

Reinterpreting World War II Atrocities through the Principles of Ecotoxicology: A Critical Historical-Ecological Framework

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Abstract: The discipline of ecotoxicology, traditionally centered on the study of pollutants and their effects on biological systems, also offers a robust framework for evaluating systemic harm beyond environmental chemistry. The objective of this paper is to demonstrate that the ten principles of ecotoxicology (POE) extend beyond their conventional roles in regulation and scientific assessment to serve as foundational ethical principles that guide responsible environmental stewardship. This paper applies the ten POE: 1) Source–Pathway–Receptor, 2) Dose–Response, 3) Bioavailability, 4) Accumulation, 5) Mode of Action, 6) Ecological Relevance, 7) Mixture Toxicity, 8) Community Effects, 9) Toxicokinetic, and 10) Risk Assessment, to reflect critically on the human and environmental consequences of wartime atrocities during World War II (WWII), specifically the crimes committed by Nazi Germany and Unit 731. These historical events demonstrate the misuse of scientific and toxicological understanding, weaponizing principles of exposure and systemic disruption to inflict widespread sufferings of living humans. By reframing these actions within ecotoxicological principles, the paper emphasizes the enduring importance of ethical science, ecological accountability, and peace-focused scientific education.

Keywords: World War II; Nazi Germany; Unit 731; Dose–Response; Environmental Ethics

Introduction: It is always not easy to teach students to a subject matter and specialized area of focus study in our biological system such as ecotoxicology. In this paper, I draw ten principles of ecotoxicology (POE) which can provide a comprehensive framework for understanding how contaminants interact with biological systems and ecosystems. These include: 1) Source–Pathway–Receptor, 2) Dose–Response, 3) Bioavailability, 4) Accumulation, 5) Mode of Action, 6) Ecological Relevance, 7) Mixture Toxicity, 8) Community Effects, 9) Toxicokinetic, and 10) Risk Assessment, [1-3]. These principles are foundational to both predictive toxicology and regulatory ecotoxicology and have continued to evolve with the integration of ethical standards, advanced analytical tools, and green chemistry approaches [4-5].

Ecotoxicology examines how toxic substances affect living organisms, populations, and ecosystems through pathways of exposure and mechanisms of harm. Although traditionally focused on industrial pollution, agricultural chemicals, and synthetic contaminants, ecotoxicology has expanded to encompass integrated ethical principles, molecular tools, and collaborative data-sharing frameworks [6-7]. It has also become central to addressing complex challenges related to climate change, environmental justice, and sustainable development [8]. Importantly, its foundational principles offer a broader lens to understand systemic abuses of science in history.

During World War II (WWII), science was tragically misappropriated by totalitarian regimes such as Nazi Germany and Japan's Unit 731, not for environmental protection but for mass harm and human experimentation. Unit 731 developed and released pathogens into civilian populations under the guise of scientific advancement, while Nazi scientists deployed chemical agents and carried out medical atrocities in concentration camps [9-11]. These acts, far from ignorance, represented an intentional reversal of scientific principles meant to protect life; subverting toxicology and ecological knowledge for war, torture, and genocide [12-13]. Applying the 10 POE as a critical lens not only allows us to assess these actions as violations of environmental and biological ethics, but also reinforces the enduring importance of safeguarding science through accountability, transparency, and ecological literacy [14-15].

The objective of this paper is to demonstrate that the 10 POE extend beyond their conventional roles in regulation and scientific assessment to serve as foundational ethical principles that guide responsible environmental stewardship. By integrating

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ecotoxicological theory with historical evidence from WWII atrocities and contemporary environmental challenges, the paper aims to reposition ecotoxicology as both a scientific discipline and a moral framework for preventing ecological harm and safeguarding planetary health.

