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The Biggest Explosions at Ammunition Depots During the Russia-Ukraine War

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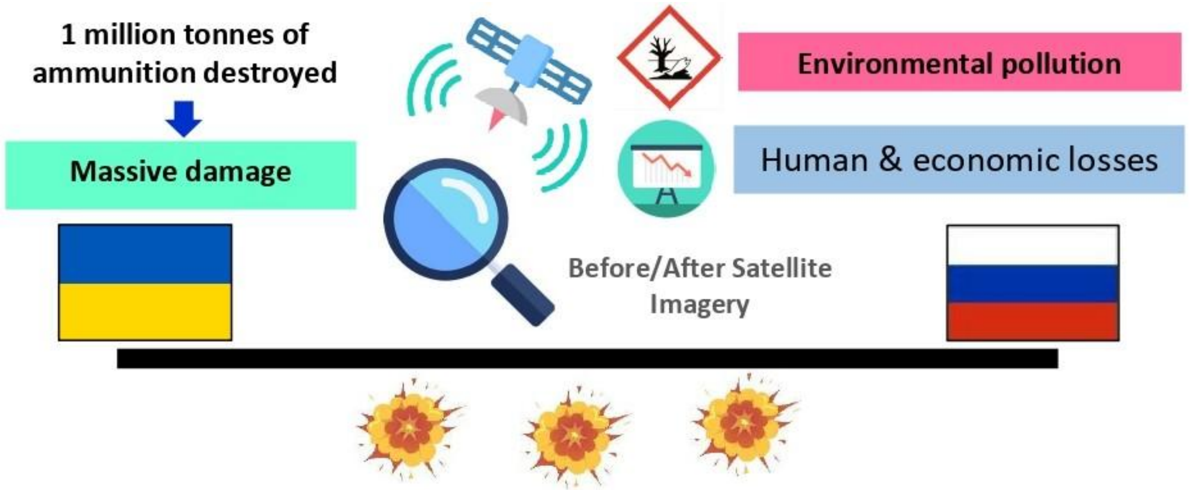
Graphical Abstract

This study examines the largest ammunition depot explosions during the Russia-Ukraine war, highlighting their devastating consequences. Over one million tonnes of ammunition have been destroyed, leading to significant human casualties, economic losses, and severe environmental pollution. The use of remote sensing technologies has been crucial in assessing the scale of destruction and its long-term impacts



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Abstract: Since 2014, both Ukraine and Russia have witnessed big explosions at ammunition depots. The total mass of destroyed ammunition has now reached about one million tonnes. In the process, many people have been killed or maimed; economic loses are estimated in billions of dollars; and the air and soil have been significantly polluted.

Keywords: *Explosions, Ammunition, Russia-Ukraine, Remote sensing.*

Introduction

Every war is destructive – of the environment, economy and society – and scientists have contributed their particular insights to the sad chronicle [1-6]. The Russia-Ukraine war, which began in 2014 and intensified on February 24, 2022, is no exception [7-9]. By October 2023, almost 500 000 combatants and more than 30 000 civilians had been killed or wounded; more than 11millions displaced; and damage to civilian infrastructure and the environment, including widespread chemical pollution of air, water and soil, was estimated at $56.4 billion [7]. More than a year on, these losses have doubled, with the dead and injured now close to one million. The environmental impacts of the war are widely reported [8,10-19]; about 30% of Ukraine's territory has been sown with mines and unexploded ordnance, and landscape destruction, shelling, forest fires and pollution afflict 30% of Ukraine's protected areas.

Remote sensing provides invaluable evidence and oversight; thus Shevchuk *et al.* [15] identified the destruction of oil depots, forest fires, and pollution caused by the destruction of a water treatment plants. Hostilities are often accompanied by fires which can be studied through primary processing of remote sensing data. MODIS Terra and Aqua satellites have special channels designed for fire monitoring, and have become the primary sensors for active fire detection [20], as applied by Shevchuk *et al.* [15] and Tomchenko *et al.* [21].

