

War and Weapon Geochemistry: Key Areas, Applications and Impact on the Sustainable Development Goals

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جيوكيمياء الحرب والأسلحة: المجالات الرئيسية والتطبيقات والتأثير على أهداف التنمية
المستدامة

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Abstract

This study aimed to clarify the key areas and applications of war and weapon geochemistry. War geochemistry examines the wide-ranging effects of war on Earth's chemical cycles, including metal and explosive contamination of air, soil and water. In order to comprehend post-conflict pollution, weapon geochemistry fundamentally bridges military technology and geochemical processes by concentrating on the materials found in weapons, their chemical composition, release mechanisms, and interactions with the environment. In short, weapon geochemistry is the study of the source materials (munitions, agents) that cause those impacts, while war geochemistry is the impact on the entire Earth system. In order to manage resources for present and future generations, sustainable development requires stable, peaceful conditions. War breaks this foundation, causing natural disasters that impede growth, making militarism itself a serious sustainability crisis. Clearly, war and weapon geochemistry can be regarded as subfields of environmental geochemistry.

Keywords: War Geochemistry, Weapon Geochemistry, Environmental Geochemistry.

الملخص

هدفت هذه الدراسة إلى توضيح المجالات والتطبيقات الرئيسية لجيوكيمياء الحرب والأسلحة. تدرس جيوكيمياء الحرب الآثار واسعة النطاق للحرب على الدورات الكيميائية للأرض، بما في ذلك تلوث الهواء والتربة والمياه بالفلزات والمنتجرات. من أجل فهم التلوث ما بعد النزاع، تربط جيوكيمياء الأسلحة بشكل أساسي بين التكنولوجيا العسكرية والعمليات الجيوكيميائية من خلال التركيز على المواد الموجودة في الأسلحة، وتكوينها الكيميائي، وآليات إطلاقها، وتفاعلاتها مع البيئة. باختصار، جيوكيمياء الأسلحة هي دراسة المواد المصدرية (الذخائر، العوامل) التي تسبب تلك التأثيرات، بينما جيوكيمياء الحرب هو التأثير على نظام الأرض بأكمله. لضمان إدارة الموارد للأجيال الحالية والمستقبلية، تتطلب التنمية المستدامة ظروفًا مستقرة وسلمية. وتؤدي الحرب إلى زعزعة هذا الأساس، متسببة بكوارجت طبيعية تعيق النمو، مما يجعل النزعة العسكرية بحد ذاتها أزمة استدامة خطيرة. من الواضح أن جيوكيمياء الحرب والأسلحة يمكن اعتبارها مجالات فرعية من الجيوكيمياء البيئية.

الكلمات الدالة: جيوكيمياء الحرب، جيوكيمياء الأسلحة، الجيوكيمياء البيئية.

1. Introduction

To comprehend natural processes and the effects of human activity, environmental geochemistry investigates the sources, distribution, and interactions of chemical elements in Earth's systems (rocks, soil, water, air, and life). It focuses on element mobility, biogeochemical cycles, contamination, and health effects, and it uses chemical principles to manage resources and clean up pollution (e.g., Siegel, 2002; El-Kammar et al., 2007; Ruggieri et al., 2010; Shaltami, 2012; Fuge and Johnson, 2015; Sharafi et al., 2018; Shaltami et al., 2021; Wang et al., 2023; Duan et al., 2025).

War geochemistry examines how geology affects military strategy (terrain analysis, resource location) and how warfare affects Earth's materials (air, water, and soils) through contamination (heavy metals from munitions) and physical alteration (bomb craters). It covers both contemporary uses, such as military geology for engineering and resource mapping, and long-term battlefield legacies, such as the changed soil chemistry and metal pollution from World War I, which illustrate the significant geochemical fingerprint of conflict on landscapes. Numerous studies have explored the geochemical impacts of war (e.g., Durakovic et al., 2003; Carvalho and Oliveira, 2010; Bakhmutsky et al., 2013; Albarède et al., 2016; Salama et al., 2019; Williams and Rintoul-Hynes, 2022; Gordienko, 2025).

