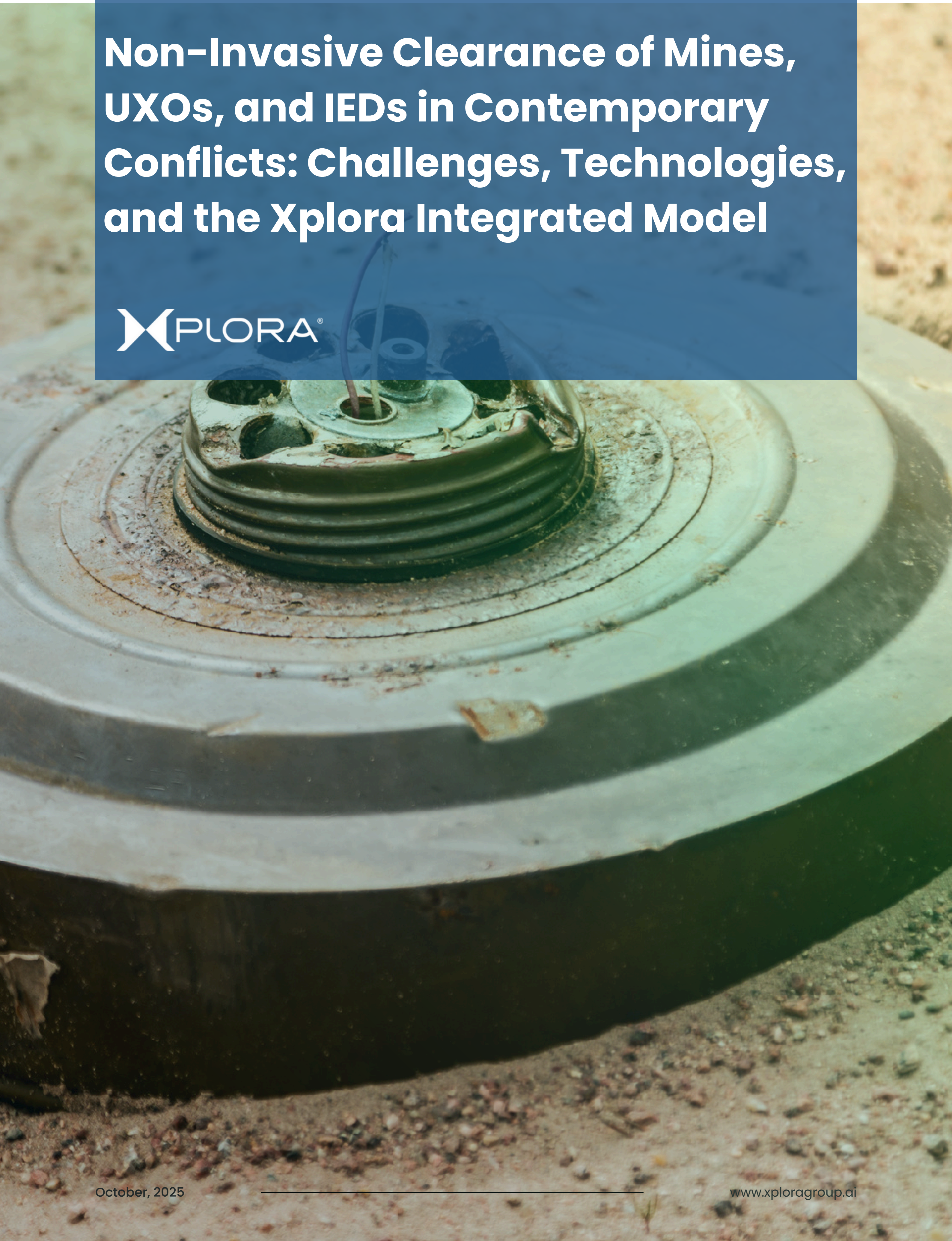
Non-Invasive Clearance of Mines, UXOs, and IEDs in Contemporary Conflicts: Challenges, Technologies, and the Xplora Integrated Model