The Ten Principles of Ecotoxicology in the Context of WWII Atrocities: Figure 1 The table synthesizes how core principles of ecotoxicology were repurposed during WWII by Unit 731 and Nazi Germany to transform scientific inquiry into instruments of harm: both regimes operationalized the source–pathway–receptor framework by deliberately releasing pathogens or engineered gases into environments where air, water, and vectors maximized human exposure; dose–response relationships were perverted through degraded human exposures and poison testing to identify lethal thresholds; and bioavailability experiments, probing dermal, inhalation, and ingestion routes that were used to optimize pathogen uptake rather than to prevent it. These actions produced long-term accumulation of physiological damage and environmental contaminants, clarified modes of action by mapping organ failure and degradation pathways, and demonstrated ecological relevance as pathogens and toxins were introduced into field settings to destabilize trophic structure and feedback loops.

Mixture toxicity and cumulative stressors amplified morbidity, dismantling community supports through destruction of farmland, water sources, and social infrastructure, while toxicokinetic observations recorded internal progression of agents in unanesthetized subjects. Finally, what should have been an ethical risk-assessment loop to minimize harm was inverted into a strategic calculus that evaluated environmental variables and deployment strategies to maximize lethality, revealing the profound moral collapse when technical expertise is decoupled from humanitarian oversight.

Connections of Principles of Ecotoxicology during WWII Atrocities		
Characteristic	Unit 731	Nazi Germany
Source-Pathway-Receptor	Intentional release of pathogens	Engineered application of Zyklon B gas
Dose-Response	Exposure to graded levels of pathogens	Dose-dependent testing of poisons and hypothermia
Bioavailability	Testing exposure routes for pathogen uptake	Controlled infections and chemical exposure assessed
Accumulation	Lasting physiological damage to survivors	Trauma and contaminants accumulate in regions
Mode of Action	Studying disease progression and organ failure	Mapping bodily degradation pathways through experiments
Ecological Relevance	Pathogens released into uncontrolled field settings	Strategic territorial control through ecological degradation
Mixture Toxicity	Exposure to multiple pathogens and starvation	Cumulative stressors amplify morbidity and mortality
Community Effects	Dismantling human communities and support systems	Destruction of farmland and water sources
Toxicokinetics	Tracking progression of agents in live subjects	Internal organ responses observed without anesthesia
Risk Assessment	Determining optimal deployment strategies	Strategic evaluation of environmental variables

Fig. 1: The overall connections of principles of ecotoxicology during WWII atrocities.

Source-Pathway-Receptor (S): Figure 2 demonstrates how biological warfare operates through a deliberate linkage between source, pathway, and receptor, where military institutions act as sources, environmental media such as air, water, and insects serve as pathways, and human populations become the intended receptors of harm. It reveals the strategic manipulation of ecological systems to maximize exposure and biological impact on targeted civilian communities.

This principle defines the origin (source) of a contaminant, its transport (pathway), and the exposed organism or population (receptor). Unit 731’s laboratory-developed pathogens were intentionally released via water, air, and insect vectors into civilian populations in China, particularly during campaigns in Manchuria, creating direct receptor exposure and widespread contamination [16-17]. These acts were carried out with logistical precision and strategic intent, mirroring the engineered application of Zyklon B gas by Nazi Germany, which was optimized for dispersal within sealed chambers to target human populations as biological endpoints [10]. The use of weather, topography, and infrastructure to enhance biological delivery systems further exemplifies how scientific understanding of environmental pathways was abused [18]. The long tail of such

practices is evident in modern forensic and historical investigations, where post-war identification of victims continues to expose documentation gaps, chain-of-custody problems, and the lasting biological signatures of wartime exposures, underscoring the ethical stakes of source–pathway–receptor decisions [19].

Moreover, state-directed wartime mobilization relied on educational and administrative systems that organized labour, logistics, and technical capacity, thereby enabling the systematic deployment of agents along efficient environmental pathways and enlarging civilian receptor pools [20]. Rather than mitigating harm, the agents were delivered with the explicit goal of maximizing morbidity, highlighting the total disregard for ecological and humanitarian integrity.