Weapon geochemistry studies elements like arsenic in chemical weapons (e.g., Lewisite), plutonium from nuclear weapons, or tracers from nuclear tests (e.g., Chlorine-36 and Tritium) to understand contamination, persistence, and health risks in soil, water, and sediment. It focuses on the breakdown, transport, and long-term fate of chemical and radiological agents from weapons. It aids in tracking bombs, evaluating the environmental risks posed by weapons abandoned at sea, and comprehending the behavior of heavy metals from

depleted uranium (e.g., Phillips et al., 1988; Oliver et al., 2006; Zhang et al., 2009; Graham et al., 2011; Danesi, 2019; Ji et al., 2022; Belkin, 2024). In summary, weapon geochemistry gives information on the pollutant, whereas war geochemistry examines pollution in the broader environment. Therefore, both sciences can be regarded as subfields of environmental geochemistry.

2. Objective

This study aims to simplify war and weapon geochemistry by focusing on:

- (1) Key areas.
- (2) Applications.
- (3) Impact on the Sustainable Development Goals (SDGs).

3. Key Areas

3.1. War Geochemistry

The key areas of war geochemistry include battlefield contamination, military geology, and geochemical signatures of conflict (Fig. 1).

3.1.1. Battlefield Contamination

Heavy Metals

War geochemistry is the process by which military operations contaminate soil and water with heavy metals such as Pb, Cu, Zn, Cr, and Cd from vehicles, munitions, and explosives. This poses long-term health and environmental risks (ingestion, inhalation, embedded fragments) to both soldiers and civilians, affecting ecosystems and necessitating continuous management in post-conflict areas.

Salinity

Warfare significantly changes the water geochemistry, causing problems with salinity due to troop and equipment use (de-icing salts, fuels), infrastructure damage (releasing deep saline water, upsetting aquifers), pollution (chemicals, waste), and the creation of saline dust and runoff. This affects the quality of water for local ecosystems and civilians, and is frequently investigated using isotopes and chemical analysis to trace sources like seawater intrusion or evaporation, which is essential for management in arid regions.

3.1.2. Military Geology

Terrain Analysis

Using GIS and geochemical signatures (such as heavy metals from ordnance) to evaluate soil strength, trafficability, defense potential, and long-term environmental impact—all essential for route planning, fortification, and post-conflict management—war geochemistry integrates standard military terrain evaluation (OCOKA: Observation, Cover, Obstacles, Key Terrain,

Avenues) with geological/geochemical data (soil, rock, water) to understand battlefield potential for movement, defense, and contamination.

