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# Water quality monitoring challenges during the war in Ukraine: new contaminants and approaches to their detection

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**Abstract:** The war in Ukraine has significantly worsened water pollution due to uncontrolled discharges of explosive residues, heavy metals, oil spills, and chemical warfare agents into natural water systems. Traditional monitoring practices, previously focused on basic parameters like pH and turbidity, are now inadequate for detecting war-related contaminants. Moreover, field access is limited due to security threats, complicating sample collection and real-time analysis. This paper outlines the urgent need for adaptive, innovative water quality monitoring strategies in conflict zones. It highlights the role of remote sensing technologies – such as satellites, drones, and hyperspectral imaging – in detecting pollution in inaccessible areas. Integration with AI and machine learning enables predictive analytics and real-time insights. However, challenges such as communication disruptions and power outages hinder the operation of IoT-based systems. To address this, portable and field-deployable solutions, including novel indicator systems based on ceramic membranes, offer promise for detecting toxic compounds like TNT, RDX, and nerve agents. These membranes selectively retain pollutants, providing reliable results even at low concentrations. Combining remote sensing, AI analytics, and innovative membrane-based sensors could form a resilient water monitoring framework in war-affected areas. The WaterS pilot project exemplifies such efforts by integrating IoT, low-power networks, and predictive algorithms. This paper emphasizes the necessity of hybrid monitoring systems that combine physical, virtual, and portable components to ensure comprehensive environmental safety amid military conflict.

**Keywords**: Water quality monitoring; conflict pollution; remote sensing; ceramic membrane sensors

Online water quality monitoring is crucial for promptly detecting pollutants and ensuring environmental safety. The ongoing war in Ukraine presents significant challenges due to hazardous contaminants entering water sources uncontrollably and difficulties in monitoring conflict zones. These unprecedented conditions necessitate innovative methods, integrating physical, virtual, and hybrid sensor or indicator systems.

Chemical pollution of Ukraine's surface waters arises from ammunition disposal, explosives degradation, rocket fuel, and industrial damage. Groundwater, supplying 25% of Ukraine's drinking water, is contaminated by explosive residues such as chlorates, perchlorates, and nitrates. Marine pollution results from sunken military vessels, aircraft, unmanned aerial vehicles, mine remnants, oil spills, heavy metals, and chemical contaminants from explosives. These factors significantly pollute water bodies with explosives such as trinitrotoluene (TNT), hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), ammonium nitrate, and various nitro-organic compounds [1].

Research indicates explosive compounds disrupt aquatic ecosystems and pose carcinogenic risks to humans [2]. Combat zones exhibit severe heavy metal contamination, including iron, lead, mercury, cadmium, and arsenic. These metals bioaccumulate in aquatic organisms, causing long-term environmental and health issues. Among the most dangerous pollutants are chemical warfare agents, such as nerve agents (e.g., sarin) and blister agents (e.g., mustard gas), reportedly used by Russian forces. Their high toxicity necessitates rapid and sensitive detection methods [3].

Currently, water monitoring in Ukraine is not conducted. Pre-war monitoring included basic parameters like pH, temperature, salinity, turbidity, dissolved oxygen, and oxidation-reduction potential. However, these are inadequate for assessing war-induced pollution, and security threats significantly limit field-based monitoring efforts.

To ensure effective monitoring amid military-related challenges, modern water quality assessment approaches must be employed. Remote sensing technologies, including satellites and drones, can detect water pollution in inaccessible combat zones. Techniques such as satellite imagery and hyperspectral analysis help identify algal blooms, oil spills, and chemical discharges in war-affected areas [4]. Artificial intelligence (AI) and machine learning algorithms analyze real-

time water quality data, identifying pollution trends and predicting contamination events. These tools are particularly useful when combined with remote sensing data and automated monitoring stations [5]. However, real-time technologies like IoT sensors, AI systems, and satellite imagery are underutilized in conflict zones due to communication and power disruptions. Therefore, portable, rapid, and field-deployable testing solutions are critical.

A promising approach for detecting specific pollutants, including those resulting from military activities, involves developing novel indicator systems based on ceramic membranes. These modified membranes selectively capture contaminants, enabling the detection of even low concentrations of toxic compounds. The procedure involves collecting water samples, filtering out insoluble substances, and passing them through modified membranes. Such indicator systems could provide an effective solution for detecting residual hazardous substances. However, integrating physical, virtual, and hybrid monitoring systems is essential to ensure comprehensive accuracy and efficiency.

Combining remote sensing, portable sensors, indicator systems, IoT tools, and AI analytics enhances water monitoring effectiveness, especially in war-affected areas. Many prototypes remain at laboratory or pilot stages awaiting large-scale deployment.

The WaterS system [5], an IoT-based pilot project, employs a low-power Sigfox network, photovoltaic panels for autonomous energy, and Long Short-Term Memory (LSTM) neural networks for predicting water quality parameters.

Given the severe challenges posed by the war in Ukraine, water quality monitoring requires adaptive and resilient approaches. A promising strategy involves implementing efficient, high-performance, and long-lasting automated monitoring systems for assessing natural water quality.

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