

1 **Assessing the impact of war on the water supply infrastructure in Tigray, Ethiopia**

2

3 Haile Arefayne Shishaye*¹, Tesfay G. Gebremicael², Hadush Meresa³, Fasil A. Gebre⁴, Shishay Kidanu⁵

4

5 *¹Southern Cross University, Faculty of Science and Engineering, Lismore, NSW, Australia*

6 *²Soil and Water Science Department, University of Florida/West Florida Research and Education*

7 *Center, 5988 Hwy 90, Bldg 4900, Milton, FL 32583, USA*

8 *³Institute of Geographic Sciences and Natural Resources Research, CAS, Beijing.*

9 *⁴Hydrology Section, The Office of Public Works, Ireland*

10 *⁵University of Alaska Fairbanks, Dept. of Civil, Geological, and Environmental Engineering,*

11 *Alaska, USA*

12 *Corresponding author: Haile Arefayne Shishaye (Ph.D.), E-mail: haile.4.hiwot@gmail.com*

13

14 **Abstract**

15 Armed conflicts throughout the world can have substantial impacts on private and public
16 infrastructure and its people. Over the last two decades, the regional government of Tigray in
17 Ethiopia has invested extensively in developing surface and groundwater resources for water
18 supply leading to 61% of rural and 57% of urban populations having access to safe drinking
19 water by 2020. However, the Ethiopian Government and its allies' invasion of Tigray in the
20 early November 2020 led to considerable damage and devastation of Tigray's water
21 infrastructure. This study assessed the damage to Tigray's water supply systems and determined
22 the impact on its people. The study, conducted between late 2021 and early 2022, found that
23 the destruction reduced the rural and urban water supply coverage of the region by over 50%
24 (i.e., reduced to 28% and 25%, respectively). The war exposed more than 3.7 million people in
25 Tigray to a shortage of drinking water supply and water-related risks, such as disease and food

26 insecurity. Over the past 15 months of the war, the damage to the water supply infrastructures
27 in Tigray was considerably higher than in other regional conflicts, with the damage in Tigray
28 being 15% higher than the damage to Syria's drinking water supply infrastructures over 10
29 years of conflict and 6% higher than the damage to Yemen's water supply infrastructures over
30 seven years of conflict. This study shows the significant and long-term impacts armed conflict
31 can have on a developing country's water infrastructure and people. In future conflicts,
32 monitors and aid agencies must assess this more adequately to limit the impact on civilian
33 populations.

34

35 **Keywords:** Damage assessment, Ethiopian and Eritrean invasion, Tigray war, urban and rural
36 impacts of war, Water Infrastructure

37 **1. Introduction**

38 Water is not only an important element of life but also a central factor in the economic and
39 social development of countries. The United Nations described water as a vital resource for
40 reducing the global burden of disease and improving the health, welfare, and productivity of
41 populations, and is the heart of adaptation to climate change, serving as the crucial link between
42 the climate system, human society, and the environment (UN Water, 2015). Water carries
43 increasing importance for developing countries in the world, including countries in Sub-
44 Saharan Africa, the Middle East, and Central Asia. This is because of the limitedness of their
45 renewable resources' development, urbanization, and rapid population growth (Tuncok et al.,
46 1999; UN Water, 2015). Further, the political instabilities – mostly in developing countries,
47 including armed conflicts, power asymmetry, the strength of institutions, and the interests of
48 stakeholders contribute to decision-making in water resources management and utilization,
49 which affects human lives both directly and indirectly (Wu et al., 2017). To overcome the
50 impacts of these and other factors on water resources development and management in
51 developing countries, a well-defined framework of policies and strategies are required. These
52 policies and strategies should include at least district-level water resources planning,
53 management, and utilization plans (Goyal et al., 2020).

54 The Tigray region of Northern Ethiopia has abundant surface and groundwater resources to
55 satisfy the region's domestic water supply, irrigation, and hydropower requirements (Haile et
56 al., 2018; Awulachew et al., 2007; Gebremicael et al., 2017). The region possesses three main
57 river basins (Tekeze, Danakil, and Mereb) with a total potential discharge of approximately
58 10.1 billion cubic meters per year (Awulachew et al., 2007). However, despite the large
59 potential, the region's capacity to exploit its water resources for water supply, sanitation, and
60 overall economic development has traditionally been hindered by environmental, technical,
61 economic, and institutional factors (Berhe et al., 2020; Haile et al., 2018; Gebrehiwot, 2006).

62 In the last two decades, despite the extensive amount of available water resources, communities
63 had limited access to potable water, safe hygiene, and sanitation practices, even before the
64 Tigray war which started in late 2020 (Gebrehiwot et al., 2006; Shiferaw et al., 2018). The
65 water supply systems in Tigray mainly depend on sources including, groundwater (i.e., deep
66 and shallow wells, and springs), surface water systems including artificial structures such as
67 dams (Fig. 1), and other structures like roof water harvesting and ponds (Berhane et al., 2016;
68 Fagan, 2019; Shishaye et al., 2020). The Tigray government had invested extensively in
69 developing both the surface and groundwater resources for water supply and sanitation in urban
70 and rural areas (Woldearegay et al., 2018; Kifle et al., 2017, Haile et al., 2018; Tafesse, 2006).
71 This had been further supplemented by the Ethiopian central government and local and
72 international non-governmental organizations (Beriha et al., 2013; Admasu et al., 2011).
73 However, this whole effort has resulted in an improved regional average water supply access
74 for only 58% and sanitation for only 7.7% of the population (Azage et al., 2019).

75 The Tigray war began in early November 2020 by the allied forces, which includes the
76 Ethiopian National Defence Force (ENDF), the Eritrean National Defence Force (ErNDF), the
77 Amhara militia, special police forces, and *Fano* (a group of separate armed forces who are not
78 under the control of the federal government of Ethiopia), and special police forces from other
79 Ethiopian regional states, and technical support, such as drone technologies and operators, from
80 the UAE, Turkey, Iran, Russia and China (Gesese et al., 2021; Gebregziabher et al., 2022;
81 Demissie et al., 2022, Reuters, 2021a; Zelalem, 2021; Walsh and Dahir, 2022). Before the war,
82 the regional government of Tigray including the Tigray Water Resources Bureau was actively
83 developing water supply systems in the region to achieve the goals laid out in the government's
84 Growth and Transformation Plan for safe water supply and improved hygiene and sanitation
85 (Tigray Water Resources Bureau, 2021; Berhane et al., 2018; Tafesse, 2006). The activities
86 and goals outlined in the plan showed that access to safe water and improved sanitation and

87 hygiene are not separate pursuits and that coordinated efforts are required among governmental
88 agencies, civil society organizations, and private sectors. The Bureau recognized the fact that
89 results will only be sustainable if responsibilities are shared and resources are devolved, and
90 communities are empowered to manage their resources. This practice, therefore, had added
91 improvements in water, sanitation, and hygiene (WASH) infrastructure compared to practices
92 from previous decades (Admasu et al., 2011; Berhane et al., 2016). However, the ongoing war
93 in Tigray has reversed the progress made on water supply systems and caused the people to
94 face serious water shortages and water-related problems.

