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Consequences of human conflicts on aquatic ecosystems in drylands areas: Future management perspective

Luciana G. Barbosa [a,*], Ilia Ostrovsky [b,**], Manuela Morais [c], Elena Anufriieva [d], Gema Parra [e], Egor Zadereev [f,r], Antonio Camacho [g], Antje Schwalb [h], Simonetta Bagella [i], Rosemberg F. Menezes [j], Luz Marina Soto [k], Carlos López [l], Maria Ilheu [m], Eduardo A. Morales [c], Abdullah A. Saber [n], Hichem Kara [o], Peter Riad [p], Gizachew Teshome [q], Nickolai Shadrin [d]

[a] *Limnology Laboratory, Plant Technology and Environmental Sciences Department, Center for Agrarian Sciences, Federal University of Paraíba, Campus II, 58397-000, Brazil*
[b] *The Yigal Allon Kinneret Limnological Laboratory, Israel Oceanographic and Limnological Research, Migdal, 14950, Israel*
[c] *Department of Biology, Water Laboratory & Institute of Earth Sciences, University of Évora, Portugal*
[d] *A.O. Kovalevsky Institute of Biology of the Southern Seas of RAS, 2 Nakhimov avenue, 299011, Sevastopol, Russia*
[e] *Animal Biology, Plant Biology and Ecology Department, Centre for Advanced Studies in Earth, Energy and Environmental Sciences, University of Jaen, Jaen, Spain*
[f] *Institute of Biophysics, Krasnoyarsk Scientific Center, Siberian Branch Russian Academy of Sciences, Krasnoyarsk, Russia*
[g] *Cavanilles Institute of Biodiversity and Evolutionary Biology, University of Valencia, Paterna, E-46980, Valencia, Spain*
[h] *Institute of Geosystems and Bioindication, Technische Universität Braunschweig, 38106, Braunschweig, Germany*
[i] *Department of Chemical, Physical, Mathematical and Natural Sciences, University of Sassari, I-07100, Sassari, Italy*
[j] *Departamento de Fitotecnia e Ciências Ambientais, Centro de Ciências Agrárias, Universidade Federal da Paraíba (UFPB), Areia, Paraíba, Brazil*
[k] *Technical University of Manabí, Faculty of Veterinary Sciences, School of Aquaculture and Fisheries, Bahía de Caráquez, Manabí, Ecuador*
[l] *Centro del Agua y Desarrollo Sustentable, Escuela Superior Politécnica del Litoral, ESPOL, Guayaquil, Ecuador*
[m] *Department of Landscape, Environment and Planning, & MED-Mediterranean Institute for Agriculture, Environment and Development, Evora University, Evora, Portugal*
[n] *Botany Department, Faculty of Science, Ain Shams University, Abbassia Square, Cairo, 11566, Egypt*
[o] *Marine Biology Department, Badji Mokhtar Annaba University, Annaba, Algeria*
[p] *Irrigation and Hydraulics Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt*
[q] *Department of Biology, College of Natural and Computational Science, University of Gondar, Ethiopia*
[r] *Siberian Federal University, Krasnoyarsk, Russia*

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ABSTRACT

Aquatic ecosystems in dryland regions are among the most vulnerable globally, facing escalating threats from climate change, population growth, and human conflicts. Historically, water disputes have been a significant driver of tension. Over the past three decades, at least 59 water-related conflicts have occurred in drylands, predominantly in Asia and Africa, with approximately 50 % of these conflicts directly linked to water scarcity. The primary ecological consequences include the loss of hydrological connectivity, declining biodiversity, heightened water scarcity and pollution, and the degradation of physical habitats. The lack of conservation efforts during and after conflicts further destabilizes these fragile aquatic ecosystems, eroding their resilience. Such environmental disruptions reduce water availability and quality and pose serious risks to human health, food security, and socioeconomic stability. Moreover, the destruction of water infrastructure and ecosystem degradation caused by conflicts undermine progress toward achieving the United Nations Sustainable Development Goals (SDGs), particularly those related to clean water, health, and biodiversity conservation. Addressing these challenges necessitates enhanced transboundary water governance, robust climate adaptation strategies, and the development of international legal frameworks to mitigate the long-term ecological impacts of human conflicts in dryland regions. This review explores the direct and indirect environmental effects of human conflicts on aquatic ecosystems in drylands, supported by critical case studies that underscore the urgency of these issues.

* Corresponding author.
** Corresponding author.
E-mail addresses: lgomesbarbosa@gmail.com (L.G. Barbosa), ostrovsky@ocean.org.il (I. Ostrovsky).

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1. Introduction

Water is fundamental for life, shaping ecosystems and sustaining human civilization. Since ancient times, human populations have developed where water was available. It has always been directly related to survival, food and energy production, transportation, waste disposal, industrial development, and human health. This limited resource often has to be shared with neighboring countries, leading to negative interactions (Wolf, 2007; Gizelis and Wooden, 2010). Freshwater resources are unevenly distributed, with drylands—home to approximately 2 billion people—facing chronic water scarcity (Safriel and Adeel, 2005; Wale and Dejenie, 2013). Access to water has historically fueled conflicts, which have intensified in the face of climate change, population growth, and geopolitical tensions. Conflicts over water resources have escalated significantly in recent years, leading to profound ecological and economic repercussions. Between 2014 and 2023, over 1060 water-related conflicts were reported, marking a 2.4-fold increase from 49 incidents in 2014 to 117 in 2023 (DownToEarth, 2024). Notably, between 2020 and 2023, Western Asia experienced the highest number of conflicts (156), followed by Southern Asia (97) (Statista, 2024). The degradation of aquatic ecosystems in these regions is a pressing concern, as human disturbances and climate change exacerbate the vulnerability of freshwater communities (López-López, 2021). The ecological damage resulting from water-related conflicts includes the destruction of water infrastructure, contamination of water supplies, and biodiversity collapse. In some cases, water has been deliberately weaponized during armed conflicts. While the exact number of water-related conflicts is unknown, it is evident that hundreds of such disputes have occurred, causing substantial ecological and economic damage worldwide.

In regions where water is scarce, competition for access to limited water resources can lead nations to perceive water security as a critical issue affecting national stability and geopolitical strategy (Mishra et al., 2021). This is especially evident in arid areas, where transboundary water sources have often been central to interstate disputes, violent conflicts, and military targeting (Suleymanov, 2024). Several new and dramatic environmental threats with international political implications have emerged. These include the misuse and degradation of essential ecosystem goods and services, growing inequities among nations in resource use, and the heightened risk of water-related conflicts. The scarce resource wars hypothesis suggests that as essential resources become more limited, competition over access will intensify, increasing the likelihood of conflict among individuals, groups, or nations (Le Billon, 2001). This has been particularly evident in regions where water plays a central role in both livelihood security and state relations, such as the Nile River Basin, where tensions between Ethiopia, Sudan, and Egypt have escalated over control of the Grand Ethiopian Renaissance Dam (GERD) (Tawfik, 2016; Salman, 2018). Similarly, in the Tigris-Euphrates River system, political tensions between Turkey, Syria, and Iraq over upstream water control have raised concerns about long-term regional stability (Gleick, 2014).

Beyond direct conflicts, water scarcity has also been weaponized in warfare, with the strategic destruction of dams and reservoirs exacerbating environmental and humanitarian crises. In Syria, the deliberate targeting of water infrastructure during the civil war has led to severe water shortages, affecting millions of civilians and increasing regional instability (Jones et al., 2019). These cases highlight how water-related disputes can evolve into broader geopolitical challenges, requiring international cooperation and sustainable water management strategies. This situation has fueled a broader debate on the need for new definitions of security that explicitly incorporate environmental concerns, particularly about water governance and management (Gleick, 1993). Research suggests that transparent conceptual frameworks are necessary to understand and manage water conflicts better, as well as to integrate findings across multiple studies on water resource security in conflict settings (Schillinger et al., 2020a,b).

The relationship between climate change and conflict remains widely debated (e.g. Hsiang et al., 2013). Some studies suggest that water scarcity, extreme droughts, and resource competition increase the likelihood of armed conflicts, as observed in Syria (2007–2011) and Ethiopia (2015), where severe droughts exacerbated migration pressures and social instability (Kelley et al., 2015; UNCCD - United Nations Convention to Combat Desertification, 2014). Other scholars argue that political, economic, and governance factors are more critical than climate-induced resource scarcity in triggering conflicts (Nordas and Gleditsch, 2007; Buhaug, 2010). Despite these differing perspectives, water-related tensions in drylands are escalating, driven by rising demand, erratic precipitation patterns, and transboundary disputes. The Tigris-Euphrates Basin, the Nile River Basin, and the Afar-Amhara regions of Ethiopia are among the many hotspots where competition over water resources fuels geopolitical instability (Kibaroglu and Scheumann, 2013; Abebe et al., 2023).

