Ethical and Safety Concerns for UAV-Assisted Data Collection for Disaster Management

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ABSTRACT

Emergency scenarios threaten human survival and well-being, requiring proactive risk assessment, hazard identification, and swift responses. In addition to several essential services, communication systems are very much useful for information exchange and situational assessment but are often disrupted by landslides. Unmanned aerial vehicles (UAVs), with their 3D maneuverability, can be deployed to effectively restore connectivity and collect safety data during such events. Key challenges include optimizing UAV placement as base stations and designing optimized trajectories for data collection, ensuring sufficient channel gain between UAVs and users. Estimating a propagation channel map through location-based measurements offers a potential solution. However, deploying UAVs to gather information raises ethical concerns, including safety, privacy, and moral implications. Addressing these requires a technoethics framework grounded in principles like beneficence, non-maleficence, autonomy, justice, and explicability. A literature review and expert consultations can provide critical insights to navigate these challenges.

Keywords

UAV, Technoethics, Radio Propagation Map, Privacy, Sensor-based Data Collection, Emergency Management

INTRODUCTION

Ethical challenges such as privacy, safety, irrelevant or excessive data collections have been raised to respond to suggestions from scholars and emergency management practitioners on the deployment of unmanned aerial vehicles (UAV) or commonly named drones to help areas experiencing unexpected disaster events, such as in landslide disaster (T. Li & Hu, 2021) or other disasters. Scholars and practitioners are aware of the impact of emergency situations that require proactive risk assessment, identification of hazards, and taking swift response to effectively manage the situation. The presence of reliable communication systems is crucial for ensuring the timely exchange of information between responders and affected individuals. These systems enable responders to collect critical information from those impacted, facilitating timely alerts about potential dangers and issuing specific instructions, such as evacuation routes, safe zones, and hazardous areas. Additionally, integration of data from ground sensors, including thermometers, radiation detectors, toxic pollutant sensors, and animal detectors, is vital for efficient disaster management and the provision of relief assistance (Daud et al., 2022).

In today's digitally interconnected world, smartphones have become indispensable in daily life. Beyond traditional communication, these devices offer features such as social connectivity, entertainment, and access to a wide range of Internet services. Taking Norway as an example, a study by the Norwegian School of Economics found that Norwegians check their mobile phone on average 80 times a day, which is equivalent to once every 12 minutes (Arista Recovery, 2024), indicating the seamless connectivity has been a part of their life.

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In emergency situations, ensuring network connectivity is crucial for affected individuals to communicate with loved ones, address safety concerns, and alleviate stress or trauma, even for those located in relatively low-risk zones. In addition, mobile positioning data serves as valuable information in emergency response efforts. It enables the precise location of affected individuals, facilitates efficient evacuation planning, supports emergency communication systems, and optimizes the allocation of critical resources (Tominga et al., 2023). In such situation, connectivity is important, and drones can fulfill these needs. However, there is limited discussion knowledge on the ethical issues concerning this idea.

This study focuses on utilizing UAVs, using the landslide disaster as a scenario to illustrate the role of UAVs in providing connectivity. Landslide characterized by the downward movement of significant volumes of soil, debris, and rock often result in extensive damage to physical infrastructure, including houses, roads, bridges, communication systems, and power lines, within the affected region. In such situation, communication infrastructures, such as base stations, are likely to be inoperative. The areas impacted by landslides are extremely volatile; therefore, setting up a new terrestrial communication infrastructure or restoring a damaged system is a time-intensive process.

Recently, UAVs gained popularity in wireless communication domains to provide network connectivity to ground devices without the need for terrestrial infrastructures. UAVs can be equipped with on-board communication transceivers (can transmit and receive), commonly named aerial base stations, to provide communication services to ground terminals such as mobile users, sensors, which commonly referred to as UAV-assisted communications (B. Li et al., 2018; Merwaday & Guvenc, 2015). By deploying low-altitude UAVs with communication capabilities, short-range line-of-sight communication links can be established between the UAVs and the ground terminals. Aerial base stations are deployed to improve the capacity, reliability, and coverage of wireless networks (Mozaffari et al., 2019; Shakoor et al., 2019). Additionally, UAVs can be used to collect (or disseminate) safety-critical information from (or to) ground sensors distributed in an area. We have graphically represented the potential usages of UAVs in landslide condition represented in Fig 1. We consider the region is affected by landslide, in effect, the communication infrastructure is damaged. In such a highly unstable condition, UAVs are equipped with a communication transceiver that can act as aerial base stations to communicate with ground users.

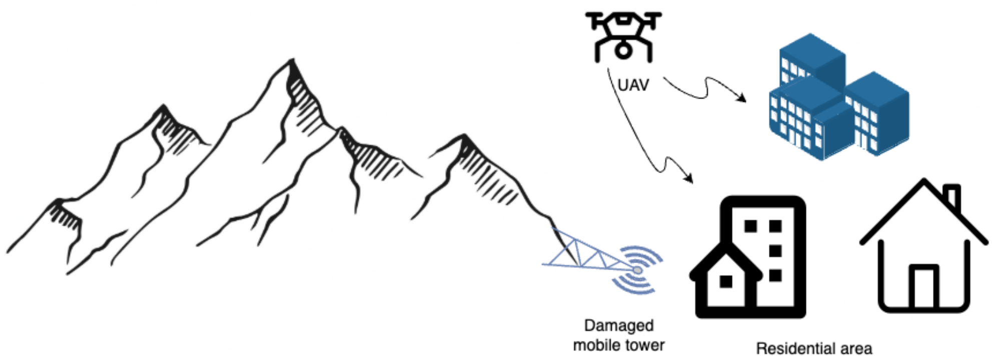

Figure 1. UAV as potential aerial base station to provide network connectivity to the ground terminals

Despite the many benefits of UAVs in wireless communications, integrating UAVs in wireless communication networks such as the placement of aerial base stations, providing optimal communication links, planning the trajectories of UAVs, etc., are challenging. The deployment of aerial base stations is crucial for effectively serving the ground terminals such as mobile users, sensors, etc. This requires prediction of channel characteristics before the UAV is actually placed at a given location. A communication channel refers to the medium between an aerial base station and a ground terminal. Most existing works (El Hammouti et al., 2019; Kalantari et al., 2016; Perabathini et al., 2019) consider that the channel gain between an aerial base station and a ground terminal is only dependent on the distance and elevation angle between them. However, the channel gain is also affected by the propagation environment, such as the presence of obstacles, buildings, and ground clutters (Romero et al., 2022). A promising solution is to estimate a radio propagation map between aerial base stations and ground terminals to characterize the propagation environment between them (Romero & Kim, 2022). Several empirical models have been developed to quantify channel gain, but no single model is capable of consistently characterizing the propagation environment (Phillips et al., 2012). To solve the limitations, radio map estimation was proposed where a set of measurements is collected from a geographical location using spatially distributed sensors along with their locations (Romero &

Kim, 2022). The measurements are used to construct a radio propagation map of the geographical area using some form of interpolation techniques. The estimated radio propagation maps are useful for the effective placement of aerial base stations and for designing optimal trajectory for UAVs to collect safety-critical information from sensors placed in the geographical area.