XPLORA®



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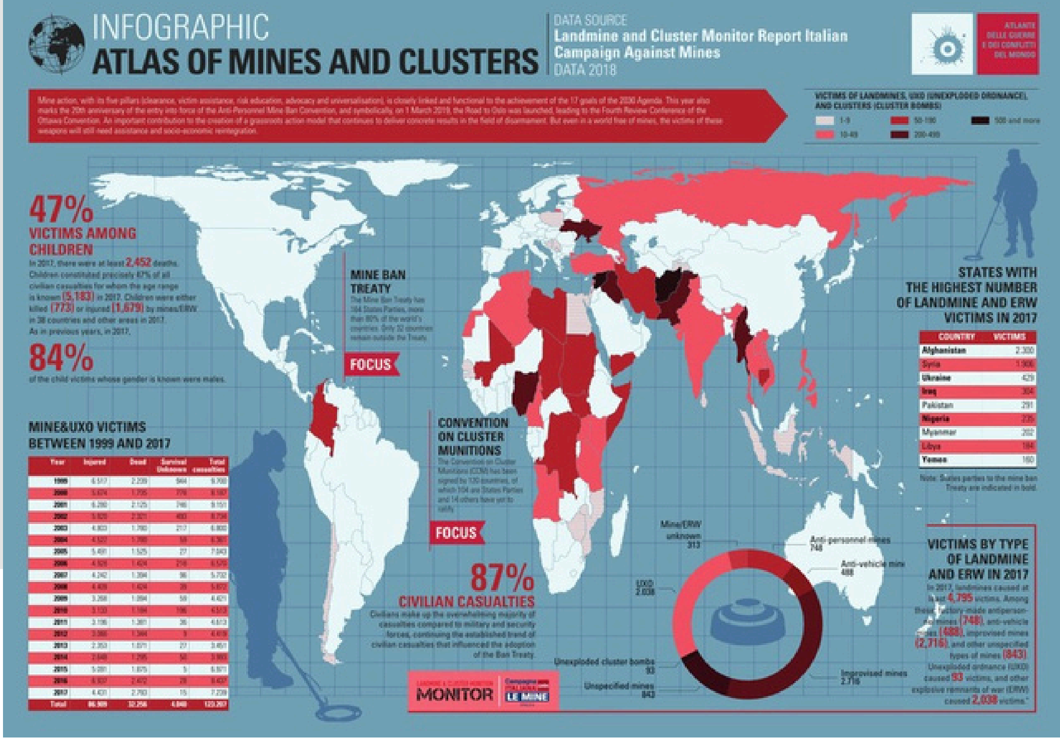

INTERNATIONAL AND EUROPEAN LANDSCAPE

GLOBAL DISSEMINATION OF CONTAMINATION FROM ORDNANCE

Armed conflicts in the 20th and 21st centuries have resulted in millions of landmines, anti-tank mines, cluster munitions, unexploded ordnance, and improvised explosive devices dispersed across various terrains. The 2025 report from the United Nations Secretary-General on Assistance in Mine Action Activities indicates that at least 58 states and territories are affected by landmines, while more than 60 are contaminated with remnants of IEDs.
In Ukraine, it is estimated that around 10% of the most fertile agricultural land is currently rendered unusable due to contamination from explosives.

The Landmine Monitor 2023, produced by ICBL and its partners, indicates that despite years of demining efforts, the volume of newly deployed ordnance and the technical challenges associated with its clearance are intensifying the issue. archives2.the-monitor.org

In nations such as Yemen, the "Project Masam" initiative has successfully eliminated hundreds of thousands of mines, unexploded ordnance (UXO), and improvised explosive devices (IEDs) by 2024, clearing tens of thousands of hectares. Nevertheless, the majority of these removals pertain to shallow or moderately buried devices, while deep clearance continues to pose a significant technical challenge on a large scale.

The Office of the High Commissioner for Mine and Humanitarian Action (UNMAS) and its partner organizations underscore that the "technological stalemate" in deep detection methods represents a significant obstacle to realizing a "mine- and UXO-free land."

HISTORICAL HERITAGE IN EUROPE AND ITALIAN LEGISLATION

In Europe, numerous rural and peri-urban areas remain contaminated by remnants of warfare from the First and Second World Wars, including unexploded ordnance, bullets, and aerial bombs. In Italy, for instance, unexploded ordnance has been intermittently discovered in agricultural subsoils and peri-urban regions for the past 80 years. The significant geological variations, such as gravel, clay layers, and aquifers, render traditional remediation exceptionally challenging. Invasive technologies pose a risk of damaging infrastructure, water networks, and the soil matrix, leading to unsustainable costs and timelines.
In Italy, the management of risks associated with unexploded ordnance (UXO) is regulated by a multifaceted framework that encompasses Legislative Decree 81/2008 concerning construction site safety and Ministry of Defense Directive No. 177/2012, which mandates a UXO detection Assessment (WRA) for all public and private projects on potentially contaminated land. According to this legislation, surveys must accurately identify the presence of UXO prior to the commencement of any excavation or drilling activities.

RECENT CONFLICTS AND EASTERN FRONTIERS

The Russian invasion of Ukraine, which commenced in 2022, has reintroduced the issue of mine and unexploded ordnance (UXO) contamination to the forefront of European security policies. The conflict has resulted in a significant dispersal of both conventional and improvised explosive devices (IEDs), contaminating extensive agricultural, infrastructural, and urban regions in eastern Ukraine, thereby critically affecting food security, civilian mobility, and the nation's capacity for reconstruction. According to UNMAS and the Landmine Monitor, Ukraine is currently regarded as one of the most contaminated regions globally by explosive remnants of war, with millions of hectares requiring clearance and an increasing number of civilian casualties.

Furthermore, several Northern European nations, including Finland and Estonia, have indicated a possible withdrawal from the Ottawa Convention (IFRC+1 Mine Ban Treaty) in 2025, against a backdrop of heightened geopolitical tensions. This potential institutional disengagement renders the adoption of advanced detection and remediation technologies, even beyond conventional avenues, imperative.