Historically, human populations in arid and semiarid zones are exposed to water scarcity, but the interaction of generations with different traditional experiences of aquatic system use promotes ecosystem sustainability and their production of resources and services (Vidal-Abarca et al., 2022). Currently, in addition to human pressure and economic activities, climate change is an important change driver, causing social and ecological consequences of temperature increase and reduction of precipitation (Zadereev et al., 2020; IPCC – Intergovernmental Panel on Climate Change et al., 2022). This will inevitably affect water availability and water quality as well as the structure of biological communities of aquatic freshwater and saline ecosystems, which will influence ecosystem services (Camacho et al., 2019) and intensify ongoing conflicts owing to water shortage. Furthermore, while climate change is expected to exacerbate water scarcity, some scholars argue that socio-political and economic factors—such as governance, institutional capacity, and regional cooperation—play a more decisive role in determining whether water scarcity leads to conflict or cooperation (Wolf, 1998; Dinar et al., 2019).

Dryland areas have been deeply affected by conflicts over time, with adverse effects on the aquatic ecosystem resilience, destruction or fragmentation of reservoirs, rivers, and a substantial increase of the contaminants in water, resulting from weapons, residual effects of the military equipment and human bodies not being disposed adequately (Leaning, 2000). Impacts associated with this contamination, including surface and groundwater (McLaren and Willmore, 2003), can be observed many years after the end of a war. For example, the long-term effects of the Iraq War have hindered the recovery of wetlands in the Mesopotamian marshes, affecting the resilience of aquatic ecosystems and traditional Arab livelihoods (Ahram, 2015).

The present review aims (1) to Analyse the ecological consequences of human conflicts on aquatic ecosystems in drylands, emphasizing biodiversity loss, water scarcity, and pollution; (2) to examine case studies where warfare, transboundary disputes, and climate-driven resource competition have disrupted water availability and ecosystem services; (3) to discuss policy recommendations for mitigating environmental damage, including conflict-sensitive water management, ecosystem restoration, and legal frameworks to protect aquatic resources in war-affected regions.

2. Material and methods

The methodology used is based on qualitative and quantitative analyses. The review synthesizes existing literature on the impacts of human conflicts on aquatic ecosystems in drylands, with a focus on future management perspectives. The information was gathered through a literature review of peer-reviewed journal articles, reports from international organizations (e.g., UNCCD, UNEP, IPCC), based on the conflicts identified for the present study and the regions associated with them.

A total of 1920 water conflicts were analyzed, using the Pacific

Institute's chronology (https://www.worldwater.org/conflict/list/), and 59 were selected as conflicts that occurred in drylands over the past 30 years. The main exclusion criterion was location in drylands zones as described by Williams (1999). These conflicts were classified according to the Pacific Institute's framework, in which water can be considered a trigger, weapon, or causality in human conflicts. The causes of these conflicts and their ecological and socio-economic impacts on dryland aquatic ecosystems were analyzed by region or country (https://www.worldwater.org/conflict/list/; Francis, 2011; Zwijnenburg and Te Pas, 2015). After identifying the location of the affected aquatic ecosystems, we obtained their geographic coordinates from the literature and plotted on shapefile maps of dryland zones using R (R Core Team, 2020).

3. Results and discussion

Over the past 30 years, approximately 59 violent conflicts related to water rights have occurred in dry zones (Fig. 1). Prolonged and severe droughts in countries like Somalia, Ethiopia, Syria, and Yemen exacerbated these conflicts (Femia and Werrell, 2012; Salehyan et al., 2014; Funk, 2020). Among them, more than 52 occurred in arid regions of Asia and the Middle East, where drought severely threatened water security in the affected areas (Karrou and Mourid, 2008). The remaining seven conflicts occurred in Africa. The main ecological consequences include increased nutrient and pollutant levels, potentially leading to the siltation of rivers and lakes, the proliferation of toxic and harmful species, the spread of exotic species, and ecosystem destruction (Table 1).

During the Gulf War, a massive volume of oil was released on land, forming approximately 250 oil lakes and contaminating groundwater, thereby affecting aquatic resources (Linden et al., 2004) (Fig. 2). This led to the disruption of ecosystems and natural resources in deserts, forests, and soils (Omar et al., 2009). The war also significantly increased the concentration of trace metals in coastal areas of the Persian Gulf (Bu-Olayan et al., 1998), negatively impacting local aquaculture (Mathews et al., 1993), by causing mortality among birds and mammals, and contributing to a decline in marine biodiversity (Linden et al., 2004).

Water sources are frequently targeted due to their critical role in water security and economic stability (Shannon, 2017). Between 2001 and 2011, approximately 25 dams were attacked worldwide (DHS – Department of Homeland Security, 2012), with incidents occurring more frequently in dry regions, such as Afghanistan and Iraq (DHS – Department of Homeland Security, 2012). Therefore, ensuring that water sources remain functional, safe, and secure is crucial for both national and international stability (e.g., Shannon, 2017). In conflict zones, maintaining environmental sustainability is often not a priority due to the collapse of social and economic systems. Essential infrastructure for human survival suffers severe damage, disrupting services such as water supply, sanitation, and food security (ICRC – International