Incidents at ammunition depots in Ukraine between 2014 and 2018 reported by Zabrodskyi *et al.* [9] destroyed over 210,000 tonnes of ammunition, a significant part of which was 152mm shells and rockets for multiple-launch systems. For comparison, in the first five years of the war in Donbas, the Armed Forces of Ukraine spent about 70,000 tonnes of ammunition. Chornohor [22] describes explosions at ammunition depots in Svatove and Balakliya, the latter the biggest in Eastern Europe extending over 3.7 km^2 and holding 125,000-175,000 tonnes of ammunition. A more precise quantity (138,000 tonnes) is given by Ovcharenko & Tabunenko [23], about half of which exploded, releasing three times the energy of the atomic bomb dropped on Hiroshima. Moreover, these munitions contain lead, zinc, nickel, barium, manganese, copper, antimony, depleted uranium, etc. – all toxic in varying degrees – that can enter our bodies not only with air or water but, also, through the skin and hair [12].

Beyond Ukraine, in 2011, Russian military intelligence (GRU) detonated an ammunition depot in the Bulgarian village of Lovnidol, near Gabrove, that contained 3120 152mm shells; secondary explosions lasted for several days [24,25]. There were two similar incidents on October 16 and December 3, 2014, in the Czech Republic, near Vrbetice, where about 7,000 tonnes of military material and about 1,000 tonnes of explosives were stored. The first, which claimed two lives, was followed by 355 uncontrolled explosions; after the second incident on December 3, there were fewer uncontrolled explosions. Then five evacuations were ordered, 2 000 people were forced to leave their homes, work or schools [26,27]. The saboteurs included the two men who, in 2018, attempted to assassinate former Soviet spy Sergei Skripal, in Salisbury, England. Subsequently, the Czech Republic expelled 18 staff of the Russian embassy. The situation has deteriorated since Russia's invasion of Ukraine in 2022; there have been with several incidents at industrial enterprises in the UK, USA and elsewhere that supplied weapons to Ukraine [24].

In the face of the incessant hazard, this study is initiated as a tool for research and publicity for big explosions at ammunition depots.

Materials and Methods

Study Area

The Russia-Ukraine war has encompassed an extensive area not only of Ukraine but, also, of Russia. At the outset, incidents were confined to Ukraine but they soon spread to Russian territory; in some cases, as far as 500 km (Fig. 1).

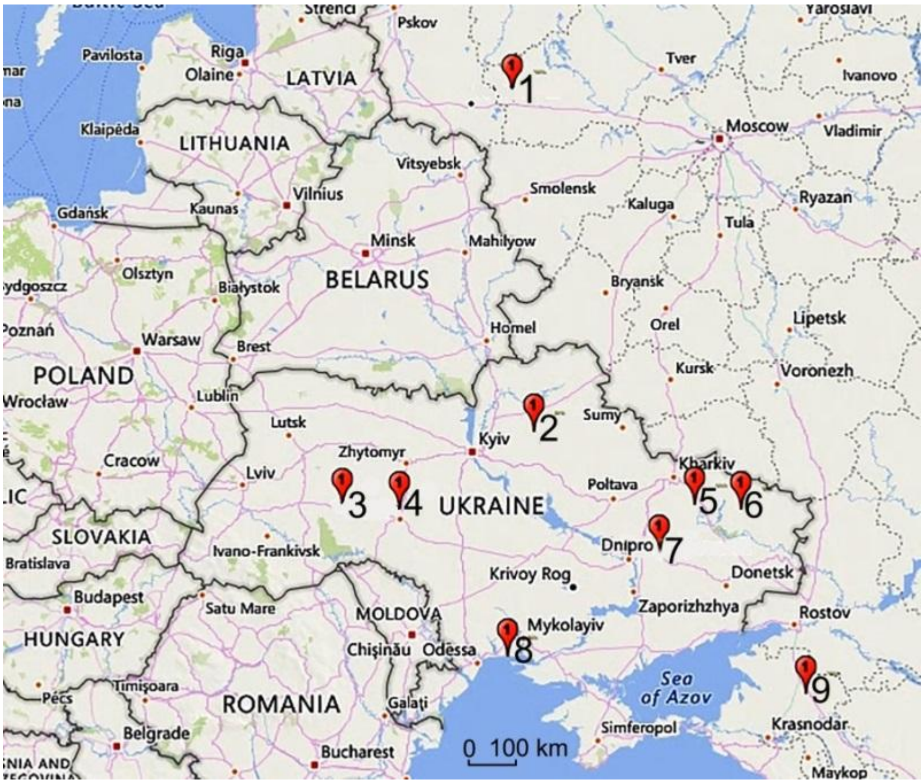

Figure 1. Location of ammunition depots experiencing significant explosions: 1, Toropets; 2, Druzhba; 3, Gruzevitsa; 4, Kalynivka; 5, Balakliya; 6, Svatove; 7, Pavlohrad; 8, Ochakiv; 9, Tikhoretsk.

