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REVIEW

Planet under Siege: The Law and Morality of Pollution during War in a Changing Climate

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ABSTRACT

This article presents a systematic and critical review of scholarly literature on war pollution and environmental ethics, tracing how ethical, legal, and scientific debates address environmental destruction in armed conflict. Using the PRISMA framework and Scopus as the primary database, a structured multi-stage search and screening process identified 435 peer-reviewed papers published between 1946 and 2025. Using VOSviewer-based bibliometric mapping, eight principal thematic clusters were identified: environmental protection and policy ethics; philosophical foundations of environmental ethics; war pollution and toxic exposure; climate change and sustainability; environmental education and values; governance and ethical decision-making; risk assessment and remediation; and interdisciplinary theoretical perspectives. Drawing on debates on slow violence, ecocide, planetary health, and potentially polluting war wrecks, the article proposes the Lawful Environmental Ethics Framework for Wartime Pollution (LEEF-WP), a six-pillar structure that links ethical principles to concrete legal obligations, institutional mechanisms, and post-conflict restoration responsibilities. A SWOT–TOWS analysis evaluates the strengths, weaknesses, opportunities, and threats of LEEF-WP and situates it within current reform efforts in international humanitarian law, including constraints related to state sovereignty, political resistance, and the limits of the International Criminal Court. Overall, the review reframes war pollution as a central concern for environmental ethics, international humanitarian law, and planetary health, and argues that integrating robust environmental duties into wartime governance is an urgent moral and legal requirement in the Anthropocene.

Keywords: Environmental Ethics; Wartime Pollution; International Humanitarian Law; Ecocide; Planetary Health

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1. Introduction

Compared with civilian casualties, displacement, or economic devastation, the environmental consequences of war have often been treated as secondary or invisible. Yet wars generate long-lasting deforestation, soil and groundwater contamination, marine pollution, biodiversity loss, and atmospheric degradation that outlive the conflict itself and affect distant ecosystems and generations. Sedimentary archives and ice cores now register these legacies in measurable geochemical signals. Using sediment records, Siano et al.[1] showed that World War II and post-war agricultural intensification produced irreversible shifts in plankton communities linked to nutrient and contaminant inputs, while Legrand et al.[2] reconstructed bismuth pollution peaks in Alpine ice cores that coincide with intense military use during World War II. Similarly, McConnell et al.[3] used Greenland ice cores to link episodes of warfare, epidemics, and imperial expansion to spikes in lead pollution, demonstrating that the history of war is also a history of long-term environmental degradation, even if these archives do not by themselves prove deliberate intent to pollute.

Classic examples such as the Kuwaiti oil-well fires during the 1991 Gulf War, the deployment of Agent Orange in Vietnam, and the legacy of uranium and heavy-metal contamination in Iraq illustrate how military operations can inflict severe and sometimes irreversible harm on ecosystems and human health[4,5]. More recent conflicts have amplified these concerns. Sand[4] showed that the deliberate release of oil and destruction of coastal infrastructure during the Gulf War weaponised the marine environment and outpaced existing legal controls. Westing[5] described how pollution burdens in post-war Vietnam were unevenly distributed, with marginalised communities continuing to live in contaminated neighbourhoods that received little attention in reconstruction agendas. In Ukraine, Solokha et al.[6] and related geophysical work on Bondar et al.[7] documented heavy-metal contamination associated with shelling, industrial disruption, and collapsing infrastructure. Recent conflict-related environmental assessments further highlight elevated particulate pollution, wildfire-related emissions, land-use alteration, damage to water-treatment facilities, and increased downstream river contamination resulting from warfare. These studies underscore that war-induced pollution extends beyond acute chemical releases and interacts with existing environmental vulnerabilities to generate long-term ecological pressures.

Foundational overviews now emphasise that environmental ethics cannot be reduced to abstract value theory but must engage concretely with biodiversity loss, climate change, and environmental injustice[8–12]. Recent contributions argue for re-thinking environmental ethics in the Anthropocene through concepts such as ecocide, relational ontologies[13–16], and expanded notions of responsibility that include non-human beings and future generations[17–20]. However, these developments have not been fully translated into binding international legal norms governing wartime conduct. The Geneva Conventions and Additional Protocol I introduced the familiar requirement that environmental damage in war must be "widespread, long-term and severe" to be prohibited, yet the vagueness and high threshold of this formula have limited its justiciability in practice, especially in relation to cumulative or low-visibility harms[4,18]. The gap between moral intuition and legal enforceability is particularly stark in conflict settings, where military necessity is routinely invoked to override environmental concerns and where evidence of harm is temporally delayed, scientifically complex, and politically contested.

At the same time, environmental theorists have highlighted the temporal and spatial complexity of war-related harm. Nixon[21] introduced the concept of slow violence to describe environmental damage that is incremental, often invisible, and disproportionately borne by vulnerable communities. This framing is highly relevant to conflict zones, where unexploded ordnance, toxic sediments, particulate pollution, and degraded food webs can continue to affect ecosystems decades after hostilities end. Wartime shipwrecks exemplify this dynamic. Global assessments of potentially polluting wrecks (PPWs) estimate that thousands of vessels sunk during World War II still hold substantial quantities of oil, fuel, and munitions that pose escalating ecological risks as hulls corrode. Site-specific investigations of wrecks such as *Coimbra* and *Munger T. Ball* have shown that corrosion, sediment disturbance, storm events, and microbial activity can trigger episodic releases of hydrocarbons and metals into surrounding waters, creating localised but persistent pollution hazards. These slow-moving legacies illustrate that war pollution is not confined to immediate battlefield effects but constitutes a transboundary and intergenerational environmental problem[22].

This review therefore offers a systematic and critical assessment of the scholarly literature on war pollution and environmental ethics, rather than a comprehensive survey of environmental ethics as a whole. It asks four interrelated questions. First, how have war-related environmental harms been conceptualised in ethical, legal, and scientific scholarship, and how do notions such as slow violence, environmental justice, and ecocide reframe these harms [20,22]? Second, what major thematic clusters and research trajectories can be identified across empirical, legal, and philosophical works on war pollution, including studies of toxic exposure, environmental governance, and normative theory [1–3,6–8,10,11,13–21,23]? Third, where are the key gaps in linking environmental ethics with international humanitarian law and international environmental law, particularly regarding standards of proof, thresholds of harm, and duties of remediation [4,14,16–18,20]? Fourth, how might a structured ethical–legal framework, the proposed Lawful Environmental Ethics Framework for Wartime Pollution (LEEF-WP), advance both normative clarity and practical governance by connecting ethical principles to concrete legal reforms, institutional mechanisms, and post-conflict restoration duties?

2. Materials and Methods

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework to design and report a systematic literature review on the nexus between war pollution and environmental ethics [24] is used in the present study. The overall objective was to identify dominant scholarly debates, thematic concentrations, and research gaps that could inform global environmental policy and ethical governance related to armed conflict. The PRISMA process is summarized in a flowchart that shows the stages of identification, screening, eligibility, and inclusion for the final corpus of articles (**Figure 1**).