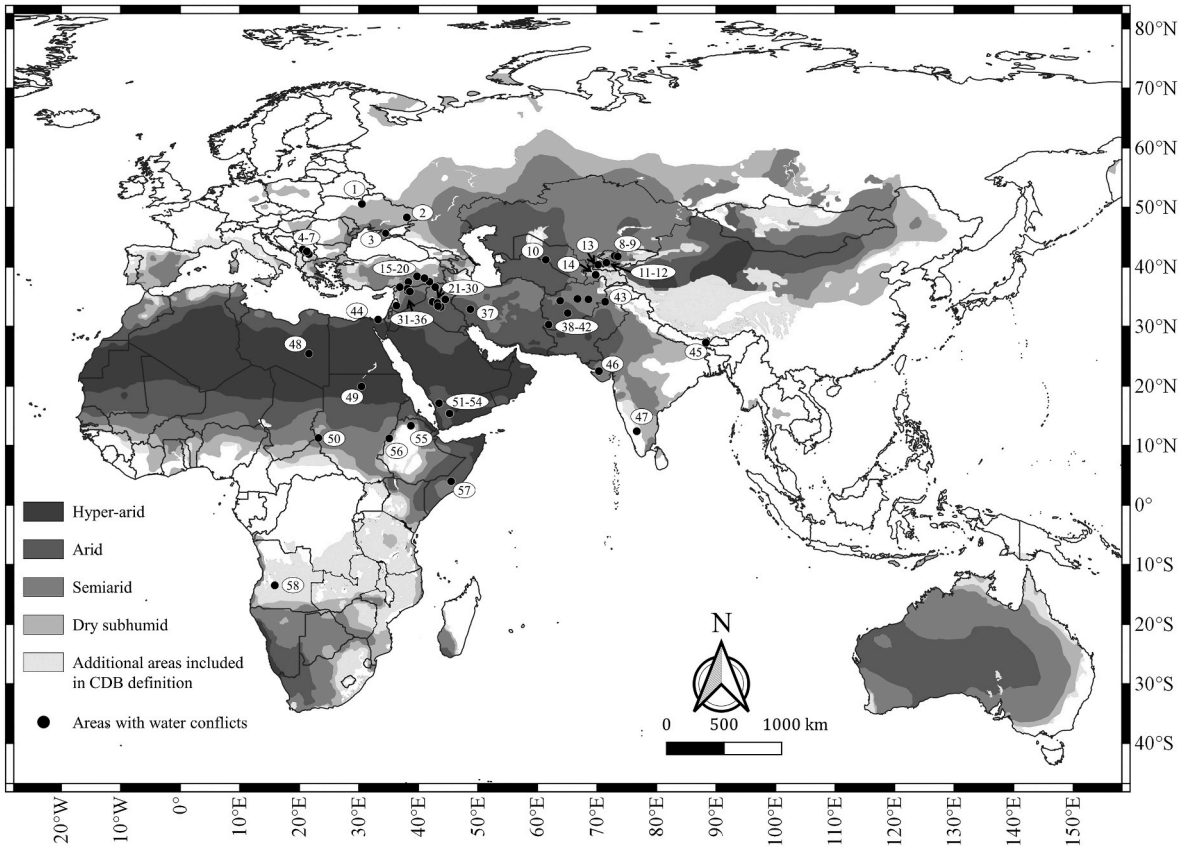

Fig. 1. Distribution of the aquatic ecosystems in countries and zones under conflicts over dryland regions. **Ukraine**: 1 - The hydropower stations in the Dnieper River, 2 - Horlivka Reservoir. **Crimea Region, Ukraine**: 3 - Sivash. **Kosovo**: 4 – Gazivode Lake, 5 - Badovc Lake. **North Macedonia**: 6 - Glažnja Lake, 7 - Lipkovo Lake. **Kyrgyzstan**: 8 - Toktogul Reservoir, 9 - Kambarata 1 Dam; **Uzbekistan and Turkmenistan**: 10 - Tyuyamuyun Reservoir. **Uzbekistan**: 11–12 - Fergana wetland. **Tajikistan**: 13 - Kairakum Reservoir, 14 - Rogun Dam. **Turkey**: 15 - Tigris River, 16 - Silvan Dam, 17–18 - Ilısu Dam, 19–20 - Atatürk Dam. **Iraq**: 21–22 - Mosul Dam, 23 - Euphrates River Dam, 24–25 - Haditha Dam, 26 - Thatthar Dam, 27 – Tharthar Lake, 28 - Ramadi Dam, 29 - Falluja Dam, 30 - Ramadi Lake (Habbaniyah). **Syria**: 31 - Afrin Dam, 32 - Tishreen Dam, 33 - Assad Lake, 34–35 - Tabqa Dam and Tabqa River, 36 - Barada River. **Iran**: 37 - Dez River. **Afghanistan**: 38 - Hari Hud River, 39 - Helmand River, 40 - Salma Dam, 41 - Kajaki Dam, 42 - Kamal Khan Dam. **Pakistan**: 43 - Warsak Dam. **Egypt**: 44 - Lagoon Bardawil. **India**: 45 - Rangit Hydropower Project, 46 - Kankavati Dam, 47 - Cauvery River. **Libya**: 48 - Great Man-Made River. **Sudan**: 49 - Kajbar Dam, 50 - Darfur region. **Yemen**: 51 - Al Wahabiyah area, 52 - Marib Dam, 53 - Wadi Dhana, 54 - new Marib Dam. **Ethiopia**: 55 - Tekeze Dam, 56 - Grand Ethiopian Renaissance Dam. **Somalia**: 57 - Bulo Burto in Hilraan region. **Angola**: 58 - Gove dam.

Table 1
Causes of human conflicts, ecological and socioeconomic consequences for inland waters in dryland zones over the last 30 years (Based on: https://www.worldwater.org/conflict/list/; Francis, 2011; Zwijnenburg and Te Pas, 2015).

Region/Water System	Contributing Factors	Conflict Type & Water Resource Impacted	Key Ecological Consequences	Sources
Bardawil Lagoon (Egypt)	Overfishing, regional conflicts, climate change	Blocked sea openings due to war (Arab-Israeli Wars, 1967–1973)	Increased salinity, collapse of fisheries, economic loss	Anufriieva et al. (2018); El-Shabrawy et al. (2018)
Sivash Lagoon (Crimea, Ukraine)	Political conflict (Ukraine-Russia), water diversion	North Crimean Canal water supply cut-off (2014)	Salinity increase, fishery collapse, loss of agricultural productivity	Shadrin et al. (2018); Anufriieva et al. (2022)
Tigris-Euphrates Basin (Turkey, Syria, Iraq)	Water scarcity, transboundary disputes, climate variability	Dams as political leverage (Turkey's GAP Project)	Disrupted river connectivity, reduced water flow to Iraq/Syria, increased salinization, habitat degradation	Kibaroglu and Scheumann (2013); Al-Ansari et al. (2018)
Afar-Amhara (Ethiopia)	Climate change, severe droughts, resource competition	Localized water conflicts, tribal disputes	Depletion of groundwater, reduced pasture lands, increased migration due to water scarcity	Abebe et al. (2023)
Nile River Basin (Egypt, Sudan, Ethiopia)	Transboundary water disputes, dam construction	GERD dam filling process (2020)	Reduced downstream water levels, altered sediment transport, decreased groundwater recharge	El Ghany et al. (2020); Mokaddem and Mquimi (2020)
Syria (2007–2011)	Extreme drought, poor governance, migration pressures	Water scarcity linked to social unrest	Agricultural collapse, desertification, groundwater depletion	Kelley et al. (2015)
Yemen Conflict (2015–Present)	Armed conflict, failing water infrastructure	Attacks on water infrastructure, control over water access	Increased waterborne diseases, loss of drinking water supply	ICRC – International Committee of the Red Cross, 2015
Gulf War (1991, Iraq-Kuwait)	Military conflict, oil spills, infrastructure destruction	Deliberate destruction of oil fields, groundwater contamination	Trace metal pollution, loss of aquatic biodiversity, desertification	Linden et al. (2004); Bu-Olayan et al. (1998)
Afghanistan & Iraq (2001–2011)	Military occupation, terrorism, weak governance	Targeting of reservoirs and dams	Hydrological disruption, loss of irrigation water, pollution from explosives	DHS – Department of Homeland Security, 2012
Palestine-Israel	Political and armed conflict, targeting of civilian infrastructure, over-extraction of shared water resources	Long-term water disputes on Palestinian water access, destruction of water supply systems	Depletion of mountain and coastal aquifers, loss of potable water, increased salinity, sewage contamination, pollution of groundwater	Gleick (1994); Zeitoun (2008); Selby (2013); The Guardian (2024); The Atlantic (2025)
Sudan (2023–Present)	Armed conflict, political instability	Attacks on water facilities, displacement of populations	Water insecurity, reduced agricultural productivity, increased conflict over water access	UN Reports, 2024
Ethiopia (2015)	Severe drought, food insecurity	Drought-induced displacement and instability	Crop failure, livestock death, loss of water access for millions	UNCCD – United Nations Convention to Combat Desertification, 2014
Sahel Region (Chad, Niger, Mali)	Climate change, land degradation, competition over water	Armed conflicts between farmers and herders over shrinking water sources	Desertification, loss of wetland biodiversity, declining fisheries	UNEP - United Nations Environment Programme, 2022
Somalia (1991–Present)	Political instability, drought, famine	Armed groups controlling water resources	Increased waterborne diseases, loss of irrigation capacity, malnutrition crisis	FAO - Food and Agriculture Organization, 2023
Aral Sea (Kazakhstan-Uzbekistan)	Water mismanagement, Soviet-era irrigation policies	Overuse of rivers for agriculture, diversion of Amu Darya and Syr Darya rivers	Loss of 90 % of water volume, ecosystem collapse, rising salinity levels	Micklin (2007)
Lake Chad (Nigeria, Niger, Chad, Cameroon)	Climate change, overuse of water, desertification	Shrinking lake size due to excessive water extraction	Biodiversity loss, increased water scarcity, conflicts between communities	GIZ - German Agency for International Cooperation, 2021

Committee of the Red Cross, 2015). In countries such as Yemen, Syria, and Iraq, human conflicts have significantly impacted water systems and, consequently, agricultural production, affecting local economies (Gleick, 2014; ICRC – International Committee of the Red Cross, 2015). For example, the Gulf War and other conflicts, have had a significant impact on the Mesopotamian marshes in southern Iraq, including the diversion of water from these wetlands, which led to a reduction in water volume and the subsequent drying and degradation of these areas (e.g., Ahram, 2015). One of the long-term consequences of these conflicts in Iraq has been the prevention of wetlands recovery in the Mesopotamian marshes, undermining the resilience of aquatic ecosystems and traditional Arab livelihoods (Ahram, 2015).

Historically, violence associated with water disputes has threatened civilizations. In conflict-affected countries, water can be used as a weapon, a trigger, a casualty, or a target (Gleick et al., 2020; Gleick and Shimabuku, 2023). Water might be used as a weapon, typically when using military equipment to target structures or people in a war zone (Gleick, 2019; Gleick et al., 2020; Shadrin et al., 2018). On the other hand, water as a target occurs when water bodies and sanitation structures become the focus of conflict (Gleick, 2019; Gleick et al., 2020). Water infrastructure, such as hydropower dams and dikes, was frequently destroyed to impede the movements of opposing groups (Francis, 2011). Additionally, deliberate contamination of water sources, such as the poisoning of wells, has been reported as a warfare strategy in dryland regions, exacerbating water scarcity and threatening human and ecological health (Abebe et al., 2023; Brito et al., 2021; Lutz et al., 2011; Richer, 2015; Sterzel et al., 2014).

