Analyzing the Capabilities of UAV Technology in Humanitarian Disaster Relief and the Implications of Their Shortfalls

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

Nora Wilkerson

Spring 2024

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Advisor

Karina Rider, Department of Engineering and Society

Introduction

Climate-related disasters have dramatically increased in recent years, with over 7,300 reported incidents between 2000 and 2019. Extreme natural events like hurricanes, wildfires, and floods are occurring at an unprecedented rate. Over the past two decades, the number of recorded disasters has nearly doubled compared to the previous period, largely due to climate change-induced alterations in weather patterns (UNDRR, 2023). As these disasters intensify, the need for effective and timely humanitarian assistance becomes increasingly urgent. However, traditional disaster response strategies often suffer from logistical inefficiencies due to slow communication and data collection, leading to delays in aid distribution, misallocation of resources, and heightened risks for responders.

One potential solution to these challenges is the use of Unmanned Aerial Vehicles (UAVs) in disaster response. While manned helicopters, such as those used by Helicopter Express (2025), offer large cargo capacities and the ability to transport survivors and deliver water for firefighting, they also pose significant safety risks to emergency responders and are heavily limited by adverse weather conditions. UAVs, on the other hand, present a promising alternative by bypassing many of these obstacles, enhancing the speed and safety of aid delivery, and providing aerial reconnaissance to assess damage and locate survivors. However, their implementation is not without limitations, raising concerns about technological constraints and ethical considerations. Given this context, this paper seeks to answer the research question: How have UAVs enhanced disaster relief efforts, and what limitations do they still have in this role? To answer this question, I will analyze UAV-based relief efforts in two regions affected by major climate-related disasters: California, during the wildfires of 2022 and 2025, and Haiti, following the 2021 earthquake. A comparative case study of these events will provide insight into the

effectiveness of UAVs in different disaster scenarios and highlight the persistent challenges associated with their deployment.

This research adopts an intersectional Science and Technology Studies (STS) approach to explore how disaster response technologies may interact with certain social inequalities. Disaster relief efforts do not impact all communities equally; marginalized populations, particularly low-income and historically disenfranchised groups, often experience disproportionate harm. By incorporating an intersectional analysis, this study investigates how UAV implementation affects different social groups, considering factors such as race, class, and geographic accessibility. This paper also evaluates whether UAV technology exacerbates existing disparities and/or serves as a tool for more equitable aid distribution. Ultimately, this research aims to provide a nuanced understanding of UAVs in disaster response. By critically assessing both their capabilities and the ethical and socio-political concerns they raise, this paper contributes to ongoing discussions about properly integrating emerging technologies into humanitarian aid strategies while ensuring equitable and effective disaster relief.

Background

Disasters are defined as any event that negatively impacts the well-being of affected populations and their communities. The most significant distinction pertaining to this paper is natural disasters, which arise from environmental events such as earthquakes, tornadoes, landslides, floods, wildfires, and more. A rapid response is typical in the face of a natural disaster and necessitates proper disaster management; the steps of mitigation, response, and recovery must be accomplished (Daud et al., 2021). The deployment of UAVs in humanitarian aid has become increasingly prominent due to their capacity to navigate challenging environments and

provide timely support. During the 2010 Haiti earthquake, UAVs supplied critical aerial imagery that helped map damaged bridges, levees, buildings, and infrastructure in inaccessible areas, facilitating real-time data for resource allocation (T-Kartor Team, 2024). In the 2018 Sulawesi earthquake, UAVs were also utilized to deliver medical supplies to isolated communities, demonstrating their ability to respond quickly in regions with damaged infrastructure (American Red Cross, n.d.).

The growing intensity and frequency of natural disasters due to climate change further underscore the need for improved disaster response strategies (IPCC, 2021). According to the UN Office for Disaster Risk Reduction (UNDRR), climate-related disasters have increased by nearly 35% in the past two decades, significantly straining global humanitarian response efforts (UNDRR, 2023). In response, UAVs have been increasingly integrated into emergency response frameworks, with organizations such as the World Food Programme leveraging them for medical deliveries and damage assessment in certain crisis zones (WFP, 2022).

