After the Blast

Mapping environmental risks from explosive weapons in Ukrainian towns and cities

PAX

Colophon
April 2024

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Cover image: A devastated Bakhmut, Ukraine, seen from a drone while embedded with the 93rd Mechanized Brigade of the Ukrainian Army, May 19, 2023 (© Tyler Hicks. Redux/New York Times Syndication)

This research was funded by Giro 555 / Dutch Postcode Lottery.

Content

Executive Summary

The destructive nature of Russia's invasion of Ukraine is starkly visible in the cities and towns that have faced intense bombardment, fighting and shelling. Millions of rounds of explosive weapons have been fired into densely populated areas, completely destroying residential areas, damaging industrial zones and critical infrastructure. Tens of thousands of civilian lives have been lost, with many more wounded and displaced. In the wake of the destruction, looming environmental reverberating impacts from the explosive violence can have both acute and long-term public health impacts, with wider implications for Ukraine's ecosystems and biodiversity.

According to current estimates by the World Bank at least 10 percent of the total housing stock of 20 millions units of buildings have been damaged and destroyed, not counting industrial enterprises. This destruction has generated at least dozens of millions of tons of debris, though this will likely be over 100 million tons of conflict rubble, often mixed with asbestos and other hazardous materials from facilities such as power plants, factories, and oil storage tanks located in or near urban areas. First responders and people remaining in the affected areas could face exposure to the toxic dust and other hazardous materials during removal work. These destructive impacts also have long-term environmental consequences as millions of tons of rubble need to be safely processed, while damage to and destruction of industrial sites and energy infrastructure can also leave behind many tons of chemicals and hazardous substances that can pollute soil, groundwater and surface water. Beyond that, the immense amount of cement and reconstruction materials needed will lead to an increase of natural resource extraction, a massive rise in carbon emissions, further contributing to climate change.

This report aims to demonstrate the environmental reverberating impacts of explosive weapons through the lens of six cities in Ukraine, each with a unique profile that underscores the complexity of the war's relationship with environmental destruction. From the massive destruction of Bakhmut and Hostomel to the damaged industrial zones in Chernihiv, and from the chemical industry in Rubizhne and Severodonetsk to the ongoing fighting around the massive coke factory and its toxic waste ponds in Avdiivka, the wartime destruction will leave a toxic legacy. What is clear is that the use of explosive weapons in populated areas will have long-lasting implications for civilians and their environment.

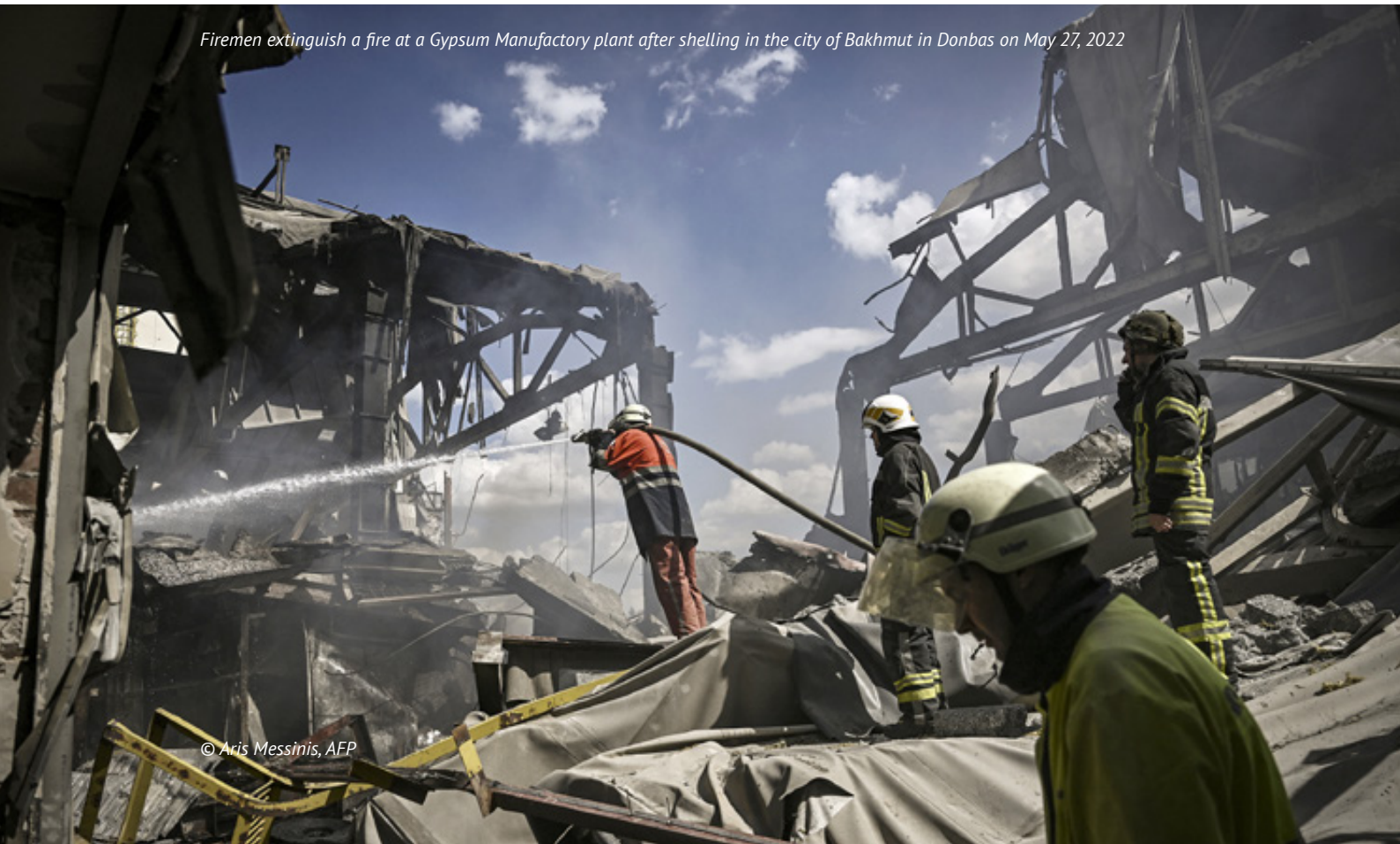
The findings of this research show the utility of documenting the environmental dimensions of war through our open-source methodology, combined with existing and new datasets on urban damages based on remote sensing analysis. The report is the fifth in a series that PAX has published that demonstrates the various, complex layers of environmental destruction in Ukraine.

Introduction

Russia's full-scale invasion of Ukraine has been marked by one of the most intensive uses of explosive weapons in populated areas (EWIPA) since World War II. Beyond the thousands of civilian casualties they have caused, the use of missiles, rockets, mortars and other explosive weapons has produced widespread destruction in Ukrainian towns and cities. Images of Ukrainian urban areas reduced to rubble have raised parallels with the devastation witnessed recently in Syria and Iraq, where entire city blocks and towns have been obliterated, generating millions of tons of debris and rubble. Beyond the humanitarian and economic impacts of the destruction of residential areas and industrial infrastructure, the severe damage caused by EWIPA poses acute environmental risks, which in turn can have long-term impacts on human health in affected areas.

This report outlines the environmental and public health risks from the use of explosive weapons in populated areas through the lens of six Ukrainian towns and cities damaged by the war. Examination of the specific implications of explosive weapons for the selected locations provides more insight on the impact of EWIPA on civilians and the environment. This study not only highlights the need for the provision of timely and adequate funding and assistance, but also underscores the necessity and urgency of the current international efforts to better protect civilians against the use of EWIPA.

This publication is part of a wider series of analyses on the environmental impact of war in Ukraine funded by the Netherlands' Giro 555. Previous reports on Ukraine focused on attacks against energy infrastructure, agro-industrial sites, oil and gas infrastructure and the destruction of the Kakhovka dam, outlining the consequences of these attacks for the environment and public health.



Firemen extinguish a fire at a Gypsum Manufactory plant after shelling in the city of Bakhmut in Donbas on May 27, 2022

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Methodology

Using publicly available urban damage assessments and data on hazardous facilities and critical infrastructure, we mapped environmental risks in six different Ukrainian towns and cities, with a focus on the unique environmental consequences associated with the use of explosive weapons in each case study. Since February 24, 2022, PAX has been monitoring military incidents caused by explosive weapons in Ukraine, with a focus on environmental risks. Through social media monitoring, as well as publicly available databases such as Bellingcat's and the Center for Information Resilience's (CIR) "Eyes on Russia" project, data on hazardous facilities from REACH, as well as OpenStreetMap and PAX's own monitoring data on damage to hazardous facilities (for details see table 1), PAX has compiled its own dataset, using geolocation and satellite imagery to further analyze and verify the incident reports.

Damage assessments

The level of damage to build-up structures, including residential areas, commercial and industrial sites, has been documented and used in this report using a variety of sources. There is currently no overall standardized damage assessment of urban areas, and therefore this report draws upon various methods applied by UN agencies, government institutions and academics. The most used and reliable method is applied by UNOSAT's damage assessments, that is using MAXAR and Airbus Very High Resolution (VHR) resolution satellite imagery (40-50cm) and checking before and after impact locations, giving it a different grade of damage, ranging from minor damaged to completely destroyed. A more recent method of damage assessment is applied by UA Damage, a group of Ukrainian engineers that is using both satellite imagery and drone cameras for full scale 3D mapping of damage. The US-based Conflict Observatory, a broad collaboration of universities and experts to map different types of damages from the Russian invasion in Ukraine, is collaborating with Planet through the application of its PlanetScape Artificial Intelligence for urban damage detection, as well as using MAXAR WorldView VHR imagery. This is combined with building layers from OpenStreet Maps and Microsoft Bing Maps Machine Learning model as a reference. And lastly, this research is using Dr. Ollie Ballinger's Open Access Damage Detection using Sentinel-1 Synthetic Aperture Radar (SAR) that applies a Pixel-Wise T-Test (PWTT) for a building damage assessment algorithm. This method is less accurate compared with VHR building damage assessments but provides an indication of the percentage of buildings damages that supports visualizing the intensity of the destruction. The latter application was used in absence of up-to-date publicly available VHR imagery for Avdiivka and Bakhmut.

The six case studies in this publication were selected based on the following criteria:

- General level of destruction by explosive weapons, based on satellite imagery analysis and available damage assessments carried out by UNOSAT, the Ukraine-led initiative UA Damage, Ollie Ballingers's Sentinel-1 SAR analysis, and the Conflict Observatory data.

- Available information in the public domain on certain aspects of impact, such as damage to water infrastructure, energy infrastructure, industrial areas and other high-risk sites, estimated amounts of debris, impact on waste management and specific impacts on healthcare facilities, collected from PAX and CIR databases, using Google Maps identification of buildings, and WikiMapia and Yandex Maps data on type of buildings.
- Geographical spread of cities, including cities that faced attacks in the early stages of the invasion, cities that have been liberated by Ukraine after Russian occupation, and cities that are still occupied by Russian forces.
- Specific conditions that create unique concerns, e.g. proximity to heavy industry or mining activities or densely populated areas.

The case studies in this publication aim to provide a quick visualization of the damage from explosive weapons. These risk identification mappings demonstrate the scale of the destruction and the additional environmental health risks associated with the type of facilities or buildings damaged. It is important to note however that the information used in this report is based on remote sensing and other forms of open-source research that was not verified on the ground, which comes with inherent limitations. We expect that this report represents an underreporting of environmental risks for several reasons: manual mapping of critical infrastructure has most likely led to overlooking some important facilities in each town; the locations of satellite-derived building damage and manually mapped critical infrastructure sometimes do not overlap for the same infrastructure[1]; and satellite-derived damage assessments can only identify damaged buildings from above, i.e. when they have partly collapsed or when the roof is damaged. Internal structural damage, not visible via these methods, often results in demolition in a later stage due to safety risks.

Fire at the fuel storage of the Avdiivka Coke and Chemical Plant that is under Russian occupation, April 9, 2024. Source: Social media

The damage assessments used also account for different dates, which means that the information is already outdated for locations where the fighting is ongoing, such as Avdiivka, or that continue to face shelling, such as Chernihiv. Therefore, while the case studies should not be seen as an up-to-date and factual representation of the situation on the ground, they do provide a likely pattern of environmental risks, which can inform both policymakers and humanitarian responders.

1 To count the number of damaged critical infrastructure, we delineated a 30m zone around the damaged locations and around the mapped location of the critical infrastructure. We then identified the geospatial overlap between both damage and critical infrastructure zones.For larger infrastructure in particular, such as warehouses, there is a possibility that the damage zone and critical infrastructure do not overlap and are thus not identified as damaged in our analysis.