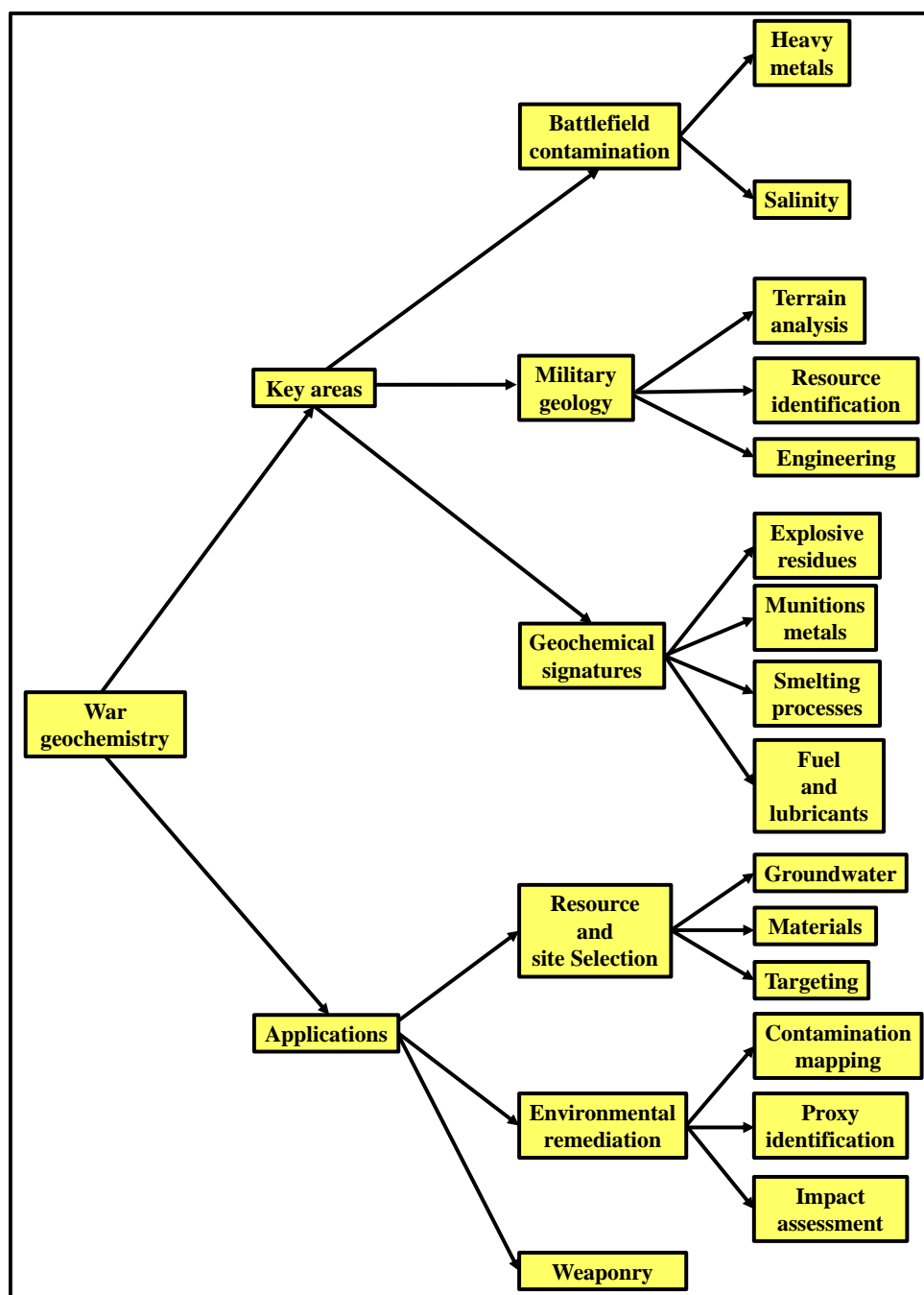


Fig. 1: Key areas and applications of war geochemistry.

Resource Identification

By identifying elemental anomalies and using GIS/AI for pattern recognition, war geochemistry uses chemical analysis of soils, rocks, and water (geochemical data) to find valuable minerals (such as Cu, Au, and critical elements) for national security/economy, comprehend the effects of war (such as oil spills), or even identify past military activity (such as laundry areas). In

order to find resources or trace pollution or activities—which are essential for strategic planning and remediation—it uses statistical modeling, machine learning, and data collection.

Engineering

Evaluating soil mechanics for infrastructure and building (roads and airfields).

3.1.3. Geochemical Signatures

Explosive Residues

In soil and water, byproducts from TNT, RDX, and other explosives leave behind distinct organic compounds and nitrogen isotopes.

Munitions Metals

Metals are released into the environment by fired shells and bullets, causing localized pollution.

Smelting Processes

Metals like Zn, Cd, and As are introduced during the smelting of weapons and ammunition.

Isotopic Signatures

Stable isotope variations can identify the geological origin of mined metals and connect them to conflict areas. Moreover, isotope analysis of ancient conflicts to comprehend resource acquisition related to war.

Fuel and Lubricants

Hydrocarbons are added to soil and water by vehicle petroleum wastes.

3.2. Weapon Geochemistry

Chemical warfare agents, arsenic-based weapons, nuclear materials, and depleted uranium are the key areas of weapon geochemistry (Fig. 2).

3.2.1. Chemical Warfare Agents

Examining the solubility and hydrate formation of breakdown products (such as 1,4-thioxane from mustard gas) in marine environments.