Three main categories of UAVs are used in humanitarian aid: compact multirotor and single-rotor UAVs, fixed-wing UAVs, and hybrid UAVs (O'Driscoll, 2017). Each category has notable limitations, particularly in payload capacity. Rotor-based UAVs are generally restricted to carrying small, lightweight items, such as medical supplies, vaccines, or communication devices. Clarke and Moses (2014) argue that "current UAV designs are not equipped to transport heavy or bulk supplies," which limits their utility in large-scale relief operations. Additionally, some UAVs are reliant on batteries, restricting their mission duration (T-Drones, 2023). The need for frequent recharging reduces the efficiency of UAVs in long-distance missions. Fixed-wing UAVs are the most commonly used in disaster scenarios, offering greater range but requiring significant space for takeoff and landing.

Adverse weather conditions, like heavy rainfall and strong winds, could limit UAV performance. These conditions can destabilize and impair their sensor functionality. Sometimes, the weather poses disruptions that "significantly reduce the reliability of UAV operations," underscoring the need for improved weather-resistant designs and enhanced power systems to ensure UAV effectiveness in disaster zones (Clarke and Moses, 2014).

Methods

The use of UAVs and their limitations will first be outlined through detailed case-study analyses of the 2022 and 2025 California Wildfires and the 2021 Haiti Earthquake. Both cases will be addressed separately to assess the benefits and limitations of UAV technology, focusing on an intersectionality approach to understand underlying issues in the distribution of aid using drone technology. Outlining the intersection between multiple parts of a community's identity and the gaps in disaster aid that drone technology can fill to save human lives is crucial in this research. I will use data about the spread of natural disasters from rescue, recovery, and relief websites, blogs, and organizations, and data surrounding the geography and community involved in said disasters.

Findings and Data

Case Study A: The 2021 Haiti Earthquake

In August 2021, Haiti was struck by a devastating 7.2-magnitude earthquake, resulting in over 2,200 fatalities and over 12,000 injuries (CORE, 2023). The widespread disaster destroyed or damaged approximately 137,000 buildings, leaving many communities in dire need of assistance (Abdessamad, 2023). The combination of high population density, weak

infrastructure, and economic instability exacerbated the devastation. Many Haitians were already struggling with poverty and political turmoil, making the recovery process even more intense.

The earthquake's impact was disproportionately severe on socioeconomically disadvantaged households. More than two-thirds of households in the Grande Anse Department reported being affected, with the most vulnerable experiencing the greatest losses (Jaupart et al., 2023). Communities with poorly constructed housing saw widespread damage and destruction, forcing families to seek refuge in overcrowded, uncomfortable shelters and makeshift tents. This disparity underscores how natural disasters exacerbate existing inequalities, leaving marginalized communities at heightened risk. With limited access to financial resources or the insurance necessary to recover what they lost, many affected families were left with no means to rebuild.

Women and girls faced disproportionately severe effects following the 2021 earthquake in Haiti. A Rapid Gender Analysis conducted by UN Women and CARE, in partnership with the Ministry for the Status of Women and Women's Rights and the General Directorate of Civil Protection, revealed that women experienced greater difficulty accessing health services (54% of women compared to 46% of men) and were also more likely to become homeless (18% of women compared to 12% of men), with greater perception of the risks of gender-based and sexual violence, backed Service providers also reported that women's health was more adversely affected due to increased infections and stress-induced chronic conditions. Maria Noel Vaeza, UN Women's Regional Director for the Americas and the Caribbean emphasized: "We need to make sure that the rights of women and girls are taken into consideration at all levels of the response and guarantee their participation and leadership in the recovery strategy" (UN Women, 2021).