City/town	Type of data	Date of gathering	Source	Method of gathering
Sievierodonetsk, Rubizhne, Avdiivka, Chernihiv, Hostomel, Bakhmut	Critical urban infrastructure, hazardous facilities	Apr 2023 - Feb 2024	PAX analysis using Wikimapia, Google Maps, Sentinel-1, Sentinel-2, REACH, open-source data.	Searching, filtering and visually identifying several types of infrastructure
Sievierodonetsk	Damage assessment	25 July 2022	UNOSAT	Detection from Maxar satellite imagery
Rubizhne	Damage assessment	9 July 2022	UNOSAT	Detection from Maxar satellite imagery
Avdiivka	Damage assessment	9 July 2022	UNOSAT/ Ollie Ballinger	Detection from Maxar and CNES satellite imagery, Sentinel-1 SAR
Chernihiv	Damage assessment	9 July 2022	UNOSAT, PAX partners	Detection from Maxar satellite imagery
Hostomel	Damage assessment	9 July 2022	UNOSAT, UA Damage	Detection from Maxar satellite imagery and drone footage
Bakhmut	Damage assessment	9 July 2022	Conflict Observatory/ Sentinel-2/ CIR, Ollie Ballinger.	Detection from Maxar satellite imagery

Table 1. External data source details per case study. Critical urban infrastructure includes energy infrastructure, medical facilities, industrial sites, waste management sites, and water infrastructure.

Background on Explosive Weapons in Populated Areas

Most of the civilian casualties and destruction from Russia's full-scale invasion of Ukraine result from the use of explosive weapons in populated areas. Explosive weapons include a range of air-dropped and ground-launched weapons, such as aerial bombs, artillery shells, rockets and missiles. They function through the projection of blast and fragmentation around the point of detonation. Most problematic are explosive weapons with wide area effects, owing to the great risk they pose to civilians when used in populated areas. Wide area effects are created when these weapons have a large blast and fragmentation radius, have inaccurate delivery systems, and/or deliver multiple munitions. When explosive weapons are used in towns and cities, they cause a pattern of tremendous civilian harm, as they kill or injure civilians through blast and fragmentation of the explosive weapon upon impact. The explosions also cause buildings to collapse and debris to fly through the air, creating more harm to civilians.

The use of explosive weapons in cities, towns and villages also causes indirect and reverberating effects arising from damaged infrastructure, interrupting services which civilians depend upon. These effects can last for extended periods. As part of PAX's work on both EWIPA and the environmental consequences of armed conflicts, our aim is to highlight the environmental harm from the use of explosive weapons, their potential direct impact on public health from exposure to hazardous substances, and their long-term consequences for the ecosystems people depend on. In the last decade, the widespread use of EWIPA has been a cause for concern among the international community. A political process with the aim to better protect civilians against the impact from the use of explosive weapons in populated areas led to the signing of the Political Declaration on Strengthening the Protection of Civilians from the Humanitarian Consequences arising from the use of Explosive Weapons in Populated Areas by 83 states in November 2022.

The declaration is the first formal recognition of the direct and indirect impacts of EWIPA on civilians. Among other things, the declaration commits states to restrict or refrain from the use of explosive weapons in populated areas where civilian harm can be expected, to collect and share data on EWIPA and to provide assistance to victims and their communities. The declaration also references the impact from EWIPA on the environment, through the contamination of air, soil, water and other resources. Endorsing states must consider these impacts in the implementation of the declaration's commitments, including taking into account the direct and indirect effects of EWIPA in the planning and execution of military operations. Neither Russia nor Ukraine has joined the declaration at the time of publication. PAX calls upon all states to join and implement the political declaration without delay.

Caption: A destroyed tank amid ruined buildings in Hostomel, Ukraine, April 25, 2022

Impacts of Explosive Weapons in Populated Areas in Ukraine

Russia's full-scale invasion of Ukraine has been marked by one of the most intensive uses of various types of explosive weapons since World War II. According to data provided by President of Ukraine Volodymyr Zelensky in August 2023, Russian troops have used more than 6,500 missiles and 3,500 kamikaze drones to strike Ukrainian territory since the start of the invasion. The State Emergency Service (SES) of Ukraine has reported that 30% (174,000 sq. km) of the country's total land is contaminated with mines and unexploded ordnance, while more than 420,000 munitions have already been discovered and neutralized on 936 sq. km that have been examined to date. According to experts, if Ukraine follows international standards of demining, it will take decades to entirely clear the landmines. The impacts of EWIPA are numerous, ranging from civilian casualties and dire humanitarian consequences to infrastructure damage, negative effects on socio economic development, environmental degradation and public health deterioration.

Casualties and infrastructure damage from EWIPA

Since February 24, 2022 till January 2024, the Office of the United Nations High Commissioner for Human Rights has recorded roughly 30,010 civilian casualties in Ukraine, including over 10,378 killed and 19,632 injured, although the actual numbers may be much higher. The British organization Action on Armed Violence (AOAV), basing its findings on English-language media reporting, assessed that as of February 2024, 95% of civilian casualties in Ukraine have resulted from the use of EWIPA.

As of June 2023, over 167,200 housing facilities in Ukraine have been damaged or destroyed, the Kyiv School of Economics (KSE) has reported. The most heavily damaged housing areas were reported in the Mariupol, Kharkiv, Chernihiv, Sievierodonetsk, Rubizhne, Bakhmut, Maryinka, Lysychansk, Popasna, Izyum and Volnovakha. According to preliminary estimates cited in the report, 90% of housing in Sievierodonetsk has been damaged, while cities such as Bakhmut and Maryinka have almost no undamaged buildings.

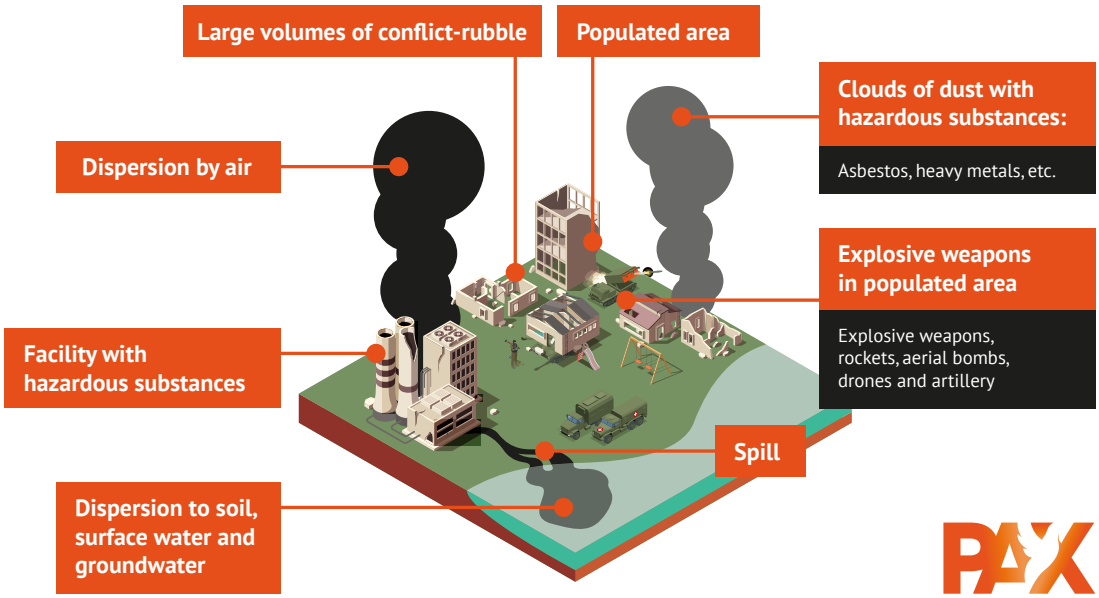
Besides housing facilities, the KSE report states that over 1,200 healthcare facilities have been damaged or destroyed, as well as 997 educational infrastructure facilities destroyed and 2,380 damaged until June 2023. Research by Insecurity Insight and its research partners found that one out of every ten hospitals in Ukraine has been damaged by attacks, with an average of two hospitals attacked per day between late February and late December 2022.

Extensive use of air strikes, missile strikes and artillery shelling has also caused substantial damage to critical infrastructure, including fossil fuel sites and energy production facilities, some of which are located in or near populated areas. The immense impact of strikes on urban and critical infrastructure has had a devastating impact on civilians, leading to displacement, decreases in the availability, accessibility and quality of healthcare, reduced provision of education and a decline in other essential services such as access to clean water and electricity.

Environmental dimensions of EWIPA

Direct environmental effects include bombed civilian and industrial facilities, which is potentially exposing civilians to a range of hazardous substances and chemicals, while large amounts of inhaled toxic dust can cause both acute and long-term health problems. Indirect impacts include the contamination of soil and water from the millions of tons of contaminated rubble produced by EWIPA, often mixed with a range of hazardous materials such as asbestos, as well as from the release of hazardous substances from explosive weapons. All these issues will be discussed in detail in this report.

Damage to critical infrastructure can hinder access to clean water, worsen the spread of communicable diseases and result in toxic coping strategies for energy production. One example of this is the construction of makeshift refineries for fuels using plastics, as seen in urban areas in Syria.



These are clear lessons learned from the heavy urban destruction that took place in Syria, where entire neighborhoods of cities such as Aleppo, Damascus, and Homs were obliterated, creating tens of millions of tons of debris and rubble. A full estimate of the destruction is still needed, but over hundred million tons of rubble were likely produced, with at least 320,000 houses and buildings damaged or destroyed. In Iraq, intense urban battles against the Islamic State in 63 cities, towns and villages have created an estimated 55 millions tons of rubble with their inherent environmental risks, according to the UN. The February 2022 earthquake in southern Turkey and Syria has also highlighted the public health risks from toxic dust and hazardous materials present in the millions of tons of debris.

EWIPA also results in damage to, or destruction of, industrial facilities, leading to concentrations of toxic chemicals, while the debris and post-conflict reconstruction can also pose additional environmental challenges related to safe storage, the reuse of conflict debris, and growing needs in raw materials and energy for producing materials for new construction.

In Ukraine, since the Russian invasion in 2014, several of these environmental risks have become very visible. Various international and Ukrainian organizations and experts have already undertaken urban damage assessments on towns and cities in Ukraine, including UNOSAT, REACH, the US-led Conflict Observatory, the UA Damage team, as well as scientific studies and open-source machine learning damage assessments by Ollie Ballinger, an open-source and remote sensing specialist. The UNDP is actively involved in debris clearance and the sustainable processing of rubble from damaged urban areas in Ukraine. All these efforts help to paint a better picture of the scale of damage throughout Ukraine, as well as further contributing to understanding the environmental risks associated with the use of explosive weapons in urban areas.

IMPACT FROM THE USE OF EWIPA IN UKRAINE

1 Implications from **damaged sites** by EWIPA

ENERGIE INFRASTRUCTURE	AGRARIAN INFRASTRUCTURE	FUEL INFRASTRUCTURE	WATER INFRASTRUCTURE	OTHER CIVILIAN INFRASTRUCTURE
Facilities of power generation and transmission, heat production plants	Poultry farming, livestock, warehouses, silos, agro-chemical facilities, farmfields, irrigation systems	Oil and gas falicites, gas stations	Pumping stations, filtration plants, water supply networks and sewage treatment plants	Buildings of civilians, education and healthcare

• Disruption of power dependent facilities with no access to
  • Drinking water
  • Sewage use
  • Industrial cooling systems
  • Refrigeration units
  • Heating system
  Healthcare services
  Public transport
  Mobile & internet
	• Disruption of watering by irrigation systems
	• Mined agrarian lands
	• Soil destruction and degradation
	• Decrease of agrarian production due to damaged facilities and equipment
		• Disruption of heating system, incl healthcare and education facilities
		• Stop of enterprises and other fuel dependent facilities
			• Disruption of access to:
			  • Drinking
			  • Water
			  • Sewage use
			  • Heating systems
			  • Industrial cooling systems
				• Disruption of access to services:
				  • Public transport
				  • Health care and education
				  • Mobile & internet

- Release of hazardous substances and debris accumulation

2 Implications from **explosive weapons**

Areal bombs, small to large caliber munitions, including mortars, rockets and artillery shells

- Release of hazardous substances from the fuel contained in the weapon and from the exploded facilities
- Explosive remnants of weapons

Environmental and health risks from EWIPA

Risks to the environment	Risks to public health	Main consequences
• Air and Water pollution • Destruction of soil's fertile layer • Soil and Groundwater contamination • Land occupation by conflict-rubble and debris • Noise pollution • Habitats of living organisms are polluted or destroyed	• Waterborne Diseases • Cold-related Illnesses • Food Poisoning • Food insecurity • Cancer-related and other Diseases by Chemical & Radiation Exposure	Humanitarian crisis: • Destroyed homes, healthcare and education facilities • No critical infrastructure services • Displacement of civilians • Acute and long-term health impact Environment degradation: • Losses of Ecosystems Service and Biodiversity

Environmental Footprint and Public Health Risks from EWIPA

The use of EWIPA destroys both residential and non-residential buildings, including critical infrastructure that supports the livelihoods of the population. Damage to populated areas from heavy shelling can result in acute public health problems and long-term environmental harm. The destruction of cities and towns leads to the disruption of life-supporting services, the release of hazardous materials from industrial sites, contamination with unexploded ordnance, and the creation of millions of tons of rubble and debris from damaged buildings and equipment. All of this can lead to degradation of the environment, deteriorating public health and exacerbation of the humanitarian crisis, as the charts below explain.