95 Other armed conflicts in the world have resulted in widespread and long-term damage to
96 critical water infrastructures. For example, the instability and prolonged war in Afghanistan
97 (2001 to 2014) have hit the water sector (Groninger et al. 2015), leaving 70% of violence-prone
98 locations with insecure water supplies (<https://www.wionews.com/south-asia/afghan-crisis>).
99 Similarly, from 2014 to the present (2022), the war in Yemen had a significant impact on the
100 quantity and quality of water and sanitation services, exposing the majority of the people of
101 Yemen to use untreated water, especially from 2013 to 2016 (Schillinger et al., 2020; Aklan et
102 al., 2019). The Yemen conflict constrained access to water for millions across the nation and
103 has contributed to recent cholera outbreaks and other waterborne diseases (Camacho et al.,
104 2018; Spiegel et al., 2019; UN, 2018). In Syria, the war, which started in March 2011 and is
105 still ongoing, resulted in extensive destruction of water infrastructure, with 40% of water
106 supply facilities destroyed (Faour and Fayad, 2014; ICRC, 2021). A greater understanding of
107 the scale of destruction and impact on water resources and their delivery during armed conflicts
108 in developing countries is crucial, as these services are essential to survival and quality of life
109 and can be impacted long after the conflict has ceased.

110 The impacts of war on water supply and other infrastructures are not well-studied worldwide
111 (Schillinger et al., 2020). The fact that the impacts of such wars on water supply infrastructures

112 (and hence health, food security, etc.) are not well documented scientifically (not beyond
113 advocacy narrations and social media posts) as a result of which the understanding of the degree
114 of the impacts of war by the academic community and decision-making bodies is limited.
115 Therefore, this study will provide scientific evidence on the impacts of war on water supply
116 systems and infrastructures, which could be an important input to any comprehensive global
117 overview of the impacts of war on water and other infrastructures. Further, the study also shows
118 how much the current damage to the water supply infrastructures in Tigray drags the water
119 system of the region back in time. This will be done by comparing the pre-and post-war status
120 of the water supply systems. It also aims to compare the impacts of the war in Tigray with other
121 regional conflicts. This can provide a basis for post-war reconstruction and attain better socio-
122 economic development in the region.

123 **2. The Tigray region of Ethiopia**

124 The Tigray regional state, with a total population of approximately 7.1 million (CSA, 2007), is
125 situated in the northern part of Ethiopia which extends from 12°15' to 14°50'N and between
126 36° 27' to 39° 59'E (Fig. 1). Tigray is bordered by Eritrea and Sudan to the north and west,
127 respectively. Other Ethiopian regions include the Amhara region which borders Tigray from
128 south to southwestern and the Afar region from east to south-eastern. The total area of the
129 region is approximately 54,000 km² and is divided into six administrative zones: Western,
130 North-Western, Central, Eastern, South-Eastern, Southern, and one administrative capital city,
131 Mekelle (Fig. 1). The majority of the region is characterized by undulating terrains and steep
132 slopes with a fragile environment – mainly fragile soils, erratic distribution of rainfall, and
133 sparse vegetation cover.

134

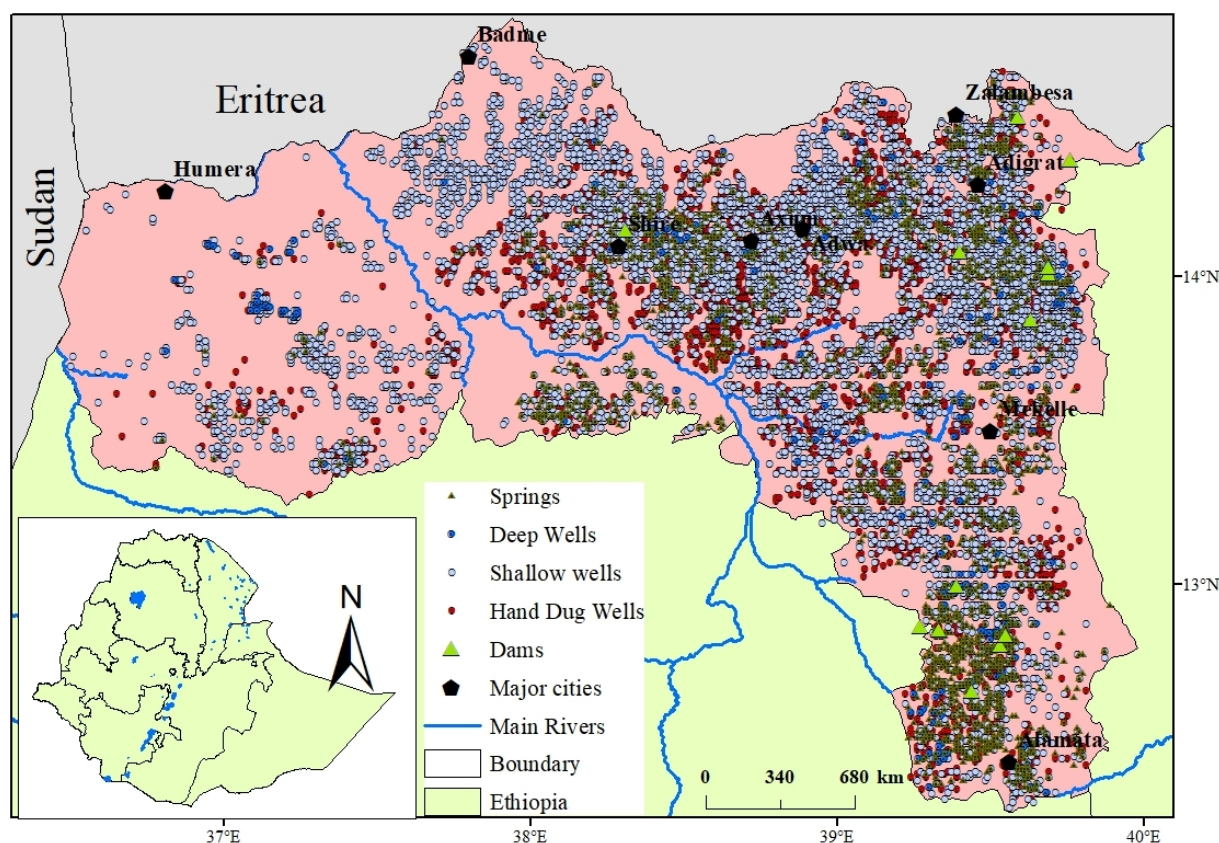


Figure 1. Study area and water supply infrastructure locations, Tigray, Ethiopia.

137 The Tigray region is mainly characterized by semi-arid and semi-humid climates, with
138 distinctive, long-term dry (October to May) and wet (June to September) seasons (Gebremicael
139 et al., 2017). Average rainfall over the region ranges from below 500 mm/year in the northeast
140 lowlands to more than 1200 mm/year in the southwestern highlands (Gebremicael et al.,
141 2019c). More than 70% of the annual rainfall occurs between July and August. The annual
142 discharge of the rivers in the region follows the pattern of rainfall, with 80% of river flows
143 occurring in the wetter months. River flow largely ceases during the dry season from October
144 to May and consequently, the habitat in the region is vulnerable to water shortage during dry
145 seasons. Intense and long-term recurrent drought has considerably impacted the region with
146 droughts, including one of its worst in history from 1984 to 1985 (Gebrehiwot et al., 2011;
147 Haile et al., 2018).

148 **3. Methods**

149 Data for this study were collected through field surveys and observations from five of the six
150 administrative zones of the region. Data collection in the Western zone was not possible
151 because it is still occupied by the invading allied forces. Secondary data were gathered from
152 peer-reviewed articles, regional and national governments, and international non-governmental
153 organizations' reports.

154 **3.1. Pre-war assessment**

155 The condition of the water supply infrastructures and the overall water supply coverage of the
156 region before the war were reviewed from the existing official government reports and
157 published articles. The 2019, 2020 and 2021 official annual reports of the Tigray Water
158 Resources Bureau were mainly used to review the pre-war coverage and functionality of the
159 water supply infrastructure in the region. However, existing published papers were also
160 reviewed, although they were limited in number.

