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Military Environmental Management in Military Operations: A Quantitative Gap Analysis of NATO Requirements

Hana MALACHOVÁ[1], Natálie HANÁKOVÁ[2]*, Alena OULEHLOVÁ[3]

[1]*Department of Military Logistics, Faculty of Military Leadership, University of Defence, Kounicova 65, 602 00, Brno, Czech Republic*
[2]*Research, Expert and Technology Centre, University of Defence, Kounicova 65, 602 00, Brno, Czech Republic*
[3]*Department of Military Science Theory, Faculty of Military Leadership, University of Defence, Kounicova 65, 602 00, Brno, Czech Republic*

*Correspondence: *natalie.hanakova@unob.cz*

Abstract

This study evaluates the implementation of NATO environmental protection requirements across operational phases using a checklist-based gap analysis. Eight environmental domains within the Czech Armed Forces were assessed by comparing current and target states of compliance. Results indicate overall high to full implementation, with full compliance achieved in waste management, POL handling, HAZMAT and water management. Higher implementation gaps persist in air quality, energy management, and infrastructure planning, reflecting sensitivity to operational constraints. The findings confirm that environmental compliance is phase-dependent and influenced by infrastructure, logistics, and resource availability, highlighting the need for scalable and early integrated environmental measures.

KEY WORDS: *environmental impact, environmental protection, GAP analysis, military activities, NATO*.

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1. Introduction

Armed conflicts throughout history have repeatedly demonstrated that military activities can have significant—and often long-term—environmental impacts. Illustrative examples include the use of chemical weapons during the First World War and the large-scale application of defoliants in the Vietnam War [1–3]. Technological advances in the means and methods of warfare have simultaneously increased the potential for widespread damage to ecosystems, landscapes, and natural resources [3]. The conflicts of the 20th century were largely symmetric and characterized by the employment of the most advanced weapon systems of their time [4], which left measurable environmental legacies in affected regions. By contrast, after 2001, asymmetric conflicts and guerrilla warfare predominated [4, 5] particularly in parts of the Middle East, where environmental impacts were often not sufficiently pronounced to trigger a systematic institutional response comparable to that seen in high-intensity wars. The ongoing conflict in Ukraine, however, again underscores the environmental risks associated with conventional armed confrontation: the scale of destruction and contamination may extend well beyond the immediate period of hostilities, with enduring consequences for habitats, ecosystem services, and the quality of life of civilian population [6, 7].

In response to increasing environmental risks, legislative and institutional frameworks aimed at environmental protection have progressively evolved since the 1960s and have become a central component of global sustainability agendas. Within military organisations, environmental considerations have historically played a secondary role; however, their importance has significantly increased over the past decade, including within NATO structures [8]. NATO doctrines now incorporate environmental protection requirements into operational planning and execution, particularly through standards such as AJEPP-2 [9] *Environmental Protection for Military Camps in NATO Operations*. Despite these developments, rigorous quantitative approaches to evaluating the integration of environmental requirements remain underdeveloped. Current literature is largely characterized by descriptive analysis and lacks the granularity required to address implementation variances across distinct operational stages. Addressing this deficiency, this research proposes a structured evaluative model aligned with AJEPP-2. The framework translates doctrinal requirements into a systematic checklist-based tool, utilizing a gap analysis approach to quantify the variance between theoretical compliance and practical implementation across the *initial*, *intermediate*, and *sustainment phases* of military operations.

2. Current State Analysis: Operational Phases and Support Levels

In response to the burgeoning recognition of the environmental ramifications associated with modern military operations [10], it is imperative to examine the integration of these considerations within contemporary NATO operational frameworks. While strategic directives and doctrinal frameworks increasingly prioritize environmental protection, practical implementation remains contingent upon operational conditions, logistical constraints, and the specific phases of deployment. The discrete phases of an operation—namely (i) initial, (ii) intermediate, and (iii) sustainment—exhibit a direct correlation with established echelons of logistical and infrastructural support, categorized as Support Levels (SL) 1, 2, and 3. These levels not only delineate the minimum sustainment standards for deployed forces but also fundamentally dictate the feasibility and substantive efficacy of implementing environmental mitigation measures.

2.1 Initial Phase

Spanning a duration of several weeks to months, the initial phase is characterized by high operational dynamism, nascent infrastructure, and a prioritized focus on unit mobility [9, 11]. Logistics support during this period relies predominantly on organic assets—resources that are inherently transportable or man-portable by the deployed units [12]. At this stage, environmental management is primarily situated within the domain of planning and the establishment of foundational frameworks.