Data and Methods

The main source of data is provided by remote sensing, especially the EU Copernicus website (https://browser.dataspace.copernicus.eu) that holds images taken by Sentinel 2 satellites, which have a revisit time of 3-4 days and a spatial resolution of 10m. Combination of spectral channels B12, B8 and B3 gives a good picture of fire; not quite so good by combination of B11, B8 and B4.

Information on thermal anomalies was also abstracted from https://firms.modaps.eosdis.nasa.gov/map, which holds data from the NOAA-2, Suomi NPP, Aqua and Terra satellites. Their spatial resolution is much poorer than Sentinel 2 but the site is good for quick searches for hotspots; https://worldview.earthdata.nasa.gov also presents the results of Earth surface imaging by the Aqua and Terra satellites, supplemented with information on air quality, cloudiness, *etc.* In some cases, we employed high spatial resolution data from Google Earth Pro. In many cases, the first alert was provided by the media, initiating the search for additional data on incidents.

Results and Discussion

Big explosions began early in the Russia-Ukraine war. Our research reveals about a dozen ammunition depots destroyed on the territory of Ukraine (Tab.1), which significantly depleted supplies to the Armed Forces of Ukraine.

Table 1. The biggest explosions at ammunition depots.

Date	Location	Coordinates
29-30.10.2015	Svatove, Luhansk oblast, Ukraine	49°24′03″N 38°11′36″E
23.03.2017	Balakliya, Kharkiv oblast, Ukraine	49°28′55″N 36°52′35″E
26-29.09.2017	Kalynivka, Vinnitsa oblast, Ukraine	49°24′37″N 28°29′56″E
03.05.2018	Balakliya, Kharkiv oblast, Ukraine	49°28′55″N 36°52′35″E
09.10.2018	Druzhba, Chernihiv oblast, Ukraine	50°48′17″N 32°19′46″E
09.01.2023	Ochakiv, Mykolaiv oblast, Ukraine	46°36′08″N 31°32′53″E
30.04.2023	Pavlohrad, Dnipropetrovsk oblast, Ukraine	48°34′42″N 35°50′50″E
13.05.2023	Gruzevitsa, Khmelnytskyi oblast, Ukraine	49°27′05″N 26°52′33″E
18.09.2024	Toropets, Tver oblast, Russia	56°30′29″N 31°42′52″E
20-21.09.2024	Tikhoretsk in Krasnodar oblast, Russia	45°53′08″N 40°02′27″E
21.09.2024	Toropets, Tver oblast, Russia	56°21′34″N 31°38′42″E

Explosions at Ammunition Depots on Ukrainian Territory

Svatove, Luhansk oblast on 29-30 October 2015

Svatove is located about 150km southeast of Kharkiv. About 3 000 tonnes of ammunition was stored at a depot in the southeastern outskirts of the town. Fires and explosions began on October 29, 2015, and continued the next day. Several members of the Armed Forces of Ukraine were killed and injured and the arsenal was practically destroyed. The consequences of this incident were studied using Google Earth Pro data (Fig. 2).

Figure 2. Satellite images from Google Earth Pro of ammunition depot in Svatove: on the left, taken in August 2013; on the right, in June 2016.

Balakliya, Kkarkiv oblast, 23 March 2017

Ammunition depot 65, belonging to military unit A1352, was located about 1 km north-east of Balakliya town (Fig. 3) and extended over 3.7 km^2.