As mentioned earlier, deploying UAVs for collecting information raises serious ethical concerns. Previous studies have investigated several issues that can arise from deploying UAVs, for example safety issues, ethics and morales, legal, privacy, airspace, information integrity, human vs. machine and commercial related. This study aims at extending the discussion on technoethics implications of a novel approach on UAV-assisted communication through radio propagation map to support quick recovery of the communication damage. These ethical implications were derived from a simulated, theoretical work to explore such UAV deployment.

Moreover, European Group on Ethics in Science and New Technologies (EGE) acknowledges that in a crisis functioning of a society is under threat (Dratwa, Murphy, et al., 2022). The challenges for strategic crisis management are the facts that the response to the situation often developed promptly under uncertainties, with time and social pressures, and should be implemented simultaneously with ongoing crisis, thus values are becoming important when facing priorities and dilemmas. EGE (Dratwa, Murphy, et al., 2022) have formulated different ethical issues related to technology, including "Values in times of crisis", where "Data Communication and Public Trust" issue is one of seven ethical values requiring attention in science and new technologies. Under this value, several relevant themes have been highlighted including data accessibility and responsible data sharing, compliance with data protection rules, and the importance of communication strategy.

To address technological advancements and ethical concerns, we adopt a technoethics approach (Luppicini & So, 2016), a field that examines how technology shapes society by assessing its ethical use to influence development and improve daily life. Scholars have explored the ethical dimensions of new technologies through the technoethics perspective, which emphasizes principles like beneficence, non-maleficence, explicability, justice, and autonomy (Formosa et al., 2021). However, these values require further contextualization as new technologies, such as UAVs, introduce diverse ethical dilemmas in disaster scenarios, including privacy concerns, trust in technology, and questions about moral acceptability for organizations and societies.

In this article, alongside a literature review on UAV deployment in landslide conditions, we employ a simulation-based approach to replicate technical developments in software before physical implementation, and a workshop. The simulation approach involves simulating UAV-assisted measurements for estimating radio propagation maps to support network connectivity and data collection in a virtual environment. In the workshop, this simulation served as an illustration for UAV experts, helping them assess deployment through societal, technical, economic, and environmental perspectives across three key stages: preparedness, response, and recovery. This approach enabled experts to derive technoethics principles and identify ethical concerns based on beneficence, non-maleficence, autonomy, justice, and explicability.

LITERATURE REVIEW

Technoethics in Literature

Technoethics, introduced in the mid-1970s, encompasses various definitions and perspectives. Bunge (1977), who coined the term, emphasizes technologists' personal responsibility for their actions, asserting their accountability to humanity, not just employers. He advocates for integrating scientific knowledge and explicit values into moral norms, suggesting moral rules should be constructed like technological rules—grounded in both fact and value.

Technology significantly impacts society and the environment. Technologists must ensure their work is beneficial and not harmful, both short- and long-term, while navigating conflicting interests through value-based moral decisions. Public interest should ideally take precedence over private and professional interests. Not all technology is inherently good; harmful technologies, such as weapons, are ethically problematic and should be controlled.

Bunge (1977) highlights the need for ethics to learn from technology, proposing that moral norms align with scientific knowledge and valuations. A value theory can help balance means, goals, and side effects, ensuring actions are both feasible and ethical. He advocates for power-sharing among technologists, managers, and politicians, with large-scale projects involving expert teams and public oversight. Ultimately, Bunge (1977) calls for a science of technoethics, where technologists address moral challenges and develop ethical frameworks for responsible and efficient conduct, prioritizing societal and environmental welfare.

Galvan (2003) defines technoethics as an ethical framework highlighting technology's central role in achieving human perfection. He underscores the anthropological importance of technology, distinguishing technoethics from engineers' professional ethics by focusing on guiding all technical activity toward positive ends. Galvan applies technoethics to humanoid robots, categorizing machines into inanimate tools, life-assisting machines, and symbolic machines. Humanoids are seen as the pinnacle of symbolic machines, replicating human symbolic capacities, including language and body language. However, Galvan (2003) notes that humanoids lack free will, a critical element of true symbolic capacity. Thus, while humanoids can enhance human symbolic expression and improve quality of life, they cannot replace human actions driven by free will, such as the unique, irreplaceable gesture of a caress.

Luppicini (2008) consider technoethics concerned with all ethical aspects of technology within a society shaped by technology. It deals with human processes and practices connected to technology embedded within social, political, and moral spheres of life. The rationale for technoethics is to create a comprehensive framework for addressing ethical issues related to technology across various fields. It aims to connect disparate areas of knowledge, promote interdisciplinary collaboration, and address the unique ethical challenges posed by technological advancements. Technoethics emphasizes the importance of considering technology and in ethical discussions, recognizing the evolving relationship between technology and human activity. This approach helps guide ethical decision-making and policy development to ensure the responsible use of technology for societal benefits.

Amrute (2019) argues that technoethics should be revitalized through the concept of techno-affects, which focuses on the relational and affective dimensions of technology. It emphasizes the importance of considering the embodied experiences and material conditions of marginalized groups in the development and application of technology. This approach advocates for a more inclusive and context-sensitive ethical practice that addresses the social, environmental, and embodied costs of digital economies. In summary, technoethics is broadly defined as the study and application of ethical principles to the development, use, and impact of technology, considering the responsibilities of technologists, the integration of scientific knowledge and values, and the inclusion of diverse perspectives and experiences.

