence to justify a systematic review of drone use in disasters. We propose that future reviews incorporate settings, populations, and a variety of drone applications that were not considered in this scoping review. It is obvious that drone applications should be further explored; with a particular emphasis on drone assistance to humans, particularly in victim identification. As demonstrated in this review, drones are an excellent tool for mapping, search and rescue, transportation, and training. However, an assessment of drones' ability to identify victims should be conducted, as this is critical in a disaster scenario. Additionally, the lack of validation in determining the efficacy of drones in assisting with disaster victim identification is evident, which could be a result of ethical concerns associated with conducting research in real disaster situations. Numerous primary studies have reported on disaster simulated events with significant variation, necessitating the development of a standard disaster simulation checklist to minimise biases.

In disaster situations, the disaster victim identification (DVI) team frequently encounters difficulties locating and retrieving victims, resulting in body decomposition and identification delays. Although conventional victim identification methods are available, they have been ineffective in gathering victim information due to geographic location or disasters involving inaccessible sites. With the assistance of drone technology, concerted effort and cooperation from relevant multidisciplinary teams, and evidence-based data, it may be possible to avoid DVI delays and the numerous problems that accompany them.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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