A pivotal element is the integration of environmental considerations into the *Operational Planning Process* (OPP), specifically through the incorporation of environmental directives into *Operational Orders* (OPORDs) and the delineation of clear accountability within the command structure [13]. Although environmental factors are formally integrated into the commander's decision-making process, their relative weight may be moderated by overarching operational exigencies [14]. The selection of military encampments or exercise areas constitutes a critical task, requiring a robust assessment of environmental hazards, such as flooding, erosion, wildfires, and potential geogenic or anthropogenic contamination [9]. Concurrently, it is imperative to evaluate the availability of vital resources—most notably potable water—while assessing potential externalities on local populations, including noise pollution, atmospheric emissions, and pressures on existing transport infrastructure [15, 16]. An integral part of this is respecting buffer zones and minimizing disturbances to sensitive ecosystems.

Furthermore, the design of initial camp infrastructure should reflect principles of footprint minimization, utilizing optimized facility siting, demountable structures, and the mitigation of soil disturbance [13, 17]. Comprehensive personnel training is also initiated, focusing on environmental awareness and fundamental protocols that are further developed in subsequent operational phases in alignment with environmental education standards [12]. Finally, the initial phase necessitates baseline soil and water sampling to facilitate longitudinal comparisons with data collected during the closure phase, thereby ensuring compliance with *Zero Footprint* mandates.

2.2 Intermediate Phase

The intermediate phase delineates the transitionary trajectory from initial deployment toward operational stabilization, typically spanning a temporal horizon of several months with a potential extension up to a biennial period [18]. During this phase, infrastructure is gradually being developed and the environmental measures established [19]. Consequently, environmental management shift from strategic conceptualization to field execution and procedural auditing.

Within the domain of *energy management*, emphasis is placed on monitoring fuel and energy consumption, evaluating these figures, and gradually implementing measures to improve energy efficiency. These data-driven evaluations are essential for enhancing thermodynamic and operational efficiency [20]. This encompasses the optimization of mechanical asset utilization, demand-side management, and, where technically feasible, the integration of high-efficiency or low-emission technological tiers [21]. *Water management* remains a critical focal point, entailing the safeguarding of hydrological assets through the delimitation of protection zones, contamination prevention, and periodic water quality surveillance [20]. Closely allied with this is a comprehensive *wastewater management* system incorporating systematic collection, pre-treatment, and effluent disposal, frequently leveraged through Host Nation Support (HNS) or outsourced frameworks.

Furthermore, *waste management* evolves into a structured system of source segregation, inventory logging, and serialized disposal protocols [22]. Specific emphasis is allocated to *hazardous waste* streams, which mandate distinct handling protocols and stringent regulatory oversight [19]. Safe management of POL (Petroleum, Oil, and Lubricants), chemical reagents, and other high-risk substances is integrated into the operational routine, bolstered by spill prevention measures and robust contingency readiness [20]. Concomitantly, measures aimed at the preservation of edaphic conditions, floral biodiversity, and natural resources are enforced, including the regulation of vehicle manoeuvres and the protection of ecologically sensitive sites. A pivotal component is continuous *Environmental Monitoring and Reporting* (EMR), encompassing systematic site inspections, incident logging, and performance analytics, which facilitate the iterative optimization of environmental mitigation strategies [23].

2.3 Sustainment Phase

The sustainment phase represents the long-term stage of an operation, typically lasting several years. The phase is characterized by stable, well-developed, and often semi-permanent or permanent infrastructure [13]. This level of support allows for the full implementation of environmental standards and ensures a high degree of compliance with NATO doctrinal requirements [20]. During this phase, environmental aspects are managed systematically based on long-term monitoring and data analysis. The information gathered is used to optimize operations, reduce the environmental footprint, and increase the effectiveness of specific measures. At this stage, environmental management reaches a level comparable to civilian standards, including the use of advanced technologies and sophisticated control mechanisms [24].

Continuous education and staff training play a key role in maintaining high environmental awareness and ensuring that established procedures are followed [13]. At the same time, the closure of the operation and site restoration must be systematically planned. This process needs to be initiated well in advance of the actual withdrawal of forces [25]. The final stage involves reclamation measures, the removal of environmental hazards, waste disposal, and the dismantling of infrastructure [13]. An essential part of this process is verifying the state of the environment through soil, water, and vegetation testing, including an *Environmental Closure Survey* (ECS) [26]. The objective is to ensure the site is returned to a condition meeting environmental standards and that the long-term negative impacts are minimized [26, 27].