Amrute (2019) criticizes the top-down approaches to ethics, such as the “Ethical OS toolkit”, which provides rules and guidelines for ethical behavior but fails to address the underlying issues of who gets to define ethical dilemmas and how ethical concerns are incorporated into technical processes. These approaches often reinforce narrow definitions of who makes decisions about technologies and what counts as a technological problem. The author argues that technoethics can be revitalized through the concept of techno-affects, which focuses on the relational and affective dimensions of technology. This approach considers how subjects and technologies are aligned and realigned, and how these relationships can be used to practice ethics in a way that critically assesses situations, imagines different ways of living, and builds structures to support those lives (Amrute, 2019). Drawing on feminist perspective, Amrute (2019) advocates for a relational approach to ethics that centers gendered, raced, and disabled bodies. This approach asks whose knowledge counts in technical domains and emphasizes the importance of including marginalized voices in the development and application of technology. Amrute (2019) emphasizes that ethical practice should not solely focus on human responsibility but should also consider the interaction between humans and technical systems. The author further introduces the concept of attunements, which are approximations subject to adjustment, to describe how ethical engagements can be practiced. Attunements involve training the senses to recognize and act in technical situations, considering social relations, affective, political, and climatic factors, and the labor of both humans and technical systems. Amrute’s perspective on ethics in technology involves a more inclusive, relational, and context-sensitive approach that incorporates the experiences and knowledge of marginalized groups, critiques top-down ethical frameworks, and emphasizes the importance of attunements in practicing ethics.

In summary, while all scholars agree on the importance of ethical considerations in technology, they differ in their focus, scope, and approach to implementing technoethics. On the approach, for example, Galvan (2003) and Bunge (1977) advocate for a structured approach to technoethics, with clear moral norms and responsibilities. Luppicini (2008 and Amrute (2019) take slightly different approach, suggest a more flexible and inclusive approach, considering the broader social context and the experiences of diverse groups.

To derive ethical principles for the use of UAVs in providing network connectivity and gathering information from the landslide affected areas, we follow a systematic approach that considers ethical principles in the context of technology, societal needs, and the specific challenges of disaster management. We identify the scope and context of the UAVs in such conditions, specifically, in order to restore network connectivity and gathering crucial information from the environment. We consider a more flexible and inclusive approach in order to manage the situation where our intention is to quick and effectively deploy UAVs in disaster assistance while ensuring safety and security. We examinethe ethical issues from several perspectives such as humanitarian (e.g., well-being, safety, privacy, equity), technological (e.g., coordination, reliability, trust) to compare with.

Literature on UAVs and Ethics

The use of drones or UAVs, has expanded rapidly from military applications to various civilian and commercial uses, raising significant ethical, social, and regulatory concerns (Luppicini & So, 2016; Nelson & Gorichanaz, 2019; Novitzky et al., 2018; Wernaart et al., 2023; West & Bowman, 2016). These concerns are multifaceted, encompassing issues such as privacy, safety, legality, and the balance between innovation and regulations (Luppicini & So, 2016; Nelson & Gorichanaz, 2019; Novitzky et al., 2018; Wang et al., 2022).

Privacy is a major concern, as drones equipped with cameras can easily invade personal spaces without consent (Nelson & Gorichanaz, 2019; Resnik & Elliott, 2019; Strawbridge, 2022; Wernaart et al., 2023). Strawbridge (2022) addresses the ethical and sustainable issues associated with civil drone use and proposes a revised code of ethics and sustainability. The rapid proliferation of drones in various applications, such as aerial photography, delivery, surveying, inspections, and surveillance, has raised significant privacy and sustainability concerns that need to be addressed. Drones equipped with various sensors, including optical cameras, thermal cameras, GPS, and LIDAR, can unintentionally or intentionally breach privacy. These breaches can occur during flight or post-flight data analysis. For instance, drones can capture private information about individuals' locations, associations, behaviors, and even private conversations. Scholars highlight the need to consider all types of sensors, not just cameras, in privacy discussions. Incidents like a real estate drone photographing a woman sunbathing in her backyard without her knowledge highlight the potential for significant privacy breaches. Public perception of drones is mixed, with concerns about privacy violations, air traffic safety, and the potential for drones to be used for spying (Resnik & Elliott, 2019; Strawbridge, 2022; Wernaart et al., 2023; West & Bowman, 2016).

Acceptance is higher when drones are used for public benefits, such as emergency healthcare, compared to commercial or leisure applications (Wang et al., 2021, 2022). Safety is another critical issue, with the potential for drones to cause accidents or be used for malicious purposes (Luppicini & So, 2016; Novitzky et al., 2018; Resnik & Elliott, 2019; Wang et al., 2022). Regulatory bodies like the U.S. Federal Aviation Administration (FAA) have struggled to keep pace with the rapid development of drone technology (Nelson & Gorichanaz, 2019; Wernaart et al., 2023).

The FAA's initial ban on commercial drone use until proper regulations were implemented underscores the tension between fostering innovation and ensuring public safety (Luppicini & So, 2016). The European Union's U-space regulation aims to enable autonomous drone operations in urban environments, but it will take time for member states to establish the necessary certifications and procedures (Wernaart et al., 2023).

The dual-use nature of drones, initially developed for military purposes but increasingly utilized in civilian domains, raises ethical concerns about their transfer and application (Luppicini & So, 2016; Novitzky et al., 2018). The Dakota Access Pipeline protests exemplify the dual-use dilemma, where both protesters and law enforcement used drones for surveillance, raising concerns about potential abuse and the ethical implications of such surveillance (Wernaart et al., 2023).

In humanitarian contexts, drones offer valuable opportunities for disaster response and aid delivery but also pose ethical challenges (Wang et al., 2022). The use of drones in post-disaster Nepal for hazard analysis highlighted the issues of community consent, data safety, and regulatory challenges (Wernaart et al., 2023). The Framework for the Ethics Assessment of Humanitarian Drones (FEAHD) was developed to support value sensitivity in humanitarian drone activities, emphasizing the importance of ethics preparedness and stakeholder responsibility (Wang et al., 2022).

Trust is a fundamental factor in acceptance of drones as an emerging technology. Regulations are seen as a way to reinforce trust by ensuring ethical use and providing mechanisms for enforcement (Nelson & Gorichanaz, 2019). Involving citizens in the design process of new drone technologies and services is crucial to ensure that drone technology is responsible, accepted, and desired by society (Wernaart et al., 2023).

In conclusion, previous literature have discussed the integration of drones into civilian life presents significant ethical, social, and regulatory challenges. Addressing these challenges requires a balanced approach that considers privacy, safety, legality, and the need for robust regulation and oversight. By involving citizens and adhering to ethical principles, it is possible to harness the benefits of drone technology while mitigating its risks (Nelson & Gorichanaz, 2019; Novitzky et al., 2018; Wang et al., 2021; West & Bowman, 2016).