4. Causes of water conflicts in drylands

The most severe water conflicts in drylands arise from using transboundary water bodies (Zeitoun, 2008). In this study, we considered causes of conflicts, the interruption of water flows, extreme droughts, military attacks, and cross-border competition for water (Table 1). Limited access to water, extreme climate events such as droughts and floods, inadequate government action to mitigate the effects of climate change, poor sanitation and hygiene infrastructure, and even the use of weapons of mass destruction, jeopardize economic stability and global health security (WEF – World Economic Forum, 2019). These insecurity scenarios could lead to water supply crises and the spread of diseases, which have severe consequences for human health. In conflict-affected countries, diarrhea and other waterborne diseases pose significant public health challenges and can increase mortality rates (Abbara et al., 2021). Unfortunately, studies on the rise in morbidity due to water scarcity and poor water quality in conflict zones remain scarce and insufficient, probably due to the destruction of health systems,

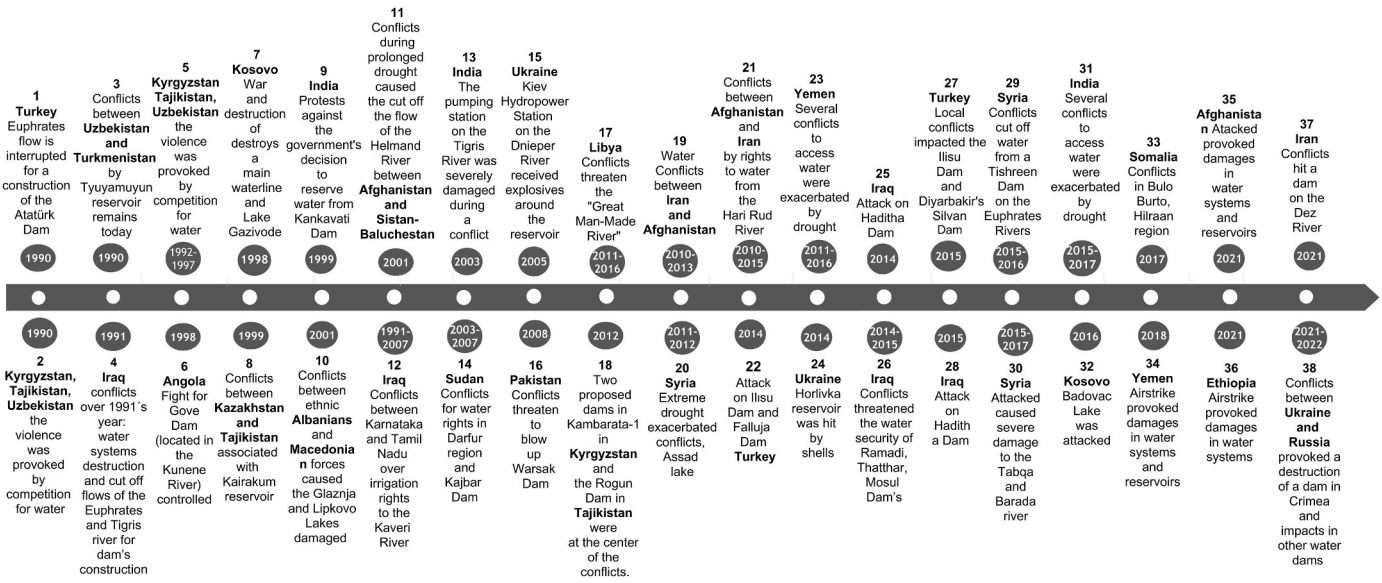

Fig. 2. Chronological order of human conflicts over the past 30 years in drylands zones (Based on: https://www.worldwater.org/conflict/list/). In chronological order, some conflicts were grouped because they occurred in the same country/region during the same year or period.

preventing access to databases.

Water scarcity, likely to intensify in many arid and semi-arid areas due to climate change and resource overexploitation (Kahil et al., 2015; Morante-Carballo et al., 2020), has been linked to conflicts at the national and international levels. In recent years, extreme droughts have emerged as one of the most serious global challenges, damaging economies, ecosystems, and natural resources (IPCC – Intergovernmental Panel on Climate Change Climate Change et al., 2014; Kelley et al., 2015; Smirnov et al., 2016). Some studies suggest that drought can contribute to conflict, particularly in regions where water and food security are already fragile. For example, extreme droughts that affected Syria between 2007 and 2011, contributed to social instability and migration pressures, which played a role in the escalation of conflict (Kelley et al., 2015). Similarly, in Ethiopia, a severe drought in 2015 impacted approximately 10 million people, leading to widespread crop failures and livestock losses, further straining local economies and livelihoods (UNCCD - United Nations Convention to Combat Desertification, 2014).

Additionally, meteorological drought has been linked to increased migration and heightened conflict risks, mainly through its impact on crop production and rural economies (Eklund et al., 2022). Conversely, other studies emphasize that conflicts can exacerbate water scarcity by disrupting infrastructure, mismanaging water resources, and displacing populations. In the Jordan River Basin, ongoing political tensions have worsened water scarcity by limiting cooperation on shared water resources and increasing competition between Jordan, Israel, and Palestine (Giordano et al., 2002). In Syria, overexploitation of water resources, driven partly by conflict-related mismanagement, has further aggravated drought vulnerability (Kelley et al., 2015). However, it is important to acknowledge that not all research supports a direct causal link between climate variability and conflict. Some scholars argue that political, economic, and institutional factors are more significant in driving conflicts than climate-related variables alone (Nordas and Gleditsch, 2007; Buhaug, 2010). For example, Buhaug (2010) assessed African civil wars and found no statistically significant correlation between climate variability and conflict when controlling for governance, economic development, and demographic pressures. Similarly, Sutton et al. (2010) argue that while warming may exacerbate existing vulnerabilities, it does not directly increase the risk of civil war in Africa. These perspectives highlight the complexity of conflict dynamics and emphasize the need for interdisciplinary approaches considering a wide range of social, economic, and environmental factors. More research is needed to fully understand the interactions between climate variability, water scarcity, and conflict, as well as the broader socio-political contexts that mediate these relationships (von Uexkull and Buhaug, 2021). Studies in Africa have highlighted the region's high vulnerability to extreme and prolonged droughts, with consequences including economic downturns, food insecurity, and migration pressures (Masih et al., 2014; Ayugi et al., 2022; Maconga, 2023). According to the United Nations Convention to Combat Desertification (UNCCD), approximately 80 % of armed conflicts in the preceding five years occurred in vulnerable dry ecosystems (UNCCD - United Nations Convention to Combat Desertification, 2014), underscoring the importance of sustainable water management in conflict prevention. Other underlying factors, such as political instability, governance issues, and economic conditions, significantly shape conflict dynamics and resource scarcity (von Uexkull et al., 2016). While some findings suggest that in conflict-prone countries, drought may have a limited direct impact compared to political and economic instability, in fragile regions with already stressed food and water systems, drought can increase the likelihood of conflict (von Uexkull et al., 2016).

In 2015, the northern regions of Ethiopia experienced a severe drought, impacting about 10 million people. The arid conditions caused widespread crop failures, leading to the loss of livestock and economic devastation for thousands of farmers. Historical records indicate recurring droughts in Ethiopia's northern regions over the past few centuries. The primary causes of drought are often a combination of natural climatic processes and human activities, and its consequences extend beyond the environment to economic, social, and political spheres (Mekonnen and Gokcekus, 2020). Drought has broad ramifications that affect society, including the environment, the economy, social elements, and politics (Mekonnen and Gokcekus, 2020). A notable example is central-northern Mali, where prolonged drought, climate change, and ethnic fractionalization have exacerbated water-related conflicts and biodiversity loss (Mach et al., 2019; Schleussner et al., 2016; UNEP - United Nations Environment Programme, 2011). In this country, resource scarcity has intensified tensions between pastoralist and agricultural communities, contributing to cycles of violence and environmental degradation.

The Human Development Report (2007/2008) underscored the significant consequences of climate change for human security (UNDP – United Nations Development Programme, 2007; IPCC –

Intergovernmental Panel on Climate Change Climate Change et al., 2007), rather than viewing it solely as an environmental issue. Africa is frequently described as a continent where climate-dependent economic sectors are at risk of violent ethnic conflict (Helman et al., 2020; Mach et al., 2019). Studies suggest that rising temperatures, extreme weather variability, and climate-related disasters increase the risk of violent conflict, particularly in ethnically fractionalized regions (Schleussner et al., 2016). Climate projections for Africa indicate growing water scarcity, a heightened risk of violent conflict, and declining agricultural yields, particularly in the Horn of Africa (Carius, 2009; OECD – Organization for Economic Co-operation and Development, 2008; UNEP - United Nations Environment Programme, 2011). Burke et al. (2009) found significant correlations between temperature fluctuations, high rainfall variability, and the likelihood of violent conflict events in Africa.

5. Direct and indirect consequences of conflict on aquatic ecosystems

Direct effects of wars on aquatic ecosystems and landscapes include: i) Physical destruction of landscapes due to bombings, landmines, and other military activities; ii) Depletion of water and natural resources caused by overuse and mismanagement during conflicts; iii) Contamination by weapons and military residues, including heavy metals, synthetic pollutants, and explosives that enter water bodies (Helman et al., 2020; Xie et al., 2022); iv) Industrial waste and chemical spills from damaged infrastructure, further degrading aquatic ecosystems (Jha, 2014; Garzón and Valánszki, 2020); v) Deforestation and desertification, which reduce water retention and increase sedimentation in freshwater systems. In addition to the immediate destruction caused by conflicts, long-term and indirect consequences further degrade aquatic ecosystems: i) Overexploitation of natural resources, as displaced populations and weakened governance lead to unsustainable water extraction and fishing practices; ii) Reduction of resources for conservation programs, as funding and efforts shift toward conflict management rather than environmental protection (Jha, 2014; Garzón and Valánszki, 2020); iii) Destruction of landscape connectivity, which disrupts aquatic corridors and affects species migration patterns; iv) Loss of biodiversity, as species decline due to habitat destruction, pollution, and altered hydrological conditions.