161 **3.2. On-site assessment and measurements**

162 Data were collected by two assessment teams commissioned by the Tigray Water Bureau in
163 each zone between September 2021 to January 2022. One of the teams incorporated
164 electromechanical experts to assess damage to the water supply infrastructures. The second
165 team consisted of multi-discipline experts and was responsible for the assessment of water
166 supply facilities including buildings, office equipment, and loss of human resources. The site
167 visits were accompanied by utility, district, and zonal coordinators and
168 beneficiaries/community representatives. In total, 17,080 of the 18,481 water supply schemes
169 in the five zones were assessed.

170 At each site, general infrastructure damage was first inspected visually to check if it had been
171 destroyed or removed (Table 1). The remaining infrastructure was then classified as

172 “functional” if it is giving services, and “partially damaged” if the damage is
173 maintainable/repairable but not functional for a time being. For example, water wells with
174 totally damaged submersible pumps and production casings were classed as “completely
175 damaged”, while wells with their pumps either missing or damaged, but with a fully
176 functioning production casing, were considered as “partially damaged”. When classifying the
177 functionality status of the water supply systems in the region, the completely destroyed and
178 partially damaged infrastructures were classified as “non-functional”, while the active water
179 supply infrastructures were classified as “functional”. This was because maintenance is still
180 impossible, as there is no possibility to import spare parts due to the complete siege and
181 blockade. Further, in urban areas, the damages were classified as either “functional” or “non-
182 functional”, as the infrastructures were either completely damaged or looted, and as they were
183 close to the roads and easy for the invaders to transport them to the area of their interest.

184 Table 1. Type of infrastructures inspected, and data gathered. The category ‘Others’ includes
185 pipes and fittings, welding machines, water quality testing kits, chemicals, and tools.

Data type	Evaluation method
Borehole damage	Inspection & measurement
Dam damage	Inspection & measurement
Spring damage	Inspection & measurement
Generators & surface pumps	Inspection & testing
Switchboards	Inspection & testing
Transport	Inspection
Office, office furniture & Laboratories	Inspection
Others	Inspection
Property value	Market values

186

187 **4. Results and Discussion**

188 **4.1. Pre-war assessment results**

189 More than 80% of the population in Tigray lives in rural areas where sources of water supply
190 are mainly shallow wells, open water sources, springs, and some deeper wells. Water supply
191 in urban areas is mainly dependent on dams and deep wells (Oyedotun, 2017; Tigray Water
192 Resources Bureau, 2020). The regional water consumption standards in Tigray were set to 25
193 L/c/d (Liter per capita per day) at a 1 km radius (on spot schemes) for rural areas, and 40 to 80
194 L/c/d (based on population sizes) for urban areas (Tigray Water Resources Bureau, 2020; 2021;
195 Admasu et al., 2019). The standards range from 40 L/c/d for population size less than 20,000:
196 50 L/c/d for 20,000 to 50,000, 60 L/c/d for 50,000 to 100,000, and 80 L/c/d for 100,000 to
197 1,000,000 population sizes. Accordingly, access to water supply by August 2020 (2 months
198 before the war) was 61% for rural and 57% for urban populations, with a regional average of
199 58%. Before the war, the Tigray region had 19,421 active water schemes that were fully
200 functioning (Tigray Water Resources Bureau, 2021). This includes 7,541 hand-dug wells
201 (HDW), 299 deep wells (DW), 6 dams, 1,775 SPD (spring water development), 65 RF (roof
202 water harvesting) structures, 29 ponds, 718 institutional WASH, 201 RPS (rural pipe system),
203 and other 9,279 on the spot schemes like shallow hand-dug wells (SHWs) (Fig. 1; Tigray Water
204 Resources Bureau, 2021).

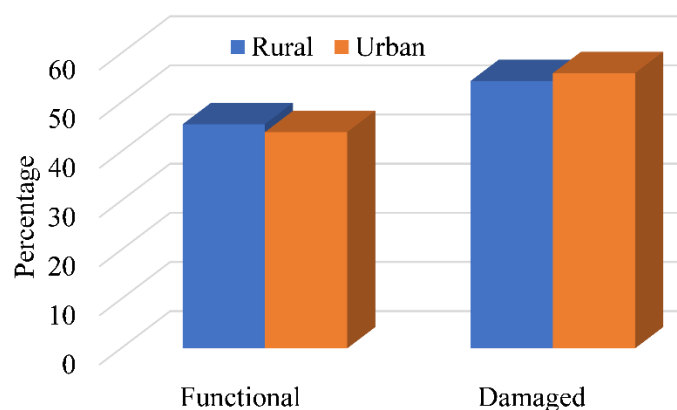
205 **4.2. Overall damages to the water supply systems of Tigray**

206 This study found that the war in Tigray has resulted in damage to about 55% of the overall
207 water supply systems of the region (as of January 2022) (Fig. 2). Before the war, the average
208 water supply coverage in the region (rural and urban water supply) was approximately 58%,
209 with a non-functionality rate of 7.1% (Tigray Water Resources Bureau 2021; Azage et al.,

210 2020). As of this assessment, the total damage in rural (54.4%) and urban (56%) areas (Fig. 2),
211 increased the non-functionality rate to more than 64%. This has resulted in approximately 3.7
212 million people (2.3 million in rural and 1.4 million people in urban areas) without water supply
213 services. This implies that the damage to the water supply infrastructures in Tigray has led to
214 food insecurity for >50% of the population (3.7 million of the total 7.1 million), as water
215 insecurity directly means food insecurity (WFP, 2022). The destruction of the water points and
216 lack of basic health care services resulting from the war exacerbated the situation in the region
217 and has already led to emergency levels of acute malnutrition (WFP, 2022). Further, the
218 systematic damages to the water supply infrastructures have affected the health system of the
219 region, with 86.8% of the water supply systems of the health facilities in the central zone,
220 91.6% in the Eastern, 76.3 % in the North-west, and 80% in South-east zones were damaged
221 by the Ethiopian and Eritrean forces (Debeb, 2022). The hospitals and clinics in Tigray can
222 neither process blood for transfusion nor store it for later use due to the lack of water and power,
223 as a result of the damage to the infrastructures due to the war (Yemane et al., 2022). The people
224 of Tigray are also exposed to waterborne diseases such as cholera because the damage to the
225 water supply infrastructure has exposed the public to fetch water from open and untreated water
226 sources like rivers and lakes (Zwizwai, 2022). Importantly, these crises consider only the
227 damages incurred until January 2022, and locations bordering Eritrea and the whole Western
228 Zone were not included as the armed conflict continues in this region.

229 The findings of this study showed that the war in Tigray has significantly exacerbated the
230 existing water shortage problems in the region. The United Nations (UN) recommends that
231 personal and domestic water consumption should be between 50 and 100 L per day (UN Water,
232 2015). Further, the UN's recommendation states that the water must be safe, adequate, and
233 affordable (a maximum of 3% of household income) and be within 1 kilometer of a person's
234 home (UN Water, 2015). With the pre-war water supply in Tigray being about 50% of the

235 recommended standard, already below the UN's recommendation, the war in Tigray further
236 reduced it by 55%, which brought the water supply coverage in the region down to under 25%.