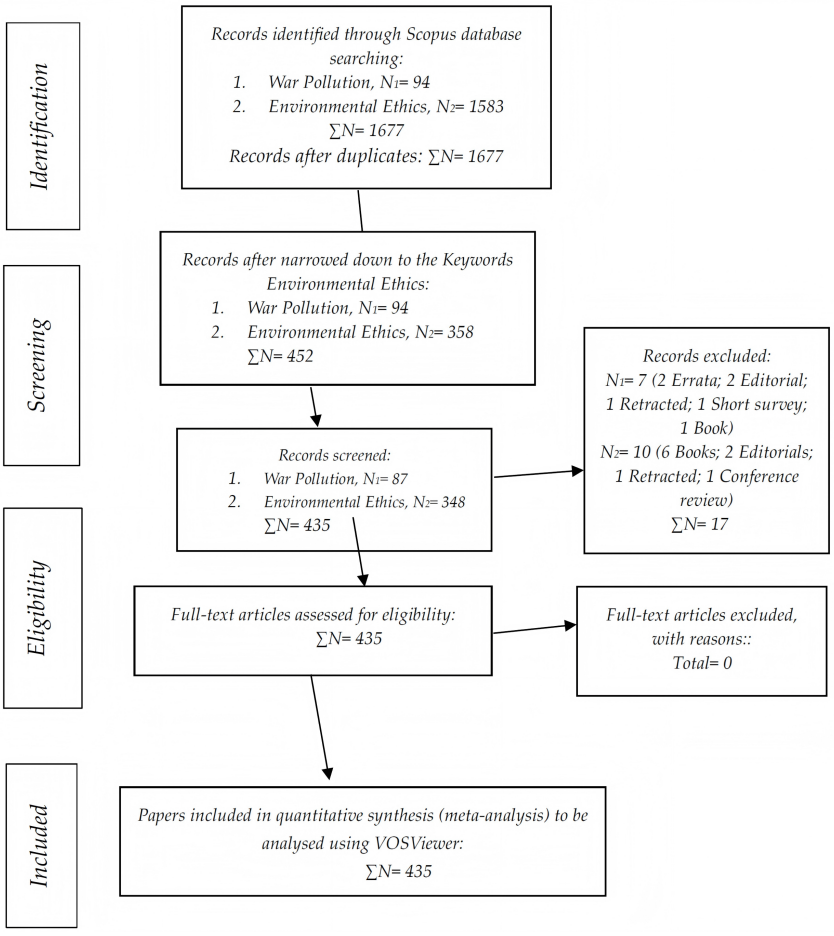

Figure 1. Flowchart of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) used in the present study. Source: Moher [23].

2.1. Search Strategy and Eligibility Criteria

The review followed a structured PRISMA protocol [24]. Scopus was selected as the primary database because it provides broad multidisciplinary coverage of peer-reviewed journals across environmental science, law, philosophy, and the social sciences and is widely used for large-scale bibliometric and review work [25,26]. Using a single, well-documented database also allowed for transparent replication and consistent application of inclusion and exclusion criteria.

The search was conducted on 4 June 2025. Two conceptually distinct but overlapping keyword families were defined in advance. The first was a war-pollution set containing terms such as "war pollution", "wartime pollution", "conflict-related pollution", "military pollution", "toxic remnants of war", and "environmental damage in armed conflict". The second was an environmental-ethics set including "environmental ethics", "ecological ethics", "environmental philosophy", "environmental justice", "planetary health", "rights of nature", and "ecocide". These two keyword families were combined using Boolean operators and applied to the Article Title, Abstract, and Keywords fields in Scopus.

To focus on scholarly contributions with sufficient methodological detail and peer review, we restricted the search to articles and reviews in English, published between 1946 and 2025. This yielded 1677 records in the initial identification phase, of which 94 were retrieved through the war-pollution keyword set and 1583 through the environmental-ethics set. Automatic and manual de-duplication produced 1677 unique records, as the two sets had limited overlap at the initial search stage.

Screening was conducted in two steps, first at title–abstract level and then, where necessary, at full-text level. Articles were included if they explicitly addressed environmental impacts of war, armed conflict, military activities, or post-conflict reconstruction and/or if they engaged substantively with environmental ethics, environmental philosophy, or closely related normative frameworks with clear relevance to environmental harm. We included empirical analyses, conceptual and theoretical arguments, legal and policy analyses, and case studies relevant to war-related environmental degradation or ethical governance. We excluded non-peer-reviewed material such as editorials, news items, short opinion pieces without substantive argument, book reviews, and commentaries that did not present new analysis. We also excluded purely technical military engineering papers that contained no environmental or ethical component and articles dealing solely with peacetime pollution without any explicit link to conflict, militarization, or war-related governance.

Applying these criteria, we retained articles that contained at least one war-related term and at least one environmental-ethics-related term in the title, abstract, or main text. This process resulted in a screened pool of 452 records, comprising 94 primarily war-pollution articles and 358 primarily environmental-ethics articles. Seventeen records (seven from the war-pollution subset and ten from the environmental-ethics subset) were removed at this stage because they were errata, retracted papers, conference summaries, or lacked substantive content on the nexus between war pollution and environmental ethics. The final corpus consisted of 435 full-text articles that met all criteria and were included in the qualitative and bibliometric analyses.

At the eligibility stage, all abstracts and, where ambiguity remained, full texts were examined to confirm that each article either analysed environmental impacts of war, conflict, or military activity or developed environmental-ethical or philosophical arguments with clear implications for conflict-related environmental harm. No further articles were excluded at this point. The decision to begin from two overlapping but distinct keyword families was deliberate. It ensured that the review captured, on the one hand, work explicitly focused on conflict-related pollution and, on the other, broader environmental-ethical scholarship that, while not always framed in wartime terms, offers crucial conceptual and normative tools for thinking about environmental harm in armed conflict. In the subsequent analysis, the two sets were not treated as separate meta-analyses but as a single integrated corpus, with attention to thematic overlaps and conceptual bridges.

2.2. Bibliometric Mapping with VOSviewer

To identify dominant research clusters and their temporal evolution within the 435-article corpus, we conducted bibliometric network analysis using VOSviewer (version 1.6.20; Leiden University) [27–29]. From each article we extracted author keywords and indexed keywords. Because unconstrained keyword networks can become highly fragmented and noisy, we imposed minimum thresholds to ensure

analytical robustness. Only keywords that appeared at least five times in the full dataset and were present in a minimum of three different articles were retained for network construction. This resulted in 1335 unique keywords overall, of which 139 met the occurrence threshold and were used in the co-occurrence analysis.

The co-occurrence networks using the full counting method were constructed, in which each co-occurrence of a keyword pair in a given article contributes equally to the link strength between those keywords. VOSviewer was then used to generate two complementary visualisations. The network visualisation depicts clusters of keywords coloured according to co-occurrence strength, allowing identification of thematic groupings such as war-related pollution and toxic exposure, environmental ethics and philosophy, environmental governance and law, and education and values. The overlay visualization shades keywords according to their average publication year, which provides an indicative picture of how interest in particular topics has shifted over time within the war-pollution and environmental-ethics nexus.