Armed conflicts have significantly contributed to wildlife decline in the Sahara-Sahel region by exacerbating habitat degradation, increasing poaching, and limiting conservation efforts. Addressing these challenges requires integrated policies that balance security concerns with biodiversity conservation (Brito et al., 2018). Among these impacts, positive feedback has a dual effect on ecosystems and aquatic resources, both due to the reduction of natural water availability and indirectly by affecting the ecological health of aquatic ecosystems due to human conflicts.

In conflict-affected regions like Mali, such destruction disrupts human activities and has severe environmental direct effects and consequences, including habitat degradation and threats to biodiversity. For instance, the degradation of wetlands and water sources in Mali has intensified pressures on wildlife, including the endangered desert elephants, which rely on these ecosystems for survival. Conservation efforts in these conflict zones emphasize the importance of community engagement and sustainable management to protect both human and ecological systems (Canney, 2021; Canney and Ganame, 2014). The abrupt destruction of dams can lead to ecological consequences, such as siltation and the mortality of fish and other wildlife both upstream and downstream (Clark and Jorgenson, 2012; Vyshnevskyi et al., 2023) (Table 1). Additionally, it can also pose a risk to human lives.

Over the past three decades, numerous violent conflicts linked to water rights have occurred in dry regions, driven by resource scarcity, political instability, and competition among different user groups. These conflicts, often characterized by armed confrontations, displacement, and infrastructure destruction, highlight the critical role of water security in maintaining stability in arid and semi-arid areas. However, estimates of such conflicts vary widely depending on definitions and data sources, underscoring the need for more comprehensive assessments (e.g., UNCCD - United Nations Convention to Combat Desertification, 2014; Sterzel et al., 2014). The potential direct impact of armed conflict on the water supply has recently been observed in Ethiopia, specifically in its northern region, where the conflict has essentially destroyed 55 % of its overall water supply infrastructure (Shishaye et al., 2023). On the other hand, insecurity and disruption of governance structures can lead to the uncontrolled exploitation of aquatic resources, such as fish stocks, exacerbating overfishing and disrupting aquatic food webs. In Somalia, conflict and lack of governance have led to overfishing and the depletion of fish stocks in coastal waters, affecting marine ecosystems and local livelihoods (FAO – Food and agriculture organization of the United Nations, 2018).

Freshwater ecosystems are highly vulnerable to the effects of warfare. In warfare scenarios, aquatic ecosystems face multiple threats, including (i) habitat degradation caused by the disruption of river connectivity; (ii) the use of water as a weapon in cross-border areas, where dams and reservoirs are destroyed by bombing; (iii) targeted attacks on aquatic ecosystems, disrupting their connectivity and directly killing species; (iv) increased environmental pollution due to the accumulation of synthetic pollutants and heavy metals from explosives and nuclear weapons; (v) the intentional or unintentional introduction of alien species through military activities; and (vi) the poisoning of wells, which not only affects human populations but also disrupts freshwater ecosystems and biodiversity (Francis, 2011).

Armed conflicts may also adversely affect wildlife habitats due to military strategies involving army activities, mines, and explosives (Gaynor et al., 2016). For example, explosives and ammunition can contaminate soils and water resources leading to negative impacts on wildlife and ecosystems. However, the effects of post-war residual substances remain poorly investigated (e.g., Lawrence et al., 2015; Gaynor et al., 2016). The overexploitation of groundwater reserves in dryland zones, such as Saharan Africa and the Middle East, represents a potential source of conflicts (Döring, 2020). For example, explosives and munitions can contaminate soils and water resources, negatively impacting wildlife and ecosystems. The presence of landmines and unexploded ordnance (UXO) further exacerbates environmental degradation, restricting habitat use for both humans and wildlife. In North Africa, post-war landscapes have been mapped to assess the distribution of landmines, which pose long-term threats to biodiversity and ecosystem stability (Brito et al., 2014). However, the effects of post-war residual substances, including heavy metals and chemical pollutants, remain poorly investigated (e.g., Lawrence et al., 2015; Gaynor et al., 2016).

Several conflicts have resulted in significant human casualties and damage to water supply systems and infrastructures in various countries and in border areas, where water scarcity is often a primary trigger for violence (Pacific Institute, 2022). The ecological consequences of these conflicts remain insufficiently understood. However, population displacement, along with the destruction of dams and other water sources, have been documented (Femia and Werrell, 2012; Gleick, 2014). For instance, the Darfur conflict in Sudan has led to severe habitat destruction along the Chad-Sudan border, impacting seasonal wetlands that are critical for migratory birds and aquatic species. de Bie et al. (2011) documented conflict-related habitat loss and fragmentation in the Darfur region, affecting biodiversity and essential ecosystem functions. Therefore, military activities, population displacement and infrastructure development associated with conflict can be directly linked to the degradation and fragmentation of aquatic habitats such as rivers, wetlands, and lakes, threatening their biodiversity and ecological integrity.

In drylands, the deliberate disruption or destruction of water systems poses a significant threat, increasing tensions and impacting economic activities such as agriculture and water supply. Damage to water and other essential infrastructure is often used as a weapon of war, endangering civilian populations and violating human rights. The impact of

military actions and associated ecological disturbances on biodiversity is expected to be particularly severe in drylands, which often harbor high levels of endemic species with significant conservation value. These regions, such as the Sahara-Sahel, are home to unique vertebrate assemblages that are increasingly threatened by habitat destruction, overexploitation, and conflicts (Brito et al., 2021). Armed conflicts in these areas have accelerated wildlife decline, directly affecting biodiversity conservation and ecosystem stability (Brito et al., 2018). The quantification of endemic species in conflict-affected drylands highlights the urgent need for targeted conservation policies to mitigate biodiversity loss in these fragile ecosystems. While drylands generally exhibit lower species richness than tropical forests, they often feature high intraspecific diversity due to their varied habitats and isolated populations (Davies et al., 2012). Consequently, even in small areas, the military destruction of aquatic habitats with high conservation value can pose a serious risk of species extinction. For example, the civil war in South Sudan has threatened the survival of the Nile crocodile (*Crocodylus niloticus*) due to habitat destruction, poaching, and disruption of conservation efforts (IUCN, 2020). Local conservation organizations have documented a decline in the Nile crocodile population in South Sudan as a consequence of conflict-induced environmental degradation.

In this context, the socio-economic consequences of conflicts (Table 1) are closely linked with ecological impacts, highlighting how environmental degradation reduces both the quality of life and the economic viability of countries engaged in armed and non-armed conflicts.

6. Dryland regions under conflict: some case studies

6.1. Bardawil Lagoon (Egypt): fishing overexploitation and local conflicts

The coastal Bardawil Lagoon, one of the major lakes in the north of the Sinai Peninsula, is situated at 32°40′ E to 33°30′ E and 31°03′ N to 31°14′ N (Anufriieva et al., 2018; El-Shabrawy et al., 2018). Its surface area is more than 600 km^2 when all branches are filled with water.

A sand barrier of varying width ranging from 300 to 2000 m separates the lagoon from the Mediterranean Sea, having only one natural opening at the far eastern end. Since 1927, two artificial openings, narrow channels connecting the lagoon with the sea, Boughazes I and II, were built to reduce salinity through water exchange. Although this has changed the original ecological features of the lagoon, acting as an anthropogenic impact, this was counterbalanced by the increases of provision ecosystem services, because this allowed the migration of commercial fish from the sea. Bardawil was considered one of the most non-polluted and profitable water masses because of its high-quality fish production, which was exported to Europe (Shadrin, Personal communication).

From 1985 to 2015, the average yearly fish production was 2970 t. Due to the Arab-Israeli wars (1967–1973), two openings from the sea into the lagoon were entirely blocked by accumulated sand between 1969 and 1971. As a result, the salinity in the lagoon increased considerably, reaching 100 PSU in the main part of the lagoon and up to 170 PSU in some isolated basins. The fishery collapsed, and considerable socioeconomic damages occurred (e.g., loss of fishing, rising unemployment, declining income, etc.). Nowadays, the Egyptian government is more concerned about the sustainable development of the Bardawil Lagoon, which is complementary to the Sinai development strategy and contributes to increasing fish productivity (Shadrin, Personal communication). Several recent studies have documented conflicts between fishermen in Lake Bardawil (Mustafa and Abdel-Aziz, 2020; Mansour et al., 2022). Most of these conflicts stem from the lack of support from the stakeholders and cooperatives, which negatively affects fishing activities and increases conflicts between fishermen (Mansour et al., 2022).

6.2. Lake Chad (Chad, Africa): drought as an emerging trigger in vulnerable zones

The Sub-Saharan region encompassed 48 countries under extreme climatic conditions and complex socio-economic scenarios. The region has a history of water scarcity and prolonged droughts threatening food production. In addition to scarcity, people coexist with low water quality combined with incipient management of these resources (Peña-Ramos et al., 2022). Countries such as Chad, Angola, Mali, Ethiopia, and Namibia are located in areas of extreme vulnerability to historical drought, worsening water scarcity, food insecurity, and violent conflict (Adaawen et al., 2019). Lake Chad, located in west-central Africa, has experienced a significant reduction in its catchment area due to overexploitation and severe climatic conditions (Okpara et al., 2015; Pham-Duc et al., 2020). The most severe period was the 1980s when severe droughts increased socio-political risks (Wolf et al., 2003). Among the ecological consequences, the decline in water levels caused an increase in nutrient concentrations, leading to an increase in eutrophication (Hamit et al., 2023).