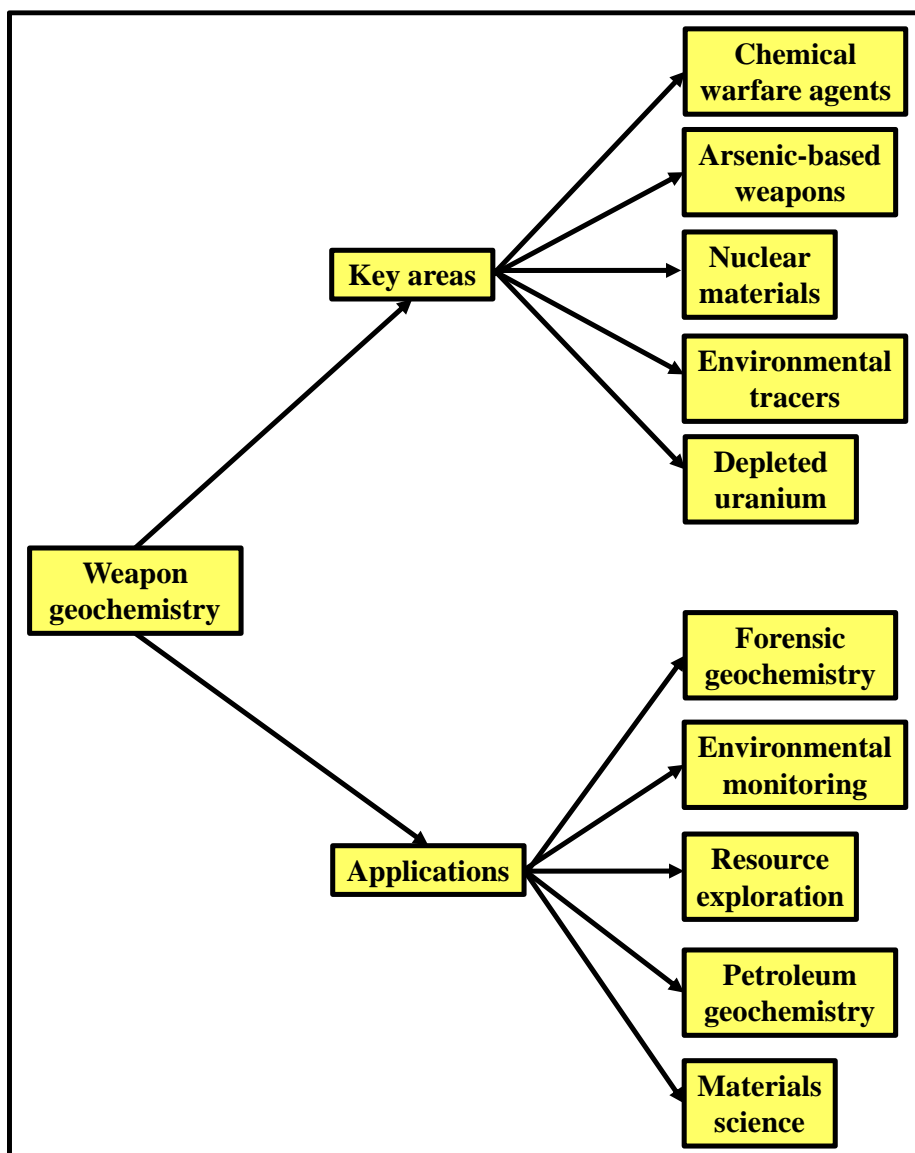


Fig. 2: Key areas and applications of weapon geochemistry.

3.2.2. Arsenic-Based Weapons

Investigating how substances like Lewisite are hydrolyzed and oxidized to produce hazardous phenylarsenic chemicals in soil and water.

3.2.3. Nuclear Materials

Studying how radionuclides from nuclear weapons development and testing, such as plutonium and americium, behave in the environment.

3.2.4. Environmental Tracers

Mapping water mobility and contamination in soil and groundwater using isotopes from nuclear fallout, such as tritium and chlorine-36.