TECHNICAL OBSTACLES IN THE ADVANCED REMEDIATION SECTOR

TECHNICAL OBSTACLES IN THE ADVANCED REMEDIATION SECTOR

Despite decades of technological advancement, the clearance of unexploded ordnance (UXO), mines, and improvised explosive devices (IEDs) continues to be one of the most intricate, time-intensive, and expensive operations to oversee. The challenges are significantly heightened when addressing deeply buried ordnance and in highly complex environmental or urban settings, where conventional invasive methods such as coring, manual excavation, or mechanical drilling are not only ineffective but also perilous, intrusive, and logistically impractical.
Geotechnical variables, soil stratigraphy, the existence of underground utilities, the degree of urbanization, and the diversity of materials involved in conflicts (metal, plastic, glass, composites) complicate the accurate differentiation between genuine threats and false positives. Consequently, this leads to slower operations, heightened costs, and a significant reliance on human intervention to verify detected signals.

In addition, there are increasingly stringent regulatory constraints, particularly in Europe, where any intervention in suspect areas—even basic civilian infrastructure—necessitates comprehensive prior assessments, military authorizations, and complete traceability of operations. In this context, the limitations of conventional remediation technologies become evident: they are inadequate to address the complex and multi-faceted environments of contemporary conflict.

Xplora recognized from the beginning that the challenge was not solely technical but also systemic. To tackle these significant issues, it created an integrated technological ecosystem capable of functioning in a completely non-invasive manner, adapting to various terrains, detecting objects at considerable depths, and, most importantly, generating objective, classified, and directly applicable output in the operational environment.

DEPTH AND ARRANGEMENT OF THE ORDNANCE

One of the most significant challenges is the depth of burial: in numerous warfare scenarios (aerial bombardment, artillery, partial detonations), ordnance can penetrate several meters beneath the surface. Although many geophysical techniques can detect objects within 1–2 meters, clearing depths of up to 8 meters necessitates highly advanced three-dimensional approaches.

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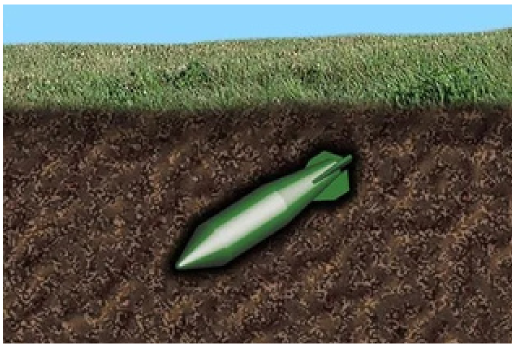


- According to a technical source at DFI Geophysics, "burial depths range from a few centimeters to several meters for airborne ordnance, with the majority being within 1 meter" — although exceptional cases may surpass this threshold. DFI Geophysics Tool
- In the scientific literature, the application of multiscale magnetometric methods has been assessed for the identification of objects buried at intermediate depths; however, sensitivity significantly diminishes as depth increases. SpringerLink
- Algorithms utilizing wavelet transforms demonstrate potential for the automatic detection of magnetic dipole depths; however, their accuracy diminishes in the presence of complex terrain or overlapping anomalies. ResearchGate
- In the realm of electromagnetic and inductive techniques, sophisticated models enable discrimination over distances of several meters; however, they necessitate costly and precisely calibrated inversion models.
- In summary, to effectively cover the 0–1 meter range with operational reliability, it is essential to integrate various technologies and employ advanced sensor fusion techniques to accurately estimate the intermediate depth.

VARIETY OF LANDSCAPES AND OPERATIONAL ENVIRONMENTS

Contaminated soils exhibit highly variable characteristics, including sand, gravel, silt, clay, wetlands, aquifers, and urban areas with subterranean infrastructure such as water mains, pipelines, and cable ducts. This diversity results in:

- **Diverse electromagnetic propagation:** Fluctuating conductivity and dielectric constant influence the signal and penetration of EM/GPR fields.
- **Local magnetic disturbances:** Metallic infrastructure, piping, and subterranean cables produce magnetic interference that obscures the signal from the devices.
- **Stratigraphic effects and layering:** Layers composed of varying materials (e.g., gravel atop clay) induce refractions, reflections, and dispersions that complicate the interpretation of signals.
- **Presence of water and soil saturation:** the existence of groundwater or elevated moisture levels diminishes penetration and modifies the propagation velocity of GPR and EM.

To address these factors, technologies must implement adaptive calibrations, site-specific geophysical models, and "self-adapting" algorithms.

LIMITATIONS OF INVASIVE AND CLASSICAL METHODOLOGIES

Conventional remediation techniques—manual excavation, coring, and mechanical drilling—exhibit considerable limitations:

- **Physical invasiveness**: they disrupt the soil matrix, underground infrastructure, and modify hydraulic systems.
- **Lengthy and costly**: sluggish operations, labor-intensive, substantial logistical support.
- **Limited accessibility**: Densely populated urban regions or areas with restricted access cannot be excavated.
- **Operator Risk**: Technicians are required to work in proximity to potentially active mines and unexploded ordnance, presenting a direct risk.
- **Limited scalability**: Addressing hectares on a national scale necessitates human resources and assets that are challenging to mobilize.

