Complex impacts of wars on global sustainable development in a metacoupled world

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Wars and armed conflicts have had profound impacts on local and global sustainable development in an interconnected world. However, evidence on the impacts of wars is fragmented and little attention has been paid to the impacts on the 17 UN's Sustainable Development Goals (SDGs), a unifying framework for achieving global sustainable development. This perspective synthesizes the scattered information to provide a holistic analysis and highlight the applications of remote sensing in assessing the impacts of wars on global sustainable development in a metacoupling world. Wars have complex impacts on all 17 SDGs, which cascade beyond conflict zones and spillover to adjacent and distant countries worldwide. Satellite remote sensing can play a significant role in monitoring environmental and socioeconomic impacts such as crop production, deforestation, pollution, urban damage, and migration. Remote sensing can provide timely, spatiotemporal, large-scale data for sustainable development impact assessment of conflict zones with restricted access. As 2023 is the middle point of the time period (2015-2030) for the 2030 Agenda for Sustainable Development, it is urgent to conduct more quantitative assessments for wars around the world such as the Russia-Ukraine war. Enhancing remote sensing applications in war-related impact assessment with advanced models and frameworks is very helpful and significant. It is also critical to rethink about global governance by incorporating the ripple effects of wars for policy adjustments to achieve SDGs by 2030.

Keywords—Metacoupling, SDG, Remote sensing, Spillover

I. Introduction

In 2015, a total of 17 Sustainable Development Goals (SDGs) were adopted by the United Nations to overcome global challenges ranging from poverty, inequality, unemployment, and biodiversity loss to public health issues [1]. The goal of peace (SDG 16) is argued to be a precondition for the success of the others [2]. The current prevalence of geopolitical conflicts has caused a severe humanitarian crisis and geopolitical risk, as well as disrupted global flows of vital commodities and depressed economic markets. Wars affect not only conflict zones, but also the rest of the world as its disruptive cascading effect runs deeper and far beyond the geographic boundaries through the globalization network [3].

Wars have complex direct and indirect impacts on all SDGs [4-6], but the information is fragmented. In this article, we first give a holistic viewpoint of war's impacts on all SDGs and then introduce the significant role of remote sensing techniques in monitoring and assessing the impacts of wars on the SDGs (Fig. 1). Some typical examples of how remote sensing can be used to examine impacts of wars on multidimensional goals and associated targets across the world are listed. Transboundary and spillover effects of wars on SDGs are highlighted.

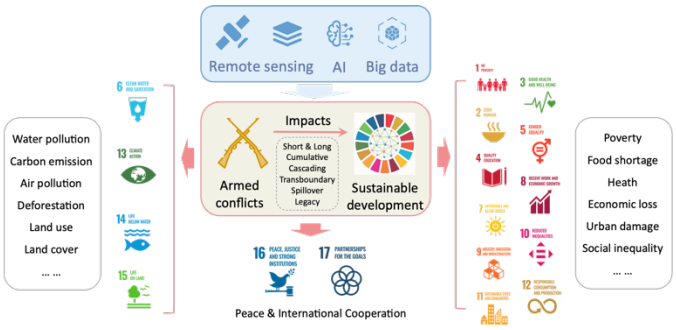

Fig. 1. Potential of remote sensing in monitoring the impacts of wars on the SDGs

II. Impact on socio-economic related SDGs

Wars could raise a range of shocking and long-lasting socioeconomic issues. SDG 16 (Peace, justice, and strong institutions) bear the brunt of war. By the end of 2022, 17,595 civilian casualties were recorded in Ukraine since the war, including 428 killed children. Globalization and global cooperation (SDG 17) as a pathway to achieve SDGs could be ruined. The war has sparked the largest refugee crisis in Europe since World War II. More than 7 million individual refugees from Ukraine are recorded across Europe (SDG 10, Target 10.7-safe and responsible migration) [7]. Potential social issues caused by the refugee crisis such as human health, education, and equality in both conflict zones and non-conflict zones may emerge. Attacks on health care systems and educational institutions including schools and universities are inevitable during wars (SDG 4: Quality education). Hospitals could be overwhelmed from physical and mental injuries, with the latter destined to be a long-term problem for people affected by wars (SDG 3: Good health and well-being).

The impacts of the war have extended to other countries around the world by international trade networks and supports/sanctions for Ukraine/Russia of different political groups. The impact of wars on global supply chains could lead to widespread food [6], energy [3], and water crises [8, 9],

undermining progress towards achieving SDG 2 (Zero hunger), SDG 6 (Clean water and sanitation), and SDG 7 (Affordable and clean energy). The achievement of SDG 1 (No poverty) would be ruined especially for countries with vulnerable households suffering armed conflicts.