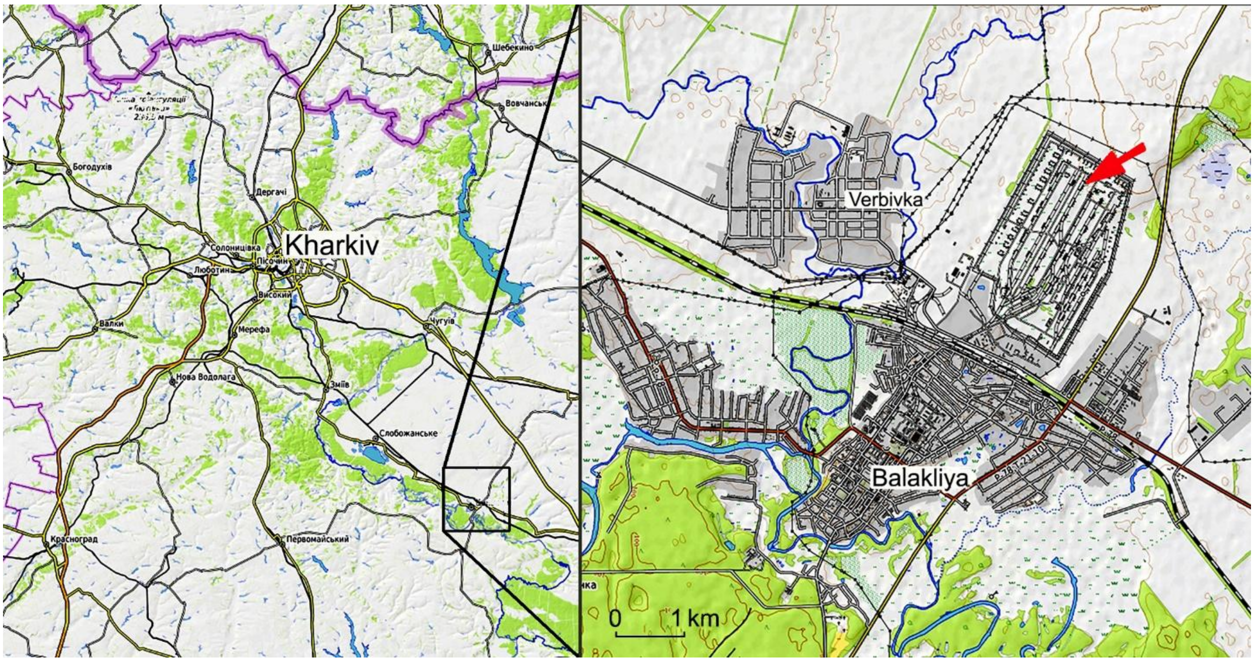

Figure 3. Location of Balakliya ammunition depot.

The depot held some 5million shells, more than all the munitions expended in the Gulf War in 1991 [3] and many left over from the days of the USSR. The ammunition was partly in underground storage, partly stacked haphazardly in the open; the ammunition boxes were rickety; the wooden underground storages were not treated with fire-retardant; and there was need to repair the lightning conductors and install a modern automatic fire alarm system [22].

Fire broke out at about 02:45 Kyiv time on 23 March 2017. Within 15 minutes, there were massive explosions; shells flew up to 1km, fragments spread from 5-10km; the column of fire reached 150-200m, and was seen at distances of up to 30km (Fig. 4); about 1kt of smoke, 35kt of carbon dioxide, 5kt of carbon monoxide, and about 500t of soot were released into the atmosphere [22].

Figure 4. Explosions at the ammunition depot in Balakliya (Chornohor 2018).

Fearing a Russian offensive, residents fled, even at night [22]. According to the Temporary Investigative Commission of the Parliament of Ukraine, more than 90% of the ammunition and military property stored there, valued at about $US 400 million, was destroyed. The explosions damaged, also, several hundred residential buildings; and 20 thousand residents of Balakliya and nearby villages were evacuated. The loss of ammunition crippled resistance to the subsequent Russian invasion. For a more complete study, Sentinel 2 satellite images taken at the time were used. A combination of B12, B8 and B3 was used to identify fires (Fig. 5).

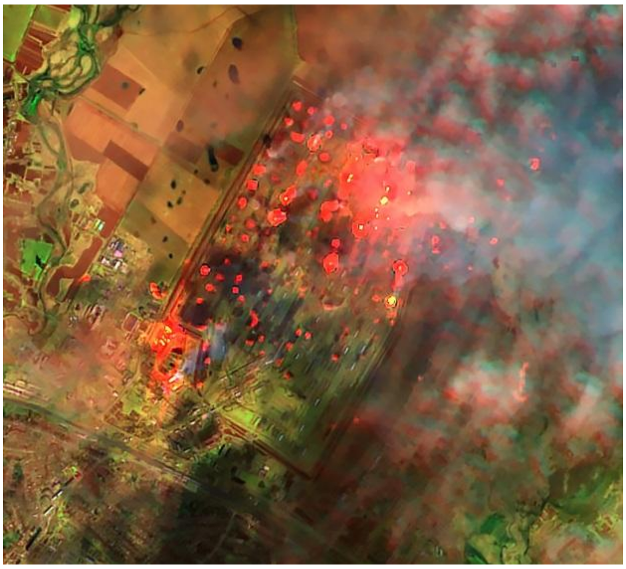

Figure 5. Sentinel 2A satellite image of explosions in Balakliya taken on 23 March 2017, obtained individually using bands B12, B8 and B3.