DISCRIMINATION AND ERRONEOUS POSITIVES

A critical challenge lies in differentiating between signals produced by innocuous metal objects (such as debris, pipes, and scrap metal) and those that pose genuine threats. An abundance of false positives can compromise the efficacy of the remediation process.

- **Classification** algorithms must be meticulously refined and grounded in calibrated local datasets.
- The application of **advanced techniques**, such as electromagnetic inversion (EMI) or the analysis of magnetic polarizabilities, enables us to assess the thickness, composition, and geometry of the target object.
- **3D GPR migration models** integrated with neural networks facilitate enhanced extraction of "hyperbolic" features and more accurate estimation of residual depth, resulting in diminished errors (e.g., the DepthNet technique for GPR).
- **The application of sensor fusion** (magnetometry + EM + GPR) aids in minimizing false positives by synchronizing results from various domains (magnetic, electrical).

OPERATIONAL LIMITATIONS, EXPENSES, AND SAFETY

In addition to the technical challenges, there are considerable operational limitations:

- **Equipment expenses**: Advanced sensory apparatus, specialized drones, and supporting infrastructure necessitate substantial investments.
- **Specialized training:** Operators are required to possess expertise in geophysics, artificial intelligence, data science, and explosive ordnance disposal security.
- **Safety Regulations and Certifications**: Numerous regions necessitate government permits, adherence to military or civilian standards, and established EOD procedures.
- **Geographic scalability and logistics:** Conducting operations in remote regions lacking infrastructure necessitates autonomous power cells, resilient data transmission systems, and comprehensive logistical support.
- **Reliability and robustness:** the system must function effectively in challenging environmental conditions without compromising performance.

	TRADITIONAL MANUAL SURVEY	METAL DETECTORS	ARMORED TRUCKS	ISR UAS
SCAN TIME:	Very High	High	Low	High
COST PER SCANNED Ha:	Very High	High	High	High
RELIABILITY/QUALITY:	Very High	Low	N/A	Low
OPERATOR RISK:	Very High	Very High	Low	N/A
INTRINSIC DEFECTS:	Errors due to stress, fatigue, and harsh environmental conditions	Errors due to stress, fatigue, and harsh environmental conditions	Soil disturbance can bring deeply buried mines to the surface.	Frequent false positives, no detection certainty.

XPLORA®

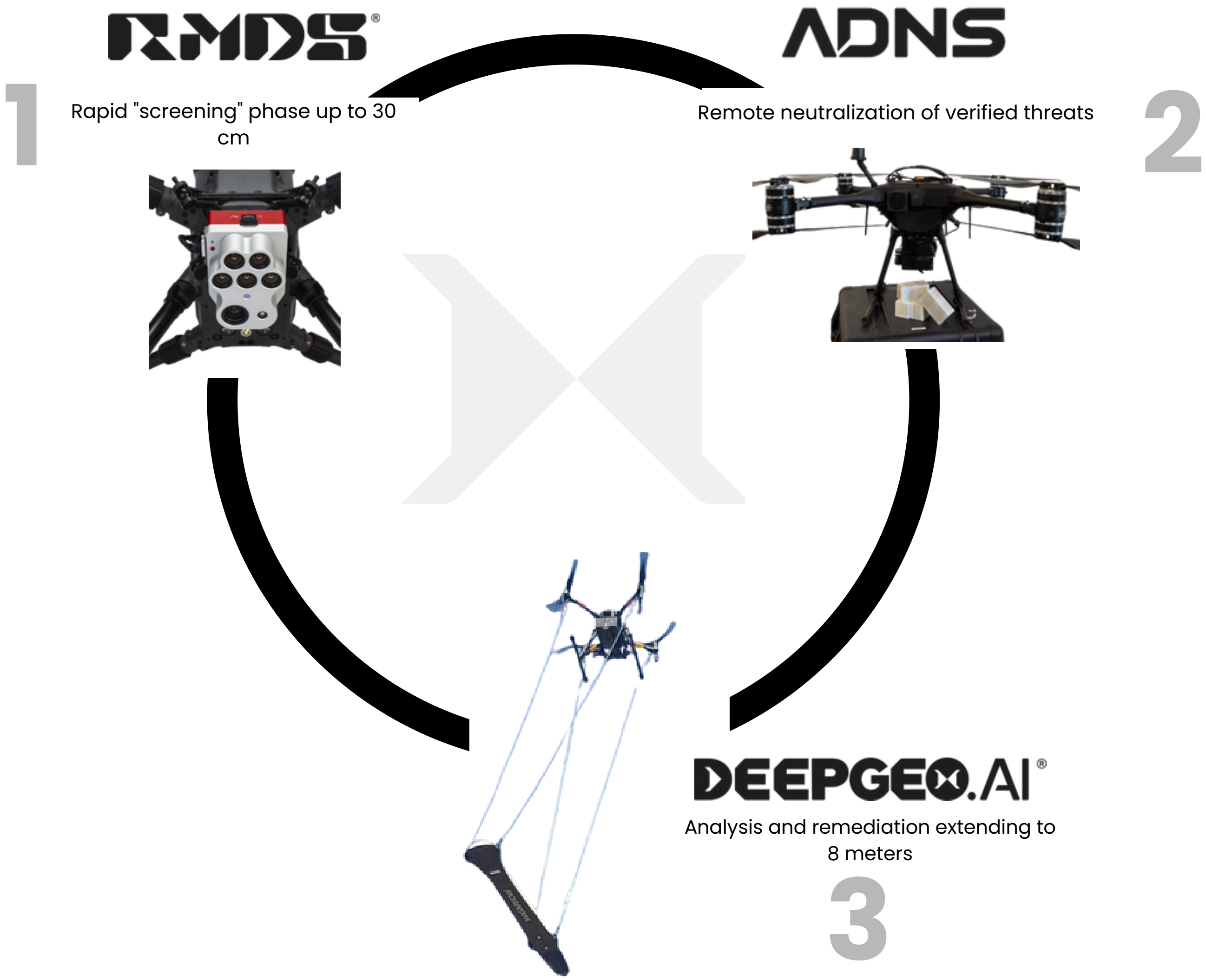
THE XPLORA INTEGRATED SOLUTION: ARCHITECTURE, PROCESSES, AND PERFORMANCE.