Wars bring long-term adverse consequences to the global economy with weakened growth, increased inflation, and disrupted supply chains. Global businesses and industries are at risk. The economic development of Ukraine has been hit hard, shrinking an estimated 45 percent with millions unemployed (SDG 8: Decent work and economic growth). This could put global businesses and industries at significant risk. Urban infrastructures such as roads, bridges and houses are often destroyed due to the bombing and fires (SDG 9, Target 9.1-reliable infrastructure), leading people internally displaced (SDG 11, Target 11.1-affordable housing). For Russia, international economic sanctions could cost Russia ~10% of its annual gross domestic product (GDP) in the long term as of 2022. On the other hand, global soaring energy prices, Russia's demand for gas payments in rubles and increased exports to India and China could boost Russia's financial revenue. For the global tourism industry, a loss of 14 billion dollars in tourism receipts is estimated for 2022, especially for countries such as Turkey and Cuba reliant on Russia/Ukraine tourists. The global tourism industry has been among the most affected sectors during the pandemic. It should have been a good time for the global tourism recovery as the global pandemic gradually subsided. But the war continues to pose a serious threat to its recovery[10].

III. Impact on environmnet-related SDGs

Environmental impacts of the war remain poorly quantified and require long-term monitoring and postwar evaluation, but more evidence is emerging about war crimes against water, soil, forests, and protected areas. More than 800 cases of negative environmental damages caused by Russian aggression have been monitored in Ukraine across both terrestrial and marine ecosystems. Heavy fighting and frequent bombings led to rampant wildfires damaging forest and threatening wildlife in protected areas (SDG 15: Life on land). War waged on ports and in seas causes marine pollution and threaten lives of marine birds and mammals (dolphins, porpoises, whales etc.) around the Azov-Black Sea (SDG 14: Life below water). Increased chemical leaks and pollutant emissions are contaminating soil, water and air. Water security and air quality are at risks and may threaten human health and well-being. For instance, 1.4 million people have no access to safe water (SDG 6: Clean water and sanitation) in the east of Ukraine and a further 4.6 million people with only limited access as damaged water and electricity networks. The postwar restoration of degraded and destroyed natural ecosystems could be a long and difficult task. Climate and biodiversity are at increasing risks as the war continues. To cope with shortages and high prices of energy, the calls and actions for adopting increased carbon-intensive coal to secure energy supplies in many countries are damaging climate-mitigation efforts (SDG 13: Climate action). But experts also expect that the war could also accelerate the clean-energy transition and renewable energy investment, especially for European countries that plan to cut energy dependency on Russia. Biodiversity is directly and indirectly affected by the war and related polices (SDG 15: Life on land). Ukraine, which hosts 35% of Europe's biodiversity, is now under threat of the war with risks of destroyed landscapes, wildlife injuries and kills, protected area degradation and massive deforestation. Biodiversity in other countries may also be affected. For example, European Union countries have considered cultivating crops on fallow land due to grain shortages and increasing prices. To meet the demand for fertilizers that have been reduced from Russia, Brazil plans to develop biodiverse Indigenous lands in the Amazon.

IV. Applications of remote sensing techniques

With the escalation of geopolitical tensions and ongoing armed conflicts worldwide, the uncertain development of these situations will further hinder progress towards achieving SDGs [5]. The environmental and human system impacts in conflict zones are highly complex and challenging to assess due to restricted access to field data. The current quantitative assessment of the impact of war still faces significant uncertainty and various challenges. Advanced remote sensing techniques can offer a promising solution to overcome these challenges and support the implementation of SDGs [11, 12] (Table 1).

Table 1. Examples of remote sensing applications in assessing war and armed conflict outcomes linked to SDGs.

Conflicts	Satellite data	Impacts
Russia-Ukraine war[13]	Landsat Sentinel-2	Food security, cropland dynamics
Syrian civil war[14]	Landsat, MODIS DMSP/OLS	Food security, wheat production
Russia-Ukraine war[15]	TROPOMI EMI	Atmospheric nitrogen dioxide (NO_2)
Russia-Ukraine war[16]	Sentinel-3B SYN	Atmospheric aerosols
Syrian civil war	Landsat	Freshwater resource
Russia-Ukraine war[17]	Sentinel-1 Radar Sentinel-2 Optical	Building damage
Syrian civil war[18]	Landsat SPOT-6	Urban damage
Iraqi civil war[19]	Suomi/NPP-VIIRS	Night-time light dynamics
Rohingya conflict[20]	Pléiades-1A	Environmental degradation
Somalia civil war[21]	Landsat	Land use and land cover
World War II[22]	Corona	Forest cutting

V. Applications of remote sensing techniques

Chemicals and explosive weapons have been used in wars and conflicts for decades, causing short and long-term damage to the environment and human health. Monitoring these effects is a challenging task that cannot be achieved solely through visual observation [23]. Additionally, collecting data from conflict zones through field visits can be extremely difficult due to safety concerns and limited access. Remote sensing is an effective tool for detecting both short-term and long-term impacts of conflicts. It enables the detection of various impacts,

such as food security, air pollution, land cover change, and urban damage. For instance, satellite observations from Landsat and Sentinel-2 can detect reduced wheat production in conflict zones [13], help identify people in hunger and food insecurity. Using night-time light satellite data as a proxy for war impact intensity in Syria, it was found that cropland close to severely impacted urban settlements faced greater disruption [14]. Atmospheric pollution can be easily mapped across space and time during the conflict [15, 16]. Land use and land cover change such as deforestation [22] and urban infrastructure disruption [17, 18] caused by bombing and war-related fire can be effectively detected using high-resolution images from satellites such as Landsat and Sentinel. By analyzing satellite images, the extent and degree of the environmental damage caused by conflicts can identify and quantified, which could aid in the development of effective conservation and restoration strategies.