To break down the environmental footprint of EWIPA, three main aspects are considered to analyze potential impacts that can create serious health problems. First, the toxicological profile of munitions and their remnants; second, the risks from damaged hazardous facilities of different types; and lastly, the environmental and health consequences of large volumes of conflict rubble.

1. Munitions Impacts

The intense use of a wide variety of explosive weapons and other munitions in populated areas results in large quantities of UXOs and remnants of munitions constituents, such as energetic materials from munition (residues) and heavy metals, in these areas. Hundreds of thousands of mortar rounds, artillery shells, multiple rocket launchers and air dropped-munitions have been fired on urban areas throughout, leaving their own environmental footprint. These toxic remnants of war pose additional public health and environmental risks that have been well documented in the scientific literature. Examples include acute exposure to toxic substances in solid and liquid propellants from rockets and missiles and chronic exposure to energetic materials such as trinitrotoluene (TNT), cyclonite or RDX (1,3,5-trinitro-1,3,5-triazine), nitroglycerine (NG) and octogen (HMX), all essential components in munitions and propellants. Through the leaching of pollutants from unexploded ordnance, low-order detonations or high-order release from explosions, these substances can contaminate soil and water sources and form pathways of exposure for civilians, depending on the type of pollutant and the manner of its contamination of the soil or water. Current discussions in the US around the remediation of firing ranges highlight the risk for nearby communities from leakages of energetic materials from munitions.

Many types of munitions contain a range of heavy metals such as lead, antimony, tungsten, depleted uranium and bismuth that can contaminate soil and drinking water sources, creating long-term risk for civilians. Ukraine and Russia both have depleted uranium (DU) anti-tank munitions in their stockpiles. This is a toxic and radioactive metal used in armor-piercing munitions with no safe level of exposure. PAX has been advocating for over a decade to ban these weapons due to civilian exposure risks. Despite a widely supported UN resolution that called for the precautionary principle on the use of DU, the US and the UK decided to deliver DU munitions to Ukraine. There are likely already documented uses of Soviet stockpile DU munitions by Russia or Ukraine, according to the Geneva Center for Humanitarian Demining's Explosive Ordnance Guide for Ukraine. The accumulation of heavy metals and munition-origin toxic residues could result in various pathways of exposure for civilians, either directly or indirectly. The effects on human populations, flora and fauna depend on the receptors, dose and longitude of exposure, with many heavy metals and toxic rocket propellants having known acute effects or long-term health risks.

Many rockets and missiles used in strikes in Ukraine contain propellants with known hazardous characteristics. Mèlange and hydrazine in particular, both used in larger missiles, are known toxic fuels that are an acute health hazard. Prior to the invasion Ukraine was already dealing with clean-up of this military legacy pollution from Soviet era rockets that were dismantled with the support of the OSCE; these propellants have also been an issue with demining in Libya.

During the fighting in Ukraine, long-range ballistic missiles, surface-to-air missiles and multiple rocket launcher systems (MLRS) have been used against cities. At the same time, these launchers were also targeted in counter-missile fire and destroyed or damaged, both in situ or at military depots close urban areas. Incomplete detonations, duds and damaged depots can result in contamination from missile and rocket remnants containing toxic hypergolic liquid propellants, with the ensuing risks for civilian exposure.

Ukrainian cities and towns have also witnessed the use of incendiary munitions. These types of munitions come in many forms, including flamethrowers, rockets, grenades and bombs and containing napalm, thermite, phosphorus, magnesium alloy and/or chlorine trifluoride. PAX has to date documented the use of thermite-based incendiary munitions delivered by 122mm MRLS in Ukraine, while documentation by humanitarian deminers has shown usage of mortars with incendiary ammunition. Monitoring by Human Rights Watch has confirmed 82 cases of ground-launched incendiary weapon use, including in populated areas. Though there are currently no known health risks associated with thermite based incendiaries, their use could affect civilians from direcposure or resultant fires, burning houses or crops.

2. Damage to Hazardous Facilities

The shelling of urban areas has regularly resulted in damage to industrial sites, factories and other facilities, including critical infrastructure and facilities storing substances hazardous to the environment and public health. In previous publications, PAX has elaborated on the environmental and health risks from attacks on energy, fuel, and agro-industrial sites. Below are examples of specific threats expected from damaged industrial facilities in the case of release of hazardous substances into the environment within populated areas.

Energy sector facilities. The main risk for the environment and public health in case of damage or destruction of energy infrastructure is the secondary impact - when damage halts the functioning of various life-supporting enterprises dependent on the power source. For example, stopping the operation of a water treatment plant after power facilities have been damaged can lead to an outbreak of disease due to the ingress of untreated wastewater into drinking water sources and its contamination with dangerous bacteria. Radiation safety at nuclear power plants also depends on a stable power supply for the cooling process in order to avoid environmental disaster due to the nuclear rods melting.

At the same time, the energy sites themselves also contain various hazardous installations and materials, such as heavy fuel oil storage facilities and multi-ton storage facilities of industrial waste. Another hazardous material associated with energy facilities is polychlorinated biphenyls (PCBs). As a persistent and toxic organic chemical, PCBs can remain in the environment for long periods of time, moving long distances through the air, water or soil, while accumulating in plants, food crops, and small organisms and fish. This way people can be exposed to PCBs through the consumption of contaminated products. The potential health effects of PCB exposure included increased risks of cancer, as well as negative effects on the immune system, reproductive system, nervous system, endocrine system and other health problems.

Fossil fuel facilities. Over the course of the war, various gas and oil installations in urban areas have been targeted, including oil tanks, petrol stations and small refineries. Numerous risks to

civilians and ecosystems can result from resulting oil leaks and burning of fossil fuels. Spills from oil storage facilities can pose environmental and health risks of pollution by toxic chemicals such as hydrocarbons and metals, posing a significant hazard to land resources (fertile soil, wetlands), aquatic ecosystems (both marine and freshwater environments), flora and fauna. Oil compounds such as benzene, toluene, ethylene and xylene (BTEX) may have extreme acute health effects, while exposure to polycyclic aromatic hydrocarbons (PAHs) can lead to a variety of long-term health problems: respiratory disorders, liver problems, kidney disorders and even cancer, depending on the duration and intensity of exposure.

Another pathway of exposure to fossil fuel-linked pollutants is oil and gas fires (storages, tanks, pipelines). There are environmental risks of air pollution by emissions of particulates like elemental carbon (soot) and hydrocarbons, as well as gasses such as sulfur dioxide (SO_2) and nitrogen dioxide (NO_2). Greenhouse gasses such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) also contribute to climate change. Health risks associated with the release of these noxious fumes include the inhalation of airborne chemicals or particles carried by smoke plumes, which can lead to respiratory and skin problems. Large volumes of soot from combusted materials can deposit in water wells and soil, affecting agricultural land and ecosystems.

Agro-industrial facilities. Pesticides and fertilizers, including ammonia and nitric acid, are the main hazardous substances present at agro-industrial facilities. Their release can lead to the contamination of soil and water, with especially harmful effects on wildlife and aquatic organisms. These chemicals pose an immediate danger to all life owing to their acute toxic effects. Long-term exposure can lead to chronic health problems such as lung damage, cancer, Alzheimer's and birth defects, as well as damage to the nervous, reproductive and endocrine systems.

A man walks in front of a residential building damaged in shelling in the city of Chernihiv on March 4, 2022

© Dimitar DILKOFF / AFP

Another source of environmental damage from EWIPA can result from damaged sunflower oil terminals. Although sunflower oil is a non-toxic substance, its release can create an environmental catastrophe, owing to its ability to polymerize in water, creating a concrete-like film on the surface of the water that can kill aquatic life and birds.

Other hazardous facilities and small-scale workshops. There have been hundreds of reported cases of destruction of a wide range of other industrial facilities in Ukraine, inducing the release of substances with toxic or bacteriological hazards. These include metallurgical and mechanical engineering enterprises, construction materials factories, paint and solvents storages, food factories, plastic productions, military vehicles assemblies, large shopping malls, pharmaceutical warehouses, and chemical storage sites, among others.

In addition to the above-mentioned chemical and toxic pollution from leaks, attacks on hazardous material storage facilities also result in fires. Explosions in storage areas for petroleum products, fuels, lubricants, paints and varnishes, or vegetable oils can result in fires that last for hours or even days. This leads to air pollution by emissions, worsened by the need to extinguish such fires with the use of a large amount of foam. Such foam contains highly hazardous substances classified as persistent organic pollutants, such as PFOS (perfluorooctane sulfonate), PFOA (perfluorooctanoic acid) and per- and polyfluoroalkyl substances (PFAS). These substances are often called "forever chemicals" due to their toxicity, persistence, bioaccumulation in the food chain, and ability to travel long distances.

3. Conflict Rubble and Debris

The use of explosive weapons in cities and towns results in the large-scale destruction of buildings, producing toxic dust emissions and the accumulation of mass amounts of debris. Civilians residing in the affected areas can face sustained exposure from inhaling fine dust resulting from pulverized building materials, often mixed with heavy metals and other hazardous substances. Broader debris processing and management issues also pose additional health and environmental concerns, as outlined by UNOCHA and UNEP in their guidelines for humanitarian response in disaster settings. Even compared to the urban damage and environmental impacts from the wars in Syria and Iraq, where millions of tons of rubble was generated by urban destruction, Ukraine is likely to witness an even larger challenge of dealing with conflict rubble. At the same time, work and research conducted on sustainable cleanup in other conflict areas can provide useful lessons for Ukraine in its post-conflict reconstruction efforts.

Conflict rubble and debris can mix with industrial, medical, and household waste, as well as with various materials used in the construction and furnishing of buildings (such as water pipes, gas pipelines, electricity, wall decorations, furniture and electronic equipment). Research on health risks from dust and rubble generated by urban destruction gained more interest after the September 11, 2011 attack on New York'sWorld Trade Center, when thousands of first responders were exposed to large amounts of dust during rescue operations. A large study of the health consequences among first responders demonstrated the link between exposure to dust and debris containing toxic substances - including heavy metals (e.g., mercury, lead, titanium), silica, asbestos fibers, and wood dust - and an increased risk of pulmonary fibrosis (PF). Current estimates are that roughly 70% of the housing from the Soviet-era in UKraine contains asbestos, underscoring the broader risks of toxic dust from damaged buildings.

To create an accurate risk profile for exposure to toxic materials released during fighting in urban environments, the affected buildings should be examined for specific components used for their construction. The debris may contain one or more of the following hazardous substances:

Hazardous materials in rubble and debris

Substance	Sources	Health risks
Asbestos *Fibrous silicate mineral, carcinogen*	Roofing, flooring, insulation, concrete.	Respiratory problems, skin irritation, pulmonary diseases, lung cancer and asbestosis.
Mercury *Heavy metal with high toxicity properties*	Fluorescent light bulbs and other electronic devices.	High exposure results in permanent nervous system and kidney damage.
Lead *Heavy metal with high toxicity properties*	Paints, windows, pipes, plumbing, and other sources.	Chronic exposure is linked to kidney damage, high blood pressure, nervous system and neurobehavioral effects and cognitive dysfunction. Can have a serious impact on developing fetuses.
Polychlorinated biphenyls (PCBs) and polybrominated diphenyl ethers (PBDEs) *Man-made organic chemicals*	Common in electrical, heat transfer and hydraulic equipment; also in paint, plastics, rubber products, and old appliances.	PCBs and PBDEs are recalcitrant and bioaccumulative chemicals that resist degradation in the environment. They can harm brain development in children. Exposure to these chemicals has the potential to cause cancer-related diseases and negative effects on the immune, reproductive, endocrine, and nervous systems.
Silica *Silicon dioxide is most found i n nature as mineral quartz*	Common in construction materials (gardening supplies, bricks, cement, concrete).	Inhaling silica dust particles increases the risk of lung disease (including cancer) and kidney disease.
Cr6, hexavalent chromium *Hexavalent chromium compounds are genotoxic carcinogens*	Found in some types of metal plating, dyes, pigments, cement, leather, and wood preservatives.	Associated with multiple adverse effects. Skin irritator. Genotoxic carcinogen.
Synthetic Vitreous Fibers (SVF) *Glass-, rock-, slag-wool, refractory ceramic fibers*	Used in insulation for buildings between walls and roofing	Irritation of eyes, throat, nose; adverse effects on respiratory system.
Polycyclic aromatic hydrocarbons (PAHs) *PAHs are the most toxic group of environmental toxins*	Fire emissions and residues pollute both air and rubble with polycyclic aromatic hydrocarbons (PAHs), depending on the building material.	PAHs comprise the largest class of cancer-causing chemicals and are ranked ninth among chemical compounds threatening to humans. Many of these are genotoxic, mutagenic, teratogenic, and carcinogenic.