Google Earth Pro imagery reveals the destruction of dozens of buildings clearly visible in the image taken in 2014 but missing on the 2018 image; instead, numerous craters are visible on and around the ammunition depot (Fig. 6). Thermal anomalies after explosion in Balakliya were registered at FIRMS and WORLDVIEW websites on 23 March 2017, but disappeared next day.

Figure 6. Satellite images from Google Earth Pro at the Balakliya ammunition depot: on the left, taken in October 2014; on the right, in April 2018.

The remnants of the Balakliya arsenal were practically destroyed the following year, actually on May 3, 2018.

Kalynivka, Vinnytsa oblast, 26 September 2017

The arsenal in Kalynivka was one of the biggest in Ukraine; its area was about 5.9 km^2 and it held 188 000 tonnes of munitions [23]. The first explosions at the site occurred at around 9pm on 26th September 2017, and continued for several days. Several hundred people and more than 100 appliances were called on to contain the emergency and about 30 000 people were evacuated.

Satellite images show that some of the warehouses in Kalynivka survived (Fig. 7) but, on the day of the incident and later, cloud cover precluded high-quality pictures.

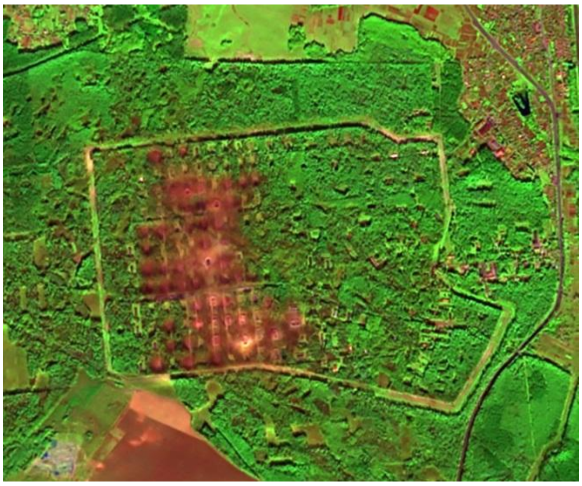

Figure 7. Sentinel 2 satellite images of the ammunition depot at Kalynivka: on the left, on 18 September 2017; on the right, on 18 October 2017.

Druzhba, Chernihiv oblast, 9 October 2018

The ammunition depot near Druzhba town was one of the three biggest arsenals in Ukraine, containing 69,500 t of ammunition, 43,000 t of which was usable, the remainder elements and components and ammunition subject to disposal. Explosions began at around 3 am on 9 October 2018. After the fire and explosions at the arsenal, only four protected concrete shelters survived, with ammunition losses amounting to about 95% of the 69,500 t of ammunition stored there. More than 12,000 people were evacuated and railway traffic through nearby Ichnya was suspended. Figure 8 shows Sentinel 2 satellite imagery of the incident.

Figure 8. Sentinel 2 satellite images of the Druzhba ammunition depot: on the left, on 7 October 2018; on the right, on 10 October 2018.

Ochakiv, Mykolaiv oblast on 9 January 2023

Ochakiv is a small town but an important centre of the land and naval Armed Forces of Ukraine with several ammunition depots. One of these, located on the seashore, stored very old anti-ship mines from the Second World War, buried in concrete. Obviously, the Russians had intelligence and, on 9 January 2023, deployed two missiles (presumably hypersonic Dagger missiles) to pierce the concrete and blow up these mines, smashing windows and roofs of more than 200 residential and public buildings, and leaving a crater 40 m in diameter (Fig. 9).

Figure 9. Satellite images of Ochakiv taken from the Google Earth Pro website: on the left, in July 2021; on the right, in March 2023.

Pavlohrad, Dnipropetrovsk oblast, 30 April 2023

The city of Pavlohrad is known for the chemical plant that produced rocket fuel – in particular for the Vilkha-M guided artillery missile and the Neptun anti-ship missile; and there is intelligence that fuel for SS-24 intercontinental ballistic missiles, decommissioned after the collapse of the Soviet Union, was stored here.