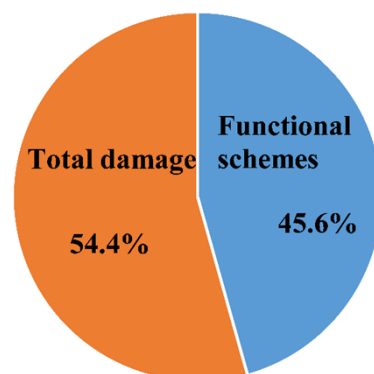


237
238 Figure 2. Overall percentages of damaged and functional water supply schemes in Tigray, after
239 15 months of the war.

240 4.2. Damages to the rural water supply systems

241 The war in Tigray resulted in damages to 54.4% of the rural water supply systems (Fig. 3)
242 reducing the water supply coverage to approximately 28%. Shallow wells were the most widely
243 used water source in the rural parts of the region, followed by hand-dug wells and springs (Fig.
244 1). The extent of the damages presented in our damage assessment results showed the invaders
245 targeted public infrastructures such as the water supply systems (Figs. 4a, b). This infers that
246 the damage and destructions were not random, rather they were deliberately executed based on
247 their predesigned purposes, which was also clearly stated by the deputy chief of staff of
248 Ethiopia – General Abebaw Tadesse (**Supplementary Video1**). Further, the deliberate
249 destruction of water infrastructures and looting of equipment were reported by international
250 media and humanitarian institutions. For example, Action Against Hunger (ACF, 2021)
251 indicated that water supply infrastructures including water pumps have been destroyed and
252 equipment were looted by the Ethiopian and Eritrean forces and the Amhara special forces and
253 militia, as a result, people throughout the region remained with no access to drinking water.

254 Zones with the highest numbers of wells (Central zone, followed by the Eastern and North-
255 Eastern zones; Figure 1) suffered high instances of damage (Fig. 4b).

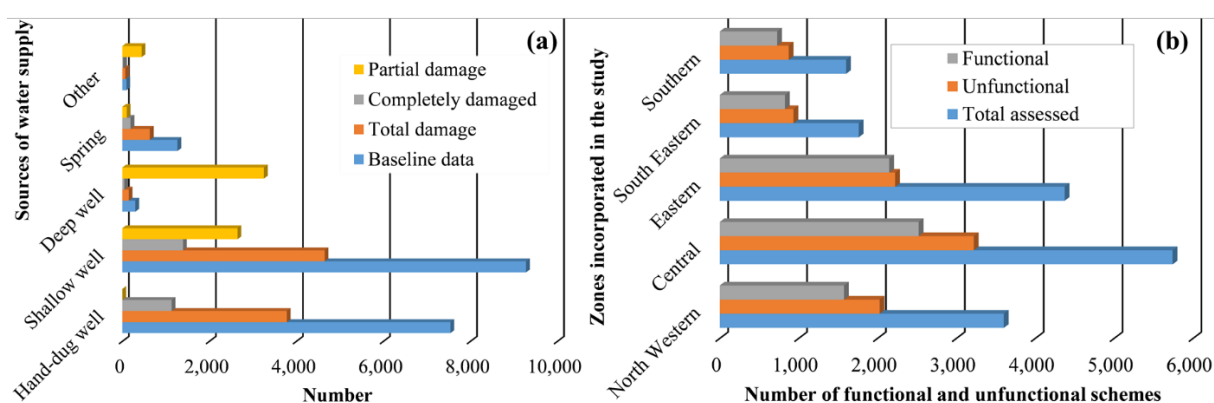


256

257 Figure 3. Percentage of damage to the rural water supply systems in Tigray.

258 The findings show that the invaders have also destroyed other infrastructures including roof
259 water harvesting schemes, rainwater collection ponds, and structures that were limited in
260 number in the region (Figure 4a). This is also another piece of evidence suggesting that the war
261 was intended to destroy the livelihood of the people of Tigray through starvation and thirst.
262 Destroying the public water infrastructures with such invasions simply means using starvation
263 and thirst as a weapon of war that can effectively shoot at each and every household (Zeitoun
264 and Talhami, 2016), as no one could survive. Destructions of public infrastructures like water
265 supply systems can, in fact, be an unfortunate side-effect of conflict and political oppression
266 (Schillinger and Heldeweg, 2022). However, acts that create conditions of mass starvation
267 through targeted destruction and looting of public infrastructures like water supply systems are
268 considered violations of international humanitarian law which are prohibited by the Geneva
269 Convention and its Protocols (Pertile and Faccio, 2020; Gleick, 2019b; Weinthal and Sowers,
270 2019; Zeitoun et al., 2014). Further, such acts are also considered as against international
271 humanitarian law, as they disrupt access to clean water leading to conditions ripe for outbreaks
272 of normally preventable diseases such as cholera, malaria, and measles (Talhami and Zeitoun,
273 2021). The damages to the water supply systems in Tigray forced local communities, and the

274 people of Tigray as a whole, to consume water from open and unprotected sources and were
 275 therefore exposed to different types of water-borne diseases (Gessesew et al., 2021). Further,
 276 in areas where open and unprotected sources of water are not available, people have to travel
 277 up to tens of kilometers to fetch water to survive. This kind of purposeful destruction of water
 278 supply infrastructures in armed conflicts is considered as weaponizing water and water
 279 infrastructures, which breaches international humanitarian law (Pertile and Faccio, 2020;
 280 Schillinger et al., 2020; Gleick, 2019a; Gleick, 2019b).

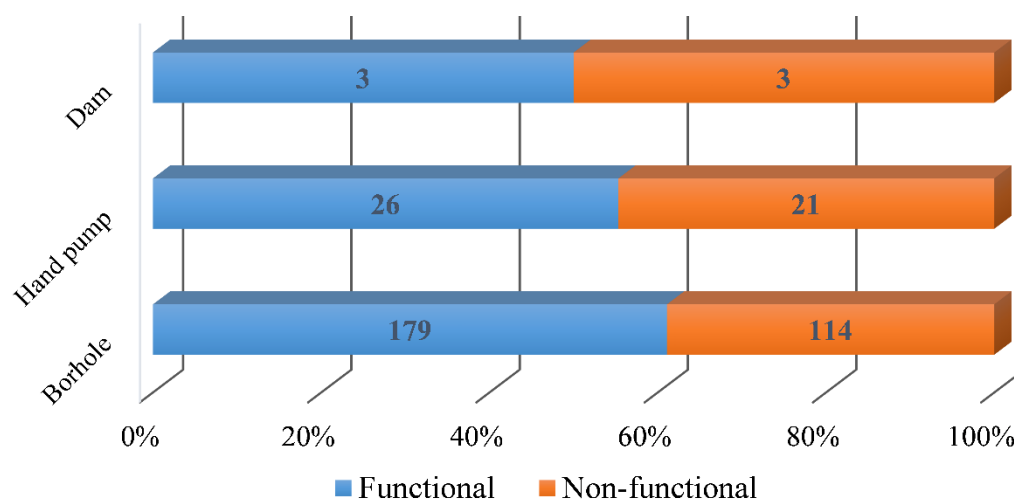


281
 282 Figure 4. Assessment of the rural water supply damage in Tigray. “Other” includes roof water
 283 harvesting and ponds. 92.4% of the pre-war infrastructure in the five zones was assessed in this
 284 study.

