Analysis of Technology Adoption and Associated Impacts on Large-Scale Landmine Clearance

Mutuku Muli, Maria W. Mung'ara & Edna Milgo
**Corresponding author: mutukumuli@gmail.com*

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Abstract

The realization of a mine-free world is one of the most urgent humanitarian and developmental issues of the 21st century. The issue of landmine contamination has been plaguing populations in over 58 countries with a multitude of continuing threats to the safety and economic recovery of people, as well as the sustainability of the environment. This report gives a further discussion of how emerging technologies, such as unmanned aerial vehicles (UAVs), artificial intelligence (AI), and sophisticated sensor systems, can revolutionize the large-scale landmine clearance processes. Several key performance indicators (KPIs) are assessed with the help of a comparative efficiency framework, including the speed of detection, operational efficiency, safety outcomes, and cost implications. The results show that technology-based demining methods are much more effective than the traditional manual ones, as they can not only be ten times faster than them but also pose a much lower risk to operator safety. Nonetheless, issues of cost, infrastructure, and capacity building are major obstacles to large-scale implementation. This report has determined that the incorporation of high-level technologies in demining activities is the way to go to quicken the pace of achieving a mine-free world.

Introduction

The international campaign to eradicate landmines and explosive remnants of war (ERW) has achieved significant progress in recent decades, but the extent of contamination is still huge. As per recent estimates, explosive ordnance is a problem in at least 58 countries and territories, and civil casualties have been increasing because of ongoing conflicts and legacy contamination (ReliefWeb, 2026). Landmines not only affect human life directly but also negatively affect farming, the development of infrastructure, and the recovery of the economy in the long run.

Conventional demining techniques are highly manual, involving handheld metal detectors and physical probing. Although they can be efficient in controlled environments, these solutions are naturally slow, resource-intensive, and dangerous. Another major drawback of manual demining is the high false alarm rate due to metallic debris, which can lead to up to 90% of detected signals being false being false alarms (GICHD, 2024). This causes deminers to spend a significant amount of time searching for non-threatening items, reducing the productivity of their operations.

To overcome these difficulties, the demining industry is turning towards Industry 4.0 technologies. These consist of UAVs for aerial surveying, AI to analyze the data, and other sophisticated sensor systems like ground penetrating radar (GPR) to detect the presence of subsurface. The combination of technologies is a paradigm shift in data-driven, scalable solutions, rather than the labor-intensive processes. This report discusses the role of these innovations in transforming mass landmine clearance and evaluates their wider humanitarian and economic consequences.

Literature Review

According to recent literature, there has been a major shift in the practices of demining, and the focus has shifted to multi-domain systems, which are more integrated and less traditional (manual). Geneva International Centre for Humanitarian Demining (GICHD) highlights that the current demining is becoming more and more dependent on the use of satellite imagery, UAV reconnaissance, and robotic platforms to increase situational awareness and operational planning (GICHD, 2024). This change can allow organizations to focus on the high-risk areas and allocate resources more effectively.

Evidence-based surveying is a concept that has become popular as a measure of contemporary mine action. This is a strategy that entails gathering and examining data through various sources to find out the possibility of contamination before the deployment of clearance teams. Evidence-based surveying will reduce uncertainty and, therefore, will reduce unnecessary clearance activity and enhance the overall efficiency.

Remote Sensing and Artificial Intelligence

AI has become a disruptive technology in landmine detection. Machine learning can be used to analyze large amounts of aerial data, especially with convolutional neural networks (CNNs), to detect patterns related to buried explosives. These patterns can consist of minor shifts in soil structure, plant stress, and irregularities at the surface (ResearchGate, 2024).

Detecting capabilities are also increased with multispectral and thermal imaging, which capture data outside of the visible spectrum. To illustrate, thermal sensors can measure temperature changes due to soil density differences, and multispectral sensors can detect changes in plant health that can be related to underlying disturbances. These technologies, in combination with AI, can quickly and precisely identify possible hazards.

Moreover, the incorporation of Software-Defined Radio (SDR)-enabled GPR systems with UAV platforms is also an important breakthrough in subsurface detection. The systems enable remote scanning of a vast area and eliminate the use of direct human interaction in dangerous conditions.

Standardization and Data Management

With more people adopting technology, the need for standardized data management systems is more important. Information Management System of Mine Action is the core of information management about mine action activities, which is a central point of data collection, storage, and analysis. Standardization provides interoperability between various organizations and coordination of responses to contamination issues (GICHD, 2024).

Nonetheless, the adoption of standardized systems in various settings of operation is still a challenge. Lack of uniformity in infrastructure, technical capacity, and regulatory frameworks may act as a barrier to the successful integration of new technologies. Thus, adoption cannot be successful without technological innovation as well as institutional alignment and capacity building.