Literature on UAVs and Emergency Management

The literature has documented the history of drone use for disaster response. Greenwood et al. (2020 report the usage of drone in the US which were first used in the U.S. for disaster response during Hurricane Katrina. It was small fixed-wing and helicopter-style UAVs were deployed to search for survivors. Afterwards, there were regulatory Challenges (2005-2016) where the FAA issued a memorandum restricting UAV operations for non-hobby purposes, including disaster response, to those with a certificate of authorization (COA). Some of the notable drone deployment were seen in 1) Western States Fire Missions: A collaboration using long-range UAVs for wildfire information gathering 2) 2014 Rim Fire where the California Army National Guard used a Predator UAV for fire monitoring. 3) 2013 Colorado Flooding where CLMax Engineering used UAVs for flood imagery, but operations were halted by Federal Emergency Management Agency (FEMA). 4) Texas Equusearch has faced legal challenges from the FAA for using drones in search and rescue operations. In the international disaster context, there were several examples of UAV applications for emergency response, such as 1) 2008 Wenchuan Earthquake (China) where UAVs were used for damage assessment; 2) Drone use in the 2011 Fukushima Daiichi Crisis (Japan) for inspecting the damaged nuclear reactor; 3) UAV use in the 2013 Typhoon Haiyan (Philippines) for mapping and disaster assessment; and drone extensive use in the 2015 Nepal Earthquake for mapping and search and rescue by NGOs. In 2016 there was Regulatory Changes (2016) where the FAA provides a clearer legal framework for commercial UAV use, including disaster response. This led to increased UAV deployment in disaster scenarios such as in the 2017 Hurricanes Harvey and Irma where drones were widely used for damage assessment, marking significant deployments by both governmental and non-governmental organizations. Internationally, entities like the World Food Programme and UNHCR have integrated UAVs into their disaster response programs (Greenwood et al., 2020).

Van Wynsberghe and Comes (2020) reported that drones have been used in humanitarian action since 2006, starting with their deployment for surveillance in peacekeeping missions in the Democratic Republic of Congo. They were later used in the Central African Republic in 2008 and again in the Democratic Republic of Congo in 2013. In the US, drones were utilized for search and rescue during the 2007 California wildfires, the 2010 Haitian earthquake. In the humanitarian response domain, the technology has since become more accessible and affordable, with off-the-shelf products available for around USD 200 or less. Drones have been used for various purposes in the humanitarian sector, including mapping, delivering essential items to remote or hard-to-access locations, supporting damage assessments, increasing situational awareness, and monitoring changes. They have also been used for medical deliveries, such as vaccines, blood supplies, and HIV diagnostic kits, particularly in countries like Lesotho, Malawi, and Rwanda. The use of drones in humanitarian contexts has grown significantly, with almost every humanitarian NGO now owning and operating their own drone (van Wynsberghe & Comes, 2020).

Wang et al. (2021) conduct scoping review and address the following considerations concerning the humanitarian drones: *Ethical considerations* include discussions on harm-benefit trade-offs, justice, respect, perceptions of humanitarians, and community-level considerations. *Legal considerations* encompass regulatory and governance aspects, focusing on safety regulations, airspace integration, and challenges with regulatory processes. *Social considerations* involve humanitarian innovation, public perception of humanitarian aid, reputational risks, and relations between organizations and the drone industry. Wang et al. (2022) suggest a quite broad framework for the Ethics Assessment of Humanitarian Drones (FEAHD) that provides a structured approach to assessing ethical considerations related to the use of drones in humanitarian contexts. It covers primary, secondary, and tertiary levels focusing on harm/benefit, justice, and respect for autonomy. The framework incorporates guidance notes, operationalization, and emphasizes values and principles like humanity, neutrality, and accountability. It addresses ethical aspects related to community, technology, data, regulation, and stakeholders, as well as cross-theme ethical considerations covering safety, operationality, and sustainability. The decision chain process involves problem identification, ethical justification, legal obligations, mission alignment, and operational consequences. Wang et al. (2021) has specifically pointed out a concern toward UAV-aided data collection especially the safety and security dimension, in terms of degree and level of data accuracy, data storage and usage and compliance mechanism and digital data management system for data sharing, also about the risks of identification of individuals.

Beyond the use of drone in the humanitarian response setting, in emergency management literature, there are numerous articles discussing use of drones in specific scenarios such as wildfire monitoring (Zelenka et al., 2023), indoor exploration (Paliotta et al., 2021; Tolt et al., 2023), data crowdsourcing (Spatharioti et al., 2018), search and rescue (Correia et al., 2020; Khalaf et al., 2018; Watanabe et al., 2021), landslide location (Vargas-Florez et al., 2019), collaborative information seeking (Grace et al., 2023).

Concerning the landslide disaster scenario, literature acknowledges the use of drones, as essential tools in monitoring and managing landslides due to their ability to provide high-resolution imagery and real-time data collection. For example, drones are utilized to take *high-resolution imagery* where drones equipped with high-resolution cameras can capture detailed images of landslide-prone areas. These images are used to create 3D models, orthomosaics, and Digital Elevation Models (DEMs) which are crucial for understanding the topography and potential risk areas (Al-Rawabdeh et al., 2016; Pattanaik & Singh, 2024; Suroso & Eko Prasetiyo, 2021). Drones are used for *Repeatable Data Collection*, by deploying repeatedly to monitor changes over time, providing valuable data for forecasting and assessing landslide activity (Dupuy et al., 2021; Mugnai et al., 2023) and *Data Processing and Analysis* using the Photogrammetry to generate 3D models of the terrain. It helps in visualizing the extent of landslides and assessing the volume of displaced material (Mugnai et al., 2023; Pattanaik & Singh, 2024). Digital Image Correlation (DIC: Applied to orthomosaics generated from drone surveys, DIC helps compute deformation maps, which are essential for understanding the movement and stability of landslide areas (Mugnai et al., 2023). To support *Real-Time Situational Awareness*, rapid data collection can be done where drones can quickly gather data in the aftermath of a landslide, providing real-time situational awareness to emergency responders. This capability is crucial for timely decision-making and resource allocation (Nair et al., 2024; Velev et al., 2019). Drones are also integrated with AI to to enhance the accuracy of landslide detection and monitoring. For instance, AI algorithms can prioritize rescue operations and improve the efficiency of disaster response (Chandra & Vaidya, 2024; Nair et al., 2024). Scholars also consider drones as *Cost-Effectiveness*, allowing an affordable monitoring, compared to traditional methods using satellite imagery or ground-based radar, for acquiring high-resolution monitoring of landslides. This makes long-term risk analysis more feasible (Chen et al., 2019; Mugnai et al., 2023). Despite challenges and ethical issues have been mentioned, but mostly about privacy and regulatory issues. Addressing these issues is considered essential for the widespread adoption of drone technology in disaster management (Nair et al., 2024), but don't know how.