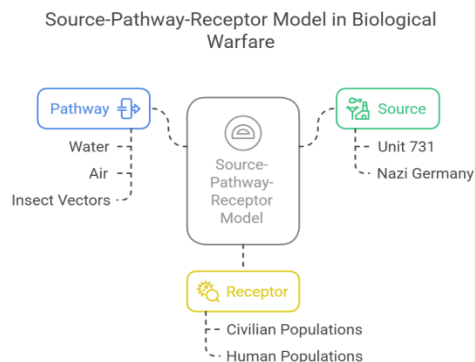


Fig. 2: The conceptual model of Source–Pathway–Receptor in biological warfare during WWII atrocities.

Dose–Response (D): Figure 3 shows how the scientific principle of dose–response, which is fundamental in toxicology for determining safe exposure levels, was deliberately perverted during WWII to identify lethal doses of pathogens, poisons, and radiation. Instead of protecting life, Nazi experiments, Unit 731 trials, and post-war neutron studies weaponized dose–response relationships to optimize mortality and refine tools of human destruction. The dose–response relationship measures how the severity of a toxic effect changes with concentration and exposure duration. In ecotoxicology, this concept is crucial for determining regulatory thresholds and ecological safety. However, in the context of WWII atrocities, it was used perversely. Unit 731 exposed prisoners to graded levels of pathogens like anthrax and cholera to assess lethal doses, with no concern for ethical practice or recovery [16,21]. Simultaneously, Nazi medical experiments involved dose-dependent testing of poisons, drugs, and hypothermia on concentration camp inmates [10]. These actions redefined the dose–response curve as a tool for determining efficiency in biological warfare, not public health protection. In Japan, concurrent efforts in neutron and radiation studies echoed this misuse of experimental dosing, revealing parallel intentions within the Axis powers [22].

Historical investigations into the civilian suffering in cities such as Celje further demonstrate the population-level consequences of exposure, where communities were subjected not only to direct toxic agents but also to cumulative environmental stressors that exacerbated mortality outcomes [21]. Similarly, mass forced relocations in regions like Kamnik created conditions of starvation, disease vulnerability, and chemical exposure, amplifying the dose–response impacts through compounded stress and deprivation [22]. The perversion of this principle illustrates how toxicological science can be weaponized when stripped of its ethical mandate.

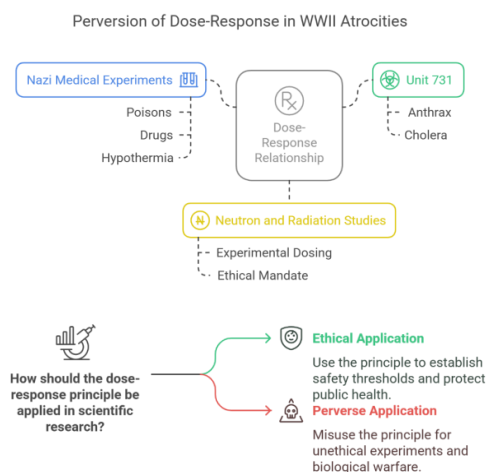


Fig. 3: The perversion of dose-response in WWII atrocities with a pertinent question to be answered.

Bioavailability (B): Figure 3 demonstrates how the concept of bioavailability, central in ecotoxicology for understanding exposure routes and protecting life, was exploited unethically during WWII to increase the efficiency of biological and chemical weapons through dermal, inhalation, and ingestion pathways. While ethical science applies bioavailability to assess risks and implement safeguards, military programs weaponized it to optimize harm against humans and animals.

Bioavailability refers to the proportion of a substance that reaches systemic circulation and exerts a biological effect. In legitimate ecotoxicological research, it is a measure used to assess risk and manage exposure. However, in the biological warfare trials conducted by Unit 731, various routes of exposure, including dermal contact, inhalation, and ingestion, were deliberately tested to determine the most effective transmission method for maximum pathogen uptake [17]. These practices were not only invasive but deliberately intended to weaponize human physiology as a testing ground for pathogenic efficiency. Similarly, Nazi scientists performed controlled infections, surgical implantation of pathogens, and chemical exposure to assess systemic distribution [10].