3. Methodology

The primary objective of this study is to synthesize NATO's current approach to environmental protection in military operations and to evaluate its practical implementation within the Czech Armed Forces (CAF). The research is designed as a structured, multi-stage analysis combining doctrinal review with empirical data collection and quantitative evaluation. The methodological framework consists of three main steps: (i) content analysis of NATO environmental standards and operationalization of requirements into measurable indicators, (ii) expert-based data collection, and (iii) gap analysis comparing the current and target states.

3.1 Content Analysis and Operationalization of Requirements

The first phase of the research involved a systematic content analysis of the NATO standard AJEPP-2 [9], which defines environmental protection principles applicable to military operations. This document represents the core doctrinal framework for environmental management within NATO. The analysis identified 15 key domains which aggregated into 8 areas, including (1) Infrastructure planning, (2) Energy management, (3) Water and wastewater management, (4) Waste management, (5) POL and spill response, (6) HAZMAT management, (7) Air quality and noise pollution, and (8) Natural resources and cultural heritage protection.

3.2 Expert Survey: Evaluating Current State via Checklists

Primary empirical data were gathered through an expert questionnaire survey. Due to the highly specialized nature of the topic, *purposive sampling* was employed to select respondents with demonstrated professional competence. The research sample (N = 6) consisted of (i) military Engineering (MILENG) units; (ii) logistics and infrastructure management personnel, (iii) environmental protection specialists, and (iv) commanders with operational experience from foreign deployments of the Czech Armed Forces (CAF). Data were collected using a structured questionnaire derived from the operationalized checklist indicators.

The questionnaire was distributed among selected subject-matter experts to capture their assessment of the level of implementation of environmental measures in military practice. Due to the applied focus of the study and space limitations, the full questionnaire is not included in this article. The questionnaire was based on the operationalized checklist and utilized a three-point ordinal scale to assess the level of implementation of each indicator:

- 0: Not implemented;
- 1: Partially implemented;
- 2: Fully implemented (*target state*).

This scale allows for a differentiated evaluation of implementation, reflecting not only the existence of measures but also their degree of functionality in operational conditions. A structured checklist serves as the primary methodological tool for data collection and evaluation. The approach is grounded in best practices of environmental auditing and standardized assessment procedures, enabling systematic and consistent verification of environmental measures across defined domains. It aligns with principles of Environmental Management Systems, particularly those defined by the International Organization for Standardization in ISO 14001, where checklist-based assessments support compliance verification and continuous improvement within the "plan–do–check–act" framework. Unlike purely binary approaches, the checklist evaluates not only the existence of measures but also the quality and consistency of their implementation over time. Each checklist item represents an operationalized requirement derived from NATO environmental doctrine and serves as the basis for calculating the *current state* (CS) within individual domains. The CS values used in the analysis are derived directly from the checklist-based assessment.

3.3 Gap Analysis: Variance Assessment Between Current and Target States

To assess the level of implementation, a gap analysis was performed by comparing the CS, derived from checklist-based evaluation, with the TS, defined as full compliance with NATO environmental standards. The implementation *gap value* (G) is calculated as:

$$G = TS - CS \quad (1)$$

where TS = 1.0 represents full compliance. The resulting gap value quantifies the degree of deviation between CS and TS across all eight aggregated environmental domains. For interpretative purposes, gap values are classified into four levels of implementation, as presented in Table 1.

Table 1. Four levels of implementations with gap values

G	Level of implementation	Interpretation
0	Full	Complete alignment with AJEPP-2 requirements.
0.01 – 0.50	High	Minor deficit; high degree of compliance.
0.51 – 0.99	Partial	Major deficit; systematic improvement needed.
1.00	Critical	Significant deficit; urgent doctrinal or structural changes required.

To support comparative analysis and intuitive interpretation, the results are visualized using radar charts, illustrating the distribution and magnitude of implementation gaps across domains. This form of visualization enables a comparative assessment of relative performance and highlights disparities in implementation levels between doctrinal requirements and operational practice, as reflected by the G values.