Moreover, the ethical issues are rarely a focus for researching drones for emergency management.

Research Gaps and Ethical Framework

Research Gaps Identified in the Literature

As to the research gaps Jansen (2015), proposes to employ futures methods focused on interaction and creativity, such as expert panels, Delphi studies, and scenario writing, to improve the accuracy and range of predictions about drone capabilities and applications. Moreover, the usage of drone and its capability (*e.g.,* to do surveillance can be investigated from three broad drone categories, *i.e.,* large drones, small general-purpose drones, and biomimetic spy drones to account for hybrid drones and other variations. The author also suggest for both comprehensive scenario evaluations and context specific evaluation to obtain a comprehensive and fine-grained picture of the ethical admissibility of various drone applications in different contexts, including disaster response context.

Jansen (2015) mentions the need to conduct an extensive study on the potential usage of drones for delivering harmful payloads and their ethical implications. For example, the increasing autonomy of drones, the ascription of moral responsibility in socio-technical contexts involving autonomous drones, and how autonomous drones can be designed to make ethical decisions, especially in high-stakes situations such as law enforcement and military operations. The author points out the importance of understanding the chilling effects *i.e.,* i.e., the social and psychological effects of pervasive drone surveillance on public behavior, social interactions, and community cohesiveness.

The literature also suggests that future research should focus on operationalizing values such as well-being and justice in the context of technological development, such as impact assessment methods to evaluate how technologies can positively or negatively impact these values (Nelson & Gorichanaz, 2019). Moreover, Wang (2020) calls for future work to establish a humanitarian innovation framework and toolkits that are value-sensitive and context-specific. Wang (2020) emphasizes the need for rigorous reflections on the ethical challenges of technological innovation and the development of responsive methodologies to assess potential harms and benefits. Wernaart et al. (2023) discuss the need for further research into human rights-based perceptions of citizens regarding drone technology. The authors also mention ongoing research initiatives such as moral data city searches, virtual moral labs, and urban mobility living labs to involve citizens in the design process of drone services. These initiatives aim to understand citizens' moral preferences and incorporate them into the design of civilian drone services.

This article will address some of the research gaps identified in our research project and applies the technoethics framework to UAV-assisted data collection in disasters.

Ethical Framework

On the ethical principles of using drones, some authors have proposed different frameworks. Steen et al. (2023) as well as West and Bowman (2016) suggest using *utilitarianism, deontology, relational ethics and virtue ethics* to portray an ethical perspective of using drones. Each of these perspectives has distinct characteristics and considerations, such as highlighting potential harms, emphasizing human autonomy, focusing on relationships between actors, and cultivating relevant virtues. Cawthorne and Wynsberghe (2020) suggest the following ethical framework that has been applied for other domains such as bioethics, cybersecurity and artificial intelligence to be adapted in our case: *Beneficence, Non-maleficence, Autonomy, Justice* and *Explicability*.

- *The beneficence principle* punctuates the moral obligation when designing technology that can support moral progress and examines which technologies are most meaningful to reinforce.
- *The principle of non-maleficence* means "do no harm." This principle pinpoints the efforts to harm others or making things worse due to the lack of ethical considerations in the design and use of UAVs.
- *The principle of autonomy* refers to respecting the free choice and self-determination of individuals and groups. For instance, informed consent by individuals should be given upon the deployment of UAVs´ assisted data collection; allowing individuals to make decisions and maintain control over what data UAVs may collect when they are deployed. In brief, this principle try to ensure that humans remain in control and responsible for the technology.
- *The principle of justice* refers to ensuring fairness and equity in the distribution of benefits and risks associated with the use of technologies, such as distributive justice, protection of vulnerable groups, avoiding exploitation and just procedure.
- *The explicability principle* refers to the need for transparency and understandability of how the new technologies are designed and function, such as if the technologies indirectly collect data and are governed by decision-making algorithms. This principle ensures that technology-based or UAV-based crisis operations and decisions are clear and comprehensible to all stakeholders.

Cawthorne and Wynsberghe (2020) have applied these principles in healthcare services, while Formosa (2021) has used the same framework to elaborate ethics in the cybersecurity domain. In further analysis, we will apply these principles to our case concerning UAV-assisted data collection for disaster management.

RESEARCH CONTEXT AND CONCEPT

In this section, we introduce the context, concept and scenario that are used in this study and developed through a simulation. As mentioned earlier, Network connectivity in landslide-affected regions is essential for several critical reasons. Accurate and timely communication enables response teams to efficiently locate and assist individuals in need. Connectivity supports real-time information exchange, allowing affected individuals to update their status while also facilitating the collection of safety-critical data from ground-based sensors, such as temperature and toxicity detectors, deployed in the area. This information is invaluable for responders to assess the situation, identify risks, allocate resources, and plan mitigation efforts. Additionally, network connectivity allows responders to relay crucial information to the affected population to ensure their safety and well-being. In many cases, however, the base stations installed on mobile towers are severely damaged or completely uprooted during such disasters, making their restoration on short notice nearly impossible. UAVs equipped with communication transceivers can provide network connectivity and gather safety-critical data due to their rapid and flexible deployment capabilities. A key challenge in deploying UAVs is determining their optimal placement to ensure effective service to ground users. Additionally, designing efficient UAV trajectories is essential to maximize coverage and provide reliable connectivity to ground sensors situated in the disaster-stricken area.

To deploy UAVs at optimal locations, it is important to consider the communication environment. The received signal at any location is influenced by both the transmitted power from the aerial base stations and the characteristics of the communication medium between the receiver and the aerial base stations. This medium, commonly referred to as the communication channel, plays a pivotal role in determining the quality of the received signal. The transmitted signal's strength diminishes with increasing distance from the transmitter due to path loss, which primarily results from free-space loss—a phenomenon dependent on the distance between the transmitter and receiver. In addition to free-space loss, the signal is affected by factors such as shadowing caused by obstacles (e.g., buildings and trees) and reflections from large objects. Collectively, these elements make the propagation environment a critical determinant of the received signal strength at any given location. To illustrate this effect, we consider an 80x80 environment containing three buildings of varying heights and areas, as depicted in Fig. 2. A transmitter is placed at the center of the environment at an elevation higher than the buildings, and the channel gain between the transmitter and various locations near to ground within the environment is calculated and visualized in Fig. 3. The channel gain is represented by the color bar on the side of the figure. The results clearly demonstrate that the channel gain is highest in proximity to the transmitter and decreases significantly with distance. Furthermore, the presence of buildings exacerbates signal degradation in shadowed regions, a trend that is evident in the plotted data.