The strategic importance of bioavailability was further reflected in Japanese military policies during and after the war, where physiological vulnerability to tropical diseases and nutritional deprivation was exploited in the management and concentration of surrendered soldiers in Southeast Asia [23]. In Europe, aerial bombardment campaigns intensified the bioavailability of toxicants by dispersing chemical residues and combustion by-products into air and water systems, exposing entire urban populations to involuntary uptake [24]. Forensic archaeology has since documented the biological aftermath of such exposures, revealing pathogen traces, contaminants, and biomarkers on remains recovered from conflict zones, evidence of systemic bioavailability induced by wartime environments [25]. Outside combat zones, military science during WWII progressed in areas such as food ration research [26] and veterinary system reform [13], where exposure science was applied within ethical boundaries; thereby accentuating the profound moral disparity with the atrocities committed by Unit 731. The clear intent to increase bioavailability for destructive purposes represents a violation not only of scientific integrity but of fundamental bioethical principles.

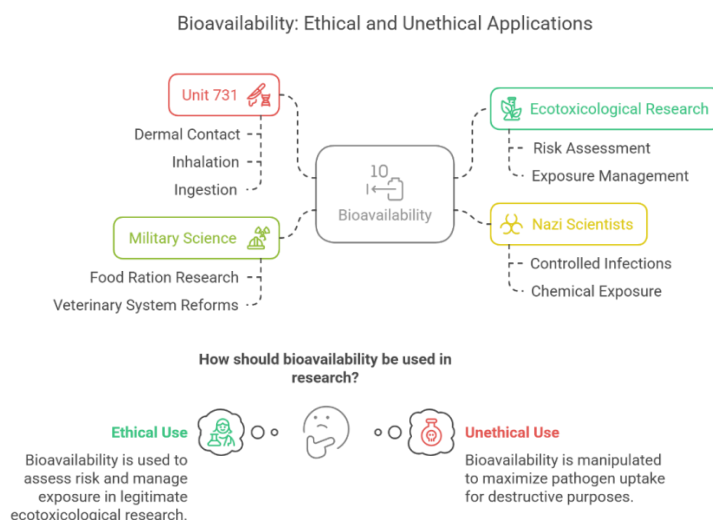


Fig. 3: The overall concept of bioavailability with ethical and unethical applications in WWII atrocities with a pertinent question to be answered.

Accumulation (A): This Figure 4 illustrates how biological warfare leads to both physical and symbolic accumulation, where pathogens, toxins, and trauma persist within bodies, ecosystems, and collective memory. It parallels ecological concepts of bioaccumulation and biomagnification, showing that unresolved historical injustice functions like a contaminant that intensifies across generations.

Accumulation, including bioaccumulation and biomagnification, describes the buildup of toxins within organisms or across trophic levels. While most ecotoxicologists study chemical accumulation in food chains, the concept applies metaphorically to the accumulation of trauma, pathogens, and contaminants in war-torn regions. The human experimentation conducted by Unit 731 left survivors, when there were any, with lasting physiological damage, often involving organ failure, immune system collapse, and irreversible psychological distress [16,27]. This form of accumulation extended beyond the individual, permeating entire communities, as the released pathogens contaminated water bodies and agricultural fields, making the environmental and epidemiological impacts multigenerational [28-33]. Legal and historical analyses of aerial warfare show how bombardment compounds exposures by layering heat, smoke, rubble dust, and contaminated water and air, creating cumulative civilian burdens that persist long after hostilities end [24].

Post-conflict forensic and archaeological work further documents the residual “material” accumulation of war, artifacts and remains that enable reconstruction of identities and exposure histories decades later, underscoring how biological and symbolic legacies co-persist in affected landscapes [25]. The failure to prosecute these crimes in the postwar period further compounded their legacy, creating a political and moral accumulation of unresolved injustice that persists in international memory and diplomacy [17,34]. Thus, the principle of accumulation, both biological and symbolic, is crucial to understanding the enduring toxic legacy of wartime ecoviolence.