Conflict rubble and debris lead to the pollution of air, water and soil in the following ways:

- **Air.** Blast pressure results in small particles being projected into the air in the form of dust from pulverized building materials, potentially containing the above-mentioned toxic compounds. This dust is then inhaled by clearance workers or others in proximity to the damaged buildings.
- **Water.** Pollutants from debris can be blown into water sources, or can leach into the soil via rain. In some cases, unexploded ordnance and remnants of munitions end up in rivers and lakes located in populated areas. This leads to drinking water being contaminated by heavy metals.
- **Soil.** Multi-ton debris requires new places for storage, leading to the long-term occupation of productive lands that otherwise could be used for agriculture, which could impact livelihoods. Existing landfills are not suitable for multi-ton debris storage, as this would raise issues of unsafe storage and overfilling. There is also a risk of soil contamination from debris storage due to hazardous materials, which are often difficult to separate or remove from conflict rubble.

4. Wartime pollution and antimicrobial resistance

Over the last fifteen years, researchers in the Middle East have been watching a rapid spike in antibiotic resistance among patients, possibly linked with conflict pollution. Acinetobacter baumannii, also known as the Iraq-bacter, is a pathogen first found in wounded US veterans of the Iraq war. Researchers have linked this phenomenon to antimicrobial resistance (AMR), in particular to pollution by heavy metals used in weapons and military equipment. Moreover, recent research showed abnormally high rates of multidrug-resistant infections even more than six years after the end of active conflict in the Iraqi city of Mosul. The findings of this research, investigating the link between conflict and rising antibiotic resistance, points to the role of such metals as lead, mercury, chromium, copper, lead nickel, zinc, antimony, barium, and boron. Beyond heavy metals from munitions, other sources could be industrial pollution and damaged water infrastructure. The problem is further exacerbated by overprescription of antibiotics, which has fueled AMR in the region. Various articles about infections of wounded soldiers in Ukraine published in 2023, indicate a developing phenomenon of antimicrobial-resistant infections of war victims in military hospitals. The global rise of antimicrobial resistance in conflict areas is still understudied and rarely addressed.

Reconstruction and Environmental Impacts

Conflict rubble and debris from the destruction of buildings and equipment by EWIPA also create a number of long-term indirect environmental impacts in post-conflict settings. Above all, the accumulated multi-ton waste requires special locations to be arranged for environmentally safe storage of this type of waste. At present, conflict rubble is either being disposed of in unprotected landfills or occupying new large areas of land that could be used in more productive ways for agricultural or construction purposes. Unsafe landfills can lead to groundwater contamination from hazardous substance leaks, affecting soil or nearby surface waters and ecosystems.

Sustainable waste management requires technological solutions for further disposal of debris, including methods for its proper pre-sorting with the aim to remove highly toxic elements and separate useful materials that can be reused. In this regard, the experience of the Mosul debris recycling center, established in 2022 by the International Organization for Migration (IOM) and the UN Environment Programme (UNEP), could be a useful example for Ukraine in the circular economy dealing with the huge volume of debris created by military activity. Existing practical initiatives and campaigns led by the Ukrainian government and environmentalist groups, as well as cooperation between Ukrainian and European waste associations on debris recycling, can ensure sustainable post-conflict recovery efforts that address these issues.

The postwar reconstruction of damaged towns, cities and enterprises will require a large amount of natural resources, along with the additional environmental footprint this entails. These include production forests for wood, which often take years to grow and restore, and the use of coal, with its associated increase in greenhouse gas emissions. Another underreported aspect of the broader environmental dimension of post-conflict reconstruction is the need for building materials, such as portland cement and heavy metals, for the rebuilding of houses and enterprises, something often associated with outdated and pollution-heavy technologies in Ukraine.

Cement and concrete production has significant direct and secondary environmental impacts linked to air contamination by dust and greenhouse gas (GHG) emissions, as well as damage to ecosystems. Such production requires large amounts of non-renewable natural resources, including limestone, clay and sand. Production of cement is also very energy-intensive, often using coal as the main energy source. These raw materials also need to be mined, placing additional anthropogenic pressure on the environment. Both concrete production and mining are a major source of GHG emissions: the production of one ton of cement leads to 600-700 kg of GHG emissions. To produce one m^3 of concrete, roughly 1,300-1,500 kg of aggregate materials (sand and gravel) are needed. Concrete is not technically difficult to recycle, a common practice in European countries, but there is no experience nor tradition of recycling concrete waste in Ukraine current practices for its disposal involve either placing it in landfills or using it for backfilling purposes.

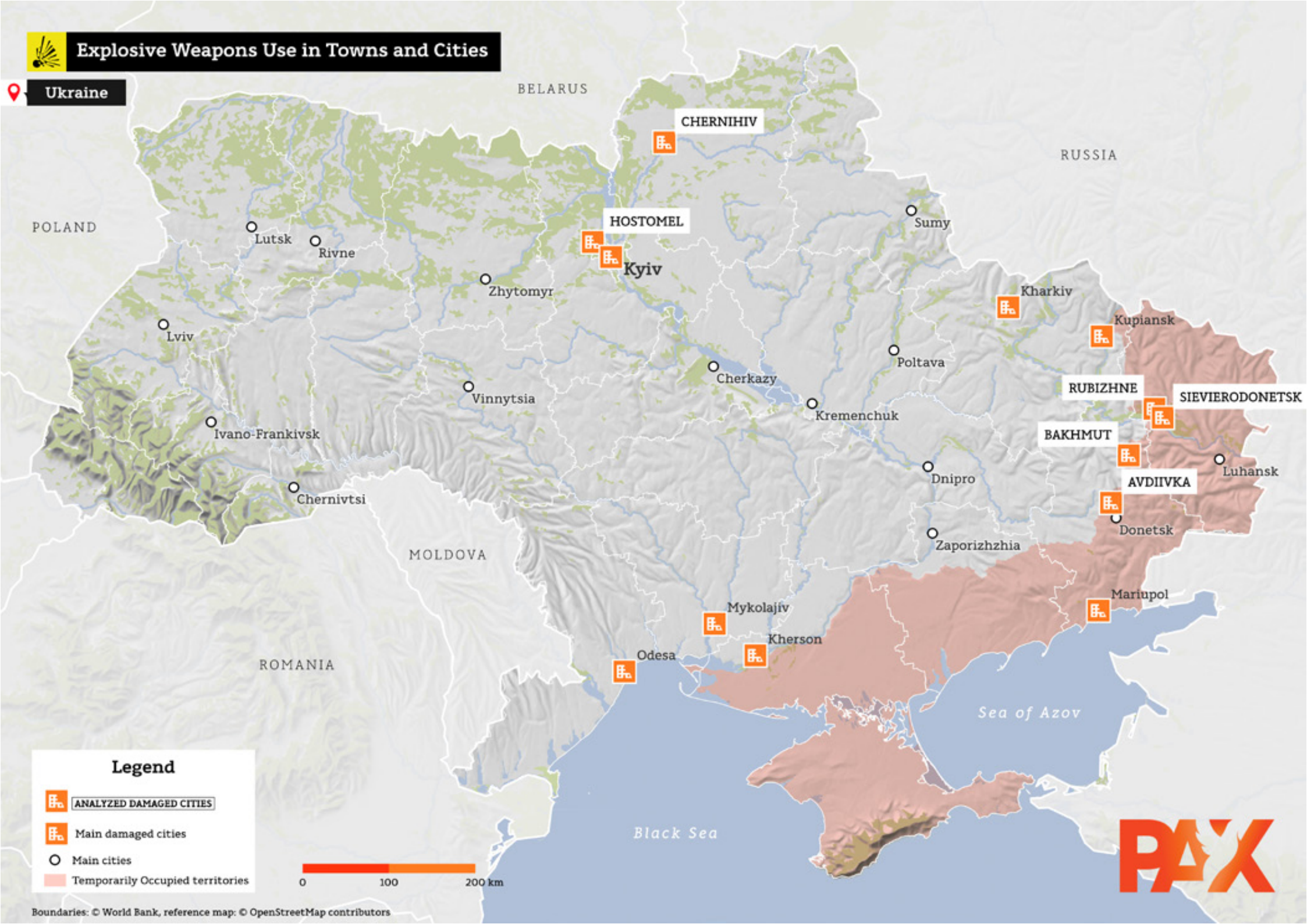
Analysis on the use of Ukrainian-made construction materials for post-war reconstruction suggests that Ukraine will need 35 mln tons of cement to rebuild the damage from the war's first eight months alone. This production will result in 23 mln tons of GHG emissions, a significant contribution to air pollution and climate change.

Urban Damage and Environmental Risks: Six Case Studies

The case studies below aim to provide a quick visualization of the damage from explosive weapons using existing damage assessments from different sources, and includes both data from the PAX database on damaged industrial sites and additional open-source data on critical infrastructure and health facilities. Analysis of the available data and PAX's mapping of the damage to the six selected towns and cities demonstrate the scale of the destruction and the resulting environmental health risks associated with the type of facilities or buildings damaged.

Five categories of potentially dangerous sites have been used to identify the environmental health risks in each city:

- **Energy facilities**: Containing hazardous materials such as polychlorinated biphenyls (PCBs), asbestos and heavy fuel oil.
- **Industrial sites**: Depending on the type of industry, these facilities often process and store large volumes of hazardous and chemical substances that can pose acute health risks and long-term environmental impacts. Using the Flash Environmental Assessment Tool (FEAT), it is possible to identify potential hazardous substances present at industrial facilities.
- **Water infrastructure.** Destruction of water infrastructure, including treatment plants, sewage facilities and pumping stations can affect public health by localized pollution from untreated waste water.
- **Waste management sites:** Solid waste landfills and storage facilities with industrial waste pose additional environmental risks, such as the burning of large volumes of hazardous substances with toxic or bacteriological properties.
- **Healthcare facilities**: Hospitals, clinics and pharmacies often have hazardous materials stored, including X-ray machines and various chemical compounds used for treatments or medicine production.


Explosive Weapons Use in Towns and Cities
Ukraine
BELARUS
RUSSIA
POLAND
ROMANIA
MOLDOVA
CHERNIHIV
HOSTOMEL
Kyiv
Sumy
Lutsk
Rivne
Zhytomyr
Kharkiv
Kupiansk
Lviv
Poltava
Cherkazy
Vinnytsia
RUBIZHNE
SIEVIERODONETSK
Kremenchuk
Ivano-Frankivsk
BAKHMUT
Luhansk
Dnipro
AVDIIVKA
Chernivtsi
Donetsk
Zaporizhzhia
Mariupol
Mykolajiv
Kherson
Odesa
Sea of Azov
Black Sea
Legend
ANALYZED DAMAGED CITIES
Main damaged cities
Main cities
Temporarily Occupied territories
0
100
200 km
Boundaries: © World Bank, reference map: © OpenStreetMap contributors
PAX