These findings highlight the importance of gender-sensitive disaster response, particularly in ensuring the safety and inclusion of displaced women and girls living in overcrowded and unsafe shelters. UAV deployment strategies must account for these intersectional vulnerabilities by ensuring that data collection reflects the needs of women and marginalized groups, and that drone-enabled assessments lead to targeted support for populations most at risk. When drone operations are decided by gender-disconnected data and community leadership, they have the potential to make aid delivery more equitable and responsive to the lived realities of those most affected.

Case Study B: The 2022 and 2025 California Wildfires

The 2022 and 2025 California wildfires highlight how climate-induced disasters disproportionately impact marginalized communities and underscore the potential and limitations of UAVs in disaster response. Analyzing these events through an intersectional lens reveals systemic inequities in disaster preparedness and recovery. While wildfires affect all communities, those with fewer financial and social resources struggle the most, emphasizing the need for equitable disaster management. In 2022, devastating wildfires exposed the heightened vulnerability of marginalized groups, particularly Black, Hispanic, and Native American communities, who face a 50% higher wildfire risk due to historical redlining and inadequate infrastructure (The Nature Conservancy, n.d.). Similarly, the 2025 wildfires in Los Angeles County disproportionately affected Latino communities, who encountered socioeconomic barriers to emergency services and health care (Pech et al., 2025). Undocumented immigrants also feared deportation when seeking aid, further complicating recovery efforts. Drones have proven valuable in wildfire management by providing real-time data and assisting firefighting efforts. During the 2025 Los Angeles fires, UAVs equipped with AI and sensors monitored fire

progression and damage assessment (Fox-Sowell, 2025). However, high winds limited their deployment, and UAVs could not replace traditional firefighting methods due to payload constraints. Interestingly enough, UAV's can get in the way of larger, more effective fire-fighting aircraft. An unauthorized private drone flight interfered with an emergency operation of a Quebec "super scooper" aircraft, which can carry more than 1,500 lbs of water. This caused delays and aircraft damage (Howe, 2025; Deliso, 2025), delaying critical rescue flight operations for days where help was most needed. The private use of drones in disaster areas underscores the need for more legal enforcement on UAV usage in disaster zones, and potentially, a technological weakness of the radar capabilities on the disaster relief aircraft used.

The health and economic consequences of these fires were severe, with overwhelmed hospitals and displaced families which exacerbated several disparities (Hill et al., 2025). Economic shifts in areas like Pacific Palisades and Altadena led to gentrification, displacing lower-income residents who could not afford to rebuild (Picciotto, 2025). Meanwhile, community-led responses, such as fundraisers and sustainability initiatives, highlighted grassroots resilience but also the over-reliance on charity rather than systemic solutions (Pollard, 2025; Teen Vogue, 2025).

An intersectional analysis reveals that socially marginalized communities are particularly vulnerable to wildfire effects due to a lack of resources necessary for preparation and recovery (Baker et al., 2024). This vulnerability is paired with systemic inequalities that hinder effective disaster response efforts. For example, wealthier communities were able to hire private firefighters and had better insurance coverage, while lower-income neighborhoods suffered from delayed response times and underfunded emergency services. UAV deployment strategies must

prioritize equity by ensuring drone-assisted disaster response efforts reach all communities, not just those with the financial means to deploy them privately.

While UAVs offer promising support in disaster management, their limitations such as operational constraints during adverse weather conditions and the potential for interference with manned aircraft must be addressed (Fox-Sowell, 2025). Developing comprehensive guidelines and integrating community input are essential for maximizing the benefits of drone technology in disaster scenarios. Future advancements, such as improved AI for fire prediction, increased carrying capacity for emergency supply deliveries, and enhanced autonomy for UAV coordination, could make drones indispensable tools in disaster relief efforts.