2.3. Quality Appraisal and Integrative Synthesis

The corpus spans heterogeneous genres, including empirical environmental and health studies, legal and policy analyses, political and historical case studies, and ethical and philosophical works. Conventional risk-of-bias tools developed for clinical trials or strictly quantitative epidemiological studies are therefore not directly applicable. Instead, we adopted a structured qualitative appraisal tailored to three broad categories of contribution: empirical environmental and health research, legal–policy and governance analyses, and ethical or philosophical work.

Empirical environmental and health studies included contamination assessments, ecological impact evaluations, and epidemiological analyses of war-related exposure. For these articles, we examined the clarity and relevance of the research question, the transparency and appropriateness of sampling and measurement procedures, the robustness of analytical methods, and the degree to which uncertainties and limitations were acknowledged. Legal, policy, and governance analyses encompassed work on international humanitarian law, international environmental law, and institutional design for environmental protection in conflict settings. For these, we evaluated the transparency of sources, the coherence of the interpretive framework, engagement with existing legal scholarship, and the extent to which the analysis addressed concrete mechanisms for implementation or enforcement. Ethical and philosophical contributions were appraised in terms of conceptual clarity, explicitness of normative commitments, careful use of examples, and their relevance to understanding war-related environmental harm rather than only peacetime dilemmas.

Across all categories, we considered the appropriateness and depth of evidence use, including whether arguments were supported by empirical data, historical records, legal documents, or engagement with counterarguments. Articles that lacked methodological transparency, relied almost exclusively on anecdotal evidence, or only gestured briefly toward war-related environmental issues were retained in the dataset for completeness but were given less interpretive weight in the synthesis. Highly speculative or very short opinion pieces were not treated as equivalent in evidential strength to detailed empirical studies or rigorous legal analyses.

To integrate these diverse materials, we combined the quantitative insights from the VOSviewer clusters with a qualitative, narrative synthesis. For each major thematic cluster identified in the bibliometric analysis, we mapped dominant sub-themes, representative case studies, recurring ethical and legal arguments, and key points of convergence or contestation. Particular attention was given to how environmental-ethical concepts such as justice, slow violence, ecocide, and planetary health are, or are not, translated into concrete legal standards and governance mechanisms. This integrative approach allowed us to respect disciplinary diversity while maintaining a coherent analytical focus on the nexus of war, pollution, and environmental ethics that underpins the subsequent development of the LEEF-WP framework.

3. Results

VOSviewer analysis of keyword co-occurrence revealed eight major thematic clusters (**Figures 2** and **3**). These clusters are not mutually exclusive; rather, they represent overlapping regions of a dense research landscape.

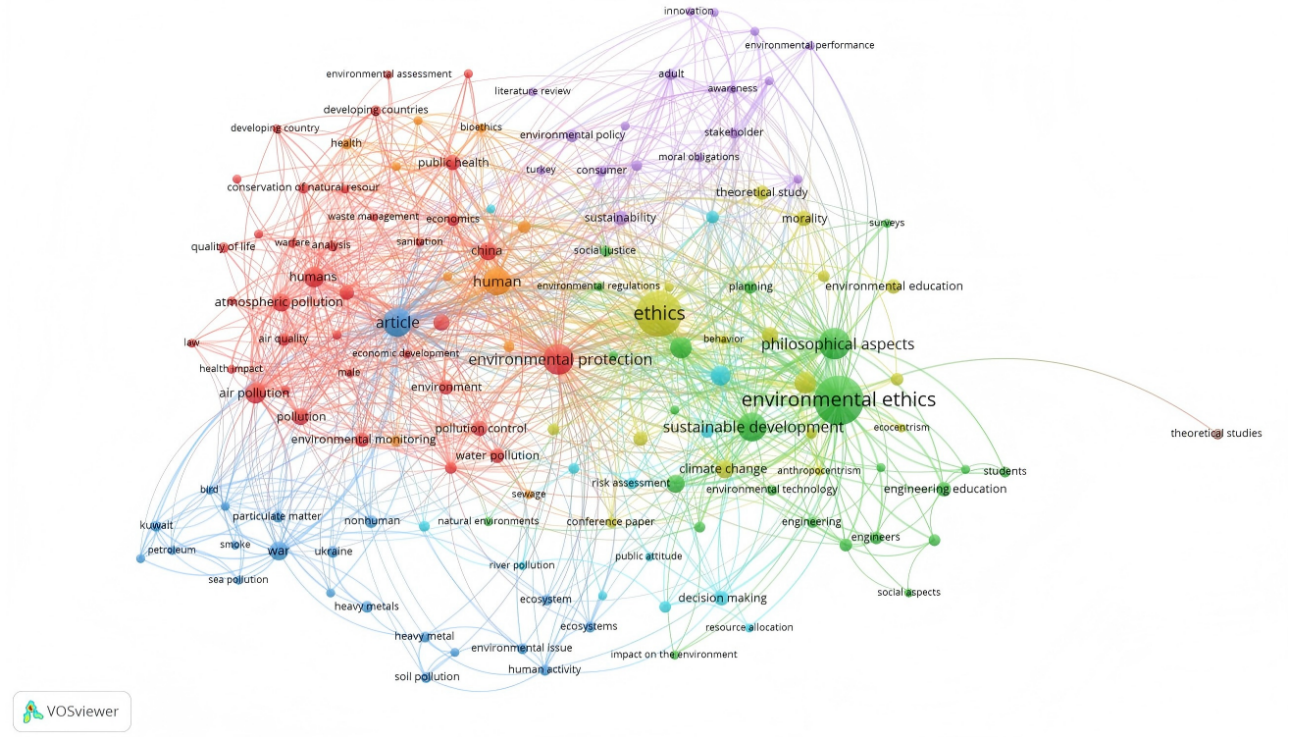

Figure 2. The bibliographic analysis using Network Visualization in VOSViewer.

Note: It outputting eight major clusters with 139 items meeting the threshold of minimum 3 number of occurrences of a keyword, in which out of 1335 keywords, 139 met the threshold based on (87 + 348) papers (1984–2025) searched in Scopus database with keyword 'War Pollution' 87 (1946–2025) plus 'Environmental ethics' 348 (1986–2025), found in the Article Title, on 4 June 2025.