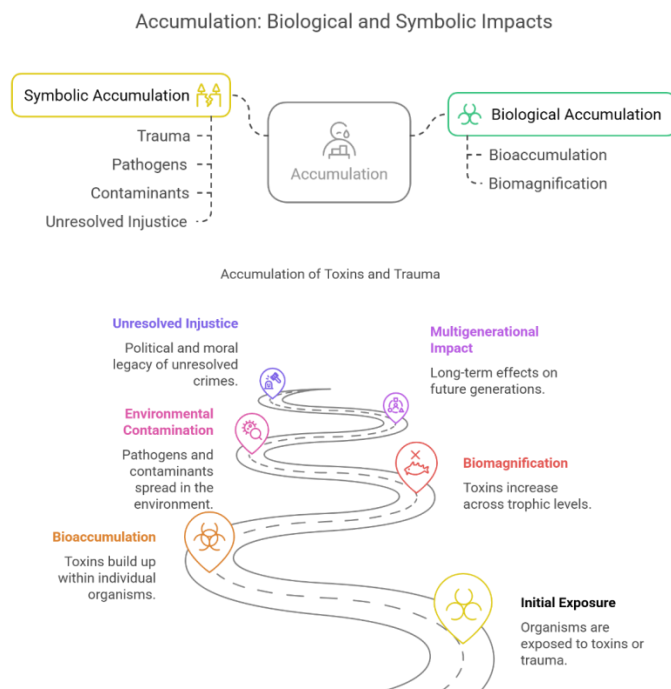


Fig. 4: The overall concept of accumulation with biological and symbolic impacts in WWII atrocities with the accumulation toxins and its traumatic impacts.

Mode of Action (M): Figure 5 demonstrates how the scientific understanding of toxicity mechanisms was harnessed not to protect ecosystems, but to design biological and chemical warfare agents with maximized destructive potential. It contrasts this misuse with the foundational goals of ecotoxicology, which aim to understand these same mechanisms to safeguard life and develop mitigation strategies.

Mode of action refers to the molecular or physiological pathway by which a toxicant causes harm. In ecotoxicology, this principle helps identify mechanisms of toxicity, guiding mitigation and antidote development. In contrast, wartime experiments under Unit 731 and Nazi Germany aimed to elucidate modes of action not for prevention but for maximized harm. Japanese military scientists used deliberate infection to study the progression of diseases like plague, cholera, and anthrax, tracking organ failure and immune collapse in real time [27-28]). Neurotoxic agents, frostbite simulations, and oxygen deprivation tests were also conducted to map bodily degradation pathways [29-33]. These experiments represented a perversion of toxicology into a tool of death rather than a science of protection. Moreover, the intent was not simply scientific curiosity but military strategy—biological warfare based on knowledge of cellular dysfunction and mortality thresholds [17, 29-33].

Additional historical analyses indicate that mechanistic knowledge of human physiology was strategically leveraged even after the war, as occupying forces in Southeast Asia managed the surrender, concentration, and disarmament of Japanese soldiers using biomedical insights into fatigue, malnutrition, and tropical disease responses [23]. Furthermore, the targeting of specific civilian populations during the final years of the conflict in Eastern Europe demonstrates how knowledge of biological vulnerability at the cellular and systemic levels was incorporated into oppressive state policies designed to control, exploit, or eliminate ethnic groups [35]. The use of mechanistic knowledge in this context exposes the dark underside of otherwise life-saving science.



Fig. 5: The overall mode of action from science to warfare in WWII atrocities with a pertinent question to be answered.

Ecological Relevance (E): Figure 6 illustrates how biological warfare strategies directly target ecological systems, resulting in degradation of soil, water quality, and biodiversity as part of broader territorial control tactics. By disrupting trophic interactions and collapsing ecosystem feedback loops, such actions transform the environment itself into a weapon of prolonged destabilization and ecological harm.

Ecological relevance ensures that toxicological studies reflect real world exposure and impact, including environmental conditions, biological diversity, and ecosystem interactions. During WWII, however, toxic agents were deployed in uncontrolled field settings, particularly in China, where Unit 731 released pathogens into rivers, villages, and farmlands, altering ecological baselines [28-33]. The effects were not contained as soil biota, water quality, and entire trophic structures were disrupted. The resultant ecological changes mirrored the worst case scenarios modelled in modern environmental risk assessments. While the loss of laboratory specimens and biological samples was often assumed in wartime [36], real world ecological loss from biological warfare was substantial and underreported.