In conclusion, the 2022 and 2025 California wildfires left a critical need for *inclusive* disaster preparedness and response strategies that consider the unique vulnerabilities of marginalized communities. *UAV technology* presents a solution; an opportunity to enhance disaster management but addressing its limitations and ensuring equitable access to these resources is imperative. By adopting an intersectional approach, emergency responders can work toward more just outcomes in the face of escalating climate-related disasters. Addressing these challenges requires not just technological innovation but also systemic reforms in emergency response infrastructure and planning, ensuring that UAVs contribute to more effective, equitable, and resilient disaster management strategies.

Discussion: Paths Toward Equitable Integration of UAVs in Disaster Relief

I: Strengths of UAV Deployment

The case studies of the 2021 Haiti earthquake and the 2022 and 2025 California wildfires demonstrate UAVs' powerful role in enhancing disaster response. Their capacity to provide

aerial surveillance allowed responders to identify damaged infrastructure and track the progression of fires; a system meant to help pinpoint areas where survivors may be most vulnerable. In Haiti, drones were able to navigate collapsed roads to map affected zones, guiding aid workers efficiently. In California, UAVs equipped with automatic sensors enabled responders to monitor fire behavior and evacuate communities in real time. These examples underscore UAVs' strengths in rapid data collection and situational awareness. Additionally, drones played a key role in the coordination between different groups. Real-time data shared among government bodies and NGOs created a more unified response. UAV-generated maps and visuals informed ground centers and helped allocate resources with greater precision and a more timely response.

II: Operational Limitations

Despite these benefits, UAVs have critical limitations. Foremost is their payload; the capability to meet large-scale humanitarian needs like distributing heavy supplies and providing medical care which is crucial for conducting rescues. During the Haiti earthquake, for example, while drones could locate survivors and assess structural damage, they were not equipped to deliver meaningful quantities of food, water, or shelter. In California, drones failed to operate during periods of high wind and thick smoke, and unauthorized private UAVs even disrupted firefighting efforts. Additionally, technological dependencies such as limited battery life, the need for unobstructed GPS signals, and weather sensitivity limit drones' utility in emergencies. In Haiti, power outages and unstable communication infrastructure further reduced the reliability of UAV operations.

III: Intersectionality in UAV Deployment

When viewed through an intersectional lens, it becomes clear that UAV technology does not serve all communities equally. In Haiti, vulnerable groups, including low-income households and women, who were most of the heads of said households, were disproportionately affected by the earthquake's aftermath. Overcrowded shelters, increased gender-based violence, and lack of access to resources exposed the limits of drone-centered aid strategies when unaccompanied by gender-sensitive planning and local partnerships.

In California, historical patterns of racial and economic marginalization led to unequal wildfire impacts. Latino, Black, and Indigenous communities often resided in more fire-prone areas due to legacies of redlining and underinvestment in infrastructure. While wealthier neighborhoods could afford private UAVs or firefighting services, lower-income communities faced delayed response times and greater property loss. For undocumented immigrants, fear of deportation further impeded access to public emergency services. These disparities reveal that while UAVs are considered more neutral tools, their deployment highlights structural inequalities depending on who controls the technology and how it is integrated into aid strategies.

IV: A More Just UAV Integration

To maximize UAV potential while addressing their shortcomings, a change in the overall philosophy of their deployment is absolutely necessary. First, humanitarian organizations should include community consent and data privacy protections in drone operations. Future UAV use should prioritize participatory mapping, where affected communities co-lead data collection and planning, and second, invest in local interaction. Training community members, particularly

those from marginalized areas, in drone operation and disaster response planning would democratize access to this technology (UNDP, 2022). Such an inclusion not only builds resilience in said communities but also ensures that aid strategies are built by those with the most at stake. Finally, UAV use must focus on complementing rather than replace human-centered disaster relief. Policymakers, engineers, and experts performing field testing should treat drones as a part of a larger framework that includes community engagement focusing on local knowledge and overall reform of culturally sensitive emergency services.