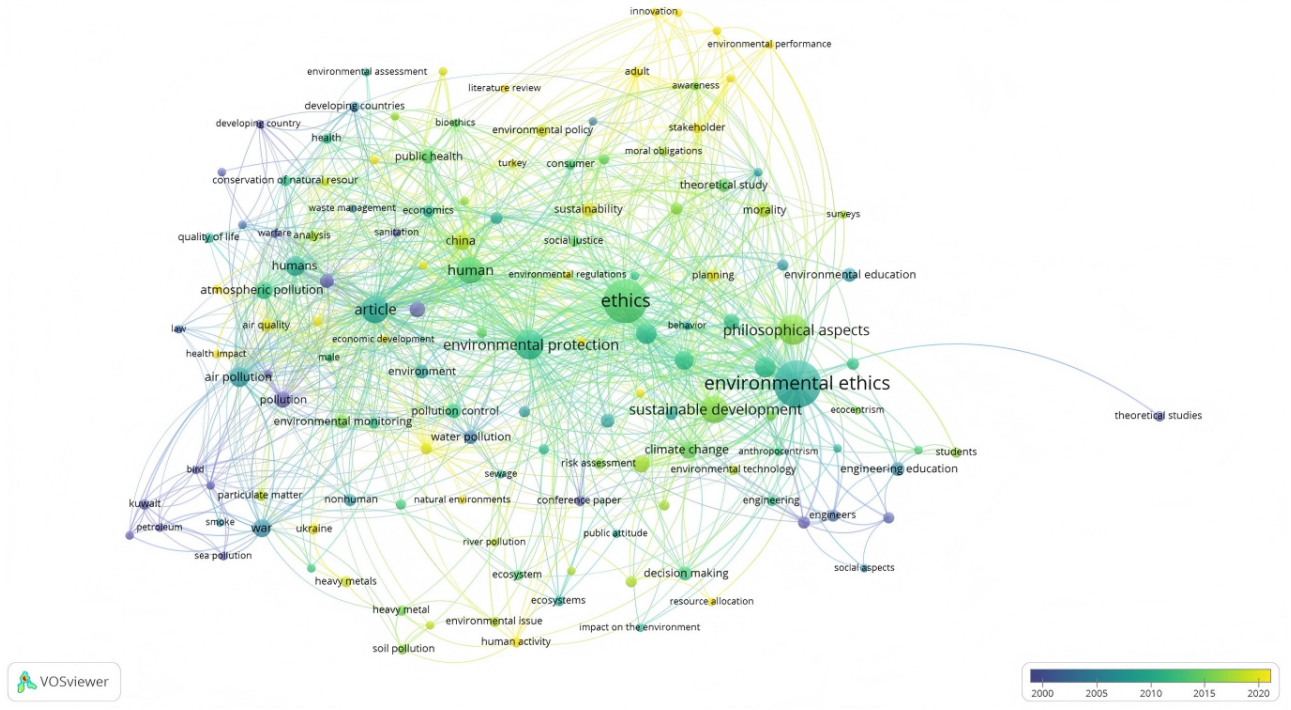

Figure 3. The bibliographic analysis using Overlay Visualization in VOSViewer.

Note: It outputting eight major clusters with 139 items meeting the threshold of minimum 3 number of occurrences of a keyword, in which out of 1335 keywords, 139 met the threshold based on (87 + 348) papers (1984–2025) searched in Scopus database with keyword 'War Pollution' 87 (1946–2025) plus 'Environmental ethics' 348 (1986–2025), found in the Article Title, on 4 June 2025.

3.1. Environmental Protection and Policy Ethics (Red Cluster)

The red cluster is one of the densest regions and focuses on environmental protection, public policy, pollution control, and conservation of natural resources. It is closely connected to terms such as human activities, environmental regulation, justice, and quality of life. This cluster captures debates about how ethical principles—such as stewardship, responsibility, and intergenerational equity—are translated into policies, treaties, and regulatory instruments. Overlay visualization suggests that this cluster is relatively older, with a concentration of publications between the early 1990s and 2010, reflecting the momentum after the Rio Earth Summit and the early development of international environmental agreements.

3.2. Philosophical Foundations of Environmental Ethics (Green Cluster)

The green cluster centers on environmental ethics, moral responsibility, anthropocentrism, ecocentrism, biocentrism, and environmental philosophy. It forms the conceptual backbone of the network, bridging policy, education, and sustainability clusters. Publications in this cluster span several decades, with continuing activity after 2010 as scholars revisit classic ethical frameworks in the light of climate change, mass extinction, and intensified militarization of vulnerable regions. Works on planetary health, rights of nature, and environmental justice further extend these debates into global and intergenerational contexts.

3.3. War Pollution and Toxic Exposure (Blue Cluster)

The blue cluster is more peripheral spatially but thematically crucial. It is associated with military waste, radioactive exposure, toxic metals, chemical weapons, soil and water contamination, and the "toxic remnants of war." Much of the early literature in this cluster, with darker colors in the overlay visualization, arises from post-World War II and Cold War pollution studies, with later waves examining Vietnam, the Gulf Wars, the Balkans, and Iraq. Recent publications focus on Ukraine, Gaza, and other contemporary conflict zones, including assessments of heavy metals, unexploded ordnance, and explosive residues.

3.4. Climate Change and Sustainability (Yellow Cluster)

The yellow cluster links climate change, sustainability, carbon emissions, ecological footprints, and planetary boundaries. It bridges ethical and governance clusters, emphasizing intergenerational equity and climate justice. The overlay visualization shows a surge of activity after 2015, coinciding with the Paris Agreement, the Sustainable Development Goals (SDGs), and growing attention to climate-conflict interactions. Articles in this cluster often discuss how climate stress, conflict, and militarized responses jointly shape environmental risk.

3.5. Environmental Education and Human Values (Purple Cluster)

The purple cluster comprises environmental education, value change, awareness, youth activism, and community participation. It foregrounds how educational practices and cultural narratives shape environmental attitudes and behaviors. Recent work connects climate anxiety, eco-grief, and youth climate movements to broader ethical debates, including how war-related environmental harm is remembered, taught, or silenced in curricula.

3.6. Governance and Decision-Making (Turquoise Cluster)

The turquoise cluster focuses on environmental law, governance, stakeholder engagement, decision-making, and institutional design. It includes scholarship on multilevel governance, just transition, environmental litigation, and the incorporation of ESG principles into public and corporate decision-making. Time trends show sustained growth over the last 10–15 years, reflecting intensifying concern over the gap between environmental norms and implementation.

3.7. Risk, Assessment, and Remediation (Dark Purple Cluster)

The dark purple cluster gathers terms related to risk assessment, remediation, toxicity, vulnerability, and environmental monitoring. It connects war-pollution studies with broader frameworks of environmental risk governance and disaster response. Methodological innovations, such as

geochemical fingerprinting, remote sensing, and AI-assisted monitoring, feature prominently here, along with debates over the precautionary principle and ethical responsibility under scientific uncertainty.

3.8. Theoretical and Interdisciplinary Perspectives (Light Green Cluster)

The light green cluster comprises critical theory, ecofeminism, postcolonial studies, indigenous knowledge, and interdisciplinary theoretical work. It is smaller but plays a crucial bridging role, linking normative theory with empirical case studies and governance debates. Recent contributions emphasize decolonial perspectives, relational ontologies, and indigenous legal orders that challenge the assumptions of mainstream environmental law and ethics.

4. Discussion

4.1. Environmental Protection and Policy Ethics: Integrating Ethics into Global Regulation

Figure 4 shows how environmental ethics in the context of conflict has evolved conceptually from neglect and disregard toward the restoration of the global environment. The red cluster highlights the ways in which environmental ethics has been incorporated, often imperfectly, into environmental policy and law. As global environmental crises such as deforestation, ocean acidification, biodiversity loss, and pollution intensify, ethical foundations of environmental governance including equity, precaution, and intergenerational justice are increasingly invoked in both policy documents and social movements. Institutions such as the IPCC, IPBES, and the Conferences of the Parties (COPs) have brought ethical questions to the forefront, especially in debates over responsibility for historical emissions, obligations toward vulnerable populations, and the distribution of mitigation and adaptation burdens.