MODULAR ARCHITECTURE AND OPERATIONAL PROCESSES

To tackle the operational and regulatory challenges associated with contemporary remediation, Xplora has created an integrated and modular platform that is adaptable to various operational scenarios, ranging from contaminated agricultural fields to densely populated urban areas. This proposed model transcends the mere implementation of advanced sensors, presenting a comprehensive technological ecosystem organized into multiple, complementary phases. It is capable of identifying, classifying, and neutralizing any type of UXO threat, from a few centimeters to 8 meters deep, without the need for excavation or invasive interventions.

The entire process is grounded in a functional stratification logic that guarantees effective progression: from non-invasive surface detection to targeted neutralization, culminating in deep remediation through sensory fusion and artificial intelligence.

Each element of the platform is meticulously crafted to interact synergistically with the others, thereby minimizing time, costs, and margins of error. The outcome is not merely a basic collection of tools, but a comprehensive and intelligent UXO detection management system, poised for integration into any authorization, operational, or infrastructure process.



1 RMDS®

The initial phase of any remediation operation in a potentially contaminated area involves identifying surface and semi-submerged threats. To address this requirement, Xplora has created RMDS® – Remote Mine Detection System, an automated aerial platform that serves as the crucial, indispensable first step in the remediation process. RMDS facilitates the identification and classification of anti-personnel mines, anti-tank mines, and potentially explosive objects up to 30 cm deep, all without ground contact and without exposing operational personnel to risk.

The system is incorporated into vertical take-off multirotor drones outfitted with multispectral sensors. These sensors facilitate terrain analysis under diverse lighting conditions, detecting anomalies that may suggest the presence of explosive devices or suspicious objects. An integrated artificial intelligence system aboard the drone processes the data in real time, recognizing spectroscopic patterns associated with genuine threats.

The primary value of the RMDS lies not only in its technical capabilities but also in its operational efficiency: threat mapping is conducted in **near real time** and is promptly georeferenced with sub-meter accuracy on either a cloud or local platform. This results in a comprehensive risk map, readily available for utilization by armed forces or civilian operators without necessitating physical access to potentially hazardous areas.

TECHNICAL SPECIFICATIONS

Performance:

- **Coverage**: approximately 2.5 to 3 hectares per hour (subject to plant density and environmental conditions)
- **Post-flight analysis duration:** < 30 minutes per hectare
- **Output:** unrefined "presence probability" map with thresholds for subsequent intervention

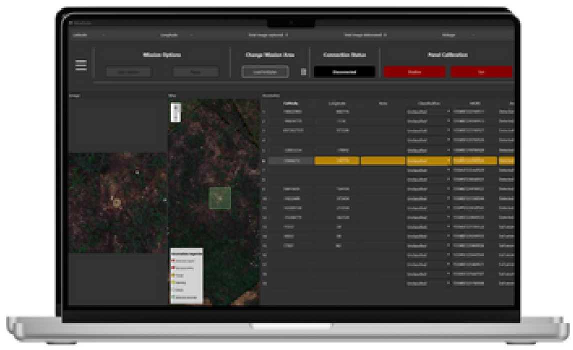
Operational advantages:

- Velocity and minimal cost per unit area
- Decreased complexity in areas with sparse vegetation or crops
- Non-invasive, without direct contact with the ground.