City level historical accounts show how wartime violence reshaped urban environments and community health, providing concrete context for ecosystem level disruption and its legacies [21]. Demographic analyses of WWII spending and army service further demonstrate persistent population health effects in marginalized groups, underscoring how wartime socio environmental stressors translate into long term shifts in survival and community resilience that ecological assessments must consider [37]. From a broader geopolitical perspective, such ecological degradation also supported strategic territorial control, transforming landscapes into hostile, unusable zones [38-39]. These actions fundamentally distorted the principle of ecological relevance, turning ecosystems into experimental arenas and collapsing the natural feedback loops that support resilience and recovery.

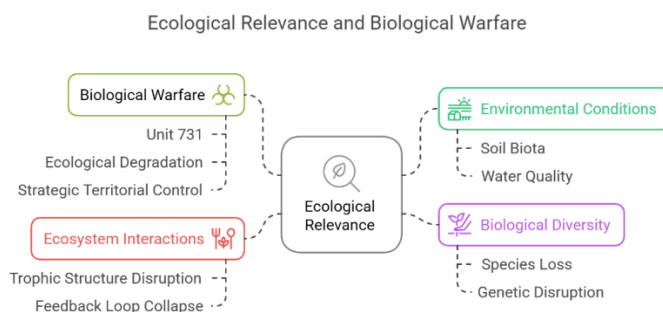


Fig. 6: The overall ecological relevance and biological warfare in WWII atrocities.

Mixture Toxicity (M): Figure 7 highlights how populations exposed to multiple wartime stressors such as malnutrition, radiation, pathogens, and psychological trauma that experience compounded toxic effects that interact synergistically to increase mortality. It underscores how entities like Unit 731 exploited post-disaster environments to study these interactive effects, weaponizing human vulnerability for experimental gain. Mixture toxicity explores how combinations of pollutants interact, often producing synergistic, additive, or antagonistic effects. The environments created by war, marked by malnutrition, physical trauma, radiation exposure, infectious pathogens, psychological distress, and unsanitary conditions, constituted toxicological mixtures of immense complexity [40-41]. Victims were rarely exposed to single agents; rather, they experienced cumulative stressors that collectively amplified morbidity and mortality. In Unit 731, for instance, individuals were subjected to multiple

pathogens simultaneously in tandem with surgical procedures and starvation conditions [42-43]. Legal and historical analyses of aerial bombardment after WWII also document how combined stressors from heat, smoke, structural collapse, and contaminated water and air produced compound civilian harms that outlasted the immediate attack, which aligns with an interaction based understanding of risk at population scale [24].

Memory studies on the extermination of psychiatric patients in Poland further show how already vulnerable communities suffered interacting biological and social insults, including malnutrition, infection, and systemic neglect, reinforcing that mixture effects are both biomedical and institutional [44]. These complex interactions mirror current concerns in ecotoxicology about the unpredictability of mixed contaminant exposures, particularly in war torn or post disaster environments [34,45]. This principle compels toxicologists to evaluate harm holistically, recognizing that real world toxicity often emerges from interaction effects across biological and environmental variables.