Figure 10. Sentinel 2 images of ammunition depot at Pavlohrad Chemical Plant: on the left, before the explosion on 30 April 2023; on the right, on 25 May 2023.

Sooner or later, there was bound to be a strike on this plant from the Russian side. It happened on 30 April 2023, injuring more than 30 people and damaging more than 100 residential, commercial, and municipal buildings (Fig. 10). More information, including high-quality satellite imagery distributed with permission, can be found at https://www.twz.com/incredible-destruction-at-ukrainian-rocket-storage-site-that-detonated-from-russian-strike.

Gruzevitsa village, Khmelnytskyi oblast, 12-13 May 2023

The 649th airborne ammunition and missile storage facility, located less than 10km from Khmelnytskyi city, was utterly destroyed on the night of 12-13 May 2023 (Fig. 11). According to available information (https://www.youtube.com/watch?v=nAwgEcx7lI8), the cost of the destroyed ammunition was $500million.

Figure 11. Natural colour imagery of ammunition depot near Gruzevitsa village taken by Sentinel 2A satellite: on the left, before the explosion on 30 April 2023; on the right, on 25 May 2023.

Explosions of Ammunition Depots on Russian Territory

Toropets, Tver oblast on 18 and 21 September 2024

The Russian arsenal near Toropets, 500 km from the nearest Ukrainian territory (Fig.1), became the first significant target on Russian soil struck by the Ukrainian Armed Forces. According to https://en.wikipedia.org, and the Institute of Study of War (Washington DC) website, Toropets hosted the 107th ammunition depot of the Main Missile and Artillery Directorate. About 30,000 t of munitions was stored there, including fuel tanks, missiles for Iskander and Tochka-U systems, guided aerial bombs, assorted artillery ammunition and, recently, munitions from North Korea.

Ukrainian drones struck the warehouse on the night of 17-18 September 2024, causing a series of explosions and fires, as well as breaking windows in neighbouring cities; the main explosion created an 82m-wide crater. Sentinel 2 imagery taken on 19 September 2024 (Fig. 12) shows fires even beyond the ammunition depot, and many more can be seen in a satellite image taken on 18 September 2024, presented on the FIRMS website (Fig. 13). Videos of many explosions in this area can be viewed on YouTube https://www.youtube.com/watch?v=ukhqqRdhcMw.

Figure 12. Sentinel 2A satellite images of the arsenal at Toropets: on the left, on 16 September 2024; on the right, on 19 September 2024.

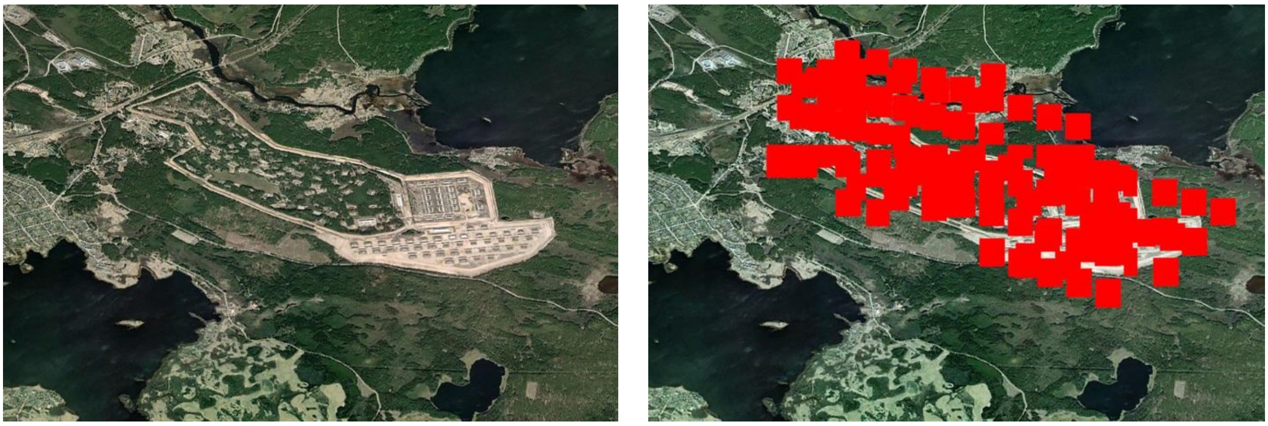

Figure 13. Satellite images of the arsenal at Toropets taken from the FIRMS website: on the left, on 16 September 16 2024; on the right, on 18 September 2024.