1. Sievierodonetsk, Luhansk region

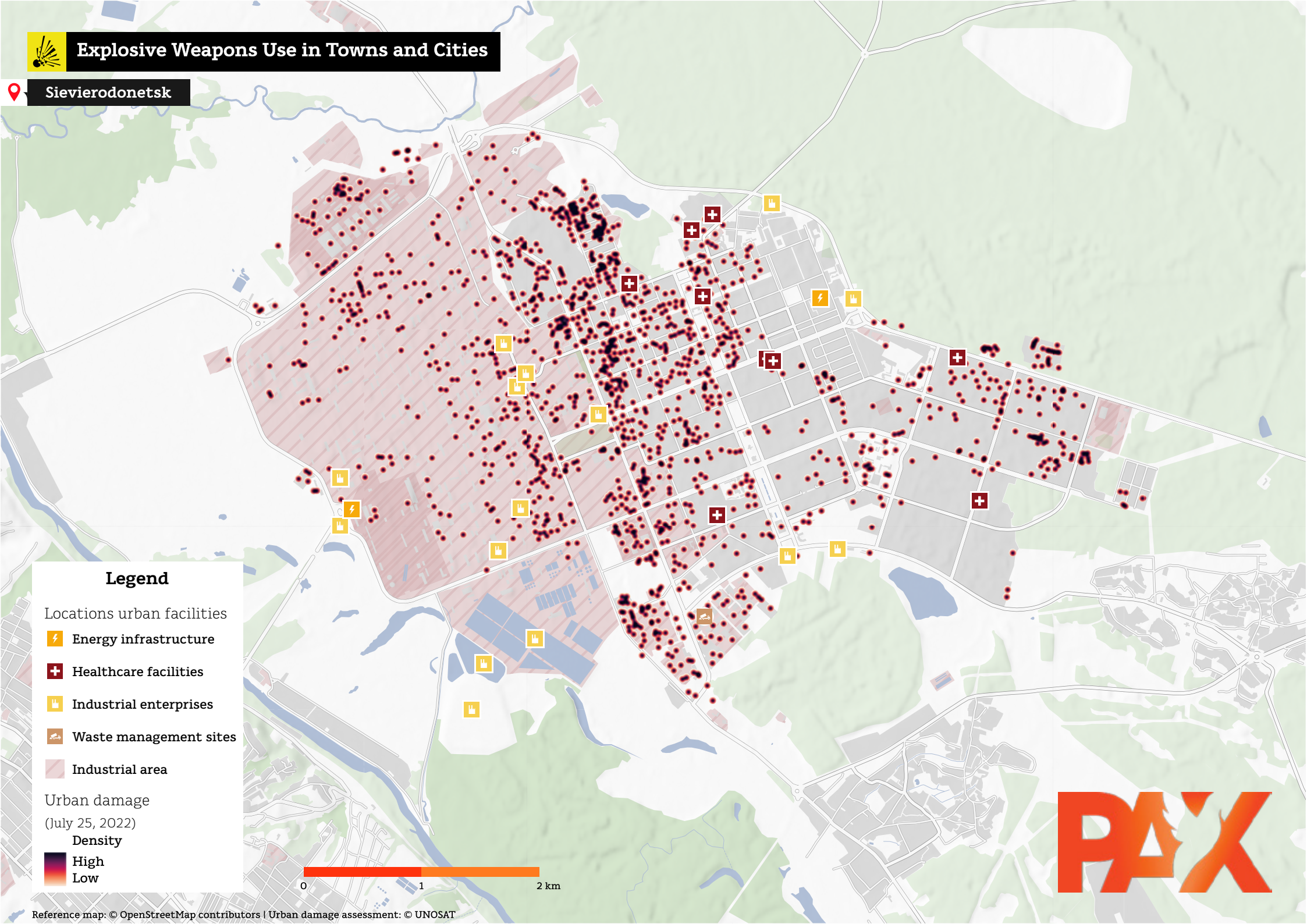
Sievierodonetsk is situated in the Luhansk region, in the eastern part of Ukraine. The Sievierodonetsk area is extremely industrialized, accommodating several chemical and pharmaceutical plants, including the Azot chemical plant (one of Ukraine's largest nitrogen fertilizer production plants) and the Microkhim plant (the largest Ukrainian producer of medicine and other substances for cardiology).

The city was captured by Russian-backed forces during the initial phase of the Russia-Ukraine war in 2014 but was regained by Ukraine within several months. It remained under the Ukrainian government's control until 2022, when the area once again became the epicenter of intense fighting. It was occupied by Russian troops between May and July 2022. Prior to the full-scale Russian invasion in 2022, Sievierodonetsk had a population of almost 100,000 inhabitants, but only an estimated 10,000 remained there as of July 2022.

Description of damage and environmental risks

Sievierodonetsk's built-up areas suffered extensive destruction in the fighting , with UNOSAT satellite analysis showing that at least 1,599 of 6,255 known buildings were damaged or destroyed, an estimated 25% of all buildings (although the open data used for the calculation of affected buildings is incomplete). Local authorities have stated that they estimate around 80% of the city's buildings have been damaged. With Sievierodonetsk hosting the Azot plant, one of the largest chemical factories for ammonia production in Europe, there are serious environmental health risks to the population from explosive weapons usage.

Numerous incidents of exploding nitric acid tanks and damage to other chemical storage facilities were reported during the fighting. A full assessment of damage and risks was presented in a case study in PAX's agro-industrial report. Several other potentially hazardous facilities and critical infrastructure were also damaged, including the Sievierodonetsk motor depot, the Ukrhimenergo plant (a large production facility for heating and electrical equipment) , a plant for producing electricity equipment, a poultry processing plant, a ceramics production factory, a large brick factory, a plant for chemical equipment, and a reinforced concrete production facility. Damage from the fighting also affected a large water treatment plant and caused damage to a number of electric substations, while in the eastern part of the city, several hospitals and medical facilities storing a mix of chemicals and radioactive materials for treatment of patients were severely damaged. This is just a small sample of the potentially hazardous damaged sites that were identified through open-source data and visible damage on satellite imagery, and a full scoping mission would be needed for a complete assessment.



Reference map: © OpenStreetMap contributors | Urban damage assessment: © UNOSAT

According to FEAT, the facilities listed above are likely to store or process significant amounts of ammonia, solvents, disinfectants (including chlorine compounds), formaldehyde, glycerin, lubricants, acids, fuel, cyanide solutions, PCBs and many other hazardous substances.

2. Rubizhne, Luhansk region

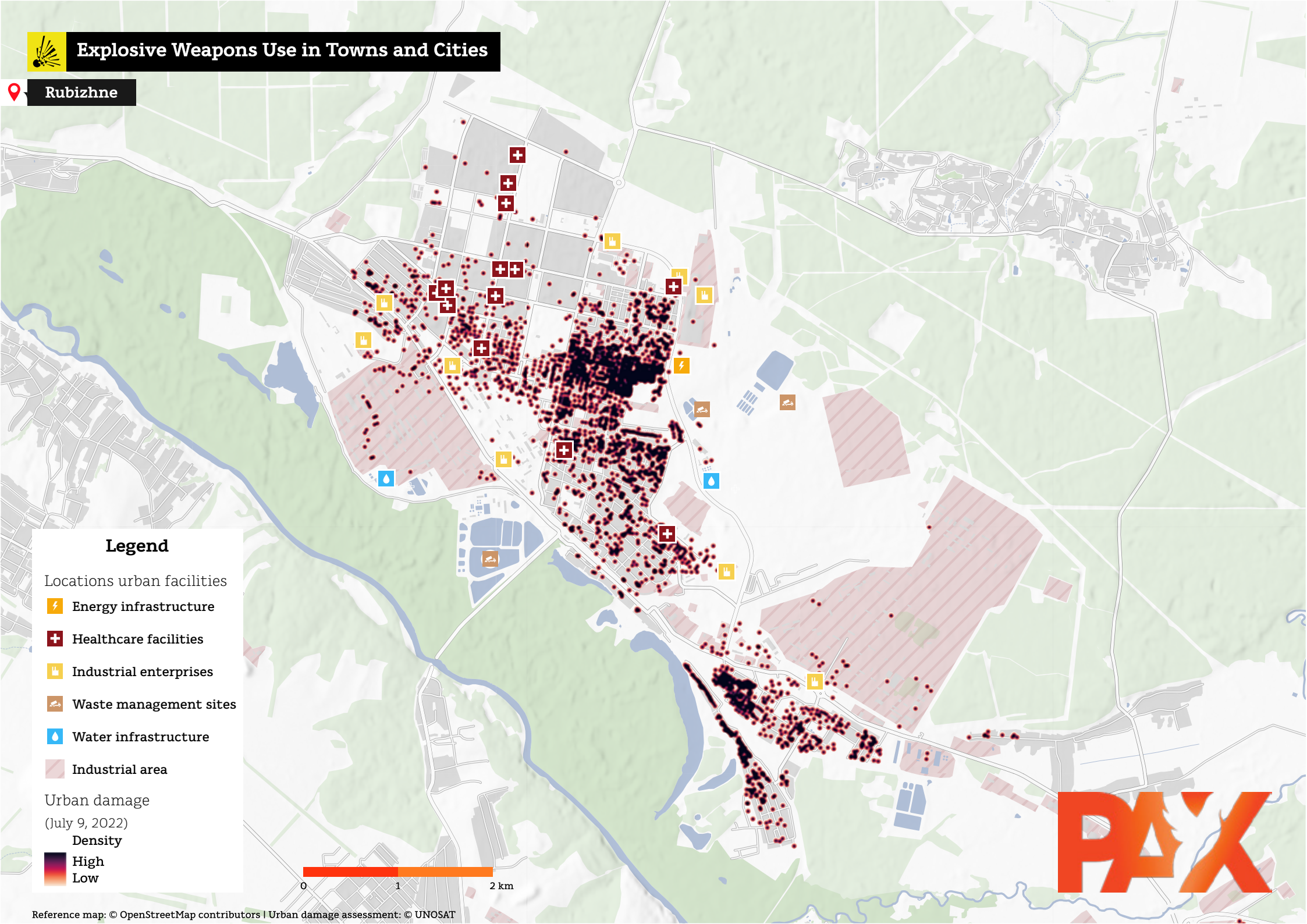
Rubizhne is located on the left bank of the Siverskyi Donets river, next to Sievierodonetsk in the Luhansk region. An industrial city, Rubizhne is also a center of Ukraine's agricultural sector, reflected in the number of agro-industrial enterprises in the city, including malt production, grain and crop cultivation facilities, oil seeds storage, production of packaging from cardboard and polymer materials, and chemical factories producing explosives and fertilizers. There is also a tailings storage facility located in the vicinity of the city, which stores more than 1.5 mln cubic meters of highly hazardous waste produced by Rubizhan Barvnyk LLC , the Zorya chemical plant, and a solid waste landfill. These fill an area of 4.4 hectares and hold 202,000 tons of accumulated (household) waste.

Russian forces began attacking Rubizhne on February 24, 2022, when a Russian warplane bombed the Zorya chemical plant. Intense strikes occurred throughout March 2022, and in April-May 2022 the city was occupied by Russian forces. Rubizhne had more than 60,000 residents before 2022, but its population was reduced to 15% of the prewar total during the fighting, with its urban area suffering significant destruction during the first two months of the Russian invasion.

Damage description and environmental risks

Analysis prepared by UNOSAT showed 2,688 structures in Rubizhne with visible damage as of July 2022: 488 buildings totally destroyed, 1,737 severely damaged, 207 moderately damaged and 256 possibly damaged, from a total of 6,931 structures in the area. The existing dataset is incomplete, making it impossible to draw conclusions about the full scope of damage.

The greatest risks in terms of environmental pollution and threats to human health are posed by damage to the city's facilities storing hazardous chemicals and toxic substances. The period of hostilities in March-May 2022 saw intense Russian attacks against civilian infrastructure, damaging energy facilities, water infrastructure and the city's main gas pipeline (Chervonopopivka-Rubizhne), while also destroying the modern grain elevator complex that was recently built. The large Rubizhan cardboard and container plant was also heavily damaged, with the southern part of the complex left in ruins. During the fighting over the city, there were concerns over toxic chemical


Explosive Weapons Use in Towns and Cities
Rubizhne
Legend
Locations urban facilities
Energy infrastructure
Healthcare facilities
Industrial enterprises
Waste management sites
Water infrastructure
Industrial area
Urban damage
(July 9, 2022)
Density
High
Low
0
1
2 km
PAX
Reference map: © OpenStreetMap contributors | Urban damage assessment: © UNOSAT

release as hazardous materials facilities were hit on various occasions, including the Golden Agro facility. This strike created a large red smoke plume from exploding nitro-phosphate or nitric acid, resulting in Ukrainian soldiers nearby suffering from chemical exposure.

Mapping the damage to Rubizhne shows that numerous industrial sites were affected by the fighting, including the Rubizhan pipe production facility, the Golden Agro grain storage and fertilizer plant, the Agregatbud railway repair plant LLC, the Zorya chemical plant and a number of other industrial production facilities and petrol stations. Several hospitals and pharmacies as well as educational facilities like colleges and schools suffered severe damage or destruction, while water treatment facilities, local thermal power plants and smaller workshops were also damaged. These hazardous facilities likely stored significant amounts of ammonia, pesticides, organo-phosphates, solvents, phosphoric acids, lubricants and fuels, among other substances.