3.2.5. Depleted Uranium

Investigating the low solubility, chemotoxicity, and health effects of depleted uranium (DU) particles from weapons as heavy metal pollutants.

4. Applications

4.1. War Geochemistry

The most significant applications of war geochemistry are resource and site selection, environmental remediation, and weaponry (Fig. 1).

4.1.1. Resource and Site Selection

Groundwater

Detecting sources for water supply utilizing hydrogeochemistry.

Materials

Finding natural resources (quarrying) to build roads, tunnels, and fortifications.

Targeting

Determining the best locations for fortifications, temporary pathways, and targeted strikes by analyzing terrain geochemistry.

4.1.2. Environmental Remediation

Contamination Mapping

Identifying heavy metal contamination in water and soil following combat.

Proxy Identification

Heavy metal hotspots in war-affected soils can be rapidly mapped using magnetic characteristics as a proxy.

Impact Assessment

Assessing how explosives affect soil and water quality in the long-term.

4.1.3. Weaponry

Selecting weapons scientifically and comprehending how they interact with subterranean surroundings.

4.2. Weapon Geochemistry

Forensic geochemistry, environmental monitoring, resource exploration, petroleum geochemistry, and materials science are the most important applications of weapon geochemistry (Fig. 2).

4.2.1. Forensic Geochemistry

Identifying the source of explosives, bullets, or gunshot residue by comparing elemental and isotopic fingerprints found in soil and debris to crime scenes or manufacturing locations.

4.2.2. Environmental Monitoring

Evaluating pollution and researching the fate, movement, and breakdown of chemical weapons in soil and marine settings.

4.2.3. Resource Exploration

Utilizing geochemical surveys to find mineral reserves for military use.

4.2.4. Petroleum Geochemistry

Using biomarkers and isotopes for source-rock correlation, comprehending oil and gas systems for energy security.

4.2.5. Materials Science

Examining geological materials to create new defensive technologies or comprehend how materials behave in extreme conditions.

5. Impact on the Sustainable Development Goals

The SDGs are negatively impacted by war and weapon geochemistry in significant and interrelated ways.

5.1.1. No Poverty (SDG 1)

By lowering worker productivity, raising healthcare costs, degrading resources (clean water, fertile soil), damaging agriculture and fisheries, and restricting education, contamination seriously impedes efforts to end poverty. This creates a vicious cycle in which poverty fuels pollution, which in turn deepens poverty, disproportionately affecting vulnerable communities.

5.1.2. Zero Hunger (SDG 2), Good Health and Well-Being (SDG 3)

Contamination from heavy metals, explosives, and radioactive materials contaminates soil and water, impacting agricultural production and generating long-term health problems, while biological weapons can trigger epidemics.

5.1.3. Quality Education (SDG 4)

Infrastructure, teachers, and basic needs (food, water, and health) are all compromised, which hinders learning and overall development. War contamination destroys schools, displaces students, causes trauma, disrupts learning, and diverts resources, resulting in lower literacy, higher dropout rates, and a lost generation trapped in poverty. These consequences have long-term effects on human capital and future peace.

5.1.4. Gender Equality (SDG 5)

By disproportionately harming women and girls, limiting access to healthcare, increasing economic vulnerability, and causing long-term reproductive health crises, war contamination—including physical pollutants and social disruption—dramatically exacerbates gender inequality. It also builds on preexisting discrimination and disrupts vital services, ultimately creating a cycle of disadvantage that affects generations.

5.1.5. Clean Water and Sanitation (SDG 6)

By destroying infrastructure (pipes, plants) and contaminating sources (sewage, chemicals, heavy metals), war contamination destroys clean water and sanitation, causing widespread waterborne illnesses (cholera, hepatitis), impeding healthcare, uprooting populations, and causing long-term environmental damage, turning water into a weapon and a major threat to civilian survival, particularly for children.