285 4.2. Damages to the urban water supply systems

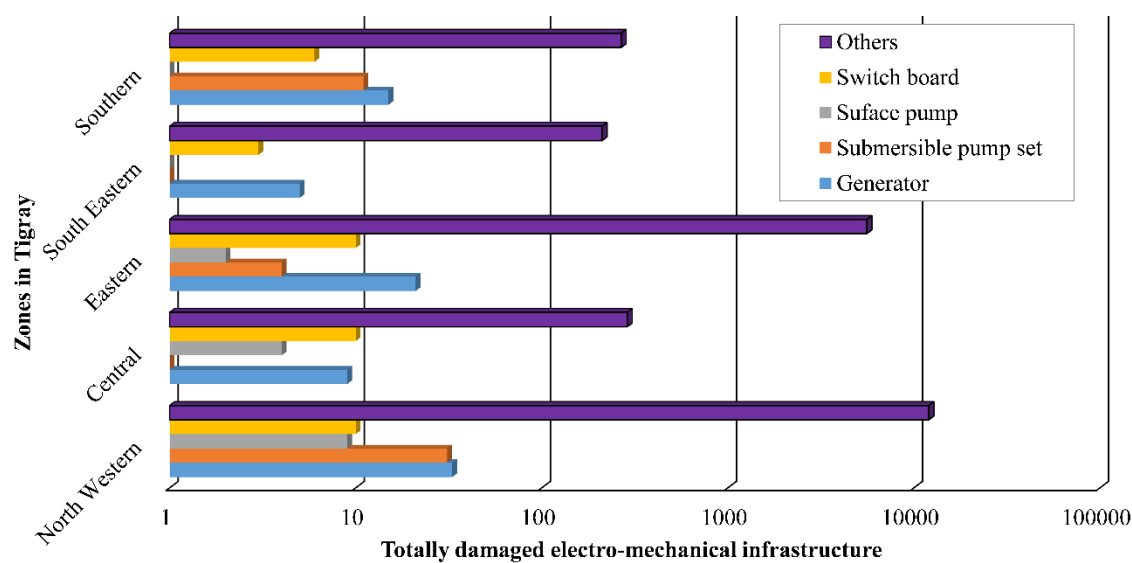
286 The damage to urban water supply infrastructure was extensive, with about 40% of boreholes,
 287 45% of hand pumps, and 50% of dams completely damaged (Fig. 5), and 90% of
 288 electromechanical equipment was either missing or destroyed (Figure 6). This equates to 56%
 289 of the urban water supply being completely damaged resulting in only 25% of urban water
 290 supply coverage. Within the urban water supply schemes, the highest number of boreholes
 291 damaged were in the Eastern zone, followed by the Central and Southern zones (Fig. 7; Table

292 S1). The ongoing siege, the shortage of money/budget in the whole region, and the extent of
 293 the damages make maintenance of the damaged wells very difficult.



294

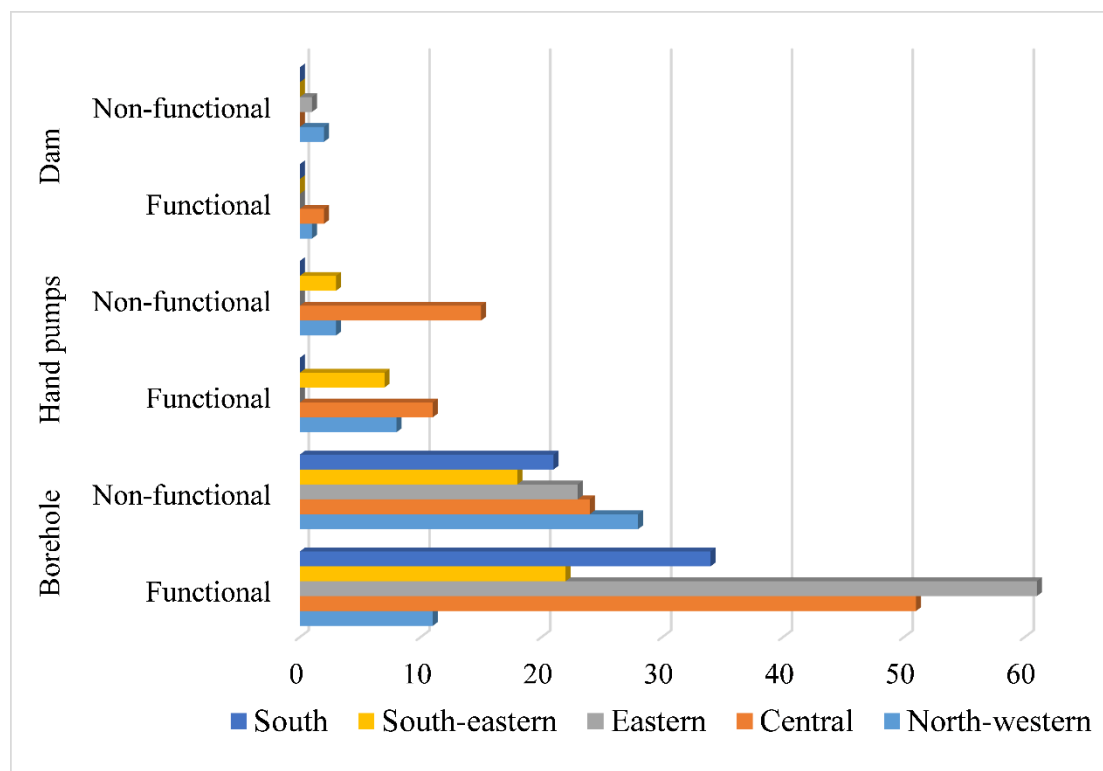
295 Figure 5. Damages to urban water supply infrastructure



296

297 Figure 6. Urban electro-mechanical water infrastructure damages. The X-axis is logarithmic.

298 ‘Others’ include pipes, fittings, tools, lab kits, and machines.



299

300 Figure 7. Functional and non-functional numbers of urban water supply infrastructure in
301 Tigray, based on administrative zones.

302 The USD400 million Giba Dam development in Mekelle was also destroyed and any of the
303 movable equipment were looted. The dam had a potential storage capacity of 430 billion cubic
304 meters, to supply water to more than 800,000 residents of Mekelle, the capital city of the region
305 (Fig. S1). During the invasion, all heavy-duty machinery, construction materials, and
306 equipment, belonging to the dam project were looted by the invading forces (Reuters, 2021b).
307 Making the impact on the water supply worse, power to the region was cut off by the Ethiopian
308 government in June 2021 (Davies, 2022; HRW, 2021; Reuters, 2021c). To compensate for this,
309 the Tigray government worked to provide power from the Tekeze hydropower plant. However,
310 after a few days of service, this was destroyed by targeted airstrikes (HRCDC, 2021; Geopioneer,
311 2021; Reuters, 2021d; Fig. 8). Further, the complete siege and blockade of every route leading
312 to Tigray by the allied forces caused the water supply systems in Mekelle city and other very
313 few areas, which survived the war, to stop working, due to lack of maintenance, spare parts,

314 and water treatment chemicals. These compounding damages resulted in more than seven
315 million people in the region with no access to a safe drinking water supply.



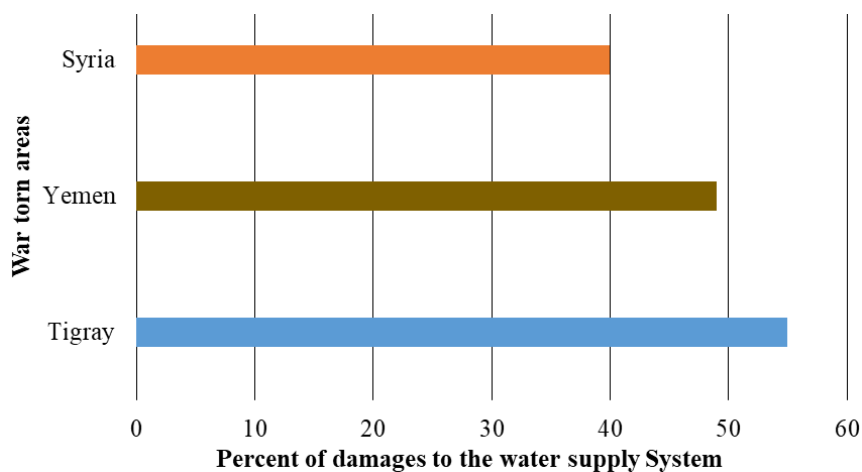
316
317 Figure 8. Destroyed hydropower station of Tekeze dam by the allied forces on November 3rd,
318 2021.