A few days later, on 21 September 2024, another ammunition depot located about 17 km south of Toropets was struck – with the same results (Fig. 14).

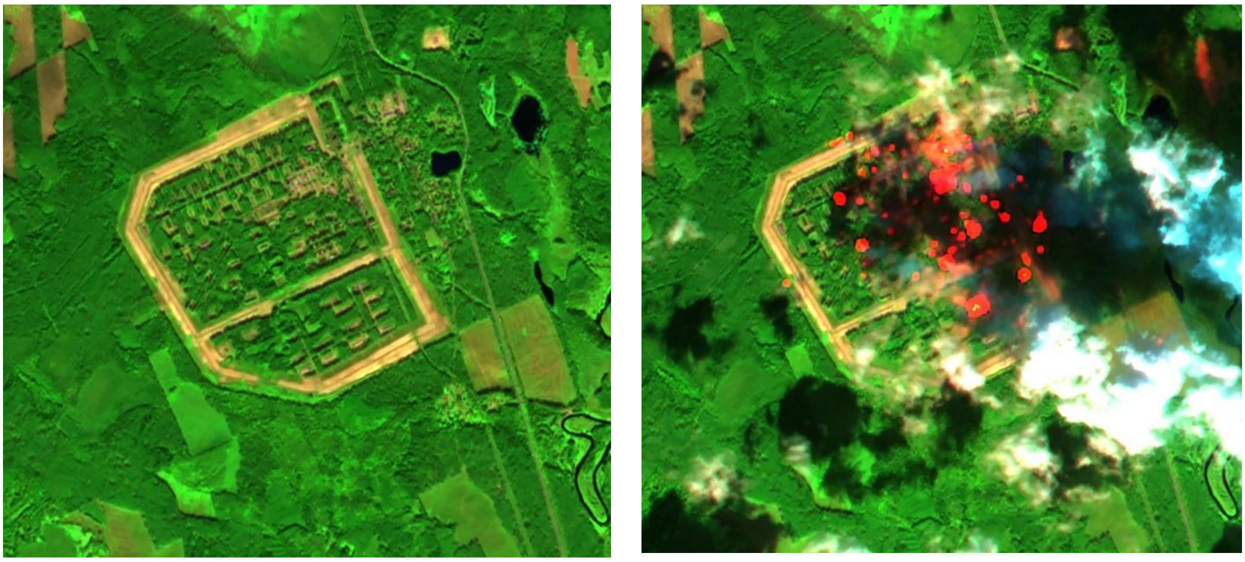

Figure 14. Satellite images of ammunition depot south of Toropets taken by Sentinel 2A: on the left, on 16 September 2024; on the right, on 21 September 2024.

Tikhoretsk, Krasnodar oblast, 20-21 September 2024

According to the media (https://www.pravda.com.ua/eng/news/2024/09/21/7476177/) the strike on the Tikhoretsk arsenal happened on the night of 20-21 September, destroying over 2 000t of ammunition, including supplies from North Korea, and also damaging the nearby military airfield (Fig. 15). Data of website https://worldview.earthdata.nasa.gov show that smoke from these fires was clearly visible from a distance of more than 30km.

Figure 15: Sentinel 2A satellite images of ammunition depot and **military airfield** near Tikhoretsk taken on 21 September 2024: above in natural colour; below, combination of B12, B8 and B3.

The war, and explosions at ammunition depots, continue: according to the media, two such cases occurred in November 2024. The first near Karachev town in Bryansk oblast of Russia (53°08′35″N 34°57′10″E) on 19 November; the second near Kotovo town in Novhorod oblast of Russia (58°28′56″N 33°30′10″E) on 20 November 20. Study of these cases is complicated by cloudy weather.

Conclusion

The unfinished war between Russia and Ukraine that began in 2014 has brought about many huge explosions at ammunition depots; the biggest in Balakliya, Kalynivka, and several other places. In 2024, a few arsenals have been struck in Russia, near the cities of Toropets, Tikhoretsk, *etc.*

About a million tonnes of explosives and several million shells were destroyed in these explosions; many people were killed or injured; the economic losses amount to billions of dollars; at the same time, the explosions have caused significant damage to the environment.

Cui bono?

CONFLICT OF INTEREST

The author declares no competing interests

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