5.1.6. Affordable and Clean Energy (SDG 7)

Even though some conflicts encourage short-term green investments because of energy insecurity, war contamination destroys affordable and clean energy by destroying infrastructure, upsetting supply chains, raising costs, and diverting funds. This results in energy poverty, a reliance on dirtier fuels, and impedes sustainable development. Toxins released by explosions, oil fires, and weapons increase pollution, and displaced people lose access to clean energy, which makes recovery more difficult and exacerbates climate change.

5.1.7. Decent Work and Economic Growth (SDG 8)

By destroying infrastructure, eliminating jobs (particularly for women and young people), disrupting trade, causing massive GDP loss, increasing poverty and unemployment, forcing unsafe labor (such as child labor), stopping investment, causing long-term instability, and diverting resources from productive activities, war contamination destroys decent work and economic growth. The effects are felt globally through supply chains and economies.

5.1.8. Industry, Innovation, and Infrastructure (SDG 9)

Massive economic collapse, long-term health crises, environmental degradation, and severe setbacks in development goals result from war contamination's devastation of industry (destroying factories, disrupting supply chains), innovation (damaging research centers, creating resource scarcity for R&D, causing brain drain), and infrastructure (power grids, water systems, transport). Recovery is extremely challenging due to the widespread presence of hazardous pollutants and explosive remnants of war (ERW), which obstruct reconstruction, impede agriculture, and cause long-term social and economic consequences.

5.1.9. Reduced Inequality (SDG 10)

By disproportionately harming the poor, vulnerable, and marginalized, destroying livelihoods, disrupting essential services (health, water, and food), uprooting populations, and reversing development gains, war contamination significantly increases inequality. This makes it more difficult for disadvantaged groups to recover and thrive than for wealthier groups, who frequently manage to adapt or flee.

5.1.10. Sustainable Cities and Communities (SDG 11)

By contaminating the air, water, and soil with munitions, heavy metals, and industrial pollutants, destroying essential infrastructure (water, energy, waste), collapsing local economies, stopping progress on sustainable development, and causing long-term health crises, food insecurity, and mass displacement, war contamination destroys sustainable cities and makes recovery difficult and time-consuming.

5.1.11. Responsible Consumption and Production (SDG 12)

The aim of responsible consumption and production is seriously hampered by war pollution. It compels a change from circular, sustainable models to highly polluting, linear, emergency-driven methods.

5.1.12. Climate Action (SDG 13)

By releasing massive amounts of greenhouse gases (GHGs) from military fuel use and destroyed infrastructure, contaminating the air, water, and soil with toxic substances (metals, chemicals, and munitions) that damage ecosystems (forests, wetlands essential for carbon sinks), destroying natural carbon absorbers, and diverting resources and attention from climate goals, war contamination seriously impedes climate action. Sustainable recovery and climate resilience are hampered by the aftermath's long-term cleanup difficulties, increased energy consumption, and disturbed land.

5.1.13. Life below Water (SDG 14)

Through physical destruction (explosions, shipwrecks), chemical pollution (oil spills, heavy metals, munitions), noise pollution (sonar disturbing mammals), habitat loss (coral reefs, mangroves damaged by runoff), and disruption of food webs, war contamination destroys marine life. This results in widespread mortality, reproductive failure, bioaccumulation of toxins, and long-term ecosystem collapse, affecting everything from plankton to whales and poses a threat to human health through contaminated seafood.

5.1.14. Life on Land (SDG 15)

By poisoning soil with heavy metals, chemicals (such as depleted uranium, explosives), and radioactive materials, destroying habitats (deforestation, habitat fragmentation), compacting soil, and producing long-

lasting hazards from unexploded ordnance, war contamination destroys land life. It also disrupts essential ecosystem services and food security long after fighting has ended.

5.1.15. Peace, Justice and Strong Institutions (SDG 16)

War contamination destroys peace, justice, and strong institutions by killing a large number of people, uprooting millions, destroying infrastructure, fostering corruption, undermining the rule of law, impeding access to justice, causing long-term instability, causing great human suffering, delaying development for generations, and causing environmental damage that lasts even longer. By making systems unavailable, bolstering criminal actors, and undermining state capability, it directly threatens justice and makes rehabilitation and peacebuilding exceedingly challenging.