Conclusion

UAVs have the potential to make disaster response faster and more effective. They can help responders understand the full scale of a crisis, help with tracking survivors, and support relief coordination in ways that traditional methods and technologies can't. But as I've explored in this paper, their benefits are not shared equally across communities. The people most affected by disasters, mainly those living in poverty, facing racial injustice, housing insecurity, or some form of legal vulnerability, often remain outside the box of technological solutions. We should reframe our thoughts to be that for a tool to be "innovative" or "useful," it requires analysis of its capabilities, who it reaches, and, of course, who it leaves behind.

Taking an intersectional approach has helped uncover how technology like UAVs interacts with systems of inequality. In both Haiti and California, the same drones that offered life-saving information to some, mainly wealthy communities, failed to serve others who needed them *just* as much, if not more. These case studies reminded me that technology doesn't operate in a vacuum; it operates in social, political, economic, and historical circumstances. For UAVs to

truly support disaster relief, they must be part of a broader shift toward justice that centers the knowledge and voices of the people most at risk.

This project leads to paths extending beyond climate disasters for further study. As drones are increasingly used in responses to man-made disasters like oil spills, terrorism, industrial accidents, etc., it is even more important to ask how we deploy them, and with what intentions. There's a real opportunity to rethink how we approach crises altogether. Technology can be part of that, but only if we commit to using it with accountability and a deep respect for human lives.

References

Abdessamad, F. (2023, September 13). *Haiti is a cautionary tale for any earthquake recovery*. DAWN. https://dawnmena.org/haiti-is-a-cautionary-tale-for-any-earthquake-recovery/

American Red Cross Team (Trans.). (n.d.). *Drone activities in the network*. Drone activities in the network - Drones in the RCRC documentation. https://americanredcross.github.io/rcrc-drones/activities.html

Baker, B., Dinh, Y., Foxfoot, I. R., Ortiz, E., Sells, A., & Anderson, S. E. (2024, January 28). *Social inequity and wildfire response: Identifying gaps and interventions in Ventura County, California*. MDPI. https://www.mdpi.com/2571-6255/7/2/41

Clarke, R., & Bennett Moses, L. (2014). The regulation of civilian drones' impacts on public safety. *Computer Law & Security Review*, *30*(3), 263–285. https://doi.org/10.1016/j.clsr.2014.03.007

CORE. (2023, January 20). *Haiti earthquake 2021*. https://www.coreresponse.org/haiti/earthquake-2021/

Deliso, M. (2025, January 31). *Drone operator charged for hitting "super scooper" plane during Palisades Fire: DOJ*. ABC News. https://abcnews.go.com/US/drone-operator-charged-hitting-super-scooper-plane-palisades/story?id=118313936

Express, H. (2025). *Helicopters in disaster relief: Unsung Heroes of Crisis response: Helicopter express*. RSS. https://www.helicopterexpress.com/blog/helicopters-in-disaster-relief-unsung-heroes-of-crisis-response

Fox-Sowell, S. (2025, January 15). *AI cameras, sensors, and sometimes drones aiding fight against L.A. wildfires*. StateScoop. https://statescoop.com/ai-cameras-sensors-drones-la-wildfires-2025/

Hill, A. C., & Mahat, P. (2025, January 22). *California's wildfires demand action*. Think Global Health. https://www.thinkglobalhealth.org/article/californias-wildfires-demand-action

Houseal, J. (2025, February 28). *This high school is tackling clothing donation waste in ways most fashion brands won't*. Teen Vogue. https://www.teenvogue.com/story/this-california-high-school-fashion-show-is-tackling-clothing-waste-in-ways-most-brands-wont

Howe, S. (2025, January 21). *Los Angeles fires highlight the promise (and problems) of using drones for firefighting*. Commerical UAV News. https://www.commercialuavnews.com/los-angeles-fires-highlight-the-promise-and-problems-of-using-drones-for-firefighting