Better understanding of war impacts on landscapes, ecosystems, and communities requires enhanced remote sensing methods and more accurate space-time mapping data. As limited ground data can be accessed in conflict zones, improved model interpretability and transparency, advanced artificial intelligence and deep learning methods are needed to provide confident evidence. More ground training data could be collected by unmanned aerial vehicle. Satellited-based quantification of war-related impacts on carbon emission, geomorphologic change, biodiversity, and ocean and coastal ecosystems have received limited attention in previous studies, despite their significant implications for the environment and human well-being linked to multiple goals such as SDG 13, SDG 14, and SDG 15. It is important to recognize the potential long-term effects of war on these natural systems and to conduct further research to better understand and mitigate these impacts.

Additionally, efforts of using remote sensing to monitor war-related impacts should also expand to more socioeconomic dimensions and pay attention to interactions among multiple goals. Currently, most studies using remote sensing are focused on war-related impacts on environmental dimensions, future studies should also try using remote sensing to quantify impacts of war on socioeconomic dimensions such as poverty, human health, education, gender equality, and economic loss linked to SDG 1, SDG 3, SDG 4, SDG 5, and SDG 8. The impacts of war on the SDGs are often interconnected and can affect multiple goals simultaneously. For instance, conflict can exacerbate poverty, hinder access to education, and disproportionately affect women and children, impacting SDG 1, SDG 4, and SDG5. Similarly, war-related environmental degradation can have negative effects on human health and economic stability, impacting SDG 3 and SDG 8. Remote sensing is of great potential collecting valuable data across multiple dimensions, facilitating informed decision-making and policy development. By taking a multidimensional approach to understanding the effects of war is critical to build resilient communities that can recover and thrive despite the challenges of conflict.

To reveal cascading and spillover effects of war on SDGs, satellite observations should also be used to explore the impacts of conflict on adjacent and distant areas beyond conflict zones. For instance, integrating remote sensing and the metacoupling framework [24] can help understand human-nature interactions within a country as well as between the focal country and adjacent and distant countries. This would allow us to examine impacts of wars on multidimensional goals and associated targets across boundaries, for example, war-related trade disruption and refugee migration can result profound impacts on countries geographically distant from the conflict zones. For example, satellite imagery has been used to explore how conflict and migration in war-torn Syria impact land and water use. Researchers have discovered sudden reductions in agricultural land and water use in Syria [8]. Furthermore, they have also uncovered an unexpected increase in transboundary water flow to adjacent Jordan during the refugee migration period.

VI. Strategies for assessing and mitigating war's impacts on global sustainability

Mitigating war impacts on global sustainability requires more accurate, safe, and quick quantitative assessments and rethinking about global governance. More rapid and systematic research, advanced space technology, artificial intelligence, and big data can help better understand how wars and armed conflicts affect global sustainable development, not only on the progress, but also on vulnerability, equality, and resilience. To uncover complex effects of wars on global sustainable development, interdisciplinary approaches, such as integrating remote sensing techniques and environmental and socioeconomic frameworks, are needed as the SDGs cover multiple dimensions such as food, energy, water, biodiversity, economy, education, and health. As the conflict continues, its effects on each goal vary across spatial and temporal scales. Quantitative impact assessment of wars on SDG progress across local to global scales is needed to provide scientific information for targeted policymaking. A nexus approach based on big data would be a powerful tool to illuminate the effects of shocks on multiple sectors and reveal their interlinkages [25]. Various features of impacts such as cumulative effects, cascading effects, transboundary effects, spillover effects, and legacy effects require further research for different SDGs. The metacoupling framework [24] can help elucidate the hidden effects and mechanisms of war on SDGs in conflict zones as well as those near and far away from conflict zones over time.

Global governance of war warrants a paradigm shift from the traditional focus on humans in conflict zones to human-nature interactions across the entire world. Impacts of war should be incorporated in all international agreements and treaties. For example, the Post-2020 Biodiversity Framework should expand to including measures for preventing war, biodiversity conservation during the conflict, and compensation for war victims. The Carbon Neutral Targets [26] for each country may need to be reset considering the impacted energy transition due to wars and armed conflicts. The Decade of Action for global sustainable development should develop targeted strategies for the food-energy crisis and elevated

international cooperation is needed for post-war recovery. Accelerating global energy transition, increasing investment in renewable energy, and reducing overconsumption are critical to end reliance on fossil fuels. Developing innovative technologies and infrastructures could increase efficiency and productivity in food and energy production thus reducing loss and waste, which could make global food and energy systems more sustainable. Remote sensing technology enables the collection of extensive space-time data, which can significantly enhance our understanding of the effects of war and facilitate the development of effective policies and management strategies during and after conflicts.

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