However, the environmental consequences of war remain marginal within most of these frameworks. Sand[4] showed that during the Gulf War, maritime pollution and resource plunder were deliberately weaponized, yet existing conventions and enforcement mechanisms did little to prevent or remedy the resulting damage. Westing[5] documented how reconstruction in post-war Vietnam left marginalized communities living in polluted districts with inadequate environmental remediation and almost no meaningful participation in decision-making. Solokha et al.[6] similarly argued that heavy metal contamination in Ukraine represents a durable ecological burden that existing governance arrangements are poorly equipped to address. Taken together, these cases underscore a structural gap: international environmental law and international humanitarian law (IHL) remain siloed, with environmental treaties largely designed for peacetime and IHL focused on immediate humanitarian protections.

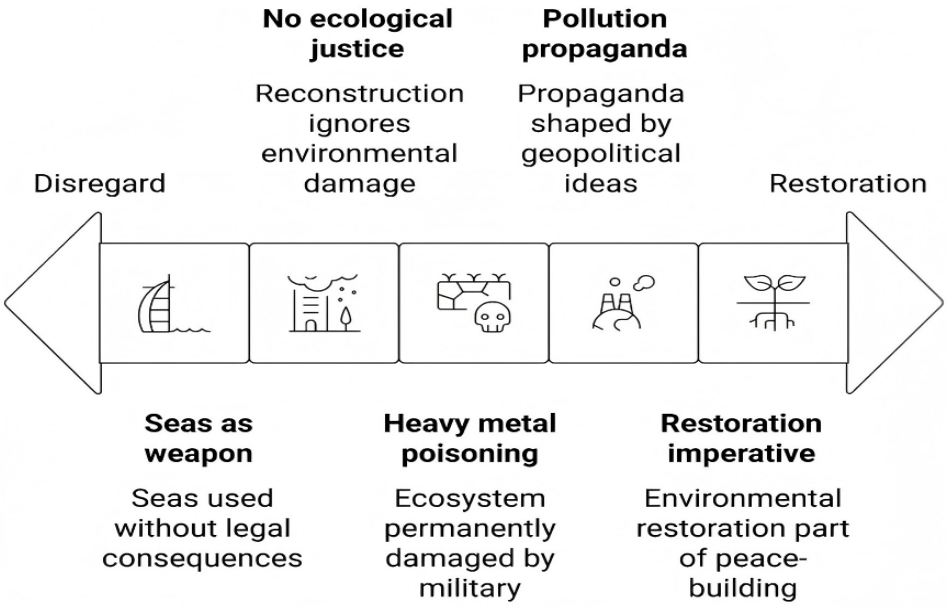

Figure 4. The overall environmental ethics in conflicts.

The Geneva Conventions and Additional Protocol I employ the well-known threshold formula of "widespread, long-term and severe" environmental damage, but its ambiguity and stringency have made it difficult to operationalize in practice. Environmental ethics literature therefore calls for a more explicit integration of environmental duties into wartime regulation. This includes legally mandated environmental impact assessments for military operations, clear obligations for post-conflict restoration, and recognition of ecosystems and affected communities as victims deserving restitution and long-term care.

4.2. Philosophical Foundations: Reframing Humans and Nature in the Anthropocene

The green cluster shows that debates on anthropocentrism, ecocentrism, and biocentrism have expanded into more complex discussions of relational ethics, planetary health, and environmental justice. In the Anthropocene, where human activity has become a dominant force in shaping Earth system processes, classical assumptions about a sharp separation between humans and nature are increasingly untenable. McConnell et al.[3] and Legrand et al.[30] demonstrated that military and industrial activities leave enduring signatures in ice cores and sediments, revealing a longue durée of human-driven environmental change in which war is a recurrent driver rather than an exceptional event[31,32]. In response to such histories, theoretical work on planetary health and One Health emphasizes the interdependence of human, animal, and ecosystem health[33].

Nixon's[21] concept of slow violence further deepens this philosophical picture by foregrounding the temporally stretched and often invisible nature of environmental harm in conflict and post-conflict settings. Slow violence captures how contaminated soils, unexploded ordnance, and toxic sediments may remain politically and morally neglected even as they continue to damage bodies and ecosystems decades after a ceasefire. Philosophical frameworks that take slow violence seriously demand an ethics that accounts not only for spectacular, immediate destruction but also for diffuse, cumulative harms that are difficult to see yet impossible to ignore.

Overall, the philosophical literature suggests that environmental ethics in the age of war and climate crisis must move beyond abstract human–nature binaries and engage with concrete histories of empire, militarization, and structural inequality. Ethical analysis must consider how war reshapes ecological relationships, redistributes risk, and perpetuates injustice across time and space, and how any response must integrate historical accountability with future-oriented responsibility.

4.3. War, Pollution, and Toxic Exposure: Ethical Blind Spots in Military Environmentalism

The blue cluster draws attention to the toxic legacies of warfare. Classic cases include the use of Agent Orange in Vietnam, where dioxin contamination continues to present major health and ecological problems, and the Gulf War oil spills and well fires, which transformed coastal and desert environments with long-lasting repercussions for human and ecosystem health, as described by Sand[4]. In Ukraine, Solokha et al.[6] documented heavy metal and chemical pollution arising from bombardment of industrial facilities, damage to infrastructure, and weapons residues, with long-term implications for soil and water quality[34]. Esu and Maddanu[34] showed that even peacetime military activities create considerable environmental burdens that often remain outside the focus of mainstream media and policy-making.

Historical records reinforce this picture. Legrand et al.[30] used Alpine ice cores to demonstrate long-term thallium deposition associated with wartime activities, while McConnell et al.[3] showed that lead in Greenland ice tracks centuries of war, epidemics, and economic expansion. These studies indicate that war-related pollution is not merely local or transient but contributes to global environmental change and can be detected far from battlefields.

Nixon's[21] notion of slow violence is particularly apt for describing the toxic remnants of war. Unexploded ordnance, contaminated aquifers, radioactive debris, and persistent organic pollutants inflict harm gradually and disproportionately on marginalized communities with limited political visibility. Global inventories of potentially polluting wrecks show that thousands of World War II vessels sunk in marine environments still contain fuel, oil, and munitions that threaten marine ecosystems as hulls corrode over time[35–37]. These wrecks and their leaking pollutants form transboundary environmental hazards, illustrating how the material infrastructure of war continues to endanger people

and ecosystems long after active conflict ends.

Existing legal frameworks only weakly address these problems. References to environmental protection in IHL, including the ENMOD Convention and the narrow environmental provisions of the Rome Statute, are rarely invoked in practice. Ethically, the literature converges on the need to view ecosystems and affected communities as genuine victims of war with corresponding rights to protection, remediation, and participation in decision-making. This perspective requires strengthening environmental monitoring and forensics, expanding legal recognition of environmental harm, and developing robust mechanisms for compensation, ecological restoration, and long-term health support.