5.1.16. Partnerships for the Goals (SDG 17)

By undermining trust, disrupting aid, raising costs, diverting resources, and harming the environment, war contamination seriously impedes SDG 17. In the end, it fractures international partnerships and delays recovery by causing widespread health crises, food insecurity, economic collapse, and forced migration, making cooperation crucial but much more difficult.

6. Conclusions

The purpose of this work was to elucidate the key areas and applications of war and weapon geochemistry. The source material (the chemicals and metals in the bomb or bullet) is provided by weapon geochemistry, whereas war geochemistry examines how those materials behave after the weapon is deployed and turn into environmental toxins, bridging the gap between Earth science and military technology. Sustainable development is deeply linked to war and weapon geochemistry. War is a major sustainability crisis because it destroys resources and pollutes the environment. It also directly undermines the Sustainable Development Goals by contaminating soil, water, and air, causing long-term health problems, and impeding post-conflict recovery. Damage can be identified and remediated using geochemical techniques. The main difficulty is preventing conflicts that harm the natural capital required for future well-being, which requires peace as a foundation.

7. Recommendations

- (1) High-resolution satellite data (WorldView, GeoEye) should be used to map the effects of conflict by identifying vehicle tracks, craters, and bomb-mixed soils (bombturbation). This process combines remote sensing with field mapping to provide a thorough impact assessment.
- (2) Evaluating chemical contamination by employing cutting-edge techniques like X-ray fluorescence (XRF) and inductively coupled plasma mass spectrometry (ICP-MS) to examine soils and water for heavy metals and explosive residues. To

measure enrichment, contaminated samples should be compared to regional background values, noting notable increases in metals from munitions.

(3) Monitoring soil alterations using geochemical techniques and magnetic susceptibility measurements to identify soil zones damaged by war rapidly.

(4) Establishing baseline geochemical data before to conflict and regularly monitoring to follow metal mobilization and possible water contamination to assess long-term risks; and

(5) Urgent monitoring of air quality is necessary to understand the extent of pollution.

References

Albarède, F., Blichert-Toft, J., Rivoal, M. and Telouk, P. (2016): A glimpse into the Roman finances of the Second Punic War through silver isotopes. *Geochemical Perspectives Letters*; 2: 127-137.

Bakhmutsky, M.V., Squibb, K., McDiarmid, M., Oliver, M. and Tucker, J.D. (2013): Long-term exposure to depleted uranium in Gulf-War veterans does not induce chromosome aberrations in peripheral blood lymphocytes. *Mutation Research/Genetic Toxicology and Environmental Mutagenesis*; 757(2): 132-139.

Belkin, H.E. (2024): Chapter 20 - Properties, utilization, and potential health and environmental issues of depleted uranium (DU) for military and civilian use. *Environmental Geochemistry (Third Edition), Site Characterization, Data Analysis, Case Histories, and Associated Health Issues*; pp. 681-696.

Carvalho, F.P. and Oliveira, J.M. (2010): Uranium isotopes in the Balkan's environment and foods following the use of depleted uranium in the war. *Environment International*; 36(4): 352-360.

Danesi, P.R. (2019): Environmental and health consequences of nuclear, radiological and depleted uranium weapons. Reference Module in Earth Systems and Environmental Sciences, *Encyclopedia of Environmental Health (Second Edition)*; pp. 360-376.

Duan, Y., Wang, Z., Gou, W., Wang, Z., Li, Q. and Li, W. (2025): Stable zinc isotopes as tracers in environmental geochemistry. *Earth-Science Reviews*; 269: 105185.

Durakovic, A., Dietz, L. and Zimmerman, I. (2003): 1048 Estimate of the pulmonary neoplastic hazard of inhaled depleted uranium in Gulf War veterans. *European Journal of Cancer Supplements*; 1(5): S312.

El-Kammar, A.M., Arafa, I.H. and El-Sheltami, O.R. (2007): Mineral composition and environmental geochemistry of the beach sediments along the eastern side of the Gulf of Suez, Egypt. *Journal of African Earth Sciences*; 49: 103-114.

