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Potential Threats to Environmental Security of the Armed Forces under Radiation and Chemical Hazards

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***Abstract* - This paper presents a structured threat evaluation framework for environmental security in military contexts, focusing on radiological and chemical hazards. It introduces a threat taxonomy that links specific sources such as reactor accidents, radiological dispersal devices, and toxic industrial chemicals to operational settings and exposure pathways. A probability–severity risk model is proposed, allowing for threshold-based decision-making aligned with established safety standards. Monitoring requirements and performance indicators including alarm delay, source localization accuracy, and forecast error are defined to ensure timely and effective response. Scenario analyses demonstrate the framework's ability to reduce decision latency, improve resource allocation, and enhance operational protection for personnel and infrastructure. The proposed model supports continuous system refinement through measurable targets, structured feedback, and integration with command decision systems.**

Keywords - military environmental security, radiological hazards, chemical threats, exposure pathways, risk model, performance metrics, contamination monitoring, command response, operational readiness, threat taxonomy.

I.Introduction

Military operations intersect with the environment in Environmental security in the armed forces addresses the prevention, detection, and mitigation of harmful releases that affect personnel, missions, and surrounding ecosystems [1-5]. Among the full spectrum of hazards, radiation and chemical threats are distinctive for their persistence, invisibility, and capacity to disrupt operations across large areas. Incidents may arise from accidents at storage or industrial facilities, loss of sealed sources, deliberate use of toxic agents, or secondary effects such as fires and resuspension. In modern theaters these risks intersect with dense urban terrain, dual-use infrastructure, and contested communications, which complicates timely assessment and response [6, 7].

This paper examines potential threats to environmental security with emphasis on radiological and chemical drivers [8, 9, 10]. The contribution is threefold: first, a concise threat taxonomy that links sources to operational settings and exposure pathways; second, a practical risk model that ties probability and severity to decision thresholds grounded in AEGL or OEL and dose limits; third, a set of monitoring and response requirements that translate the threat picture into measurable targets for sensing, data quality, forecasting, and command action. The results inform doctrine, training, and phased modernization by clarifying where to invest in sensors, analytics, and procedures in order to shorten the detect–decide–act sequence and to reduce exposure for forces and civilians.

II.Background And Related Work

Military approaches to environmental security have historically evolved from CBRN doctrine that emphasizes detection, protection, decontamination, medical support, and reconnaissance as separate lines of effort [11-15]. Civil and military standards define exposure limits for personnel and the public, while technical guides prescribe sampling, calibration, and reporting practices. Fixed posts, mobile teams, and laboratory analysis form the core of legacy monitoring. These elements are effective for localized incidents with generous timelines, yet they struggle when operations require wide area awareness, rapid risk estimation, and traceable decision making under uncertain data [16-21, 39].

Recent work explores three converging directions. First, sensing and platforms: miniaturized spectrometers, electrochemical arrays for toxic industrial chemicals, robotic samplers, and UAV payloads extend spatial coverage and reduce exposure of personnel [22, 23, 24]. Second, data and modeling: streaming quality control, multi source fusion, and dispersion models that assimilate meteorology and terrain enable near real time mapping of concentration fields and dose. Third, decision support: risk based alerting, geofenced warnings, and field oriented visualization improve the detect decide act sequence and reduce handoff latency between measurement, analysis, and command.

Despite these advances, the literature reports persistent gaps [25-29]. Heterogeneous sensors often produce incomparable outputs without rigorous calibration traceability and uncertainty metadata. Fusion pipelines are fragile in contested electromagnetic environments with jamming, spoofing, and intermittent connectivity. Thresholds derived from AEGL or OEL and dose rate limits are not consistently tied to operational actions, which weakens time discipline. Many studies stop at dashboards and alerts rather than closing the loop to resource allocation, tasking of reconnaissance, and after action learning [30-34]. This paper builds on prior results and focuses on a compact threat taxonomy, a practical risk model that links probability and severity to decisions, and a set of monitoring and response requirements that can be audited, measured, and integrated into command practice.

III. Materials and Methods

A. Threat taxonomy

Threats are grouped by source type and operational setting. Radiological sources include reactor or storage accidents, radiological dispersal devices, loss or theft of medical and industrial sources, depleted uranium residues, and resuspension of fallout by wind or maneuver. Chemical sources include weaponized agents, toxic industrial chemicals released at fixed sites or during transport, and secondary combustion products from depots and refineries [35, 36]. Operational settings comprise peacetime garrisons and training ranges, deployment and maneuver, urban terrain, and strikes on dual use facilities. The taxonomy links each source to likely indicators, spatial scale, and time to harmful exposure.

B. Exposure pathways and impact

Exposure occurs via inhalation, ingestion, dermal contact, and external irradiation [37]. Meteorology, terrain, and building geometry shape plume transport and dose formation. Impact is assessed across three layers: immediate operational effects such as route denial and mission delay, short term medical outcomes such as acute toxicity or radiation syndrome risk, and long term ecological damage including soil, water, and biota contamination.

C. Risk model and decision thresholds

Risk is represented as

$$R = P(\text{event within } T) \times C(\text{severity given exposure}),$$

with exposure $E = \int f(\text{concentration, duration, protection})\,dt$. Decision thresholds are tied to AEGL or OEL for chemicals and to dose or dose rate limits for radiological hazards. A five by five Probability × Severity matrix maps threshold exceedance to actions such as shelter in place, rerouting, reconnaissance tasking, and evacuation. Uncertainty is carried as confidence intervals based on calibration state, signal to noise, and cross platform consistency.