319 **5. Comparison to other regional conflicts**

320 The damage to the drinking water supply infrastructures in Tigray, over the 15 months of the
321 war, and still ongoing, was 15% greater than the damage to Syria's water supply systems
322 (ICRC, 2021) during the 10 years-long crisis, and 6% higher than the 7 years long, and ongoing,
323 Yemeni's conflict (Fig. 9). For simplicity and meaningful comparisons, the extents of damages
324 to the Syrian and Yemeni's water supply infrastructures that were considered in this analysis
325 were the counts before maintenance. This was because maintenance of the damaged water
326 supply infrastructures was possible in some areas during the wars in Syria and Yemen, while
327 it has been completely impossible in the case of Tigray as a result of the complete siege and
328 blockade.

329 Before the 10 years-long war in Syria, 98% of the people in urban areas and 92% of people in
330 rural communities had reliable access to safe water. Today, across Syria only 50% of water and
331 sanitation systems function properly (ICRC, 2021), with 40% of the water supply infrastructure

332 being completely damaged during the war. However, within 15 months of the war, the water
333 supply systems in Tigray were reduced by 55% less than it was before the war. Before the
334 ongoing war in Yemen, experts were reporting that the country was facing the most serious
335 water shortages and warned that its groundwater would be depleted by 2017 (Al-Kamali, 2016).
336 However, even with these natural factors, the seven years-long, ongoing, armed conflict in
337 Yemen reduced the country's water supply by 49%. This implies how shattering the ongoing
338 war in Tigray is, and if it continues as long as the wars in Yemen and Syria, the damages to the
339 water supply systems would be inconceivable.



340
341 Figure 9. Comparisons between the damages to the water supply systems in Tigray, Syria, and
342 Yemen.

343 Armed conflict can significantly disrupt water supply both in terms of the physical structure
344 and water governance (Sowers and Erika 2021). Armed conflicts in Iraq, Yemen, Syria, Libya,
345 Gaza strip, have all resulted in damage to civilian infrastructures including water supply and
346 sanitation systems (Sowers and Erikam 2021; CMWUm 2014; Abu-Lohom et al., 2018;
347 Schillinger, 2020). The damages to water supply systems can be both direct (i.e., looting and
348 physical destruction) or indirect (i.e., shelling and airstrikes). The damages to the Tigray water
349 supply infrastructure were also both direct and indirect. Any movable water supply
350 infrastructures and equipment that were in the Tigray water supply system such as pumps,

351 generators, pipes, switchboards, etc were looted, while those that were not easy to transport
352 were destroyed in situ (Figs. 10 - 13). Further, even though they are not specifically quantified
353 yet because of the complete siege and blockade, large water supply and hydropower structures
354 like the Tekeze hydropower dam were bombarded by airstrikes, and major parts of the dam
355 were destroyed (Fig. S2). Similar damages to water supply infrastructures have been seen in
356 different war-torn countries like Yemen and Syria. For example, indiscriminate shelling and
357 airstrike on public infrastructure by the Saudi-led coalition in Yemen damaged approximately
358 4% of water supply systems (Sowers and Erika, 2021).



359
360 Figure 10. Damages to a) the water supply tank in Edaga Hamus (Eastern Zone), with b)
361 evidence of bullets shot into the reservoir, c) generators and d) the switchboard (control panel).



362

363 Figure 11. Damages to a) water supply points and facilities, b) Booter pumps in Gereb-Segen
364 water supply points, c) boreholes, and d) powerhouse and borehole (with damaged casing) in
365 Southern Tigray.

366 Another form of damage to water supply systems is the forced movement of the population and
367 disruption of water supply governance (Schillinger et al. 2020). Increased internally displaced
368 people within a war zone can put additional pressure on the hosting communities' water supply
369 systems and their governance. Mekelle, Adwa, Shire, Abi'adi, and Axum cities are amongst
370 the hardest hit with regard to water supply crises in the Tigray Region because of inflow of the
371 sheer size of internally displaced people (MSF, 2021; OCHA, 2022a). In addition to the
372 physical damages, the provision of water services, maintenance, and operations of the
373 remaining functional water points is challenging as administration systems could collapse and
374 water supply technicians would flee to safer places. This had been seen in different previous
375 conflict-stricken areas, such as Syria, Yemen, and Libya (ICRC, 2021; Abu-Lohom et al., 2018,
376 Schillinger, 2020). Similarly, most of the experts and members of the management team,
377 including the head, of the Tigray water bureau joined the Tigray Defense Forces from
378 November 2020 to June 2021, which caused a significant gap in the administration system.

379 Importantly, our assessment didn't include the Western Zone of Tigray and numerous locations
380 in northern Tigray bordering Eritrea, which are still under the control of the Ethiopian and
381 Eritrean defense forces and the Amhara Special Police force, militia, and other forces called
382 Fano (HRW, 2022). Adding additional damage reports from these locations to what is already
383 reported in this paper would imply that the Tigray war was very intense with full of destruction
384 of public infrastructures, including the water supply infrastructures in the region. Further, the
385 nature of the Tigray war is not the same as the war in Syria and Yemen for many reasons: i)
386 according to the military chief of Ethiopia, the mission of the war was to destroy public
387 infrastructures in the region using four allied forces (**Supplementary video 1**), ii) the media
388 and political propaganda has played a significant role in fuelling up the war, with Tigrayan
389 affiliated media being in a complete blackout (Reuters, 2021a), iii) the main advisor to the
390 prime minister, **Mr. Daniel Kibret**, clearly stated that the main objective of the war was to
391 wipe out Tigrayan population from Ethiopia, together with their history and anything
392 reminiscent of them (**Supplementary Video 2**). The European Union's special envoy and
393 Finland's foreign minister – Pekka Haavisto witnessed that Ethiopian leadership told him in
394 February 2021 that they wanted 'to destroy the Tigrayan population' (World Health
395 Organization (WHO), 2022; **Supplementary Video 3**). For the above reasons, the destruction
396 of the water supply systems and other public infrastructures in the region could be among the
397 worst recorded in the history of armed conflicts around the world. This is because nowhere in
398 the world history of armed conflicts is recorded where a government had invited foreign forces
399 and destroyed public infrastructures and looted the properties of its own citizens (Gessew et
400 al., 2021; Demssie et al., 2022; BBC, 2021; Oduor, 2021; Fig S2). These deliberate acts of
401 destroying public infrastructures and eliminating the people of Tigray are further validated by
402 the fact that they deliberately destroyed most offices, office papers, and facilities (Figs. 12 and
403 13). For example, the destroyed documents and papers, chairs, and tables in the Gereb Giba

404 water supply development project that were inside the offices have nothing to do with collateral
405 damages (Fig. 13). In addition, the burning and destruction of water supply spare parts, after a
406 door-to-door search of such facilities and equipment, within the warehouse is another
407 indication that they have deliberately done it to harm, starve and destroy the people (Fig. 12).



408
409 Figure 12. Damages to a) offices, b) electro-mechanical spare parts, c) office properties and
410 facilities, and d) burned electro-mechanical spare parts.