- Fuge, R. and Johnson, C.C. (2015): Iodine and human health, the role of environmental geochemistry and diet, a review. *Applied Geochemistry*; 63: 282-302.
- Gordienko, O.A. (2025): Impact of war on soils (a review). *Eurasian Soil Science*; 58(127).
- Graham, M.C., Oliver, I.W., MacKenzie, A.B., Ellam, R.M. and Farmer, J.G. (2011): Mechanisms controlling lateral and vertical porewater migration of depleted uranium (DU) at two UK weapons testing sites. *Science of the Total Environment*; 409(10): 1854-1866.
- Ji, C., Zhu, Y., Zhao, S., Zhang, H., Wang, S., Zhou, J., Liu, X., Zhang, Y. and Liu, X. (2022): Arsenic and heavy metals at Japanese abandoned chemical weapons site in China: distribution characterization, source identification and contamination risk assessment. *Environmental Geochemistry and Health*; 45: 3069-3087.
- Oliver, I.W., Mackenzie, A.B., Ellam, R.M., Graham, M.C. and Farmer, J.G. (2006): Determining the extent of depleted uranium contamination in soils at a weapons test site: An isotopic investigation. *Geochimica et Cosmochimica Acta*; 70(18): A457.
- Phillips, F.M., Mattick, J.L., Duval, T.A., Elmore, D. and Kubik, P.W. (1988): Chlorine 36 and tritium from nuclear weapons fallout as tracers for long-term liquid and vapor movement in desert soils. *Water Resources Research*; 24(11): 1877-1891.
- Ruggieri, F., Saavedra, J., Fernandez-Turiel, J.L., Gimeno, D. and Garcia-Valles, M. (2010): Environmental geochemistry of ancient volcanic ashes. *Journal of Hazardous Materials*; 183(1-3): 353-365.
- Salama, E., El-kameesy, S.U. and Elrawi, R. (2019): Depleted uranium assessment and natural radioactivity monitoring in North West of Iraq over a decade since the last Gulf War. *Journal of Environmental Radioactivity*; 201: 25-31.
- Shaltami, O.R. (2012): Mineral composition and environmental geochemistry of the beach sediments along the Mediterranean Coast from Benghazi to Bin Jawwad, Northeast Libya. Unpublished PhD Thesis, Cairo University, Egypt.
- Shaltami, O.R., Fares, F.F., El-Fallah, O.A., EL Oshebi, F.M., Errishi, H., and El-Ekhfifi, S.S. (2021): Oil pollution in the Port of Benghazi. *Global Environmental Development and Sustainability: Research, Engineering and Management*, Óbuda University, Budapest, Hungary, Proceeding Book; pp. 241-249.
- Sharafi, A., Ardejani, F.D., Rezaei, B. and Sargheini, J. (2018): Environmental geochemistry of near-neutral waters and mineralogy of zinc and lead at the

Angouran non-sulphide zinc mine, NW Iran. *Journal of Geochemical Exploration*; 186: 77-93.

Siegel, F.R. (2002): *Environmental geochemistry of potentially toxic metals*. 1st edition, Springer Berlin, Heidelberg; 218p.

Wang, P., Hu, J., Liu, T., Liu, J., Ma, S., Ma, W., Li, J., Zheng, H. and Lu, R. (2023): Advances in the application of metallic isotopes to the identification of contaminant sources in environmental geochemistry. *Journal of Hazardous Materials*; 458: 131913.

Williams, O.H. and Rintoul-Hynes, N.L.J. (2022): Legacy of war: Pedogenesis divergence and heavy metal contamination on the WWI front line a century after battle. *European Journal of Soil Science*; 73(4): e13297.

Zhang, X., Hester, K.C., Mancillas, O., Peltzer, E.T., Walz, P.M. and Brewer, P.G. (2009): Geochemistry of chemical weapon breakdown products on the seafloor: 1,4-thioxane in seawater. *Environmental Science and Technology*; 43(3): 610-615.