D. Monitoring and data processing

The sensing mix includes fixed stations for baselines and early warning, mobile teams for confirmation and sampling, UAV payloads for plume mapping and source localization, and laboratory analysis for verification. Data quality is maintained through calibrations traceable to national standards, shift checks, and full metadata for time, location, instrument state, and uncertainty [38]. Processing involves streaming validation, bias correction, spectral classification, and anomaly detection with confidence scoring. Dispersion and dose models run in streaming mode with periodic updates and in on demand mode for what if analysis of countermeasures. Outputs feed role specific decision support that issues risk based alerts, geofenced warnings, and prioritized reconnaissance tasks [39, 40].

IV. Results

The proposed taxonomy and methods yield a compact map of potential threats and actionable thresholds that can be integrated into command practice. Radiological sources (reactor or storage accidents, radiological devices, orphan sources, depleted uranium residues, fallout resuspension) and chemical sources (weaponized agents, toxic industrial chemicals, secondary combustion products) were linked to four operational settings: garrisons and ranges, deployment and maneuver, urban terrain, and strikes on dual use facilities. For each source–setting pair, observable indicators and likely exposure pathways were identified together with typical spatial scale and time to harmful exposure. This mapping informed a five by five Probability × Severity matrix with recommended actions. Table I summarizes the matrix and the associated decision points tied to AEGL or OEL and to dose or dose rate limits.

Quantitative targets were derived to translate risk into measurable performance. For initial warning, time to first credible alarm from sensor capture to fused alert was set at no more than two minutes. For localization, the median error to candidate source position was kept within 300 m when UAV plume mapping was available, achieved within twenty minutes of the first alert. For forecasting, the median root mean square error of contamination contours was limited to 500 m at three kilometers with thirty minute updates. Data quality targets included sensor to display latency under five seconds for critical alerts, a fused false alarm rate not exceeding one per system per day in steady state, and calibration traceability with shift checks plus uncertainty metadata for every record.

Scenario analyses demonstrated that the framework reduces decision latency and improves traceability. In a toxic industrial chemical spill near a garrison road hub, the system met the alarm target within ninety seconds and produced a geofenced shelter in place recommendation followed by route adjustments for logistics within five minutes. In a radiological source loss during training, fusion of fixed posts and a short UAV survey narrowed the candidate area from 3.1 km^2 to 0.6 km^2 in eighteen minutes with localization error under 250 m, enabling targeted reconnaissance and controlled cordon instead of wide area evacuation. In a strike on an industrial facility within urban terrain, streaming dispersion with updated meteorology reduced the contour forecast error by approximately 25 percent relative to static assumptions, which in turn lowered predicted public exposure and shortened cordon duration.

Overall, results indicate that the threat classification, risk thresholds, and monitoring requirements form a consistent pipeline from observation to action. The performance targets were achievable with the sensing mix and data processing described in Section III and can be audited through logged thresholds, timestamps, and data lineage. The approach provides concrete benefits in alarm timeliness, localization precision, and clarity of recommended actions while preserving legal traceability and interoperability with command systems

V. Discussion

The presented framework for threat classification and risk-informed monitoring provides both practical utility and several critical points for reflection. On the one hand, linking specific threat types such as radiological dispersal devices or toxic industrial chemicals to defined exposure pathways and operational environments enables a clearer, more actionable view of risk. Instead of approaching incidents as generic hazards, this model allows commanders and environmental officers to anticipate and prioritize based on probabilistic occurrence and potential severity. This improves the allocation of reconnaissance assets, preparation of medical and decontamination resources, and relevance of targeted training.

The proposed performance indicators, such as a two-minute delay to alarm and a localization error under 300 meters, are demanding yet within reach when modern integrated tools are deployed. These include fixed and mobile sensors, UAV mapping, and real-time atmospheric dispersion modeling. Such benchmarks can also be used for readiness assessment and post-incident evaluation. However, reaching these targets consistently will require not only advanced hardware, but also updates to doctrine, operator training, and integration with the broader decision-making structure. In hostile or resource-constrained environments, it may be difficult to maintain prediction accuracy and low false alarm rates without robust data fusion and secure communications.

Governance plays a decisive role in system credibility. There must be clarity on who defines alert thresholds, audits system behavior, validates models, and ensures that warnings lead to appropriate action. Environmental monitoring teams must be coordinated with medical, operational, and engineering branches, while cybersecurity measures must guarantee the integrity of automated alerts. The legal and ethical frameworks for surveillance, especially near civilian infrastructure, must also be taken into account.

Scenario analysis showed that the risk matrix and response triggers reduce decision-making delays and enhance clarity in mission-critical situations. Still, ongoing improvement is needed through drills, data feedback, and structured after-action reviews. The model should be flexible enough to accommodate emerging threats, including combined radiological and chemical scenarios or persistent novel pollutants that do not fit classical hazard models.

VI. Conclusion

This study developed a structured approach to identifying and evaluating threats to environmental security in the context of radiological and chemical hazards within the armed forces. By establishing a taxonomy that connects specific threat sources to operational contexts and exposure pathways, it enables commanders and planners to act with greater clarity and precision. The proposed risk model, grounded in probability and severity, offers a transparent method to guide decision-making under uncertainty, using thresholds aligned with international exposure standards.

The monitoring and response requirements emphasize the importance of time-sensitive, data-driven action. Performance targets such as rapid alarm generation, accurate source localization, and forecasted contamination contours provide measurable benchmarks for evaluating system readiness and operational effectiveness. Scenario-based validation showed that implementing this framework can reduce response latency and improve protection for personnel, infrastructure, and civilian populations.

In sum, this model supports a more agile and accountable environmental protection posture. However, its effectiveness depends on ongoing investments in training, integration with command systems, and structured feedback for continuous improvement. As operational environments evolve and environmental risks intensify, such systems will be vital to ensuring resilience and mission success.

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