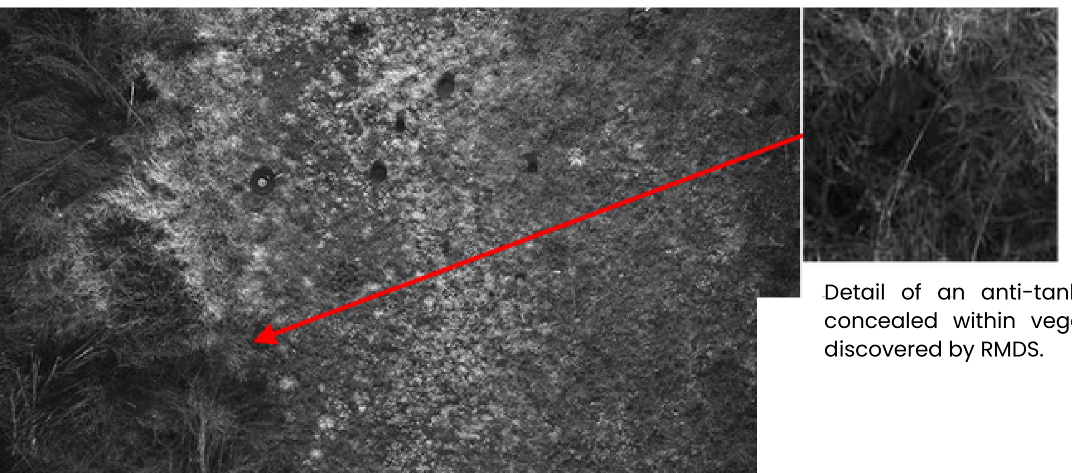
WORKFLOW - RMDS®

Interface for configuring automated flight missions.

The integrated system performs the mission and relays data to the graphical user interface.



Real-time reception of georeferenced threats



Detail of an anti-tank mine concealed within vegetation, discovered by RMDS.

2 ADNS

While RMDS embodies the system's exploratory intelligence, ADNS – Automatic Detection and Neutralization System – serves as its tactical component, tasked with translating threat mapping into definitive, secure, and autonomous neutralization actions. This constitutes the second operational phase in the Xplora technology chain, converting a mapped and classified area into a genuinely cleared zone, thereby minimizing personnel's direct exposure to zero and facilitating subsequent interventions.

The principle is straightforward yet transformative: every threat identified and located by the RMDS system is transmitted, through an encrypted digital channel, to the ADNS system. This module comprises a tactical-class VTOL drone outfitted with an integrated AI targeting system, a dynamic payload, and a command-based release mechanism. Onboard, eight pre-calibrated micro-explosive charges are prepared for deployment on designated targets, in accordance with a selective intervention logic programmed based on the classification of the detected threat.

The entire process is automated.

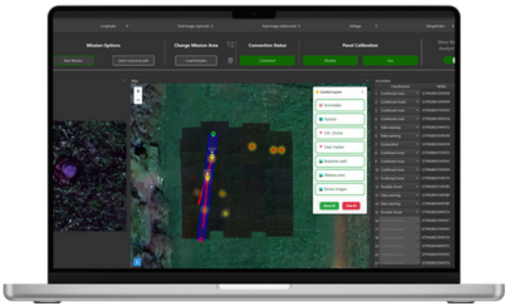
- **Flight planning:** Artificial intelligence utilizes the map generated by RMDS to construct an optimized route that addresses all identified threats, thereby minimizing both flight time and energy consumption.
- **Recognition and alignment:** upon reaching the target, ADNS conducts a visual and spectral assessment (utilizing onboard cameras) to verify the intervention point, rectify any deviations, and ensure precise positioning of the charge.
- **Neutralization**: A charge is remotely released and activated in accordance with a multi-tiered safety protocol. The explosion's energy is calibrated to damage the explosive materials while preventing hazardous secondary detonations.
- **Post-intervention verification**: each operation is documented with georeferenced data, pre- and post-event imagery, and a unique identification code that is beneficial for official reporting.

The efficiency of ADNS is attributed not only to its speed—capable of neutralizing eight threats in a single flight with a single system—but, more importantly, to its capacity to secure an operational field without the need for on-site personnel deployment. This marks a paradigm shift from traditional methods, which frequently necessitate the deployment of EOD operators, along with the associated logistical, economic, and security implications.

In military contexts, ADNS facilitates expedited troop advancement, thereby minimizing vulnerability periods. In civilian or post-conflict environments, it secures agricultural regions, settlements, and critical infrastructure within remarkably brief timeframes, promoting economic recovery and restoring normalcy for local communities.

Operationally, the system is engineered to function in continuous conjunction with RMDS: while one or more RMDS UAVs assess new regions, ADNS can concurrently operate on those already mapped, establishing a continuous, fluid, and scalable remediation pipeline on a territorial scale.