IPCC Team. (2021, August 9). Climate change widespread, rapid, and intensifying. IPCC. https://www.ipcc.ch/2021/08/09/ar6-wg1-20210809-pr/

Jaupart, P., Kharb, A., Manigat, A.-K., Tassot, C., & Tesliuc, C. (2023, December 11). *The impact of the August 2021 earthquake in Haiti: Evidence from the Social Registry's Shock Module*. PreventionWeb. https://www.preventionweb.net/publication/impact-august-2021-earthquake-haiti-evidence-social-registrys-shock-module

Mohd Daud, S. M., Mohd Yusof, M. Y., Heo, C. C., Khoo, L. S., Chainchel Singh, M. K., Mahmood, M. S., & Nawawi, H. (2021). Applications of drone in Disaster Management: A scoping review. *Science & Justice*, *62*(1), 30–42. https://doi.org/10.1016/j.scijus.2021.11.002

Mohsan, S. A., Othman, N. Q., Li, Y., Alsharif, M. H., & Khan, M. A. (2023). Unmanned Aerial Vehicles (uavs): Practical aspects, applications, open challenges, security issues, and future trends. *Intelligent Service Robotics*. https://doi.org/10.1007/s11370-022-00452-4

O'Driscoll, D. (2017, August 14). *UAVs in humanitarian relief and wider development ...* UAVs in Humanitarian Relief and Wider Development Contexts. https://assets.publishing.service.gov.uk/media/5bae0427ed915d25aec40cab/185_UAVs_in_Humanitarian_Relief_and_Wider_Development_Contexts.pdf

Pech, C., González, S. R., & Kochapum, A. (2025, January 18). *Wildfires and Latino communities*. Latino Policy & Politics Institute. https://latino.ucla.edu/research/wildfires-and-latino-communities-health-economic-and-preparedness-challenges/

Picciotto, R. (2025, March 3). *Home-selling season starts after L.A. wildfires-and there is demand*. The Wall Street Journal. https://www.wsj.com/real-estate/home-selling-season-starts-after-l-a-wildfiresand-there-is-demand-ade29d97

Pollard, J. (2025, February 27). *NYC entertainers and creatives feel connected to LA. that link is driving cross-country fire relief.* AP News. https://apnews.com/article/los-angeles-wildfires-new-york-andy-cohen-comic-relief-30ccc9421d462660f31b6ed826768cf8

T-Drones Team. (2023, July 20). *Drone battery: Explore how long they last & longevity tips*. T-Drones. https://www.t-drones.com/blog/drone-battery-complete-beginner-guide.html

The Nature Conservancy. (n.d.). *New research shows increased wildfire risk among minorities*. The Nature Conservancy. https://www.nature.org/en-us/about-us/where-we-work/united-states/washington/stories-in-washington/wildfires-impact-minorities/

T-Kartor USA. (2024, October 22). *Post-disaster damage assessment using Geospatial Data*. Discover Your World with Custom Geospatial Solutions! https://www.t-kartor.com/blogs/post-disaster-damage-assessment-using-geospatial-data

UN Women. (2021, December 16). *Rapid gender analysis in Haiti reveals earthquake-related impacts on women and girls*. UN Women Data Hub. https://data.unwomen.org/features/rapid-gender-analysis-haiti-reveals-earthquake-related-impacts-women-and-girls

UNDP. (2022, August 16). A year after the earthquake in Haiti, local communities are building resilience. https://www.undp.org/blog/year-after-earthquake-haiti-local-communities-are-building-resilience/

UNDRR. (2023, July 11). *New report shows climate disasters are reversing global development at unprecedented rates*. https://www.undrr.org/news/new-report-shows-climate-disasters-are-reversing-global-development-unprecedented-rates

WFP Team. (n.d.). *Using drones to deliver critical humanitarian aid | WFP Drones*. Using drones to deliver critical humanitarian aid . https://drones.wfp.org/updates/using-drones-deliver-critical-humanitarian-aid