3. Avdiivka, Donetsk region

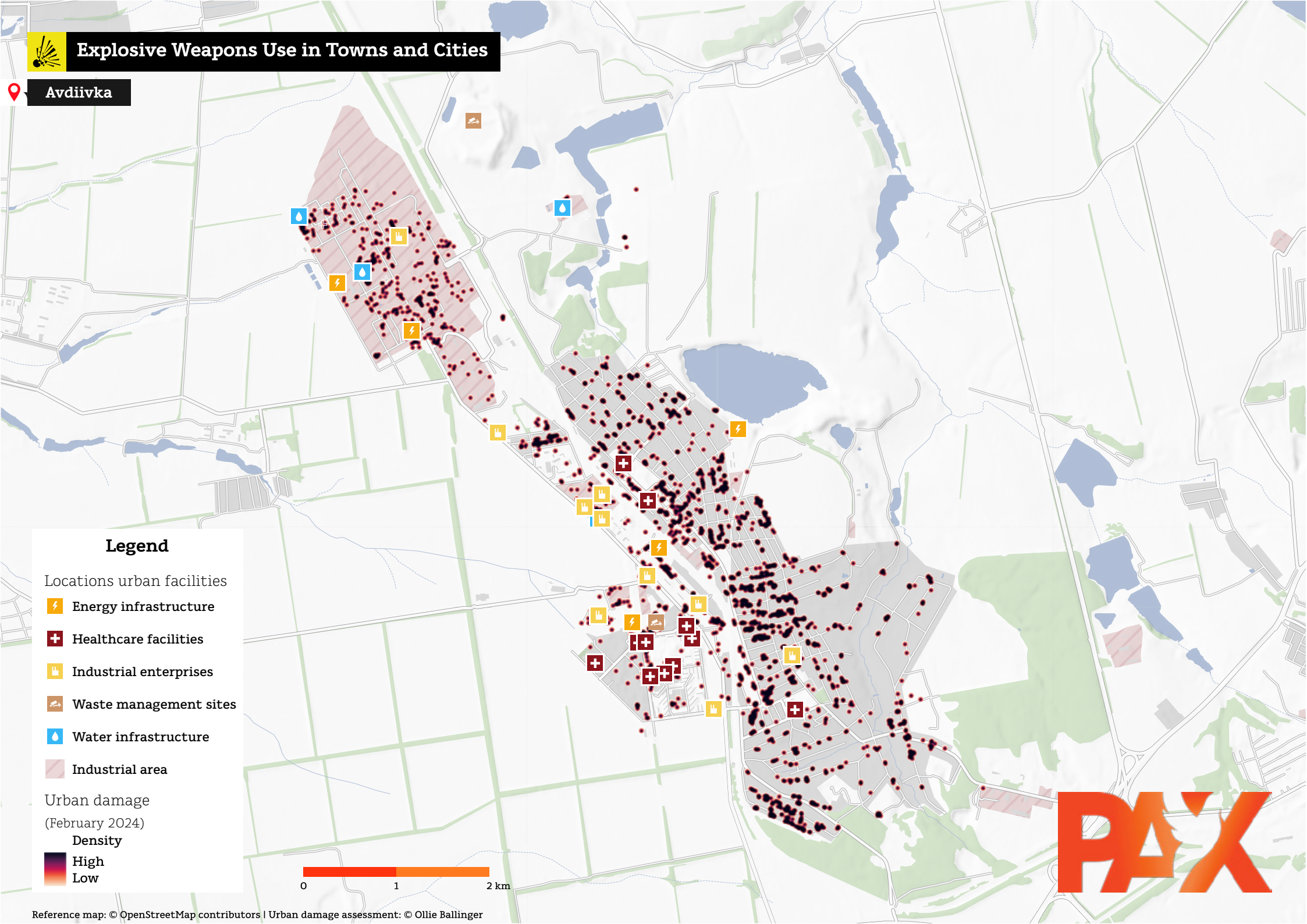
Avdiivka is a city in the Donetsk region in eastern Ukraine, with a pre-2022 population of roughly 35,000 residents. The city was built as a satellite city of the Avdiivka coke plant, one of Europe's largest coke-coal processing facilities. According to 2019 data, the nearby tailings ponds contain 6.5 million tons of waste hazard class IV coal-processing sludge and 443 thousands tons of waste hazard class II-IV chemical waste, the latter mostly consisting of resinous waste. The vast majority of the city's population was employed at this enterprise, leaving residents completely dependent on its stable work. The plant faced heavy shelling in 2017 when it became a part of the Russia-Ukraine frontline, a situation that worsened following the 2022 Russian invasion.

Since the beginning of the full-scale invasion in February 2022, Russian troops have been intensively shelling Avdiivka with various types of explosive weapons, including incendiary weapons and thermobaric ammunition. The city's urban area and coke plant have been the main targets of these attacks. The city and its infrastructure have been almost completely destroyed over two years of continuous shelling, leading to the halting of all public services in spring 2023 and the evacuation of most of the city's residents. In February 2024, Ukrainian troops retreated from the city, which was occupied by Russian forces that cut the only way for evacuation of more than 900 people remaining in the city.

Description of damage and environmental risks

According to UNOSAT estimates of Avdiivka's urban damage from November 2022, 634 structures displayed visible damage as of September 2022: 36 were destroyed, 505 severely damaged, 86 moderately damaged and 7 possibly damaged. There are at least 3,991 structures in the area according to UNOSAT data based on open source datasets. Local authorities reported in 2023 that more than 80% of the city's housing stock had been destroyed beyond any possibility of repair. As there have not been any updated damage assessments since, the PWTT tool using Sentinel-1 SAR data provides a useful addition. Using satellite imagery available upon February 2024, the analysis indicates that at least 16% of the buildings were damaged.

Mapping of Avdiivka's urban area revealed damage to, and destruction of, high-risk sites that store materials containing toxins, chemical substances and bacteria: a tuberculosis dispensary, the Avdiivka hospital, local pharmacies, multiple auto repair shops, metallurgical and construction materials plants, and water and sewage infrastructure.



Reference map: © OpenStreetMap contributors | Urban damage assessment: © Ollie Ballinger

The most dangerous site in the affected area is the Avdiivka coke plant, which halted operations in April 2022 due to constant heavy shelling. The dangerous installations containing hazardous substances moved out of the coke plant to avoid a large environmental catastrophe. Despite efforts to minimize risks by halting operations, there are still large volumes of hazardous substances at the site, as well as the nearby tailings storage facilities (TSF) with toxic waste. Damage to such chemical plants could cause serious public health risks to civilians in Avdiivka, and could have long-term environmental impacts on the nearby Skotovata and Siverskyi Donets rivers.

The offensive by Russian forces posed serious additional environmental risks to the coke plant. Social media posts and satellite imagery shows the severity of the damage around the many locations storing hazardous substances on the facility itself, and the nearby tailing ponds with toxic waste. Apart from visible damage to fuel storage tanks, coke oven batteries, the great concern is the technical state of the two main tailing ponds storing millions of tons of hazardous waste, containing toxic components like coal fuss; acid tar of sulfate compartments; waste of desulfurization solution; residues of phthalic anhydride department; polymers of benzene compartment; resins and oils of biochemical plants; residues of benzene rectification.

To remotely check the state of the area of tailings storage facilities, the remote sensing analysis with high-resolution satellite imagery was done by partner organization IMPACT. These objects were inspected at three timesteps: pre-war 2021, throughout 2022 and 2023 and in January 2024. There are a significant amount of visible impacts from artillery fire, with craters, both within and around the facilities. There are also military fortifications, including trenches, (very likely Russian) around the tailing facilities.

Looking at the scale of damage of surrounding area of TSFs provided on the satellite imagery below, apart of visible damage of the soil, there are high environmental risks of:

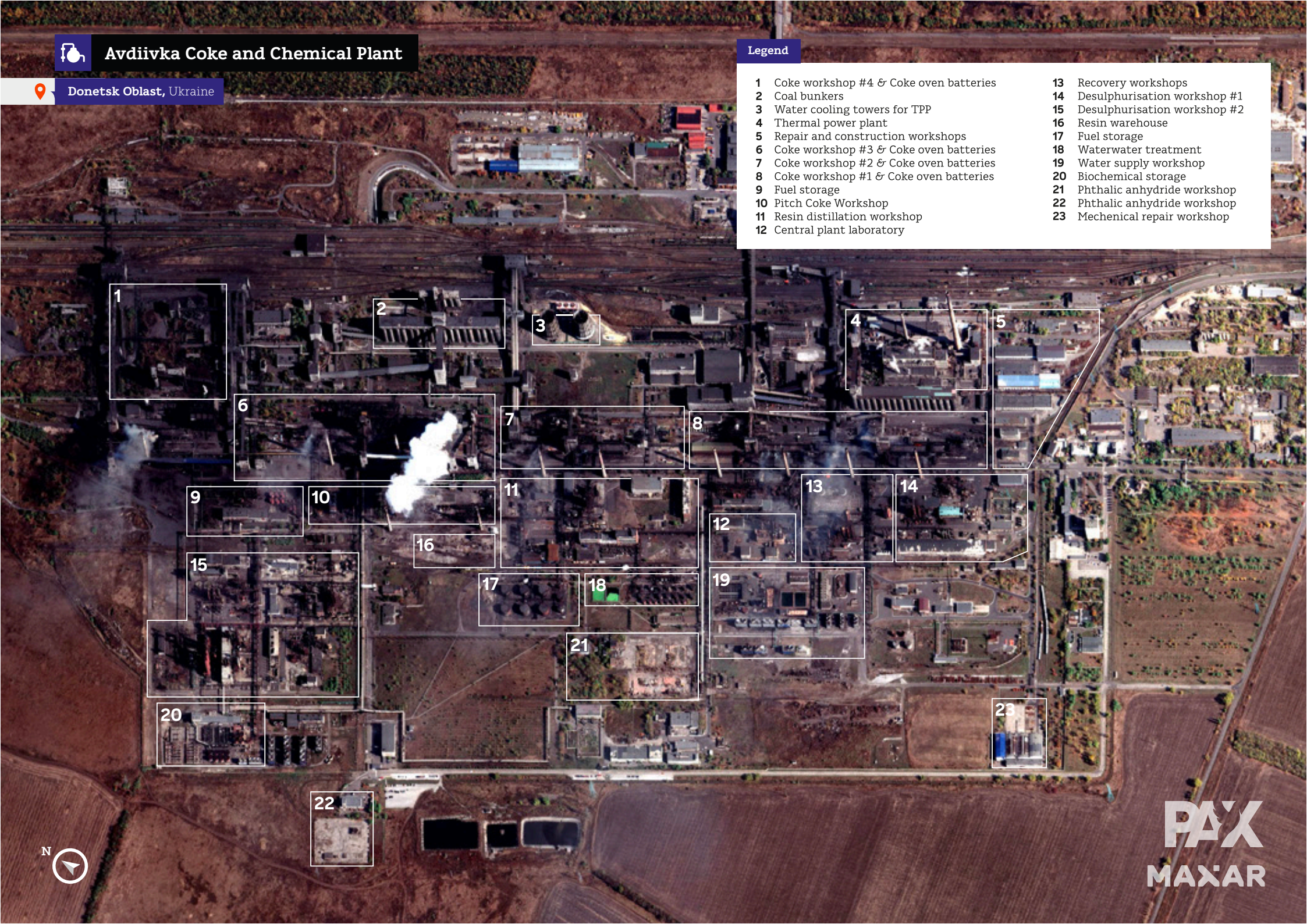
- Invisible destruction of such facilities, which can result in the dam's failure or at least leakages of liquid phase of waste from air dropped munitions or artillery shelling during two-year active hostilities.
- Not only these TSFs pose a threat to the local natural ecosystems due to military actions. Industrial area near TSFs also locates other hazardous facilities like the landfill and the concrete structured storage of used technical water of the coke plant with high levels of mineralization that is dangerous for the soil and water quality. All together bring a risk of poisoning of the environment by toxic substances.
- Soil contamination by toxic chemical substances inherent in munitions as well as the landfill, TSFs and other hazardous facilities of the coke plant.
- Groundwater can be impacted by hazardous substances as there were a few water wells built in 2019 near these facilities for the coke plant and the city use.

Avdiivka Coke and Chemical Plant

Donetsk Oblast, Ukraine

Legend

1 Coke workshop #4 & Coke oven batteries
2 Coal bunkers
3 Water cooling towers for TPP
4 Thermal power plant
5 Repair and construction workshops
6 Coke workshop #3 & Coke oven batteries
7 Coke workshop #2 & Coke oven batteries
8 Coke workshop #1 & Coke oven batteries
9 Fuel storage
10 Pitch Coke Workshop
11 Resin distillation workshop
12 Central plant laboratory
13 Recovery workshops
14 Desulphurisation workshop #1
15 Desulphurisation workshop #2
16 Resin warehouse
17 Fuel storage
18 Waterwater treatment
19 Water supply workshop
20 Biochemical storage
21 Phthalic anhydride workshop
22 Phthalic anhydride workshop
23 Mechenical repair workshop



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4. Bakhmut, Donetsk region

Bakhmut is a city in eastern Ukraine, well known for its wineries and salt mines and once an important rail hub. Located on the Bakhmutka river, the city was also home to several factories engaged in processing non-ferrous metals and producing mining equipment, tools, ceramic, pipe, glass, tile, plasterboard and dry mixes. Bakhmut also had a developed food industry, represented by mills, bread and meat processing plants, a dairy, a distillery, a champagne factory and a textile industry. As of January 2022, it had an estimated population of over 70,000 residents.