Earlier, we mentioned that measurement-based radio propagation estimation are less prone to error as compared to model-based approach. Hence, in our research work, we will take several measurements to estimate propagation characteristics of the environment affected by landslide, in particular, we will estimate channel gain between

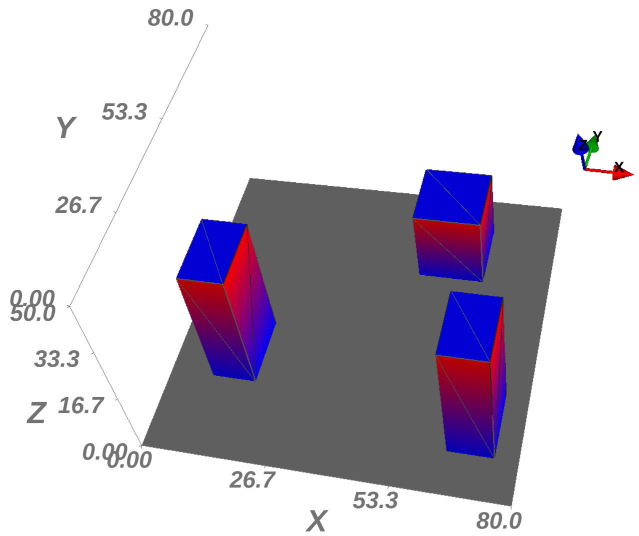

Figure 2. Pictorial representation of a typical scenario for an environment

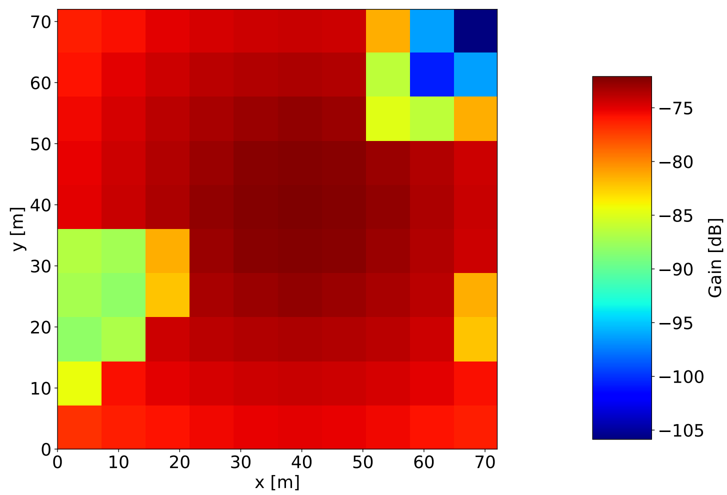

Figure 3. Radio propagation map for the above environment

transmitter and receiver locations. In existing literature, almost all works related to UAV-assisted communication considered the medium between transmitter and receiver is free space. Therefore, the channel gain between any transmitter and receiver locations is solely dependent on the distance and elevation angle (El Hammouti et al., 2019; Kalantari et al., 2016; Perabathini et al., 2019). However, in reality, it is not the case; it is highly possible that any obstacles such as buildings, trees, hills, etc., present in between two given locations. After estimating radio propagation map through measurement-based methods, we could deploy UAVs as potential aerial base stations by mounting communication transreceiver can provide network connectivity as well as to design an optimize trajectory for UAVs to collect information from the ground sensors such as thermometers, radiation detectors, toxic pollutant detectors, animal detector, etc., for effective disaster management and providing relief assistance to the affected people.

As mentioned measurement-based model are less prone to error, we will rely on measurement data to estimate the radio propagation map. As well as we will utilize the estimated propagation maps in order to design trajectory for UAVs to collect data from the ground sensors. However, before deploying UAVs in disaster management within landslide-affected areas, it is essential to address several ethical, safety, privacy, and legal considerations.

METHODOLOGY

We pursued two-stage approaches, *i.e.,* simulation-based appraoch and mini workshop. Simulation is a method of using computer software to model the operation of real-world processes, systems, or events (Beese et al., 2019; Davis et al., 2007). The method provides a distinctive methodological approach for studying various phenomena in many disciplines. Using the simulation-based approach, one can control a set of parameters and vary another set of parameters of a system in a controlled environment. By doing so, a researcher can generate massive amounts of data that enable us to capture complex relationships between the parameters of the system and its response.

In our work, we generated massive amounts of synthetic measurements data of radio propagation gain for several environmental conditions. The measurement data consist of several pairs of measurement locations, with each pair associated with a corresponding propagation gain calculated between the two specified points. The measurement data are used to feed into an AI-based model to train the model for radio propagation maps. Subsequently, the model can be utilized to estimate a radio propagation map for a new unseen environmental condition given two locations.

In actual deployment case (which is not implemented in this study), we would use UAVs to generate measurement data for a new unseen environmental condition. As UAVs are capable of collecting information from the environment, we need to consider the challenges associated with this related to addressing ethical concerns.

To elicit the ethical concern, we conducted a mini workshop with four experts. We carefully considered various options to determine the most suitable participants for the workshop, including individuals with backgrounds in emergency management or practice, those knowledgeable in ethics, and those with domain expertise in technical aspects such as UAV communication, data collection, and radio map concepts.

As this study was the first iteration of the theoretical model, the criteria for selecting the experts were based on the following aspects: 1) The participants should have an understanding of UAV concepts and simulations 2) The participants should possess knowledge and experience in radio propagation map through UAVs. However, this selection introduced certain limitations, particularly regarding the participants' understanding of ethical concepts and the breadth of coverage in this area. To overcome this drawback, we conducted the following elicitation process:

1. The participants received the workshop presentation that will be used prior to the elicitation of ethical issues from UAV-assisted data collection.

2. The participants were introduced with the concept of ethics, especially the technoethics concept of emergency management and response life-cycle. The technoethics principles (beneficence, non-maleficence, autonomy, justice, and explicability) were explained one by one with concrete examples.