Over time, regional conflicts have been observed in the Lake Chad Basin, all linked to historical and prolonged droughts and consequent water scarcity. Poor access to safe drinking water has led to violent transboundary disputes over the past 50 years, with one of the most severe occurring between Nigeria and Cameroon, resulting in 100 casualties in the 1980s (Okpara et al., 2015). Over the years, these conflicts have remained serious and persistent, jeopardizing socio-economic activities and water security, and increasing the vulnerability of people in the south of the lake, thereby strengthening extremist groups (Okpara et al., 2015). In countries such as Mali, in the sub-Saharan region, prolonged drought has triggered the actions of extremist groups by worsening economic scenarios (Maconga, 2023).

6.3. Sivash Lagoon (Crimean Peninsula): the political conflict escalated into an armed conflict

During the Soviet Union (USSR) times, Sivash Bay, the largest hypersaline lagoon in the world (46° 5′ N, 34° 20′ E) consisted of a large natural system of several interconnected shallow lagoons (Shadrin et al., 2018; Anufriieva et al., 2022). Central and Eastern Sivash were designated as protected wetlands by the International Ramsar Convention (1995). Before the construction of the North Crimean Canal (1963–1975), Sivash Lagoon was a semi-closed, shallow, highly productive hypersaline lagoon with an average salinity of about 140 g L^{-1}, and in the southern part >200 g L^{-1}. There was severe freshwater scarcity in the Crimean Peninsula, triggering the construction of the North Crimean Canal (total length of 465 km, 375 km of which are in Crimea) to improve water supply using the waters from the Dnieper River.

In 1985, 521 MM m^3 of freshwater was discharged from Crimea and 109 MM m^3 from the Cherson region. In 2009, 1100 MM m^3 of freshwater was discharged in total. As a result, the salinity began to drop in Sivash Lagoon. Average salinity had decreased from 140 g L^{-1} to 22.6 g L^{-1} by 1989, and to 17 g L^{-1} by 1997. A new brackish water ecosystem was gradually formed in Sivash Lagoon with abundant fish populations. As a result, a large-scale fishery industry developed in the lagoon, and the local human population in the watershed increased many times due to the high development of irrigated agriculture and fishery. In April 2014, during the Russian-Ukrainian political conflict, the supply of Dnieper water into the North Crimean Canal was stopped, halting the discharge of freshwater drainage, so by 2020–2022, salinity started to increase in the lagoon up to 80–120 g L^{-1}. A new transformation of the lagoon ecosystem began; fish disappeared, irrigated agriculture collapsed, and many people lost their jobs and livelihoods, though the lagoon started to return to its hypersaline conditions.

Bay Sivash is located on the northeastern coast of Crimea and has historically been an obstacle to the region's conquest due to its muddy

sediments, which cause soldiers to get stuck and sink (Kabanenko, 2023). Due to its strategic location and natural characteristics, Crimea has been the scene of battles for territorial control since before the Common Era. The annexation of Crimea to Russia in 2014 exacerbated the conflict with Ukraine (e.g., Rabinovych and Pintsch, 2024). In February 2022, the political conflict escalated into an armed conflict with the destruction of the Kakhovska dam (Vyshnevskyi et al., 2023) and as a result the worsening of the situation for ecosystems and humans in the dryland part of Crimea.

6.4. Transboundary tensions

Effective governance and strategic planning in transboundary watersheds are crucial for sustaining livelihoods, maintaining peace, and ensuring human security. However, in conflict situations, managing transboundary watershed governance becomes particularly challenging and a major source of tension due to political boundaries and the complexities of shared water resource management (Gleditsch et al., 2006). The following three sections explore transboundary tensions in the Middle East and East Africa (Ethiopia).

6.5. The Euphrates-Tigris basin

The Euphrates (760 km) and Tigris (1718 km) rivers originate in southeast Turkey and are the longest in southwest Asia, an area affected by water shortage problems. Water resources are, therefore, essential to guarantee the socio-economic and political stability of the region (Al-Ansari et al., 2018). The Tigris-Euphrates basin reveals evidence of water management projects dating back over six millennia. The power of the different empires that succeeded each other over that time was mainly built upon water availability for agriculture (Beaumont, 1998). Nowadays, the primary water utilizers in these rivers and tributaries are Turkey, Syria, Iraq, and Iran. Turkey has the hegemony over the headwaters of both rivers, contributing 90 % to the Euphrates and 40 % to the Tigris water flow (Kibaroglu and Scheumann, 2013), while Iraq and Syria are strongly dependent, located in the lower part of the basin, though Iraq contributes 51 % to Tigris water flow (Al-Ansari et al., 2018).

Before 1960, water consumption by the co-riparians was low and the relations between the three countries were considered good (Kibaroglu, 2015). After 1960, the strategic landscape of the Euphrates-Tigris basin changed dramatically, and it became unstable (Lorenz and Erickson, 2014). Unilateral and uncoordinated water development projects began to stress the river system capacity (Kibaroglu and Scheumann, 2013) with weak results due to inefficient irrigation systems and the cultivation of water-intensive crops (Lorenz and Erickson, 2014).

The tension between Turkey and Syria culminated in 1975 when, during a dry period, they simultaneously started to use the Keban and Taqba dams (Lorenz and Erickson, 2014). Later, during the 1980s and 1990s, Turkey pressured the other co-riparian states and linked water flows to issues unrelated to water (Gleick, 1994). For example, when Iraq invaded Kuwait (1990), Turkey cut off the Euphrates flow (Gleick, 1994). After this period of acute tensions between the co-riparian during the late 1990s and early 2000s, there was a significant improvement in the relations, enabling cooperation on water management (Kibaroglu, 2015). However, soon after, the collaboration came to a halt, making it problematic to collectively address the severe environmental challenges in the basin, where irrigation led to a salinity increase and pollution through chemicals, which are likely to have greater and more immediate effects on the population in the basin than a reduction in water quantity (Kibaroglu, 2015).

For more than 20 years, protracted conflicts over communal resources have hampered progress and made poverty worse in North Wollo Amhara and the surrounding Afar communities in Ethiopia. One of the main factors contributing to the majority of resource conflicts in Afar-Amhara communities was discovered to be rivalry for limited natural resources, especially water and pasture land. Due to extended dry seasons and drought years, most study areas—especially the Afar populations in Ethiopia's arid region—have a severe water scarcity issue (Abebe et al., 2023).

6.6. Impact of the Palestinian-Israeli conflict on water resources and aquatic ecosystems

In the Palestinian-Israeli conflict, water scarcity in Palestine is one of the key issues, posing a threat to the long-term survival of its population and hindering social and economic development (Obidallah, 2008). This conflict has had severe ecological consequences on water resources, water quality, and aquatic ecosystems in the region. Ongoing tensions have led to over-extraction, pollution, and degradation of key water sources such as the Coastal Aquifer, the Mountain Aquifer, and the Jordan River. In Gaza, approximately 97 % of groundwater from the Coastal Aquifer is undrinkable due to salinization and contamination from wastewater discharge, agricultural runoff, and seawater intrusion (Nica et al., 2024). Furthermore, conflicts have directly damaged water infrastructure, worsening water shortages and increasing dependence on unregulated wells and unsafe water sources (Zeitoun, 2008).

Water pollution is a major concern in the region. Chemical contamination from agricultural fertilizers and untreated sewage, leads to high nitrate levels, which exceed the World Health Organization's drinking water standards (Nica et al., 2024). Heavy metal pollution has also affected both surface and groundwater. The spread of biological contaminants, including harmful algal blooms and pathogens from wastewater effluent, further threatens public health and biodiversity (Zeitoun, 2008). These pollutants directly affect the nearby marine ecosystem, particularly in the Mediterranean Sea, where excessive nutrient loading from sewage contributes to eutrophication and hypoxia, endangering fish populations and marine biodiversity (CEJISS, 2016). The destruction of wastewater treatment facilities has exacerbated pollution. In Gaza, damaged sewage plants have led to millions of liters of untreated wastewater being discharged into the Mediterranean, with long-term consequences for fisheries and marine life (UN Reports, 2024). Additionally, declining freshwater availability reduces the ability of aquatic ecosystems to recover from pollution stress, leading to fish biodiversity losses and declining productivity (Springer, 2016).

Public health crises in Gaza have also emerged due to water pollution and scarcity, including the spread of waterborne diseases such as cholera and hepatitis. These diseases risk spreading to neighboring countries like Israel and Egypt, increasing their healthcare burdens and complicating water management (International Water Management Institute, 2020; Environmental Peacebuilding Association, 2019). The highly polluted marine ecosystem also impacts fisheries, water quality, and public health in both Israel and Egypt (World Bank, 2021; United Nations Development Programme, 2008).