4. Results and Discussion

4.1 Phased Structuring of Environmental Domains

The categorisation of environmental domains is based on the NATO environmental protection standard AJEPP-2, which defines the minimum requirements for environmental management in deployed operations. The doctrinal requirements are grouped into *three operational phases* reflecting the typical lifecycle of military deployments: (i) initial, (ii) intermediate, and (iii) sustainment phase. Each phase represents a different level of infrastructural maturity and environmental management capability. The classification in Table 2 serves as a basis for mapping environmental requirements against operational conditions and enables structured comparison of implementation levels across time-dependent operational contexts.

Table 2. Phase-based classification of environmental management domains

Initial Phase	Intermediate Phase	Sustainment Phase
• Integration of environmental requirements into operational planning • Definition of responsibilities and command structure • Site selection (risk assessment, resource availability, environmental impact) • Camp infrastructure planning and layout • Minimization of impact on local ecosystems • Initial environmental training of personnel	• Energy management and efficiency measures • Water management and protection of water sources • Waste management and disposal systems • Handling of hazardous materials and fuels • Soil and vegetation protection • Noise and emission control • Environmental monitoring and reporting	• Evaluation of environmental performance data • Continuous training and awareness • Site restoration planning • Removal of environmental contamination • Land rehabilitation and ecosystem recovery • Final inspection and documentation

4.2 Implementation Rates of Aggregated Environmental Areas

The overall implementation rate of environmental requirements across NATO operational domains was assessed using the gap analysis methodology. The results visualised in Table 3 are based on aggregated scores derived from expert evaluation of eight environmental management domains.

Table 3. Level of implementation of environmental management areas

Area	$\boldsymbol{TS}$ (AJEPP-2 requirements) (**1**)	**Mean $\boldsymbol{CS}$ (median)**	**Mean $\boldsymbol{G}$ (median)**	**Level of implementation**
Infrastructure planning	• Full integration of environmental aspects into planning processes • Detailed OPORD annexes • Implementation of EBS • Zero Footprint approach	0.67 ± 0.38 (0.75)	0.33 (0.25)	High
Energy management	• Systematic monitoring of energy consumption • Emphasis on efficiency and emission reduction	0.63 ± 0.39 (0.75)	0.38 (0.50)	High
Water and wastewater management	• Establishment of protection zones • Contamination prevention • Regular monitoring • Advanced treatment technologies	0.98 ± 0.09 (1.00)	0.02 (0.00)	Full
Waste management	• Detailed waste segregation • Record-keeping • Safe disposal	1.00 ± 0.00 (1.00)	0.00 (0.00)	Full
POL and spill response	• Strict spill prevention • Technical mitigation measures • Full personnel preparedness	1.00 ± 0.00 (1.00)	0.00 (0.00)	Full
HAZMAT management	• Strict record-keeping • Segregated storage • Secured handling areas	1.00 ± 0.00 (1.00)	0.00 (0.00)	Full
Air quality	• Emission and noise minimization • Regulation of activities • Protection of local population	0.53 ± 0.35 (0.50)	0.47 (0.50)	High
Natural resources and cultural property protection	• Protection of soil, vegetation, and sensitive areas • Minimization of environmental impact	0.78 ± 0.36 (1.00)	0.22 (0.00)	High

The analysis indicates variability in the level of implementation across environmental domains; however, all domains fall withing the range of high to full implementation. The highest gap values were observed in the areas of (i) air quality (G = 0.47), (ii) energy management (G = 0.38), (iii) infrastructure planning (G = 0.33), and (iv) natural resources and cultural property protection (G = 0.22). Figure 1 presents a radar chart illustrating the CS values across individual environmental domains within CAF.

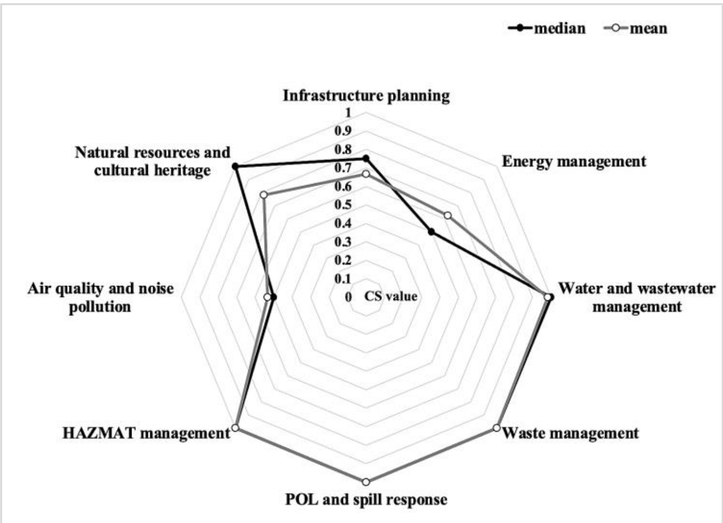

Fig. 1. Radar chart of CS values Czech Armed Forces.