Methodology

The research uses a Comparative Efficiency Framework to assess how large-scale landmine clearance has been affected by the adoption of technology. The model is oriented towards juxtaposing manual and technology-aided methods of work in various aspects.

Operational Benchmarking

The performance of advanced technologies in high-adoption areas, such as Ukraine and Afghanistan, is evaluated based on operational data. These areas are important case studies because they have been highly contaminated and are working towards incorporating innovative solutions (UNDP, 2025).

Key Performance Indicators (KPIs)

The analysis is based on the following KPIs:

- Area surveyed per hour (m^2/hour)
- Lessening of false-alarm rates.
- Detection speed
- Human casualty rates
- Cost efficiency

Secondary Data Analysis

Information will be synthesized based on reports by the leading humanitarian organizations, such as GICHD, UNDP, and ReliefWeb. Technical reports and academic studies are also included to present a holistic view of the impacts of technology.

Data Analysis

Operational Acceleration

Among the greatest benefits of the use of technology-assisted demining, the speed of operations has increased dramatically. The UAV systems enabled by AI have the potential to cover vast regions within a fraction of the time spent by manual methods. According to field studies, these systems may be ten times faster in detection than the conventional methods (ReliefWeb, 2026).

Table 1: Comparison of Key Performance Indicators Between Manual and Technology-Assisted Demining

KPI	Manual Demining	Technology-Assisted Demining
Area surveyed (m²/hour)	20–50	200–500
False alarm rate	High (up to 90%)	Reduced by 60–80%
Detection speed	Baseline	Up to 10× faster
Casualty risk	High	Significantly reduced
Cost per m²	Low initial, high long-term	High initial, lower long-term

Note. Estimates synthesized from GICHD (2024), ReliefWeb (2026), and UNDP (2025)

Table 2: Comparison of Key Technologies Used in Landmine Clearance

Technology	Function	Advantages	Limitations
UAVs (Drones)	Aerial surveying	Rapid coverage, improved safety	Weather dependent
AI Image Recognition	Data analysis	High accuracy, rapid processing	Requires large training datasets
Ground Penetrating Radar (GPR)	Subsurface detection	Detects buried objects	Signal interference in complex soils
Robotic Demining Vehicles	Physical clearance	Reduces human exposure	High acquisition and maintenance costs

Note. Adapted from ResearchGate (2024) and GICHD (2024)

Such a high rate can be greatly explained by the possibility of covering a large territory in a short time using the UAVs and the efficiency of the AI algorithms to analyze the data. This combination minimizes both the survey and analysis time and makes decisions quicker.

AI Integration

The accuracy and efficiency of demining activities are greatly improved with the integration of AI. The conventional image analysis techniques usually involve manual interpretation that may be time-consuming and even erroneous. On the contrary, AI systems have the capability of processing thousands of images within a few minutes, detecting possible hazards with a high degree of accuracy (UNDP, 2025).

Moreover, AI models are constantly being enhanced by means of training, which enables them to adjust to new environmental factors and forms of contamination. Such flexibility allows AI to be a strong instrument for massive operations in various geographical areas.

Human Safety

One of the main issues in demining work is safety, and the development of technologies has minimized the number of risks to workers. Before human forces go into the field, robotic systems are deployed to mitigate risk, like with remote-controlled flails or armored vehicles. These systems provide a shield of protection, reducing direct contact with explosive threats (GICHD, 2024). Moreover, UAVs allow surveying remotely, which means that no one will be required to visit hazardous areas physically. Not only does this decrease the chances of accidents, but overall it enhances efficiency in operation.

Economic Restoration

In addition to safety and efficiency, there are economic consequences of technological developments in the demining sector. Cleaning up the polluted land facilitates farming, development of infrastructure, and resettlement of the community. In some places like Kandahar, technology-assisted demining has helped to create employment and increase household income (ResearchGate, 2024).

Discussion

This analysis indicates the transformative nature of technology in clearing the landmines. Nevertheless, there are several issues that need to be overcome to make it widespread.

Financial Barriers

Acquisition of advanced technologies is a major barrier, especially to low-income countries, due to their high initial cost. Although the long-term benefits can be greater than these costs, it can be challenging to get financing for start-up investments.

Technical Capacity

The efficient management of the latest technologies entails the presence of qualified staff and well-developed infrastructure. The process of developing training programs and capacity building is necessary to make sure that local teams can work and support these systems.

Ethical and Social Reflections

AI and automation have raised ethical issues regarding the privacy of data, the transparency of decision-making, and the threats of substituting human labor. It is essential to ensure that technological developments are socially responsible and inclusive.