Urgent interventions are needed to restore and protect water resources. Transboundary water management agreements and wastewater treatment reconstruction can help mitigate pollution and improve water quality. Implementing advanced desalination and water recycling technologies can enhance water availability and reduce reliance on fragile aquifers (Tandon et al., 2019). Strengthening environmental monitoring, controlling agricultural runoff, and promoting sustainable fisheries management are crucial for rehabilitating affected water bodies. Establishing buffer zones and wetland restoration projects could also provide natural filtration systems, improving water quality and biodiversity resilience (Zeitoun, 2008). Thus, the Palestinian-Israeli conflict significantly impacts water resources and aquatic ecosystems through pollution, infrastructure destruction, and over-extraction. Addressing these challenges requires collaborative water management efforts, wastewater treatment restoration, and sustainable technology implementation. Without urgent ecological interventions, worsening water quality and biodiversity loss will continue to threaten both human and environmental health.

6.7. Grand Ethiopian Renaissance Dam (GERD)

The Nile River is one of Egypt's most important water sources, and the construction of GERD represented a significant change in relations between countries in the cross-border area. In 2020, the disputes among Egypt, Ethiopia, and Sudan over the GERD increased, especially when Ethiopia announced the beginning of GERD's reservoir filling. The filling process of the largest dam in Africa might jeopardize the stability of the water supply for downstream countries, especially Egypt, reducing the groundwater levels already threatened by climate change and human pressures (El Ghany et al., 2020).

Shared basins represent a potential cause of conflicts between transboundary countries. The building of dams and other changes in the natural river flow increase water availability over the hydrological cycle, as occurs in Sudan, decreasing the availability of this source for Egypt (El Ghany et al., 2020). Conversely, the sediments upstream of GERD mean a great loss of natural fertilizers to the downstream countries. The loss of the annually deposited sediments brought by the flood means a dramatic loss in the brick industry in Sudan which can cause loss of livelihoods and income for many. Despite years of negotiations, a comprehensive plan to mitigate losses and damages associated with the construction of GERD has not been successfully promoted among Ethiopia, Egypt, and Sudan, escalating diplomatic tensions between these nations.

6.8. Economic consequences of armed conflicts and their impact on ecosystem restoration

Armed conflicts often significantly reduce a nation's Gross Domestic Product (GDP), limiting financial resources available for environmental protection and ecosystem restoration. For instance, ongoing hostilities in Lebanon are projected to decrease GDP by 9 %, surpassing the economic impact of the 2006 conflict (Reuters, 2024). Similarly, countries experiencing prolonged conflicts, such as Syria, Yemen, and Libya, have suffered GDP declines exceeding 10 %, severely restricting investments in public services, including water resource management and environmental protection (). In general, civil wars lasting four years or more result in an average GDP per capita decline of 18 % (Mueller and Tobias, 2016). This sharp decrease is primarily attributed to the prolonged duration and high costs of war, with GDP remaining 15 % below pre-conflict even after hostilities cease (Mueller and Tobias, 2016) (Table 2).

Studies indicate a positive correlation between GDP per capita and investment in improved water resources (WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene, 2024). Nations with higher GDPs are more likely to allocate funds toward enhancing water quality, infrastructure, and sanitation, primarily to protect human health but with indirect benefits for aquatic ecosystems. Conversely, in conflict-affected regions where GDP declines, investments in water infrastructure and conservation efforts diminish, leading to increased reliance on unsafe water sources and worsening environmental degradation (WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene, 2024). Data further shows that mortality rates due to hazardous water consumption are significantly higher in low-GDP countries, illustrating the link between economic stability and water security (Our World in Data, 2024a).

Economic constraints during and after conflicts impede the implementation of agri-environmental policies designed to protect natural resources. Research suggests that countries with higher GDP per capita implement more environmental policies, contributing to sustainable land and water use (Our World in Data, 2024b). A decline in GDP, therefore, not only hinders immediate ecosystem recovery but also undermines long-term sustainability initiatives aimed at preserving biodiversity and ecosystem services. Thus, armed conflicts have devastating effects on biodiversity and natural resources, including forests, aquatic ecosystems, and wildlife habitats (e.g., Hanson, 2018). The most significant issue associated with economic downturns is the negative impact on biodiversity and natural resources, including forests, aquatic ecosystems, and wildlife habitats (e.g., Hanson, 2018). In conflict-affected regions, economic instability often accelerates biodiversity loss by reducing conservation funding, increasing reliance on natural resources for subsistence, and weakening environmental governance. The Sahara-Sahel region exemplifies these challenges, where armed conflicts have accelerated wildlife decline and habitat degradation, highlighting the need for effective conservation policies amid socio-political instability (Brito et al., 2018). The economic repercussions of armed conflicts extend beyond immediate infrastructural damage to significantly affect environmental restoration and protection capacities. Diminished GDP reduces investments in water resource management, environmental policies, and rehabilitation efforts, making it increasingly difficult for war-torn regions to recover from ecological degradation. Addressing these economic constraints is crucial for ensuring the long-term sustainability of aquatic ecosystems in post-conflict settings.

Table 2
Gross domestic product (GDP) for six countries before and after prolonged human conflicts.

Country	GDP (year)		
	Before	After	Recent Value
Afghanistan	264.1 (1980)	179.4 (2002)	516.7 (2020)
Iraq	10,356.9 (1990)	22.8 (1991)	5048.4 (2021)
Kuwait	8794.6 (1990)	5419.6 (1991)	24,811.8 (2020)
Syrian Arab Republic	11,820.6 (2010)	3492 (2011)	1265.6 (2018)
Republic of Yemen	1607 (2013)	758,14 (2018)	690.8 (2021)

6.9. Freshwater and saline inland aquatic ecosystems: vulnerability and services

Drylands are especially rich in ecosystem services and biodiversity despite their seemingly restrictive environment characterized by scarce and unpredictable rainfall and a homogeneous landscape (e.g., Maestre et al., 2021). Therefore, aquatic ecosystems contribute to essential provisioning and regulating services, including water supply, flood mitigation, and managing other environmental extremes (e.g., Schild et al., 2018). Changes in land use on watersheds and water pollution have placed aquatic ecosystems under extreme pressure, exacerbated by climate change (DeBeer et al., 2016; Cantonati et al., 2020; Morant et al., 2021; Barchiesi et al., 2022). Increased freshwater consumption leads to the decline and possibly extinction of many freshwater-dependent populations (IPCC – Intergovernmental Panel on Climate Change et al., 2022). Socioeconomic and political consequences of water-related hazards unduly impact vulnerable populations, most of all the poor, women, children, indigenous people, and the elderly, especially in the Global South, due to systemic inequities (IPCC – Intergovernmental Panel on Climate Change et al., 2022). Additionally, violent conflicts increase vulnerability to climate change (Field et al., 2014). The IPCC pointed out that the most relevant related water risks are on i) agriculture; ii) energy and industrial water use; iii) water, sanitation, and hygiene; iv) urban and peri-urban sectors; v) freshwater ecosystems; vi) water-related conflicts; human mobility and migrations; and vii) cultural water uses by indigenous people.

The loss of ecosystem services due to human conflicts may not only impact current inhabitants in affected areas but also jeopardize the culture and identity of future generations. The loss of ecosystem services due to human conflicts may not only impact current inhabitants in affected areas but also endanger the culture and identity of future generations. There is an observable correlation between land degradation and cultural degradation in drylands, where environmental changes often lead to the erosion of traditional knowledge and practices (Bunning et al., 2011). A striking example is the destruction of ancient

manuscripts in Timbuktu, Mali, during armed conflicts, which represents both a cultural and historical loss for humanity. This event highlights how conflicts degrade ecosystems and undermine cultural heritage and social identity, further deepening the long-term consequences of instability (Jeppesen, 2013). During the Syrian civil war, infrastructure damage and a lack of environmental regulation led to the pollution of rivers in Syria (e.g. the Orontes River) by untreated sewage and chemical discharges, posing risks to human health and aquatic biodiversity (Zwijnenburg and Te PaS, 2015). The displacement of refugees associated with conflict can put pressure on aquatic ecosystems, as displaced populations may rely on these resources for survival, leading to unsustainable extraction practices. Displaced populations from conflict-affected regions in Yemen have increased pressure on coastal and inland aquatic resources, leading to overfishing and degradation of marine habitats (Kimball and Jumaan, 2020; UN Reports, 2024; Zabara and Zumbrägel, 2022). In addition, indigenous knowledge has been eroded during conflict, which has implications for future adaptive capacity and sustainable management practices of ecosystems. Indigenous water management practices among pastoralist communities in northern Kenya have been disrupted by conflict-related displacement and loss of cultural continuity (Adams et al., 2019).