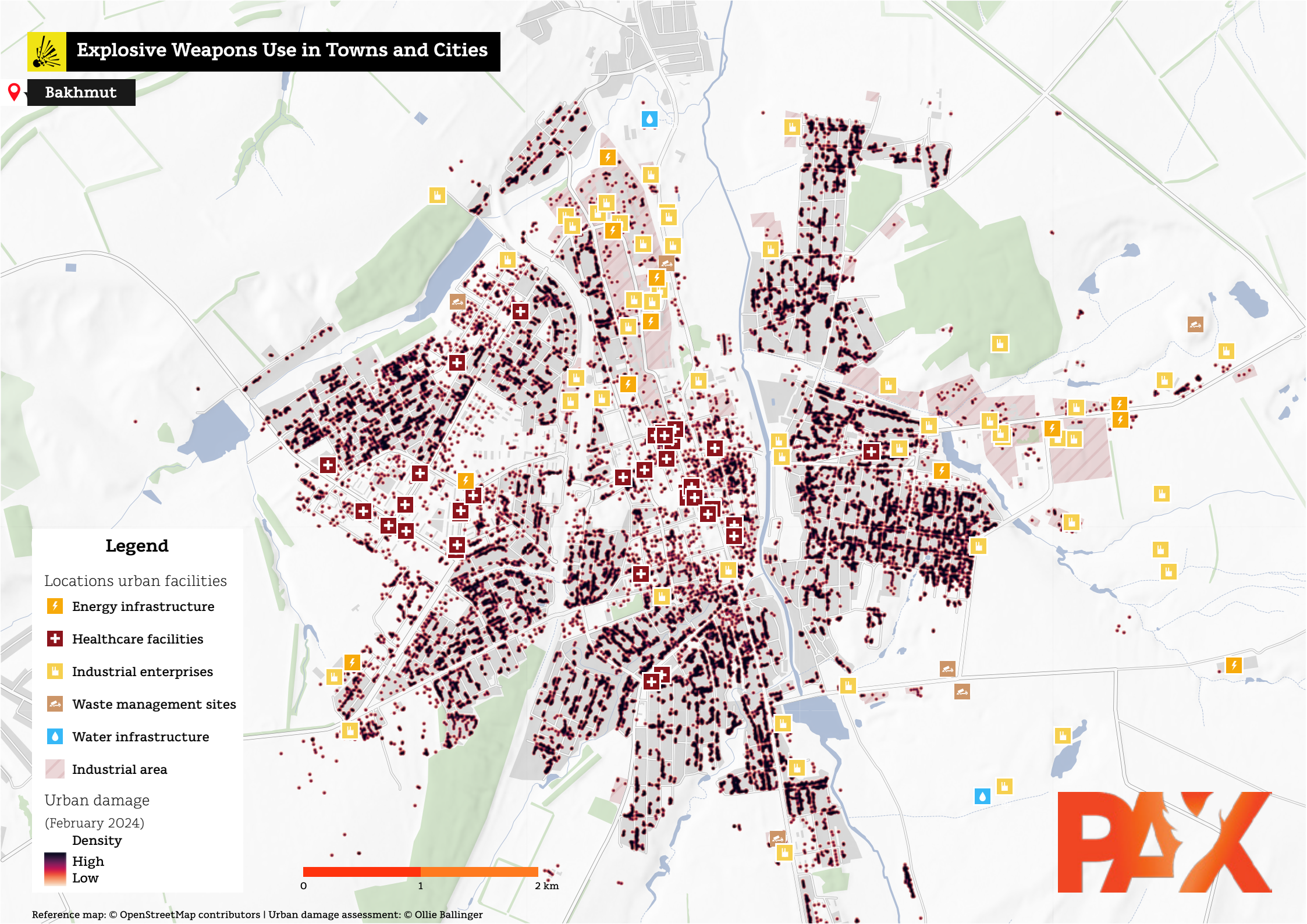
At the beginning of the 2014 war in Donbas, Bakhmut was contested by Russia-backed separatist forces, but it was recaptured by Ukrainian troops in July 2014. During the 2022 full-scale Russian invasion of Ukraine, Bakhmut once again became a frontline city and one of the key targets of Russia's offensive. The intense battle for Bakhmut, considered the war's deadliest and most prolonged urban battle, lasted for more than nine months and ended with the city largely destroyed and captured by the Russian troops in early June 2023. While Ukrainian forces have retreated from the city itself, they continue to fight in the vicinity of the city.

Description of damage and environmental risks

Images and drone footage from the city show a devastating level of destruction by Russian artillery and aviation, which Ukrainian officials compared to the war-ravaged Syrian city of Aleppo. By January 2023, when fighting was still concentrated in the eastern part of the city, approximately 20% of the 28,000 structures in Bakhmut had been destroyed or severely damaged, as reported by the Conflict Observatory. As the Russian offensive advanced further towards the central, western and southern parts of Bakhmut, the degree of destruction grew exponentially, with the most intense fighting happening in the western parts of the city in April and May, according to the media reports and by Sentinel-2 satellite imagery showing fires. Statements from local authorities indicated that almost 90% of multi-apartment buildings (605 buildings) and 35% of private houses in the city had been destroyed or damaged by June 2023. Aside from residential buildings, communal infrastructure, including the majority of the city's schools, hospitals and other medical facilities, bridges, water infrastructure and waste sorting plants were affected by the fighting. Most of the city's population has fled, while up to 500 civilians are estimated to remain in Bakhmut without access to gas, electricity or water.

Explosive Weapons Use in Towns and Cities

Bakhmut



Key environmental risks in Bakhmut stem not only from the scale of the rubble generated by the destruction of vast numbers of buildings, but also from potentially hazardous materials stored at industrial sites and energy facilities. One example is the AZOM (Artemovsky metal processing) plant in northern Bakhmut, comprised of machine-building plants, a metal press drawing factory, a heated towel rails manufacturing plant, and electrical equipment factory and other industrial facilities. The AZOM plant saw heavy fighting, including artillery shelling, in early spring 2023. After its capture by Russian forces, it was turned into a military headquarters and was hit by Ukrainian airstrikes. The Siniat construction factory in eastern Bakhmut was another area of intense fighting due to its strategic location; it consequently sustained severe damage. A number of construction materials warehouses, brick and furniture factories and auto repair shops were damaged by airstrikes or urban combat as well, according to Conflict Observatory data. Hazardous substances common at these facilities, such as nitric acid, natural gas, petroleum, isopropylene and alcohol, pose serious environmental risks when released into the environment as a result of attacks. Bakhmut's food and beverage industries have also been affected: its wineries, including the famous Artwinery, along with gypsum mines used for aging were destroyed.The city's meat processing plant, dangerous in view of its potential ammonia release, was also destroyed. Throughout the city, energy infrastructure sites, including numerous electric substations, boiler houses and gas stations, were damaged, potentially leading to the release of hazardous substances and localized water, soil and air pollution.

5. Chernihiv, Chernihiv region

Chernihiv is one of Ukraine's 24 regional (oblast) centers, located in the country's north, just 80 km from the border with both Belarus and Russia. Prior to 2022, Chernihiv's population was around 280,000 people. As one of the oldest cities in Ukraine, dating back to the Kyivan Rus' period, Chernihiv is known for its historic heritage and is one of Ukraine's prominent cultural and religious centers. Chernihiv is also home to numerous enterprises in the textile and food industry, as well as mechanical engineering and electronic technologies plants.

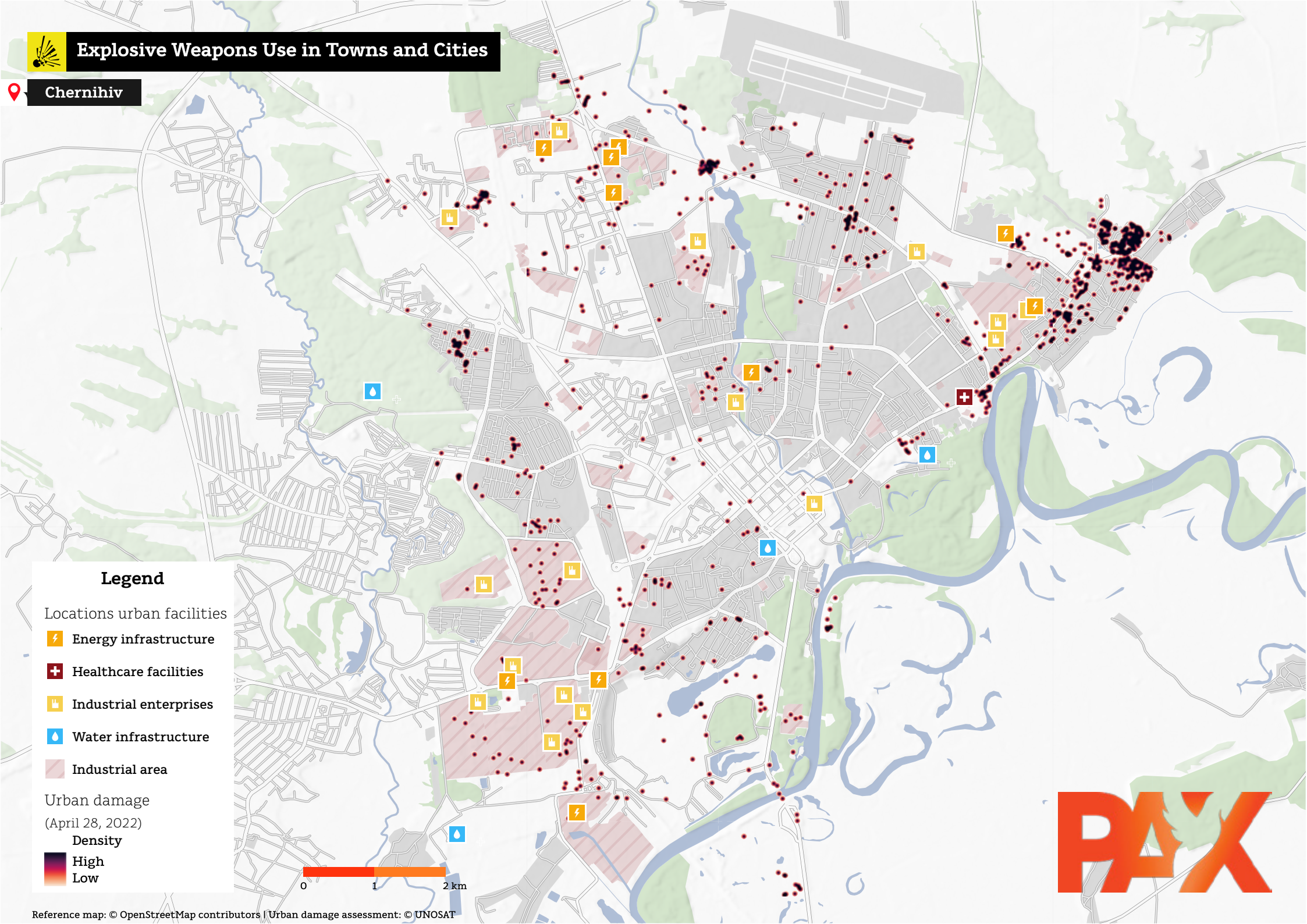
The city was attacked by Russian troops in the first days of the full-scale invasion, becoming completely besieged by early March until the Russian retreat from the region in early April 2022. During the encirclement, the city was disconnected from the national power grid and was left with no gas for cooking and heating and with limited access to clean water

Description of damage and environmental risks

The city of Chernihiv has been heavily damaged by shelling from Russian forces, especially during the initial stages of the invasion. According to UNOSAT's preliminary remote sensing-based damage assessment, over 974 of the city's roughly 18,000 structures were damaged, with 258 completely destroyed, 362 severely damaged and over 250 moderately damaged. Data received by PAX partners from local authorities indicates that 150 residential buildings hosting roughly 13,000 apartments were directly hit, with over 730 more multi-apartment buildings suffering from indirect effects of explosions. Numerous units of communal infrastructure, including water supply and sewage pumping stations, healthcare facilities, schools, transport and enterprises facilities have been destroyed or damaged. Local authorities have stated that over 5,600 structures have been damaged.

Explosive Weapons Use in Towns and Cities

Chernihiv



PAX

Reference map: © OpenStreetMap contributors | Urban damage assessment: © UNOSAT

Major environmental health risks are posed by damage to hazardous facilities in and near the city center. Targeting of fuel tankers and industrial sites by airstrikes in and near the city resulted in heavy smoke pollution and the release of a wide range of chemical substances in populated areas. The fuel tanker farm west of the city saw seven oil tanks damaged or destroyed by missile strikes, causing massive fires and smoke plumes. Each of the seven tanks contained an estimated 5,000 m^3 of diesel. Airstrikes also hit several large factories, the city's thermal power plant and chemical storage tanks in the southern industrial district, causing intense smoke from the burning of fuel and chemicals.

Broader environmental impacts can be expected from other damaged hazardous facilities in the city, including the Epicenter shopping mall in the northeast and the Ramzavod shopping center and cardboard production plant in the north. Airstrikes also hit the city's water treatment facilities in the northwest and the south, disabling access to clean water for civilians in parts of the city.