4.3 Domain-Level Assessment of Environmental Measures

Infrastructure planning. Infrastructure planning demonstrates a high level of implementation of environmental requirements (G = 0.33). Environmental considerations are integrated into OPORDs through dedicated *environmental annexes* that define key responsibilities and constraints. Although exceptions still occur, ongoing awareness-raising efforts aim to ensure the consistent inclusion of environmental annexes in all operations. Site selection procedures routinely incorporate *environmental risk assessments*, focusing on hydrological and geomorphological conditions, proximity to protected areas, and potential contamination risks. Such assessments are systematically conducted for each military training area. For this purpose, the methodology of the Ministry of the Environment of the Czech Republic is applied, particularly due to the overlap of military training areas with Natura 2000 sites. *Environmental Baseline Studies* (EBS) are commonly used to identify pre-existing environmental conditions at deployment sites. Camp design typically incorporates *mitigation measures*, including the use of existing surfaces, minimization of soil disturbance, adequate distance from watercourses and protected areas, and the deployment of modular or demountable infrastructure. Planning processes consistently emphasize *minimizing impacts on local ecosystems*. The principle of a minimal environmental footprint is partially reflected in operational practice; however, its full implementation varies depending on the operational context.

Energy management. The integration of energy management demonstrates an increasing trend; however, its implementation remains uneven across different phases of operations (G = 0.38). In long-term and stabilized operations, systematic *monitoring of fuel consumption* is conducted, accompanied by measures aimed at *improving energy efficiency* and reducing emissions. In contrast, during initial phases of deployment, these elements are often limited in favour of operational priorities. Although increasing emphasis is placed on the adoption of *low-emission technologies*, their adoption remains contingent upon available financial and material resources. The highest level of energy management is achieved in long-term operations and newly developed infrastructure projects, such as the construction of *covered vehicle parks equipped with photovoltaic panels*. Electric vehicles are being introduced primarily for use in urban environments and within military facilities. A contracted network of charging stations has been established for the CAF; however, the availability of fast-charging infrastructure remains limited.

Water and wastewater management. Water and wastewater management within the CAF achieves a full level of compliance (G = 0.02). *Protective zones are delineated* already at the planning stage, and measures aimed at preventing water contamination are systematically implemented. *Water quality monitoring* is ensured through a combination of military specialists and external hygienic laboratories, which conduct detailed analytical assessments. Wastewater is managed through integrated systems combining on-site treatment solutions—such as *grease traps and sedimentation units*—with subsequent *off-site disposal*. In long-term and stabilized camps, this approach enables the deployment of advanced technologies, including *mobile treatment plants* and *closed-loop recycling systems*. In contrast, during the initial phases of deployment, more basic yet functional solutions tend to prevail due to requirements for rapid deployment.

Waste management. Waste management is strongly standardized and achieves a full level of compliance (G = 0.00). Implemented segregation systems, including the *categorization of general and hazardous waste* streams, reach their highest level of complexity during long-term and stabilized operations. In such contexts, environmental management is further reinforced through continuous *personnel training*. A key component of the operational waste management chain is the involvement of externally certified contractors, ensuring the safe disposal and proper documentation of hazardous waste fractions. This approach facilitates compliance with both NATO environmental standards under logistically demanding conditions and the national legal framework of the Czech Republic.

Management of POL and spill response. The management of POL represents a high-priority area of environmental protection and achieves a full level of compliance (G = 0.00). The implementation of technical *containment measures*—such as bunded storage systems, double-walled tanks, and certified handling equipment—combined with regular integrity inspections, constitutes an effective preventive framework for minimizing the risk of soil and water contamination. These technical measures are complemented by systematic *personnel training*, including practical instruction in *spill response procedures* and the effective use of sorbent materials. The highest levels of preparedness and infrastructural robustness are observed within specialized logistics and engineering units, particularly in the context of long-term and sustained operations.