The good health status of freshwater ecosystems is crucial for maintaining the ecosystem services essential to human communities and well-being (MEA – Millennium Ecosystem Assessment, 2005). Additionally, ensuring healthy and safe water availability is fundamental for achieving the Sustainable Development Goals (SDGs) and transitioning all systems for adaptation. Despite the United Nations' explicit recognition of the human right to access water and sanitation in 2010, it is projected that by 2030, 69 million children under the age of five could die from preventable causes such as lack of drinking water, sanitation, and hygiene. In some regions, this right remains ineffective and may deteriorate further due to climate change, as seen in Palestine, where 90 % of the water is non-potable (Bedriñana et al., 2022). Conflicts exacerbate these challenges.

Recent studies indicate that water security significantly contributes to achieving all Sustainable Development Goals (SDGs), particularly those related to good health and zero hunger (Taka et al., 2021). Water security is gaining prominence in aquatic science and water resource policymaking due to its emphasis on the interconnectedness of water with human health, climate, and food security. In this context, the protection of water resources during armed conflicts is increasingly being recognized as a critical issue. There is a growing call to designate environmental destruction, including damage to water bodies, as a war crime, reinforcing the need for stronger legal frameworks to prevent and mitigate environmental harm during conflicts (Durant and Brito, 2019). This framework is valuable for addressing both water sufficiency and equity and societal and ecological needs (Taka et al., 2021). In vulnerability assessments, scenarios involving multiple stressors can heighten the susceptibility of aquatic systems. For example, during periods of water scarcity, the presence of chemical pollution can exacerbate ecological risks (Arenas-Sánchez et al., 2016).

6.10. *Future perspectives*

Human conflicts in drylands have profound and far-reaching consequences on aquatic ecosystems, threatening water availability, biodiversity, and ecosystem services. The destruction of dams, reservoirs, and irrigation systems, combined with pollution, salinization, and the introduction of alien species, accelerates ecosystem degradation, pushing some systems to an irreversible tipping point.

Extreme droughts have emerged as a trigger for conflict in vulnerable areas and are considered one of the most significant consequences of climate change (Trenberth, 2020). The future perspective is an aggravation of this scenario, threatening water security and reducing the availability of this essential resource for more than 2000 billion people living in drylands (White and Nackoney, 2003). In contrast, most of these countries have the highest world demographic growth, which would increase the number of people affected faster. Therefore, water security is still threatened in these countries, with growing impacts from hygiene and health crises, internal and involuntary displacement (WEF – World Economic Forum, 2023). Implementing conflict-sensitive water management in transboundary areas to reduce related tensions and involve communities in this process might be important to mitigate tensions around water resources (e.g., Keskinen et al., 2021).

Conflict and social insecurity are known to have overwhelmingly negative effects on ecosystem structure and function, and therefore their integrity (Lawrence et al., 2015; Shadrin et al., 2018), as well as an acceleration in the decline of their biodiversity (Gaynor et al., 2016; Anufriieva et al., 2022). The recent increase in global conflicts (Palik et al., 2022) stresses the need to identify hotspot conservation areas and develop effective policies to reduce the impacts on biodiversity and the ecosystems where it thrives. Reducing the negative ecological consequences of armed conflicts has become a key international priority, mainly in the context of climate change. Given the increasing frequency and severity of extreme droughts, it is crucial to develop strategies to preserve and restore the resilience of aquatic ecosystems in dryland regions. This requires comprehensive research, sustainable management approaches, and international collaboration to implement effective mitigation measures and establish a global agenda focused on drought adaptation and water security in these vulnerable areas. In areas where the development of the economy is entirely dependent on water balance, the expectations of a future increase in temperature and evaporation represent a great risk for the fragile stability of drylands. Recognizing the leading natural and political drivers of conflicts, such as dam construction or destruction and severe extreme droughts, and how this may contribute to the escalation of national and international conflicts, especially in border regions, may be the greatest challenge for governments and stakeholders. The protection of inland waters and the human right to water and sanitation could be integrated into the Geneva Conventions, establishing international legal standards for humanitarian treatment in war. Strengthening such legal mechanisms is essential, as there is increasing recognition that environmental destruction during armed conflicts should be formally designated as a war crime to ensure accountability and enhance environmental protection in conflict-affected regions (Durant and Brito, 2019).

Additionally, in 2017, the term Nature's Contributions to People (NCP) was introduced to capture both the beneficial and detrimental effects of nature on people's quality of life, highlighting the importance of safeguarding ecosystems in humanitarian law (Pascual et al., 2017). War conflicts lead to a reduction in these benefits from all the contributions that aquatic systems provide to people. Apart from losing this intrinsic value of nature, social and environmental awareness is increasing. This is an opportunity, as it helps to document and assess the environmental damage caused by conflict and fill the knowledge gaps: by understanding the impacts and consequences of the ecological level, we can also think about the solutions during recovery. The ineffectiveness of international laws to protect water bodies poses the biggest problem for access to water in conflict zones, and the subjectivity of laws also suggests a lack of punitive effectiveness (Gleick, 2019).

One of the mechanisms designed to compensate for and remediate the economic and ecological consequences of war was established by the United Nations Compensation Commission (UNCC) two months after the Gulf War (Menhinick, 2016). This initiative aimed to provide financial restitution for environmental damages caused by conflicts. However, its application is hampered by several challenges, including the difficulty of assigning an economic value to the environment and natural resources (Dickson, 2013; Menhinick, 2016). Additionally, attributing responsibility for environmental destruction—particularly when state property is deliberately targeted—remains a legal and political challenge (Dickson, 2013). Despite these complexities, the UNCC is crucial in administering compensation funds and assessing environmental losses in conflict situations. Expanding the framework for accountability

could be explored, including discussions on whether industries that directly or indirectly contribute to conflict—such as arms manufacturers—should be held responsible for funding environmental restoration. While this approach presents legal and ethical challenges, similar accountability measures are already applied to industries that exploit natural resources. The UNCC compensation mechanism, if effectively implemented, can serve as a valuable tool for post-conflict environmental restoration. However, successful recovery efforts require a broader strategy, incorporating long-term investments, robust management policies, environmental legislation, and education programs, all of which should be established as soon as conflicts arise to ensure a sustainable path forward.

Aiming to mitigate the long-term consequences of conflicts on water ecosystems, the following strategies should be prioritized: 1. Strengthening Transboundary Water Governance: 1.1 Promote cooperative water-sharing agreements to prevent conflicts over shared rivers and reservoirs (e.g., Nile, Tigris-Euphrates) and, 1.2. Implement early-warning systems for potential water-related conflicts; 2. Enhancing Legal Protections for Water Resources in Conflict Zones: 2.1 Integrate the protection of inland waters and sanitation rights into the Geneva Conventions, establishing clear legal standards for water security in wartime (Pascual et al., 2017), 2.2 Designate intentional environmental destruction during armed conflicts as a war crime (Durant and Brito, 2019); 3. Investing in Ecosystem Restoration and Post-Conflict Rehabilitation: 3.1 Prioritize rebuilding water infrastructure (dams, reservoirs, sanitation systems) in post-conflict zones, 3.2 Develop long-term environmental monitoring programs to track pollution levels, biodiversity loss, and groundwater depletion; 4. Addressing Climate Change and Population Growth in Water-Scarce Regions: 4.1 Enhance climate adaptation policies, including drought resilience programs, 4.2 Improve water-use efficiency in agriculture and industry through sustainable irrigation practices; 5. Strengthening International Compensation Mechanisms for Environmental Damage: 5.1 Expand the role of the United Nations Compensation Commission (UNCC) to include funding for ecological restoration projects post-war (Menhinick, 2016), 5.2 Establish financial liability mechanisms for corporations contributing to environmental degradation during conflicts (Dickson, 2013).

Given these complexities, future research should focus on developing cross-disciplinary frameworks that integrate hydrology, political science, and conflict studies to assess how water scarcity influences security dynamics at both local and international scales.

6.11. *Final remarks*

As conflicts escalate and climate pressures intensify, protecting water resources in drylands must become a global priority. Ensuring water security, preventing ecological degradation, and restoring damaged ecosystems are critical to promote peace, sustainability, and resilience in arid regions. Future research should explore the interplay between water scarcity, conflict, and governance, fostering innovative solutions for sustainable water management in conflict-prone regions.

CRediT authorship contribution statement

Luciana G. Barbosa: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Ilia Ostrovsky:** Writing – review & editing, Visualization, Validation, Investigation, Conceptualization. **Manuela Morais:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Elena Anufriieva:** Writing – review & editing, Writing – original draft, Methodology. **Gema Parra:** Writing – review & editing, Writing – original draft. **Egor Zadereev:** Writing – review & editing, Conceptualization. **Antonio Camacho:** Writing – review & editing. **Antje Schwalb:** Writing – review & editing. **Simonetta Bagella:** Writing – review & editing. **Rosemberg F. Menezes:** Writing – review & editing. **Luz Marina Soto:** Writing – review & editing. **Carlos López:** Writing – review & editing. **Maria Ilheu:** Writing – review & editing. **Eduardo A. Morales:** Writing – review & editing. **Abdullah A. Saber:** Writing – review & editing. **Hichem Kara:** Writing – review & editing. **Peter Riad:** Writing – review & editing. **Gizachew Teshome:** Writing – review & editing. **Nickolai Shadrin:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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