WORKFLOW - ADNS



Geo-referenced risk communication

ADNS system aerial survey

explosive charge deployment and threat identification

3 DEEPGEO.AI®

With the **neutralization** of surface threats achieved through the RMDS and ADNS modules, the operational field can now be regarded as tactically accessible. However, the cleanup remains incomplete. In numerous warfare scenarios, particularly those marked by aerial bombardments or prolonged land conflicts, the most insidious threats are often concealed beneath the surface, eluding traditional sensors and posing significant risks to infrastructure, construction sites, or residential areas. This is where DEEPGEO® becomes essential, the technology developed by Xplora for non-invasive cleanup at depths of **up to 8 meters.**

DEEPGEO® is a sophisticated sensor fusion system, integrated with an artificial intelligence software platform tailored for the **detection**, **classification**, and **localization** of deep unexploded ordnance (UXOs). This system leverages a combination of geophysical sensors, notably aerial (drone-mounted) magnetometry, coordinated by a neural engine that adapts to the characteristics of the terrain and identified anomalies.

The core of the system consists of an airborne magnetometer affixed to a multirotor drone. This magnetometer identifies fluctuations in the Earth's magnetic field resulting from ferrous or conductive objects, including bombs, unexploded ordnance, buried tanks, or metal debris. The unprocessed signal is captured during flight and transmitted to the DEEPGEO® software for processing, which employs:

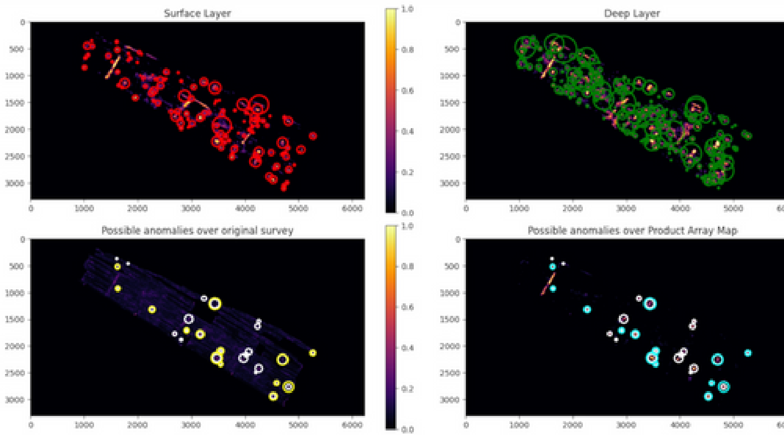
- Spatial and frequency noise **filtration**;
- **Normalization** concerning the background magnetic gradient;
- Semantic **clustering** of identified anomalies;
- **Three-dimensional modeling** of the object's depth and form.

Unlike other geophysical systems, DEEPGEO not only generates anomaly maps but also produces georeferenced, classified, and interpreted outputs, which are ready for integration into authorization processes or engineering projects. The data transcends mere indication, becoming a **decision bolstered by artificial intelligence.**

In practical operational conditions, as evidenced by Xplora's project in Iraq, the system successfully identified ordnance at depths between 0 and 8 meters, with an error margin of less than 1%. Notably, unexploded ordnance (UXOs) were detected deep beneath agricultural infrastructure, remaining undetectable by surface radar and posing significant risks if overlooked prior to construction or excavation.

Another advantage of DEEPGEO is its scalability: the system can operate in **sequential mode** (over limited and complex areas) or in **bulk mode** (over hundreds of hectares), achieving a throughput that can surpass **1 hectare per hour per drone**, contingent upon the required resolution level. This capability renders it especially suitable for infrastructure corridors, oil pipelines, energy facilities, or expanding urban regions.

Finally, DEEPGEO can seamlessly integrate with other Xplora technologies: it acquires historical data from the RMDS and ADNS modules, synthesizes information from the multispectral survey, and delivers a **comprehensive technical overview for the final validation of the area**. It effectively serves as the component that finalizes the remediation cycle, ensuring the depth, reliability, and objectivity of the intervention.



WORKFLOW - RMDS®

Automated mission planning

Automated data collection via UAV and Airborne Magnetometer

Automatic generation of characterized and georeferenced outputs.

AGGREGATE PERFORMANCE AND OPERATIONAL PROJECTIONS – QUANTIFIABLE EFFICIENCY, SCALABLE SECURITY

One of the primary advantages of the Xplora operating model is its capacity to convert a range of complex technologies into an integrated, scalable, and measurable pipeline that can be tailored to various geographical and operational contexts. Each module (RMDS, ADNS, DEEPGEO) is engineered for automatic operation, yet it functions optimally when incorporated into a sequential and interdependent framework, facilitating continuous coverage of the operational field—from initial reconnaissance to extensive remediation.

The table below summarizes the standard operational performance of the three primary modules, offering a realistic assessment of the area covered, timelines, and output produced:

Phase / Module	Estimated Area Coverage	Expected Time	Main Output
RMDS	2.5–3 ha/h	flight + analysis	Probabilistic map up to 30 cm
ADNS (on target)	variable	4 min per threat	Automated neutralization
DEEPGEO	1 ha/h	analysis + detection	Full and discretized UXO map

In typical operational conditions—level terrain, straightforward access, and minimal contamination—an Xplora team utilizing two RMDS/ADNS UAVs and two DEEPGEO® mobile units can accomplish cleanup tasks covering up to 5–7 hectares daily. This degree of efficiency is especially pertinent for extensive infrastructure projects, energy facilities, or governmental post-conflict decontamination initiatives.