Burning fuel or chemical storage tanks in Chernihic, March 21, 2022

6. Hostomel, Kyiv region

Hostomel is a town located just northwest of Kyiv, on the west bank of the Irpin river, with an estimated 18,000 residents as of January 2022. Hostomel is bordered to the southeast by a large pine forest, part of the Holosiivskyi National Nature Park. The town is mainly known for the Antonov Airport, an international cargo airport and testing facility, owned by the Antonov company, a part of Ukroboronprom, Ukraine's state-owned defense industry concern. This aircraft manufacturing and services company specializes in very large aircraft and planes that can land and take off from unprepared runways.The remainder of the town's economy runs on a number of medium-sized logistic companies and warehouses, such as BADM pharmaceutical products and the JAM warehouse complex, as well as production companies such as the Vetropack glass factory, the Buchansky starch plant, the metal products factory Kominvent, and the Unilever tea factory.

Hostomel was attacked in the first days of the Russian invasion, quickly captured by Russian troops as a forward operating base near Kyiv and retaken by Ukrainian forces in early April 2022. 400 people are reported to have gone missing during the 35 days of Russian occupation of the town, which was also a site of mass Russian atrocities.

Description of damage and environmental risks

Experts from the Ukrainian-led initiative UADamage identified widespread destruction all over town, using drone videos to assess the impact. 20% of all buildings in the town are estimated as damaged[2].

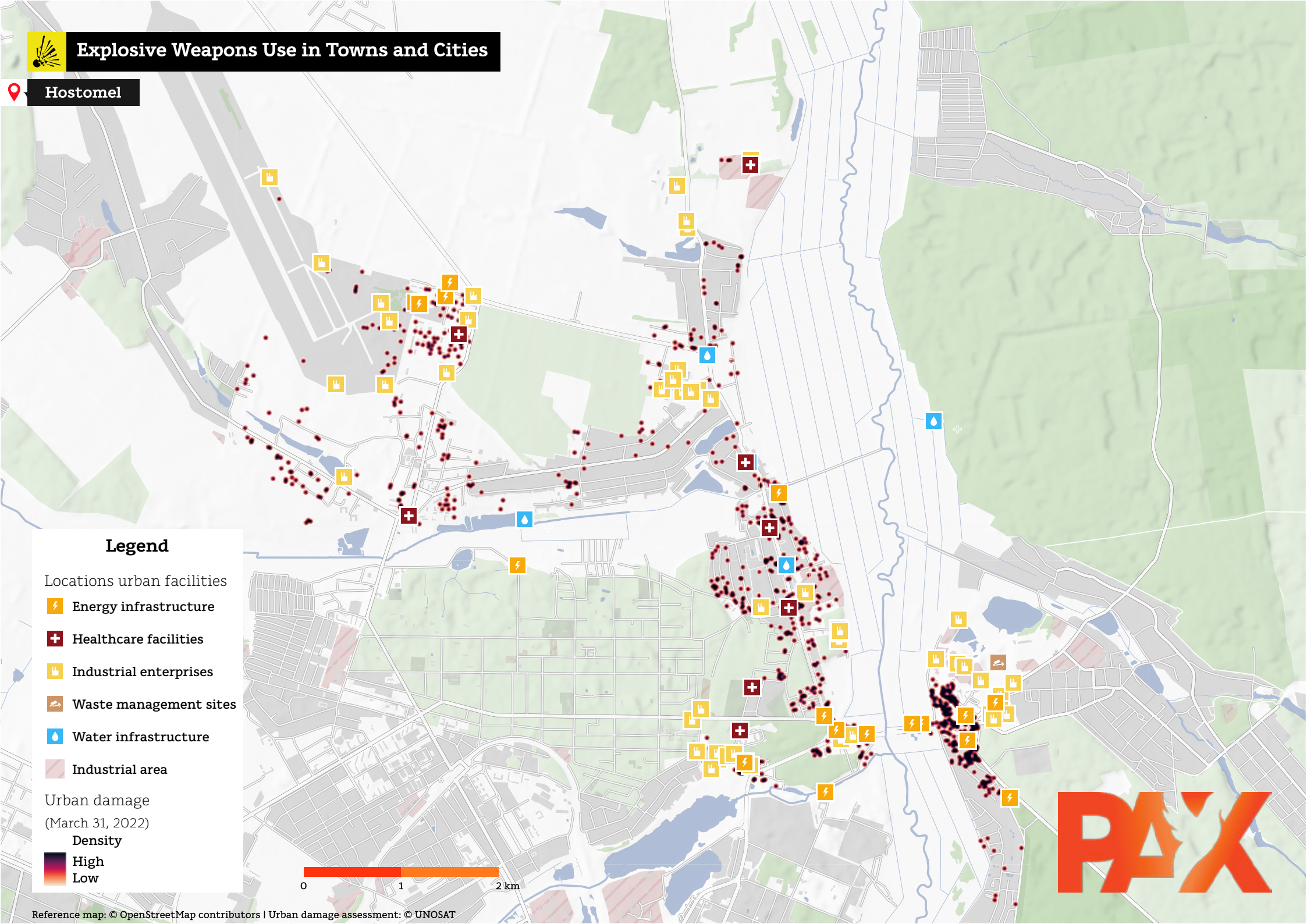
The Antonov airport was also heavily damaged. The destruction of its oil depots resulted in large fires, while severe oil pollution of the surrounding soil and ground water is highly likely. The Litak Mriya aircraft hangar was also severely damaged, resulting in the destruction of the Antonov An-225 Mriya, the world's largest freight airplane. Finally, numerous buildings and warehouses at the airport were damaged.

Further shelling resulted in the complete destruction of the BADM logistical hub for pharmaceutical products, likely leading to leakage of medical chemicals into the surrounding environment. The Keuhne and Nagel logistic hubs were damaged in the fighting, along with numerous other warehouses. There is visible damage to the Buchansky starch factory, the Kominvent metal products factory, the Irpinske 13250 motor transport company, the DAF Trakspart facility and several nearby gas stations, potentially resulting in industrial contamination of the immediate surroundings. Buildings and infrastructure around several water wells were also destroyed, likely impacting access to clean water for drinking and sanitation.

Only very rudimentary estimates exist of the amount of debris generated during the battles at Hostomel, based on a combination of the UNDP methodology developed in Syria, remote sensing of buildings, and circular economy approaches. Based on such very rough estimates, it would take decades to centuries to remove all the rubble, depending on the amount of trucks available (e.g. 50 to 200 for this estimate) and the distance of the debris disposal site (e.g. 5 km for this estimate). Hopeful pilot projects3 have been set up in Hostomel that apply circular economy principles to recycle and reuse 98% of the debris for the construction of 450 apartments.

2 A parallel, but coarser damage assessment by UNOSAT (resolution of 50 cm/pixel instead of UADamage's 5-10 cm/pixel) identified 28% destruction level (865 structures with visible damage out of a total of identified 3,116 structures). They clarify that "While no complete count of buildings for Hostomel is available an open source dataset which is visibly incomplete indicates at least 3,116 structures in the area."

3 A collaboration between neo-eco, Ukraine Resilience, and UADamage


Explosive Weapons Use in Towns and Cities
Hostomel
Legend
Locations urban facilities
Energy infrastructure
Healthcare facilities
Industrial enterprises
Waste management sites
Water infrastructure
Industrial area
Urban damage
(March 31, 2022)
Density
High
Low
0
1
2 km
PAX
Reference map: © OpenStreetMap contributors | Urban damage assessment: © UNOSAT

Conclusion

Russia's full-scale war against Ukraine has resulted in widespread destruction, with large-scale humanitarian impacts and environmental damage. Use of explosive weapons in populated areas accounts for the lion's share of this destruction and for most of the civilian casualties. Yet, while EWIPA's direct impact on people and their livelihoods is broadly documented, its environmental consequences and risks are often overlooked. Those include acute health risks from widespread damage to built-up areas with the subsequent release of chemical substances, as well as long-term impacts from the millions of tons of rubble and debris generated by EWIPA, which should be urgently addressed and mitigated.

This report used the example of six towns and cities in different regions of Ukraine as a lens to examine the particular environmental footprint of EWIPA, be it from targeting agro-industrial facilities in or near Rubizhne and Sievierodonetsk, the results of months-long battles in urban areas as witnessed in Bakhmut, attacks on petrochemical facilities in Chernihiv, the destruction of oil depots and logistical hubs in Hostomel, or the risks from Ukraine's chemical industry and toxic waste ponds around the Avdiivka coke plant. These six case studies show the breadth of environmental risks associated with the use of explosive weapons, specifically in such a heavily industrialized country as Ukraine with a large number of potentially hazardous sites.

As many of the affected plants and factories, workshops, chemical and tailings storage facilities, medical facilities, and energy infrastructure were storing materials containing toxins, chemicals or pathogens, their destruction or damage leads to the pollution of air, water and soil, detrimental for both human health and ecosystems. Besides the environmental risks emanating from the affected hazardous materials facilities, the use of a variety of explosive weapons and munitions also threatens environmental and public health due to their toxic constituents, such as energetic materials and heavy metals.

In the selected cities, thousands of buildings have been destroyed or damaged. In addition to environmental pollution by construction materials such as asbestos, lead or silica, toxic dust emissions from explosions and the mixing of conflict rubble with industrial, medical or household waste, the issues of safe storage of the multi-tons of debris also create substantial environmental and health risks. Moreover, post-war reconstruction of towns, cities and enterprises will also require an immense amount of natural resources, along with the additional environmental footprint and climate impact this entails.

In peacetime, the main guarantee of maintaining the environmental safety of any territory is preventing environmental pollution in the first place. In times of war, possible measures to at least minimize environmental damage include a combination of mapping environmentally sensitive locations, placing limitations on targeting certain areas, and addressing environmental implications as soon as the security situation allows for it. While the most effective way to prevent further humanitarian and environmental impacts of the destruction of urban areas in Ukraine would be to stop the Russian aggression and liberate Ukraine's territories, there are a number of measures that have to be taken to protect Ukraine's people and environment even while the war is still ongoing.

Recommendations

To protect civilians against the impacts of the use of explosive weapons in populated areas states should:

1. Avoid using explosive weapons, especially those with wide area effects, in populated areas, for the harm they pose to civilians, directly and indirectly. To this effect, states should join and implement the November 2022 Political Declaration on Strengthening the Protection of Civilians from the Humanitarian Consequences Arising from the Use of Explosive Weapons in Populated Areas.

To prevent the humanitarian impact from the use of controversial weapons, states should:

2. Immediately stop the use of cluster munitions and anti-personnel landmines, and accede and implement the Anti-Personnel Mine Ban Convention and Convention on Cluster Munitions without delay. States should furthermore refrain from the use of incendiary weapons and depleted uranium munitions, especially in populated areas.

To minimize the environmental impact from the use of explosive weapons, states should:

3. Provide financial and institutional assistance in emergency preparedness, developing emergency response plans for cities using modeling of probable accident scenarios from military actions in populated areas. The response plan should include a procedure of coordination between authorities, and should also consider such criteria as the environmental aspects of the locations of hazardous facilities and the properties of hazardous substances or materials. Technical capacity is needed for the cleanup of territories from unexploded ordnance and pollution localization, as well as for dealing with conflict rubble.

4. Support full-scale damage assessments of all populated areas, including environmental risk assessments, monitoring and evaluation of impacts and effects, with funding and expertise. This helps to understand environmental risks associated with urban damage and allows to develop an appropriate green reconstruction model on both the national and local levels, which supports the sustainable development of affected territories with regards to social, economic and environmental components.

5. Provide financial and institutional support in the development and implementation of long-term plans for the rebuilding efforts of urban areas of Ukraine, considering both green recovery efforts and the principle of "building back better" with measures on environmental rehabilitation, based on the results of full-scale damage assessments held for each damaged or destroyed city.

6. Highlight concerns over the environmental dimensions of the use of explosive weapons in populated areas in relevant international accountability discussions over Russia's invasion of Ukraine and in multilateral discussions on environment, peace and security.

7. Mainstream environmental protection in military doctrine and integrate policies aimed at minimizing environmental damage into training and planning, as well as share targeting data, where possible, with relevant mine-clearance organizations to improve effective environmental response. For reference, see the recent ICRC's Updated Guidelines for the Protection of the Natural Environment in Armed Conflict and the International Law Commission's Principles on Protection of the Environment in Relation to Armed Conflict.

To address the issue of conflict-rubble and debris, Ukrainian authorities and international assistance programs should:

8. Arrange debris storage facilities in an environmentally safe manner, taking into account the requirements of the relevant standards for such types of waste. Storing recyclable debris will enable future recycling once the demand for recycled debris materials materializes.

9. Develop a market demand for recycled debris materials through debris recycling trials, materials testing, demonstration of applications and ensuring that materials specifications are adopted by the construction industry.

To strengthen accountability for environmental damage, Ukraine and the international community should:

10. Initiate a Group of Friends on Protection of the Environment in Relation to Armed Conflicts to develop a plan for documenting environmental incidents caused by military actions in order to further bring Russia, as the aggressor country, to criminal and financial responsibility and include an environmental component in existing registries of damage.

Crater filled with water after a missile struck a water pipeline in the town of Bakhmut, on July 1, 2022

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