411
412 Figure 13. Damages to a) Offices and b) project documents and paper works of the Gereb Giba
413 Water Supply Development Project Office.

414 The impact on the water supply in Tigray was further exacerbated by the lack of help provided
415 through humanitarian aid. In recent armed conflicts including Ukraine (OCHA, 2022a), Syria
416 (Reliefweb, 2021), Yemen (Sowers and Erika, 2021), Iraq (Stoddard, 2021), Afghanistan

417 (OCHA, 2022b), and Libya (OCHA, 2021), humanitarian aid agencies were allowed to
418 distribute food and drinking water to people in need. In contradiction to the international
419 humanitarian laws (WHO, 2022; OCHA, 2022c), the Ethiopian government and its allies had
420 blocked all humanitarian partners, including the International Red Cross Society (ICRS),
421 USAID, and UN agencies from bringing in water treatment chemicals, motor pumps, fuels to
422 transport water, and any equipment and accessories for maintenance and operation of water
423 supply systems in Tigray (WHO, 2022; Mwai, 2022; Reuters, 2022; OCHA, 2022a; Stoddard,
424 2021).

425 **6. Conclusion and recommendations**

426 The focus of this study was to assess the impact of war on the water supply systems of the
427 Tigray region of Ethiopia. The results show that the looting and destruction of public water
428 supply systems in the Tigray region have been used as weapons of war by the Ethiopian,
429 Eritrean, and Amhara region invading forces. The majority of the water supply systems of
430 Tigray collapsed due to the devastating conflict. The war caused significant and long-term
431 damage to public infrastructure including loss of machinery, computers, office buildings, and
432 spare parts, and looting of equipment and maintenance tools. The long-term effect on the well-
433 being of the populace as the result of the war, and the consequent lack of safe water supply and
434 sanitation have yet to be studied.

435 The impacts and destructions to the Tigray water supply as the result of the conflict are greater
436 than what has previously been recorded in other recent regional armed conflicts. The
437 international community should learn from recent conflicts and introduce new measures so that
438 basic water infrastructure is protected, and where damages occur, mitigation measures are
439 taken promptly, and culprits are punished. It is hoped that this assessment and similar studies
440 in the future on the scale of impacts, which rarely garner any attention, will create greater
441 awareness among governments. Further, it is recommended that studies on damage
442 management, emergency response and reconstruction, financial sources, the long-term effect
443 of war-induced lack of drinking water supply on the well-being of the people (children, women,
444 elders, etc.), and public services such as health and education should be conducted.

445 **7. Acknowledgment**

446 Firstly, we are grateful to the Tigray Water Resources and Irrigation Bureau, data collectors,
447 including district water bureau experts, utility heads, and administrations for making the data
448 collection possible. Further, we are also thankful for the non-governmental organizations who
449 facilitated transport and other necessary inputs for the data collection. Last but not least, we
450 thank Dr. Douglas Tait, a research scientist at Southern Cross University, for his critical review
451 and feedback, which helped us in shaping the manuscript this way.

452 **8. Statements and Declarations**

453 **8.1 Funding**

454 The authors declare that no funds, grants, or other support were received during the
455 preparation of this manuscript.

456 **8.2. Competing Interests**

457 The authors have no relevant financial or non-financial competing interests to disclose.

458 **8.3. Author Contributions**

459 All authors contributed to the study's conception and design. Material preparation and analysis
460 were performed by [Haile Shishaye], [Tesfay Gebremicael], [Hadush Meresa], [Fasil Gebre],
461 and [Shishay Kidanu]. The first draft of the manuscript was written by [Haile Shishaye] and
462 all authors commented on previous versions of the manuscript. All authors read and approved
463 the final manuscript.

464 **8.4. Ethical Approval**

465 Not applicable.

466 **8.5. Consent to Publish**

467 We hereby give our consent to the publisher to publish our research paper and any associated
468 data.

469 **8.6. Availability of data and materials**

470 Our data and materials used in this manuscript are readily available for publication as either
471 supplementary material or in any way possible.

472 7. References

- 473 Abu-Lohom, N.M., Konishi, Y., Mumssen, Y., Zabara, B., Moore, S.M., 2018. Water Supply
474 in a War Zone: A Preliminary Analysis of Two Urban Water Tanker Supply Systems in the
475 Republic of Yemen [Working Paper]. World Bank. <https://doi.org/10.1596/30107>.
- 476 Action Against Hunger (ACF), 2021. Responding to the Emergency in Tigray, Ethiopia. An
477 update on action against 'hunger's work to help families impacted by the Crises. Retrieved
478 from <https://www.actionagainsthunger.org/story/responding-emergency-tigray-ethiopia>,
479 Accessed on 14 Feb 2022.
- 480 Admasu, A., Kiros, M., Memhur, A. 2011. Baseline Survey Report of Tigray Region on Wash.
481 Tigray Water Bureau, Report 1-2011.
- 482 Admasu, A., Kiros, M., Memhur, A., 2019. Baseline Survey Report of Tigray Region on
483 Wash. Tigray Water Resources Bureau, Mekelle: 1-22.
- 484 Aklan, M. M., Fraiture, C. de, & Hayde, L. G. (2019). Which Water Sources Do People Revert to in
485 Times of War? Evidence from the Sana'a Basin, Yemen. *International Journal of Environmental*
486 *Research*, 13(4), 623–638. DOI: 10.1007/s41742-019-00205-9.
- 487 Al-Kamali, F., 2016. Yemen: so critically short of water in the war that children are dying
488 fetching it. World Bank, Retrieved from [https://blogs.worldbank.org/arabvoices/yemen-so-](https://blogs.worldbank.org/arabvoices/yemen-so-critically-short-of-water)
489 [critically-short-of-water](https://blogs.worldbank.org/arabvoices/yemen-so-critically-short-of-water), accessed on 1 March 2022.
- 490 Awulachew, S.B., Yilma, A.D., Loulseged, M., Loiskandl, W., Ayana, M., Alamirew, T.,
491 2007. Water resources and irrigation development in Ethiopia. IWMI, Colombo, Sri Lanka:
492 1-20.
- 493 Azage, M., Motbainor, A., Nigatu, D., 2020. Exploring geographical variations and
494 inequalities in access to improved water and sanitation in Ethiopia. Mapping and spatial
495 analysis. *Heliyon*, 6(4), e03828. <https://doi.org/10.1016/j.heliyon.2020.e03828>.