3. The participants were introduced to the elicitation procedures, the purpose of the workshop, the expected results, and the support tool.

4. The elicitation were started, while the definition of the main concepts were accessible all the time for their reference.

We used online platform providing mind mapping capability to elicit the process. One of the researcher acted as a facilitator to guide the process and ensure that the aims of the elicitation were accomplished. We asked experts to write-down the potential concerns associated with deploying UAVs in emergency conditions, specifically for landslide condition. We considered three stages of emergency management: preparedness, response, and recovery. We have customized the idea for our case: UAV preparedness and deployment plan, UAV response, and UAV recovery. *UAV preparedness and deployment plan* refers to proactive planning, training, and readiness activities necessary to effectively use the UAVs during emergency situations. It ensures that the UAVs can be deployed quickly, safely, and effectively to assist in the emergency management. *UAV Response* refers to immediate action taken using UAV in order to protect life, property, and environment during or immediate after an emergency situation. *UAV recovery* refers to the process of rebuilding, restoring, and returning to normalcy after the immediate crisis has been addressed. This stage may deal with securing the data collected by UAV during the response stage.

Concerning the data analysis, we compiled all different points and concerns addressed by the workshop participants. Similar ideas are merged, and a walk through process were done to ensure that the items proposed by the experts are suitable for corresponding technoethic dimensions.

Table 1. The results of elicitation process

	UAV Preparedness and Deployment Plan	UAV Response	UAV Recovery
Beneficence	1. Train and plan 2. Proactive 3. Effective deployment 4. Clear guidelines 5. Trade-off 6. Positive Impacts	1.Collect information 2.Urgent aids 3.Network connectivity 4. Dissipating urgent information	1. Repair damaged items 2. Collect damaged items 3.Testimony of benefited people 4. Monitoring if hazardous conditions pop-up
Autonomy	1. Acceptance 2. Privacy in emergency 3. Acceptable procedure 4. Automated sensors	1. Assess environment 2. Informing about data being collected	1. Transfer and store data safely 2. Removes attribution
Explicability	1. Clear criteria 2. Responsible person 3. Legitimate/illegitimate data collection and payloads 4. Data access rights 5. Consent 6. Trust on operation 7. Transparency 8. Local storage log	1.Trust data analysis 2. Rely UAVs 3. UAV as complementary 4. Secured data transfer 5. Fair data processing 6. Fair prioritization 7. Information ->plan ->response	1. Collect damaged equipment 2. Transparent UAV decision 3. Assess rescue bias if any 4. Evaluate errors 5. Identify UAV-caused harm 6. Listing errors 7. Acknowledge deployment complications
Non-maleficence	1. Risk minimization 2. Harm Avoidance 3. Inaccuracy control 4. Failure minimization 5. Back-up plan 6. Explainable UAV decision	1. Avoid accidents 2. Backup UAVs 3. Don't record sensitive data 4. Avoid causing harm	1. Avoid causing damages 2. Restrict malicious use 3. Avoid personal harm 4. Track of lost UAVs 5. Minimize financial harm
Justice	1. Make clear to public face 2. Equal chance to reap benefit from UAV 3. Prioritization 4. Minimizing biases 5. Not lean to once source data collection 6. Reliable data processing	1. Avoid measurement bias 2. Equal focus 3. Respect privacy 4. Avoid further damages	1. Avoid commercialization of recorded data 2. Surveying physical damages 3. Evaluate fairness procedure of UAV deployment 4. Evaluate fair prioritization procedures

RESULTS

This section report the results from the elicitation process as seen in Table 1.

Table 1 shows the results from the elicitation process, summarized as points. In the preparation and deployment plan, elicitation on the *principle of beneficence* (second row and second column) is exemplified by implementing comprehensive training and planning to significantly reduce response time, adopting a proactive stance during disasters, leveraging connectivity benefits for coordinated efforts, and ensuring effective deployment of resources in regions with limited capacity. This includes establishing clear guidelines to identify situations where UAV operations may not be beneficial, such as harsh weather conditions, while carefully balancing the trade-offs between technological and traditional solutions. Furthermore, the positive environmental impact of these actions, such as supporting wildlife conservation, underscores the ethical commitment to the greater good.

In the response stage (second row and third column), *principle of beneficence* is exemplified by providing urgent aids (*e.g.,* foods, medicine), maintaining network connectivity to facilitate effective information collection from the environment through different sensors (*e.g.,* camera, thermal imaging, *etc.,*) in order to assess the potential risks, locate affected people, and dissipate crucial information.

The *principle of beneficence* in technoethics in the recovery stage (second row and fourth column) suggest recording testimony of the individuals who have received positive impacts of UAVs, collecting damaged items and repair those items in order to save environment and money, monitoring the environment if any hazardous condition pop-up due to overall operations.

The elicitation results suggest that concerning the *principle of autonomy* (third row and second column) in technoethics on UAV usage, it should be reflected in a system where first responder acceptance is prioritized, privacy in emergency situations is respected, procedures for deploying UAVs are designed to be acceptable to all stakeholders, and sensors are strategically placed to monitor the environment, enabling the system to operate automatically and respond when it detects any unusual occurrences.

The *principle of autonomy* (third row and third column) for UAV response stage emphasizes the need for informing or warning individuals about the collected information, getting an overview of the environment/situations to predict future incoming events.

In the recovery stage, the *principle of autonomy* (third row and fourth column) suggest that it is essential to remove attributes of the data that may identify people and create privacy issues, transfer and store the collected data safely in a secured storage.

The *explicability principle* (fourth row and second column) in technoethics for UAV deployment emphasizes the need for clear and transparent guidelines, including well-defined operator criteria, clarity on who is responsible for UAV deployment, explicit rules on permitted and prohibited data collection and payload usages, clear protocol for data access and consent processes, fostering trust in drone operation and highlighting transparent decision making, and ensuring the storage and accessibility of UAV log information to maintain accountability.

The elicitation results concerning the *principle of explicability* (fourth row and third column) in response stage suggest trusting the data analysis and explainable visualization, trust on data processing, secure data transfer procedure, making UAV operations are reliable and trustworthy, explainable UAV prioritization movement, making UAVs as complementary to other possible solution, preparedness and response should be implemented iteratively based on collecting information, planning, and response in a loop.

The *explicability principle* (fourth row and fourth column) in technoethics for UAV response is exemplified by collecting damaged equipment, ensuring transparency in UAV-related decision-making, assessing rescue bias and justify them using the collected information, listing all technical and identifiable source of errors, identify UAV-caused harmful activities, evaluating all mistakes and errors, acknowledge and address all complications encountered during deployment.