It is essential to highlight that performance is not exclusively linked to coverage speed, but rather to the quality of the output: each hectare processed generates a scientifically objective, traceable, and authoritatively validated dataset, which is directly applicable in a GIS environment. In essence, each intervention serves not merely as a remediation, but as a documented land safety measure, adhering to the highest international standards.

Thanks to its capacity for vertical and horizontal integration across phases, systems, teams, and territories, Xplora technology facilitates, for the first time, the systemic management of UXO detection on an industrial scale, significantly reducing costs, timelines, and associated risks.

Completely non-invasive

No drilling or excavation is necessary, minimizing damage to soil and infrastructure.

Operational scalability

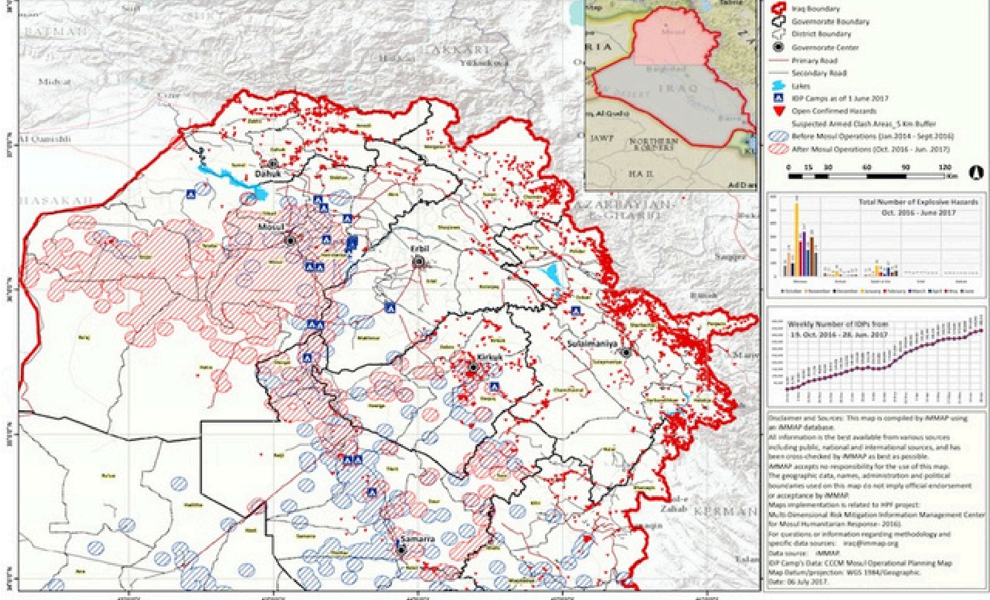
the potential for parallelizing activities across various geographical fronts.

Mitigation of risks for personnel

No drilling or excavation is necessary, minimizing damage to soil and infrastructure.

Time and cost effectiveness

attributable to the efficiency of the RMDS module and DEEPGEO automation.



Operational Case Study – UXO Clearance in the Basra Region (Iraq)

As part of a technical-operational mission to secure Iraqi territory, Xplora was assigned the responsibility of executing a thorough cleanup of a high-risk unexploded ordnance (UXO) area near Basra, in southern Iraq. The goal was to detect, classify, and neutralize every potential explosive threat—both on the surface and subsurface—across a total area of 10,000,000 m², which is equivalent to 1,000 hectares.

The project entails the integrated application of the three primary technological modules developed by Xplora:

- **RMDS®** for surface detection up to 30 centimeters;
- **ADNS** for the automatic neutralization of identified threats;
- **DEEPGEO®** for extensive remediation at depths of up to 8 meters underground.

Phase 1 – Surface Survey Utilizing RMDS

Available configuration:
- 3 RMDS systems

Average capacity per system:

- 1.5 ha/h × 6 h = 9 ha/day per unit (precautionary)
- Total = 27 hectares per day
- Time required ≈ 37 business days

Phase 2 – Automated Neutralization with ADNS

Available systems: 1
Hypothesis: 5 threats per hectare → 5,000 total threats

Operational capacity:

- 4 minutes for each threat
- 6 hours/day = 90 threats/day
- Time required ≈ 56 business days

Phase 3 – Comprehensive Survey with DEEPGEO

Available systems: 3

Operational capacity:

- 1.5 ha/h × 6 h = 9 ha/day per unit
- Total = 27 hectares per day
- Time required ≈ 37 business days

Operational Timeline – Estimated Duration per Phase (Basra UXO Clearance Project)

Phase / Module	Estimated Duration	Operational Notes
RMDS (surface detection)	~37 working days	Initial phase – sequential
ADNS (neutralization)	~56 working days (estimated)	Can run in parallel with RMDS
DEEPGEO (deep detection)	~37 working days	Starts after ADNS completion