4.4. Climate Change and Sustainability: Ethical Leadership in a Warming World

The yellow cluster links wartime pollution with broader debates on climate change, sustainability, and justice. Climate-exacerbated disasters such as heatwaves, floods, and droughts interact with conflict dynamics and militarized responses, raising ethical questions about responsibility, vulnerability, and adaptation [36,37].

Climate governance literature highlights the uneven distribution of burdens and benefits in mitigation and adaptation policies [38–41]. Greenstone et al. [38,39], Li et al. [40,42], and Shao et al. [41] analyzed China's clean air policies, documenting significant improvements in air quality alongside complex socio-economic trade-offs, including job losses and regional inequalities. Zhang et al. [43] showed that participatory governance can enhance policy effectiveness, though An [44] demonstrated how "blunt force regulation" and bureaucratic control can undermine legitimacy and public trust. These studies have direct implications for post-conflict reconstruction, where ambitious environmental remediation and decarbonization initiatives may collide with urgent livelihood needs and fragile institutions.

From an ethical standpoint, climate change and wartime pollution share several characteristics: both involve cumulative and long-term harms; both disproportionately affect vulnerable populations; and both are shaped by historical power imbalances. Climate ethics therefore provides conceptual tools such as responsibility for historical emissions, common but differentiated responsibilities, and frameworks for loss and damage that can inform debates on environmental responsibility in armed conflict. The literature suggests that an ethically robust approach to sustainability must include explicit obligations to avoid militarized environmental destruction and to repair war-related damage, particularly in ecologically fragile and climate-vulnerable regions.

4.5. Environmental Education and Human Values: Turning Ethics into Action

The purple cluster indicates that environmental ethics is not only a question of theory or law, but also of education, culture, and collective memory. Youth movements such as Fridays for Future and Extinction Rebellion have brought moral claims about intergenerational justice and planetary stewardship into public discourse, often linking climate change to broader concerns about inequality, colonialism, and militarization.

Historical case studies show that public awareness and education significantly influence environmental governance outcomes. McConnell et al. [3] illustrated how societal understandings of pollution during wartime shaped policy responses in Europe. In many post-conflict settings, however, environmental issues are largely absent from formal curricula. Westing [5] and Perera and Spencer [45] documented how communities in post-war Vietnam and Colombo continued to live with substantial environmental and health burdens that remained unrecognized in educational and policy discourse.

Recent scholarship calls for context-sensitive environmental ethics education that draws on local narratives and cultural frameworks, including Confucian notions of harmony, Islamic concepts of stewardship, and diverse forms of indigenous ecological knowledge. Nemeth [46] showed how Cold War developmental rhetoric in North Korea shaped official narratives about pollution, limiting the possibility of genuine environmental critique. These examples suggest that environmental education in war-affected societies should not only convey scientific information but also address questions of justice, memory, and responsibility. Carefully designed education can empower communities to demand environmental accountability and to participate meaningfully in remediation and environmental governance [47,48].

4.6. Governance and Decision-Making: From Rules to Transformative Ethics

The turquoise cluster foregrounds the governance challenges associated with translating ethical principles into effective practice. Formal rules and regulations are necessary but insufficient; governance also depends on institutional cultures, power relations, and meaningful participation. Despite widespread rhetoric about stakeholder participation and environmental justice, many decision-making processes remain top-down and technocratic. An[44] described how blunt regulatory tools in China sometimes undermined social legitimacy, while Greenstone et al.[38,39] emphasized the importance of transparency and accountability mechanisms for maintaining public trust.

Environmental litigation and climate lawsuits have become key arenas for advancing environmental ethics within governance systems. Cases addressing peatland fires in Indonesia or corporate responsibility for greenhouse gas emissions in Europe show that courts can serve as sites where environmental harms are reframed as legal wrongs and moral failures. Access to such avenues, however, is uneven and particularly limited in conflict-affected and authoritarian contexts.

War-related environmental governance faces additional obstacles. Decision-making authority is often concentrated in military and security institutions, and information about environmental risks may be classified. Transformative ethics thus requires not only improved legal rules but also institutional reforms that embed environmental duties and transparency into military planning, procurement, and post-conflict reconstruction.

4.7. Risk, Assessment, and Management: Ethics in Uncertain Science

The dark purple cluster illustrates how environmental risk governance is characterized by uncertainty, contested evidence, and extended temporal horizons. The precautionary principle is widely cited but applied inconsistently[47,48]. Disasters such as the Bhopal gas leak, the Flint water crisis, and persistent dioxin contamination in Vietnam show how cost–benefit calculations that discount long-term or marginalized harms can lead to profound moral failure.

In war zones, risk assessment becomes even more complex. Menshov et al.[47], Bondar et al.[7], and Raffa et al.[49] documented extensive contamination in conflict-affected areas using geochemical and magnetic methods, yet systematic risk assessments are rarely mandated as part of military planning or post-conflict recovery[50]. Technological tools such as remote sensing and artificial intelligence can enhance monitoring capacity but also raise ethical concerns about data colonialism, automation bias, and opaque decision-making processes, as indicated by policy and governance debates related to air quality management[39]. Without explicit ethical frameworks, advanced monitoring technologies risk reinforcing existing inequalities rather than mitigating environmental and health risks.

Forward-looking approaches such as anticipatory governance call for integrating ethical reflection into early stages of risk identification and policy design. For war-related pollution, this implies assessing environmental risks before military operations commence, planning for post-conflict remediation in advance, and involving affected communities in defining acceptable levels of risk and priorities for remediation and restoration.

4.8. Theoretical and Interdisciplinary Perspectives: Redefining the Frontiers of Ethics

The light green cluster underscores the importance of interdisciplinary and critical perspectives for understanding wartime pollution. Eco-feminist, postcolonial, and indigenous scholarship challenges dominant narratives that treat nature as a passive resource or battlefield and highlights how environmental harm intersects with gender, race, class, and colonial histories. Indigenous legal orders in many regions recognize rivers, forests, and other entities as living relatives or rights-bearing entities, offering alternative visions of environmental governance and responsibility.

These perspectives complicate simple dichotomies between peace and war, human and non-human, or domestic and international law. They invite a rethinking of sovereignty that acknowledges overlapping responsibilities and shared vulnerabilities. They also insist that any ethical framework for wartime pollution must confront histories of colonial violence, resource extraction, and structural injustice, rather than merely regulating "excesses" in otherwise acceptable practices. The integration of such perspectives suggests that future work on war, pollution, and environmental ethics must

be more deeply attuned to power, history, and voice.

4.9. Towards an Integrated Ethical–Legal Agenda for Wartime Pollution

Synthesizing across the clusters, the literature points to several converging themes. War pollution is deeply embedded in broader patterns of slow violence, climate change, and structural inequality [51–54]. Environmental ethics has developed sophisticated concepts including justice, planetary health, rights of nature, and slow violence, yet these concepts are only partially reflected in current legal regimes. Empirical and legal studies reveal recurrent gaps between normative commitments and institutional practices, especially in conflict settings where environmental harm is overshadowed by security concerns and short-term political priorities [55–59].