Concerning on how to uphold the *non-maleficence principle* (fifth row and second column) in UAV operation, the elicitation results suggest that it is essential to minimize risks by programming UAVs to avoid harm through collision prevention with rescue teams and objects, implementing measures to control inaccurate data collection, reducing mission failures through robust systems, maintaining backup plans such as deploying nets to recover UAVs in case of loss of control, and ensuring transparency by clearly explaining software decisions to non-experts.

The *principle of non-maleficence* (fifth row and third column) in technoethics for UAV response stage emphasizes the need for comprehensive plan for UAV operations during response efforts, ensuring safe movement to prevent accidents such as malfunctions or misuse, preparing backup UAVs and equipment, refraining from recording sensitive information, mitigating risks of crashes or collisions with infrastructure and air traffic.

Concerning the *principle of non-maleficence* (fifth row and fourth column) in the UAV response stage, the elicitation results suggest to ensure UAV operations prioritize safety by avoiding additional damage from pilot error, safeguarding UAVs against malicious use during the recovery phase, preventing personal harm, assessing any lost UAVs to determine causes, and minimizing financial losses.

Concerning on how to uphold the *justice principle* (sixth row and second column) of technoethics, authorities must clearly communicate their action plans to the public, ensure equal access to UAV assistance for all affected areas, prioritize help based on objective assessments of damage severity, minimize bias from inaccurate sensor measurements, avoid relying solely on a single data source, and utilize reliable technology to process collected data effectively.

The *justice principle* (sixth row and third column) in technoethics for UAV response is exemplified by ensuring unbiased measurement by maintaining equal focus on severely damaged areas, upholding privacy standards when obtaining consent is not feasible, and taking precautions to prevent further harm by employing only well-trained pilots.

The *principle of justice* (sixth row and fourth column) in technoethics in the recovery stage suggest to ensure the collected data is used exclusively for emergency response purposes and not for any commercial endeavors, considering conducting an additional deployment if necessary to better understand physical damages, while avoiding any exaggeration in post-disaster data collection, and thoroughly evaluate the fairness of both the deployment and prioritization procedures.

DISCUSSION

On the *beneficence* principle, the results can be interpreted that most of concrete ethical and safety concern has been focused on ensuring positive impacts on disaster-stricken areas such as reducing response times and providing essential resources and also to pay attention to environmental sustainability. However, we also notice that there is limited understanding on what mechanisms ensure that comprehensive training translates into actual benefit during operations, or how can decision-making frameworks prioritize the "greater good" while respecting localized challenges, such as adverse weather conditions? As previous literature emphasizes the privacy issues and legislation as a part of ethical perspective, the points above have not yet part of combined ethics and safety concerns.

On the *autonomy* principle, the results seem to emphasize the need to respect for privacy and first-responder acceptance in deployment, and the transparent processes for automated decision-making and data handling. The results also point out the dilemma on how UAVs navigate the tension between providing critical services and maintaining individual privacy. However, topics such as what kinds of ethical safeguards are in place for data collection and sharing during emergencies, are not completely new as this has been discussed in the literature (*e.g.,* West and Bowman, 2016). Obtaining consent in such dilemma between providing critical services and maintaining individual privacy can be challenging and has not been discussed and solve in the literature. Another concern is related to whether the UAV systems used for decision-making sufficiently explainable and acceptable to all stakeholders involved.

On the *explicability* principle our results have highlighted the importance of the transparent and accountable guidelines for UAV deployment and operations, which can be depends on the legal systems of each country on such deployment and level of transparency. While the concern on explainable and trustworthy decision-making processes as well as post-operation assessments to evaluate errors and biases, may be related to recent development of massive usage of AI, including the concept proposed in our scenario. We do believe that more research should be also targets topics such as how can operators effectively communicate the rationale behind UAV decisions, especially to non-experts, what accountability mechanisms are in place to address mistakes, biases, or harmful outcomes during operations and how can trust be built in UAV systems when public skepticism about autonomous technologies persists.

On *non-maleficence* principle, the results show more safety concerns than actually ethical concerns, as the results highlight risk minimization (*e.g.,* collision avoidance, backup systems), ensuring safety during operations (*e.g.,* protecting rescue teams, preventing accidents) and mitigating harm caused by human error or system failures. This discussion can be extended into critical questions such as what standards should govern UAV programming to preemptively minimize risks to people and property, or how can ethical considerations balance against the urgency and unpredictability of disaster scenarios.

On *justice* principle, the results can be interpreted that there is a need for fair and equal access to UAV resources during disaster response, avoiding biases in damage assessment and resource allocation and exclusively using data for its intended purpose and avoiding misuse of it such as commercial exploitation of sensitive information. Indeed, not all issues seemed to be fully answered on issues such as what methods that can ensure equal access to UAV assistance, particularly in underserved or remote areas or how is bias in UAV data analysis (*e.g.,* from sensor errors) addressed and mitigated.

In short, our paper has shown that there are numerous ethical and safety concerns on the use of UAV in emergency management that are highlighted from the results and require more future thorough discussions. The interplay between technoethics and practical deployment offers a lens to evaluate how emerging technologies such as UAVs are integrated into high-stakes environments.

CONCLUSION

This paper proposes the ethical dilemma associated with the deployment of UAVs in landslide condition for restoring network connectivity and gathering safety-critical information. The technoethics principles are considered in order to address the associated ethical concerns through group discussions with UAV experts and simulated approach. However, the article has several drawbacks. Firstly, we conducted the elicitation process with three UAV experts and an emergency management expert. Secondly, the study considered a simulation-based approach in which the generated data and proposed deployment procedure are considered using computer software instead of testing these steps physical environment. While this maybe adequate to withdraw ethical and safety implications, but physical deployment can help to verify, *e.g.,* the existence of the justice issue of connectivity distribution through UAVs. In addition to, the algorithm for estimating the radio propagation map is based on a machine learning-based approach using measurement data. However, these machine-learning based models are not 100% accurate to estimate the radio propagation map. Thirdly, several perspectives (*e.g.,* humanitarian, responders, regulator, society, environment, economic) necessary for effective and comprehensive management of landslide conditions. In this work, we mostly look into from the technologist perspectives, which can be improved.

Therefore, it is essential to consider these various angles in order to derive a comprehensive, ethical, and practical principles. To achieve these goals in future, we will organize a workshop with emergency management experts, legal and regulatory experts, as well as affected individuals.

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