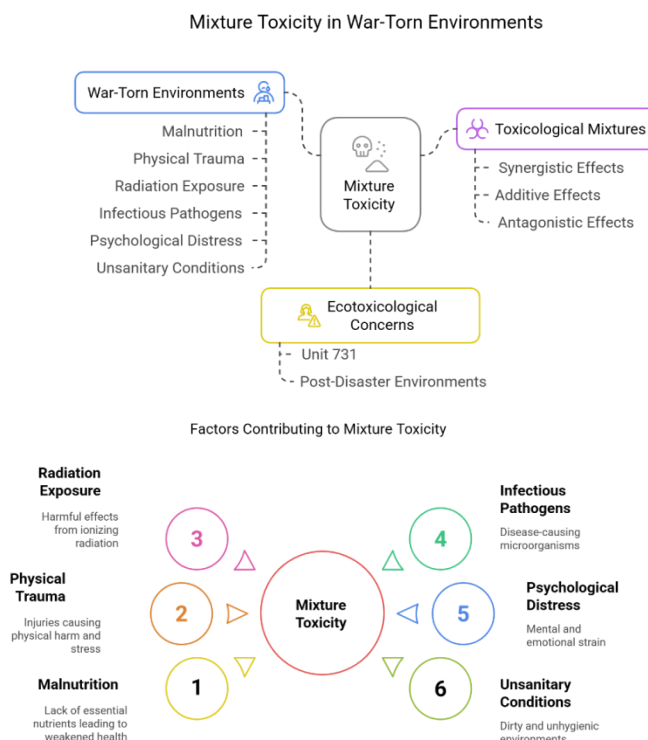


Fig. 7: The overall concept of mixture toxicity in war-torn environment in WWII atrocities with the factors contributing the mixture toxicity.

Community Effects (C): Figure 8 illustrates how populations become ecological targets when warfare strategies contaminate urban spaces, farmlands, and water sources, thereby degrading environmental security. These disruptions weaken community resilience, increase disease susceptibility, and weaponize ecosystems against human survival.

Modern ecotoxicology emphasizes the importance of assessing impacts at the population and community levels, rather than focusing solely on individuals. Similarly, the atrocities of WWII, including those perpetrated by Unit 731 and through widespread aerial bombings, resulted in the systematic dismantling of entire human communities and environmental support systems [46-49]. The ecological infrastructure of cities such as Dresden and Hamburg was obliterated, severing the relationships between people and their local ecosystems [50-52]. The destruction of farmland, potable water sources, and green urban spaces had cascading ecological consequences that persisted for decades [54-56]. Cultural and information systems also mattered: wartime museum programming in the United States circulated racialized narratives that normalized conflict and masked its social ecological costs, reinforcing patterns of exclusion and vulnerability at the community scale [57-58]. In parallel, coordinated corporate public relations efforts helped manufacture consent for total war production, shaping discourse that privileged output over environmental safeguards and thereby magnified community level harms [59].

Community level toxicological effects in these contexts included increased disease susceptibility, biodiversity loss, and breakdowns in ecological resilience. As seen in the wartime legacies of both Europe and Asia, the collapse of communal systems under sustained toxic and traumatic pressures exemplifies the long term, large scale consequences of ecological warfare [60-61].



Fig. 8: The overall community effects of the ecological warfare with the multifaceted impacts of community destruction.

Toxicokinetics (T): Figure 9 illustrates how unethical experimentation during WWII transformed human subjects and biological agents into instruments for generating data, bypassing all principles of safety and consent. Instead of protecting human health and the environment, scientific knowledge was weaponized to refine lethal thresholds and develop chemical and biological agents for maximum harm. Toxicokinetics examines how a toxicant is absorbed, distributed, metabolized, and excreted in an organism. Under normal ethical research conditions, this principle informs safety thresholds, drug metabolism, and environmental guidelines. However, in WWII, toxicokinetic data were collected through morally abhorrent experiments. Both Nazi and Japanese scientists tracked the progression of biological agents and chemical effects in live human subjects without consent, often conducting postmortem dissections to assess systemic impacts [28,40]. Subjects were infected with diseases or exposed to chemical agents such as mustard gas or cyanide, and internal organ responses were observed without anesthesia or ethical oversight [62]. Contemporary scholarship in military medicine underscores that readiness and medical learning must be grounded in ethical safeguards and informed consent, a corrective lens that starkly contrasts with the wartime perversion of toxicokinetic inquiry [63]. Memory studies that document the fates of marginalized victims further reveal how the erasure or distortion of such abuses impedes accountability and ethical reform, reinforcing why toxicokinetics must remain under robust moral governance [44]. The meticulous recording of physiological deterioration, while scientifically detailed, was used not to save lives but to refine tools of death. This unethical application of toxicokinetics highlights the indispensable role of moral frameworks in biomedical and environmental science.