An integrated ethical–legal agenda therefore needs to recognize war-related environmental harm as a central concern of both environmental ethics and IHL, rather than a peripheral issue. It must develop clear legal standards for environmental protection in armed conflict that go beyond vague thresholds. It should mandate robust monitoring, transparency, and public participation in assessing and addressing war pollution, and embed duties of remediation and restoration into post-conflict reconstruction frameworks. Such an agenda must also address the transboundary and intergenerational nature of war pollution, including issues associated with marine wrecks, atmospheric deposition, and long-lived contaminants [60–64]. The proposed Lawful Environmental Ethics Framework for Wartime Pollution (LEEF-WP) is intended as a structured attempt to translate these requirements into a coherent set of legal and ethical pillars.

4.10. Strengthening the Lawful Environmental Ethics Framework for Wartime Pollution (LEEF-WP)

The LEEF-WP framework consists of six interrelated pillars designed to embed environmental ethics in the law and practice of armed conflict and post-conflict governance. The first pillar calls for explicit environmental duties in IHL. This involves clarifying and strengthening environmental protection provisions by revising the current "widespread, long-term and severe" threshold, specifying measurable criteria such as ecological baselines, temporal scales, and cumulative impacts, and expanding the Rome Statute's recognition of environmental damage as a potential war crime. Operationally, this would require military planners to integrate environmental risk assessments into targeting, weapons selection, and operational planning, with clear lines of accountability for violations, consistent with emerging discussions on environmental responsibility in armed conflict [65–68].

The second pillar emphasizes the recognition of ecocide and environmental rights. Building on debates around ecocide, rights of nature, and environmental human rights, it proposes recognizing serious and widespread environmental destruction in war as a crime of concern to the international community. This pillar connects with developments in domestic and regional courts that have recognized environmental rights as fundamental and suggests that within the ICC framework, ecocide could be defined as a standalone crime or existing provisions expanded to cover large-scale environmental harm, with attention to both human and non-human victims [69,70].

The third pillar focuses on ethical military conduct and environmental precaution. It promotes embedding environmental ethics into military doctrine, training, and rules of engagement by adopting the precautionary principle in military operations, minimizing environmental footprints through cleaner technologies and improved waste management, and establishing environmental constraints on weapon use and targeting. Practical mechanisms include appointing environmental officers within armed forces, requiring environmental impact assessments for major operations, and designating "no-go" zones for particularly sensitive ecosystems [71,72].

The fourth pillar centers on monitoring, reporting, and forensic documentation. Effective environmental protection in war requires robust, credible evidence. This pillar calls for standardized protocols for monitoring war-related environmental harm, including satellite imagery, ground-based measurements, and community-based reporting systems. It also envisages an independent international mechanism, possibly under UNEP or a dedicated treaty body, to collect, verify, and disseminate data on war pollution, including slow-onset impacts such as contamination from wrecks, unexploded ordnance, and long-range atmospheric deposition [32–36,48–50].

The fifth pillar links restoration, reparation, and just transition. It suggests that parties to a conflict should bear legal duties to remediate contaminated sites, restore damaged

ecosystems, and compensate affected communities. This pillar emphasizes principles of just transition to ensure that environmental cleanup and decarbonization do not exacerbate existing social inequalities, particularly in already fragile, conflict-affected settings [29,38]. International funding mechanisms and technical assistance programs would be necessary to support low-income and war-torn countries in fulfilling these obligations [73,74].

The sixth pillar stresses participatory, decolonial, and multi-level governance. It recognizes that legitimate and effective environmental governance in war-affected contexts must be participatory and attentive to local knowledge and power asymmetries. This implies inclusive decision-making bodies involving affected communities, indigenous groups, and civil society organizations in defining priorities for monitoring, remediation, and legal reform. It also calls for cooperation between international organizations, regional bodies, and national governments to address the transboundary and intergenerational dimensions of war pollution, including potentially polluting wrecks and other long-range pollutants [29–33,75].

The LEEF-WP framework does not emerge from a legal vacuum. It builds on established IHL principles such as military necessity, proportionality, and distinction; environmental law doctrines such as the no-harm rule, precaution, and polluter-pays; and human rights instruments that recognize a right to a healthy environment. It complements initiatives such as the International Law Commission's work on the protection of the environment in relation to armed conflicts and civil society campaigns for the recognition of ecocide. By explicitly linking ethical concepts, including slow violence, justice, and planetary health, to concrete legal obligations and institutional mechanisms, LEEF-WP aims to bridge the persistent gap between moral rhetoric and legal practice [31–34,76].

4.11. SWOT–TOWS Analysis: Strategic Pathways for Implementation

Figure 5 presents a SWOT analysis that summarizes the strengths, weaknesses, opportunities, and threats associated with the LEEF-WP framework. The main strengths lie in its normative coherence, its integration of ethics and law, its alignment with planetary health and environmental justice discourses, and its compatibility with existing IHL and environmental law principles [27,34–38,77]. Weaknesses include its reliance on states' willingness to reform, the complexity of monitoring and attributing environmental harm in conflict settings, uneven institutional capacities across countries, and the limited precedent for prosecuting environmental war crimes [45–49,78]. Opportunities arise from rising public awareness of environmental issues, ongoing debates on ecocide and environmental rights, technological advances in environmental forensics, and a growing body of jurisprudence on climate and environmental litigation [36–39,79]. Threats include geopolitical rivalries, the securitization of information, potential backlash against international courts, and the risk that reforms remain largely symbolic without producing substantive changes on the ground [47,80].

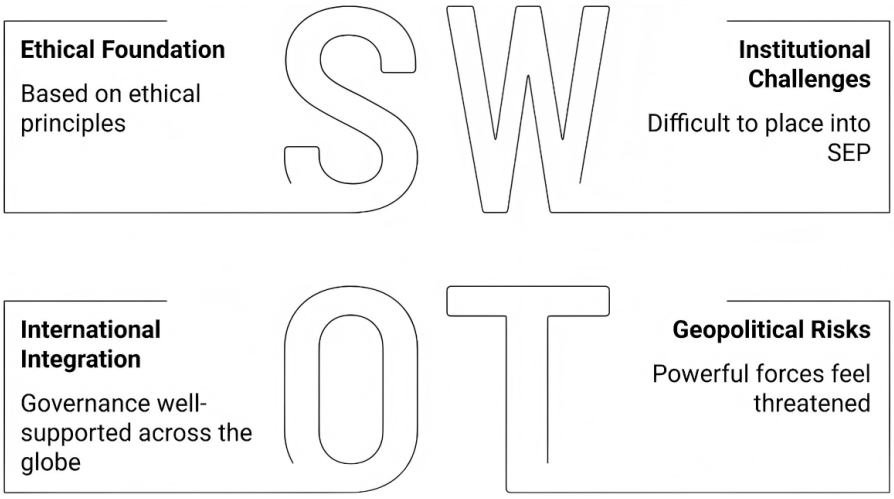

Figure 5. A SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis with a strategic summary of the issues and possibilities of the Lawful Environmental Ethics Framework for Wartime Pollution (LEEF-WP) system.