HAZMAT and substances management. The management of hazardous materials and chemical substances in field operations is subject to strict regulatory control, with rigorous adherence to environmental and safety standards contamination (G = 0.00). The analysis confirms the systematic application of segre*gated collection and standardized record-keeping*, which, in conjunction with precise planning of storage locations and the technical safeguarding of collection areas, effectively minimizes risks associated with handling hazardous materials. Such *technical measures* include compliance with *required distances* from water sources, the use of impermeable surfaces, and the implementation of containment systems. The highest level of regulatory compliance is observed in long-term operations, whereas in initial deployment phases, priority is placed on the rapid establishment of fundamental safety measures.

Air quality and noise pollution. The reduction of noise pollution and emissions is addressed through a combination of technical and organizational measures, including the *regulation of equipment use*, *temporal scheduling* of high-noise activities, and appropriate *camp siting*, resulting in a high level of compliance (G = 0.47). During the sustainment phase of operations, these processes are further supported by *communication mechanisms with local authorities* and internal regulations defining safe distances, permissible limits, and operational time windows, thereby contributing to de-escalation potential and the social legitimacy of military presence. Noise hygiene is currently an integral component of military testing procedures; however, legacy equipment remains a limiting factor. Its gradual replacement with modern systems is expected to mitigate this issue.

Natural resources and cultural heritage protection. The protection of natural resources and cultural heritage is implemented through a set of measures aimed at *minimizing soil degradation, erosion, and vegetation disturbance*, as well as the identification and safeguarding of *archaeologically sensitive areas* (G = 0.22). The movement of heavy equipment is generally restricted to designated routes in order to limit environmental impact. Sensitive ecosystems, including wetlands and protected areas, are systematically identified during the planning phase and are subject to access restrictions. Environmental protection considerations are formally integrated into site selection procedures and operational planning documentation, ensuring their consistent application across operational contexts.

5. Conclusion

This study analysed the implementation of NATO environmental protection requirements, as defined in AJEPP-2, within the context of military operations differentiated by operational phases in the CAF. Using a structured checklist-based assessment and gap analysis, the research identified variability in the level of environmental compliance across key domains of military environmental management. Despite this variability, *all assessed domains fall within the range of high to full implementation*, indicating an overall strong alignment with NATO environmental standards.

The findings confirm that environmental implementation is inherently phase dependent. The (i) *initial phase is characterised by constrained application of environmental measures* due to operational urgency, mobility requirements, and limited infrastructure. Environmental management in this phase is therefore primarily focused on ensuring basic functional standards rather than achieving full doctrinal compliance. The (ii) *intermediate phase enables partial institutionalisation* of environmental requirements, supported by improving logistical structures, although implementation remains influenced by resource availability and operational flexibility. The (iii) *sustainment phase provides the most favourable conditions* for comprehensive integration of environmental standards, supported by stabilised infrastructure, established supply chains, and extended planning horizons.

The results further demonstrate that *the extent of implementation varies across environmental domains* depending on their technical and organisational complexity. Domains such as waste management, POL and spill response, and HAZMAT management achieve full compliance (G = 0.00), reflecting a high degree of standardisation, well-established procedures, and effective utilisation of external certified contractors. Similarly, water and wastewater management approaches full compliance (G = 0.02), benefiting from a combination of systematic monitoring and scalable treatment solutions, particularly in stabilised operational contexts.

In contrast, domains requiring continuous monitoring, advanced technologies, or complex coordination—such as air quality and noise pollution (G = 0.47), energy management (G = 0.38), and infrastructure planning (G = 0.33)—exhibit higher implementation gaps. These domains are more sensitive to operational constraints, particularly in early deployment phases, where priorities related to *rapid deployability and operational effectiveness limit the scope of environmental measures*. Natural resources and cultural heritage protection (G = 0.22) also demonstrate variability, primarily due to their dependence on site-specific conditions and the timing of planning processes.

Overall, the study demonstrates that environmental management in military operations should be conceptualised as *a phased, capability-dependent process* rather than a static compliance framework. The results suggest that further improvements can be achieved through earlier integration of environmental considerations into initial deployment phases, enhanced scalability of environmental technologies, and continued development of standardised procedures supported by external expertise. Future research should focus on validating the proposed assessment framework in real operational environments and extending the analysis to multinational deployments, where differing national approaches to NATO environmental standards may introduce additional variability in implementation.

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