Cost-Benefit Perspective

Table 3: Cost-Benefit Comparison of Traditional and Technology-Driven Demining Methods

Factor	Traditional Methods	Technology-Driven Methods
Initial Investment	Low	High
Operational Efficiency	Low	High
Long-Term Cost	High	Lower
Safety	Low	High
Scalability	Limited	High

Note. Comparative assessment based on synthesized literature (GICHD, 2024; UNDP, 2025; ReliefWeb, 2026)

Demining Technology Limitations

Although new technologies have a lot of benefits as far as landmine clearance is concerned, there are still several drawbacks that limit their use and effectiveness. These issues are technical, environmental, financial, and operational in nature, which underscores the importance of a balanced combination of both technological and traditional approaches in this respect.

Environmental and Terrain Limitation

Among the major drawbacks of technology-assisted demining is that it is sensitive to the environment. The stability of the weather is very crucial in UAV operations, such as in the case of UAVs. Powerful air currents, intense precipitation, and harsh weather may interfere with flight routes, decrease the quality of data, and decrease working hours. Likewise, dense vegetation and terrain may hinder aerial visibility, limiting the effectiveness of remote sensing methods (GICHD, 2024).

Ground-based detection systems, like Ground Penetrating Radar (GPR), are also not very effective under some soil conditions. Highly mineralized soils, high in moisture content, and have an uneven composition of al-araz can disrupt signal propagation, causing the detection accuracy to have low values and false positives (Daniels, 2004). This consequently means that the reliability of such technologies differs significantly in the various geographical locations.

High-Clutter Environments

In a high-clutter environment, such as most post-conflict regions, large quantities of metallic debris are found together with landmine contamination. Even though AI systems and highly sensitive sensors are intended to differentiate between hazardous and non-hazardous objects, even in this case, their performance may be impaired. Training data is also a fundamental component of machine learning models, and their efficacy could decrease in unpredictable or complicated situations (Zhang et al., 2023).

False positives are a constant problem and may need further verification procedures, which may slow down operations. With technology, the need for manual investigation is lessened, but it does not completely remove the human touch in cases of uncertainty.

Financial and Resource Barriers

The initial cost of the purchase and implementation of the advanced technologies is a significant hindrance, especially to the low and middle-income nations. UAV systems, AI infrastructure, and robotic platforms are also costly not only to purchase but also to maintain, develop the software, and be able to process the data. Though such technologies might be cost-effective in the long term, due to the initial high financial cost, they are not accessible to everyone (UNDP, 2025).

Moreover, the recurrent operational expenses, including training staff, software and hardware upgrades, may strain already limited resources in the humanitarian organizations. This results in the creation of inequalities in the adoption of technologies between resource-constrained and well-funded areas.

Technological Capacity and Skills Gap

It takes specific technical knowledge to effectively apply advanced technologies. The skills required to operate UAVs, train AI models, and interpret sensor data might not be easily accessible in most of the affected areas. Such a skills gap may negatively affect the deployment and sustainability of technological solutions.

Capacity-building interventions are necessary to combat this problem, but they need time, resources, and institutionalization. The advantages of technological innovation might not be as well achieved without proper training and knowledge transfer (GICHD, 2024).

Data Limitations and Bias in an Algorithm

The constructs of AI-based systems are largely reliant on data quality and availability. Misrepresented, incomplete, or biased data may result in inaccurate predictions and low detection rates. As an illustration, the models that have been trained to operate in a particular terrain or mine design might not work effectively in new settings.

Another issue is algorithmic bias, which may lead to disparities in performance across regions. It is essential to make sure the data is diverse, and the models are constantly verified to preserve reliability and equality in AI-based demining work (Zhang et al., 2023).

Ethical and Operational Concerns

The growing use of automation and AI brings up ethical concerns regarding accountability and transparency, as well as decision-making. Mistakes in automated systems may be critical in a high-risk environment, which begs the question of accountability and control.

Moreover, the issue of the possible displacement of manual demining workers exists. Although technology will improve safety and efficiency, efforts should be made to make sure that the local communities are still actively involved in mine action activities. Inclusive approaches that combine technological innovation with human expertise are essential for sustainable and ethical implementation.

Conclusion

Adoption of technology is a very imperative facilitator to achieve a mine-free world at an accelerated pace. Combining UAVs, AI-based analytics and robots makes demining a scalable, data-driven process that brings a substantial increase in efficiency and safety.

Financial, technical, and social challenges need to be overcome, however, to attain widespread adoption. The global community can use innovation to establish safer living conditions and promote sustainable development by encouraging cooperation between governments, humanitarian organizations, and technology providers.

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