Figure 6 depicts the TOWS strategic pathways for implementing LEEF-WP. A TOWS matrix extends the SWOT analysis by combining internal strengths and weaknesses with external opportunities and threats to derive tactical approaches. Strength–Opportunity strategies involve leveraging the moral authority of planetary health and environmental justice to support legal reforms while using advances in environmental monitoring to strengthen evidentiary bases for litigation and advocacy[34,81]. Strength–Threat strategies highlight the security benefits of environmental protection, such as reduced resource conflicts, health burdens, and displacement, in order to counter resistance from security establishments and to frame environmental duties as enhancing long-term stability rather than undermining it[29,32,39,40].

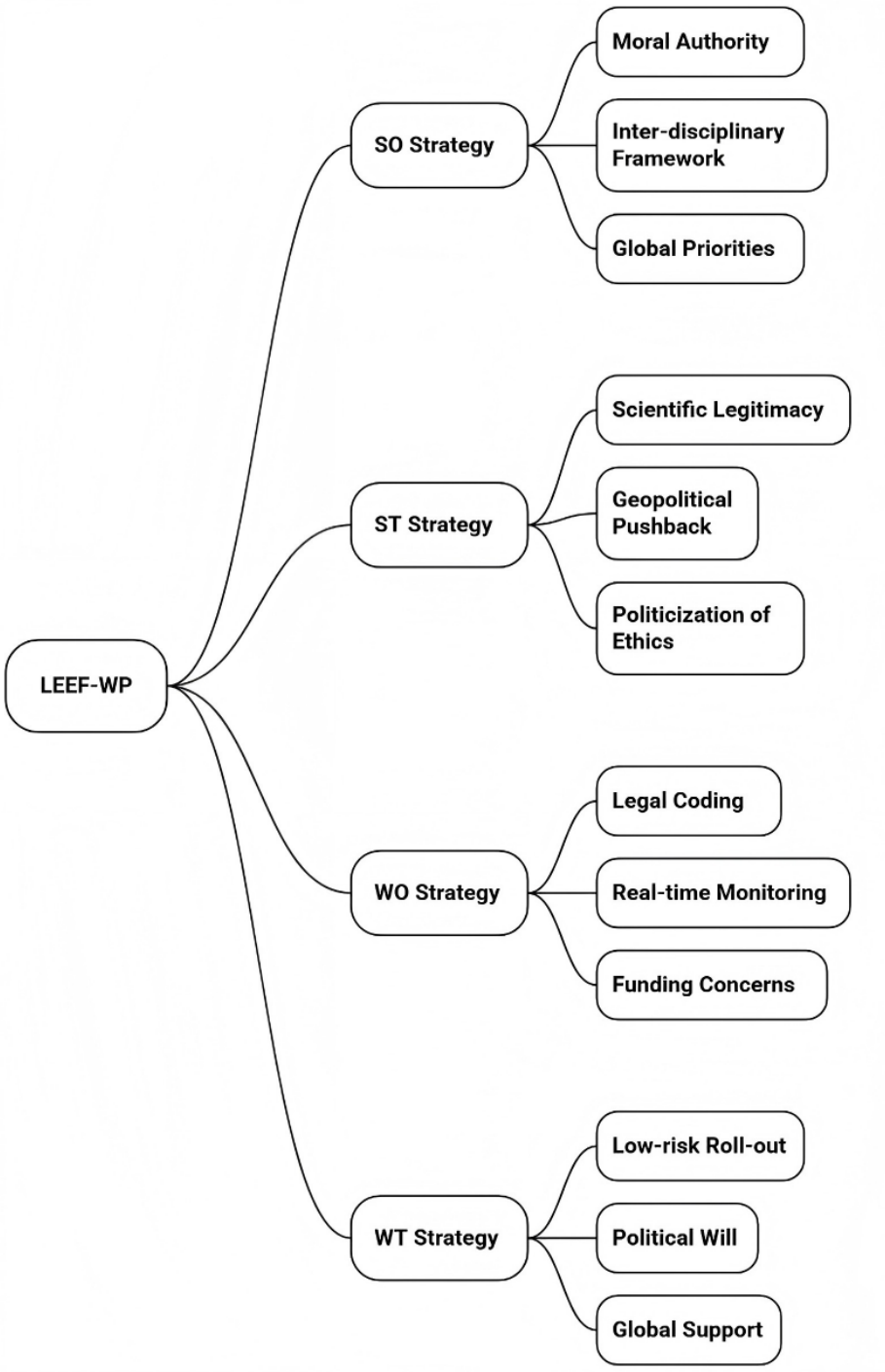

Figure 6. TOWS strategic pathways for the Lawful Environmental Ethics Framework for Wartime Pollution (LEEF-WP) implementation.

Weakness–Opportunity strategies emphasize capacity-building programs, particularly for low-income and conflict-affected states, to improve environmental monitoring, legal implementation, and access to technical expertise, supported by international funds and assistance for war-related remediation [44–48,82]. Weakness–Threat strategies stress the importance of transparency and civil society oversight to prevent purely symbolic adoption of environmental norms and encourage regional and coalition-based approaches where global consensus is blocked or stalled [44–47,83–85].

The SWOT–TOWS analysis thus emphasizes that LEEF-WP should be viewed not as a static blueprint but as a strategic and adaptive framework. Its implementation will need to evolve with changing political contexts, technological capabilities, and ecological conditions, while remaining grounded in the ethical commitment to protect ecosystems and communities from the often-hidden yet profound harms of wartime pollution [86–88].

5. Conclusions

War-related environmental destruction is no longer a peripheral concern. It is a central dimension of contemporary planetary crisis, tightly interwoven with climate change, biodiversity loss, and structural injustice. This systematic review of 435 articles shows that scholarship on environmental ethics, war pollution, governance, and risk assessment has matured significantly, yet remains fragmented across disciplinary and institutional boundaries.

Bibliometric and qualitative analyses reveal eight major thematic clusters that together map a complex research landscape. Philosophical work has articulated powerful concepts such as slow violence, planetary health, and environmental justice; empirical studies have documented contamination from Agent Orange, heavy metals, oil spills, and potentially polluting wrecks; and legal scholarship has explored the limits and possibilities of IHL and environmental law. However, existing legal regimes still struggle to translate ethical insights into binding obligations and effective enforcement, particularly in the context of armed conflict.

The proposed LEEF-WP framework responds to this gap by articulating six pillars that link ethics to law, monitoring, and governance: clarifying environmental duties in IHL; recognizing ecocide and environmental rights; embedding precaution in military practice; strengthening monitoring and forensic documentation; institutionalizing restoration and reparation; and promoting participatory, decolonial, multi-level governance. A SWOT–TOWS analysis highlights both the promise and the challenges of implementing this framework, from opportunities in emerging climate and environmental jurisprudence to threats from geopolitical rivalry and entrenched notions of sovereignty.

Ultimately, integrating environmental ethics into wartime governance is not merely a technical exercise. It is a moral project that asks what kinds of harm we are willing to recognize, prevent, and repair, and whose lives and landscapes we consider worthy of protection. In the Anthropocene, where the material legacies of war can be traced in ice cores, sediments, and corroding shipwrecks, the distinction between "war" and "environment" is increasingly illusory. Protecting the environment in war is therefore essential to protecting human and non-human life, sustaining planetary health, and realizing any credible vision of just and durable peace.

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