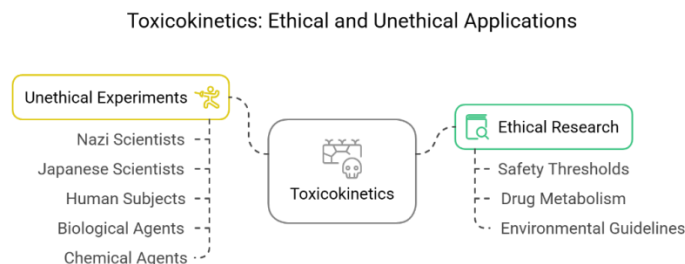


Fig. 9: The overall concept of toxicokinetics with ethical and unethical applications in the WWII atrocities.

Risk Assessment (R): Figure 10 demonstrates how risk assessment principles were weaponized during WWII, using environmental data and live human experimentation to optimize the lethality of biological and chemical agents. Instead of minimizing harm, scientific evaluation was systematically redirected to magnify strategic damage while disregarding human protection and ethical responsibility.

Risk assessment is a cornerstone of ecotoxicology, combining hazard identification, dose–response analysis, exposure evaluation, and uncertainty characterization to inform regulatory decisions. In responsible science, this framework is used to minimize harm and guide policy. During WWII, however, risk assessment was inverted, used not to reduce danger, but to enhance the lethality of biological, chemical, and ecological weapons. Unit 731 employed data from live human trials to determine optimal deployment strategies for diseases and toxins [29-33]. The deliberate omission of protective protocols, combined with the strategic evaluation of environmental variables such as wind, temperature, and water flow, served to refine attacks rather than avoid collateral damage [47-49]. Beyond the operational sphere, intellectual climates matter: the normalization and rationalization of violence in mid-twentieth-century thought provided justificatory narratives that blunted ethical constraint and eased the translation of knowledge into coercive practice [50-52]. Likewise, postwar political settlements and elite administrative networks shaped how states operationalized expertise, revealing how “praxis of power” could prioritize institutional interests over accountability and thereby weaken risk governance norms [53-55]. Additionally, political complicity during the Cold War ensured that these war crimes were never fully prosecuted, allowing those responsible to escape consequences and even gain employment in post-war scientific institutions [64-65]. Together, these dynamics show that risk assessment is never value-neutral: absent ethical guardrails and independent oversight, the same technical apparatus that protects public health can be redirected to engineer mass harm. The failure of ethical risk governance during this era remains a sobering lesson for contemporary toxicologists and policymakers.

Ethical Failures in Risk Assessment: Historical and Contemporary Implications

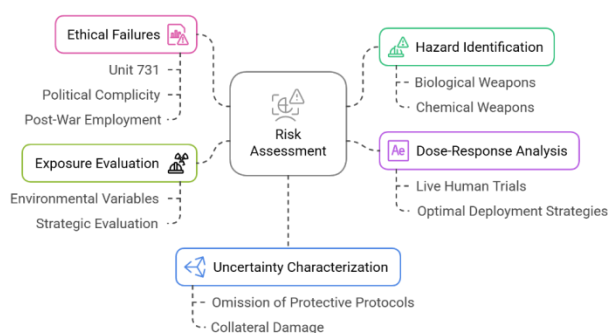


Fig. 10: The overall risk assessments with the ethical failure in the WWII atrocities, from the perspective of historical and contemporary implications.

Conclusion: The 10 POE are not merely technical tools for evaluating pollutants in natural ecosystems; they are ethical foundations designed to safeguard life. Each principle was systematically inverted during WWII by Unit 731 and Nazi research programs, not by error but through intentional weaponization of scientific knowledge. By examining these atrocities through the lens of ecotoxicology, this paper underscores that scientific principles are not value-neutral; when detached from moral responsibility, they become instruments of harm. The principles that should guide pollution control and environmental protection must also guide scientific conduct, ensuring that ecotoxicology remains a discipline committed not only to understanding ecological processes, but to upholding life, preventing suffering, and preserving the resilience of both human and natural systems.

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