- 496 Berhe, A.A., Aregay, A.D., Abreha, A.A., Aregay, A.B., Gebretsadik, A.W., Negash, D.Z.,
497 Gebreegziabher, E.G., Demoz, K.G., Fenta, K.A., Mamo, N.B., 2020. Knowledge, Attitude,
498 and Practices on Water, Sanitation, and Hygiene among Rural Residents in Tigray Region,
499 Northern Ethiopia. *Journal of Environmental and Public Health*, 2020, e5460168.
- 500 Beriha, T., 2013. Effect of Access to Potable water and Sanitation on rural Health in Tigray
501 Region. MSc.Thesis, Mekelle University, Ethiopia.
- 502 Berhane, G., Gebreyohannes, T., Martens, K., Walraevens, K., 2016. Overview of micro-dam
503 reservoirs (MDR) in Tigray (northern Ethiopia): Challenges and benefits. *Journal of African*
504 *Earth Sciences*, 123: 210–222.
- 505 Berhane, G.K., 2018. Characterization of hydrochemistry and groundwater quality evaluation
506 for drinking purposes in Adigrat area, Tigray, northern Ethiopia. *Water Science* 32(2): 213–
507 229.
- 508 British Broadcasting Corporation (BBC), 2021. Ethiopia PM Ahmed Abiy admits Eritrea
509 forces in Tigray. BBC News report. Retrieved from [https://www.bbc.com/news/world-](https://www.bbc.com/news/world-africa-56497168)
510 [africa-56497168](https://www.bbc.com/news/world-africa-56497168), Accessed on 21 Jan 2022.
- 511 Camacho et al., 2018. Cholera epidemic in Yemen, 2016–18: an analysis of surveillance data.
512 *Lancet Glob Health* 6 (2018): 680-90, doi.10.1016/S2214-109X(18)30230-4.
- 513 Central Statistical Agency, 2007. Population and Housing Census Results, United Nations
514 Population Fund(UNFPA), pp.1-113.
- 515 Coastal Municipal Water Utility (CMWU), 2014. Damage Assessment Report of Gaza Strip
516 War. Water and Wastewater Infrastructure.
- 517 Davies, L., 2022. Nowhere on earth are people more at risk than Tigray," says WHO chief.
518 The guardian. Retrieved from [https://www.theguardian.com/global-](https://www.theguardian.com/global-development/2022/mar/17/nowhere-on-earth-are-people-more-at-risk-than-tigray-says-who-chief)
519 [development/2022/mar/17/nowhere-on-earth-are-people-more-at-risk-than-tigray-says-](https://www.theguardian.com/global-development/2022/mar/17/nowhere-on-earth-are-people-more-at-risk-than-tigray-says-who-chief)
520 [who-chief](https://www.theguardian.com/global-development/2022/mar/17/nowhere-on-earth-are-people-more-at-risk-than-tigray-says-who-chief).

- 521 Debeb H.G., 2022. Tigray Health Sector 2021 Annual Bulletin, Tigray Health Bureau, 1-19.
- 522 Demissie, B., Nyssen, J., Annys, S., Negash, E., Gebrehiwet, T., Abay, F., Wolff, E., 2022.
- 523 Geospatial solutions for evaluating the impact of the Tigray conflict on farming. *Acta*
- 524 *Geophysica*, 1-10.
- 525 Fagan, G., 2019. Rural 'households' access to water resources under climate impacts based on
- 526 field evidence in Tigray Region, Ethiopia. *African Journal of Environmental Science &*
- 527 *Technology*, 1(6): 228–240.
- 528 Faour, G., Fayad, A., 2014. Water environment in the coastal basins of Syria – Assessing the
- 529 impacts of the war. *Environmental Processes*, 1(4): 533–552.
- 530 <https://doi.org/10.1007/s40710-014-0043-5>.
- 531 Geopioneer, 2021. Ethiopia airstrike destroys the Tekeze Hydroelectric power station.
- 532 Geopolitics report. Retrieved from [https://www.geopolitical.report/ethiopia-airstrike-](https://www.geopolitical.report/ethiopia-airstrike-destroys-the-tekeze-hydroelectric-power-station/)
- 533 [destroys-the-tekeze-hydroelectric-power-station/](https://www.geopolitical.report/ethiopia-airstrike-destroys-the-tekeze-hydroelectric-power-station/).
- 534 Gebremicael, T.G., Mohamed. Y., Van, D.P., Yazew, E., 2017. Temporal and spatial changes
- 535 of rainfall and streamflow in the Upper Tekezē–Atbara River basin, Ethiopia. *Hydrology*
- 536 *and Earth Systems Science* 21(4): 2127-2142.
- 537 Gebremicael, T.G., 2019. Understanding the Impact of Human Interventions on the hydrology
- 538 of Nile Basin Headwaters, the Case of Upper Tekeze Catchments. PhD Thesis. CRC Press
- 539 /Balkema - Taylor & Francis Group, Leiden, The Netherlands.
- 540 Gebrehiwot, M., 2006. An Assessment of Challenges of Sustainable Rural Water Supply: The
- 541 Case of Ofla Woreda in Tigray Region. MSc Thesis, Addis Abeba University, Addis Abeba,
- 542 Ethiopia.
- 543 Gebrehiwot, T., Van, D.A., Maathuis, B., 2011. Spatial and temporal assessment of drought
- 544 in the Northern highlands of Ethiopia. *International Journal of Applied Earth Observation*
- 545 *and Geoinformation* 13(3): 309–321. <https://doi.org/10.1016/j.jag.2010.12.002>.

- 546 Gebregziabher, M., Amdeselassie, F., Esayas, R., Abebe, Z., Silvia, H., Teklehaimanot, A.A.,
547 Korte, J.E., Pearce, J.L., Cochran, J.J., 2022. Geographical distribution of the health crisis
548 of war in the Tigray region of Ethiopia. *BMJ Global Health* 7(4): 75-84.
- 549 Gesesew, H., Berhane, K., Siraj, E.S., et al., 2021. The impact of war on the health system of
550 the Tigray region in Ethiopia: an assessment. *BMJ Global Health* 6: 2-8, doi:10.1136/
551 bmjgh-2021-007328.
- 552 Gleick, P.H., 2019a. Water as a weapon and casualty of armed conflict: A review of recent
553 water-related violence in Iraq, Syria, and Yemen. *WIREs Water* 6(4), e1351.
- 554 Gleick, P.H., 2019b. Water as a Weapon and Casualty of Conflict: Freshwater and
555 International Humanitarian Law. *Water Resources Management*, **33**: 1737-
556 1751, doi:10.1007/s11269-019-02212-z.
- 557 Goyal, V.C., Garg, A., Patil, J.P., Thomas, T., 2020. Formulation of integrated water
558 resources management (IWRM) plan at district level: a case study from Bundelkhand
559 region of India. *Water Policy* 22(1): 52–69. doi:10.2166/wp.2020.157.
- 560 Groninger, J.W., Ruffner, C.M., Christenson, L., 2015. Water resources development
561 considerations for civilian and military institutions working in highly insecure areas:
562 lessons from Afghanistan, *International Journal of Water Resources Development*, 31 (4):
563 487-498.
- 564 Haile, G., Gebremicael, T.G., Girmay, A. 2018. Economic and environmental rehabilitation
565 through soil and water conservation, the case of Tigray in northern Ethiopia, *Journal of*
566 *Arid Environments* 151: 113-124.
- 567 Human Rights Watch (HRW), 2022. "We will erase you from this land: Crimes against
568 humanity and ethnic cleansing in "Ethiopia's Western Tigray Zone, *AFR* 25/5449/2022, 1-
569 240.

- 570 Human Right Watch (HRW), 2021. Ethiopia: Blocking Tigray Aid Harms Rape Survivors.
571 Report. Retrieved from [https://www.hrw.org/news/2021/11/09/ethiopia-blocking-tigray-](https://www.hrw.org/news/2021/11/09/ethiopia-blocking-tigray-aid-harms-rape-survivors#)
572 [aid-harms-rape-survivors#](https://www.hrw.org/news/2021/11/09/ethiopia-blocking-tigray-aid-harms-rape-survivors#), Accessed on 23 Jan 2022.
- 573 Hydro Review Content Directors (HRCDC), 2021. Was 'Ethiopia's Tekeze Dam and 300-MW
574 hydro project destroyed in a bomb attack? Hydro review. Report. Retrieved from
575 [https://www.hydroreview.com/dams-and-civil-structures/was-ethiopias-tekeze-dam-and-](https://www.hydroreview.com/dams-and-civil-structures/was-ethiopias-tekeze-dam-and-300-mw-hydro-project-destroyed-in-a-bomb-attack/#gref)
576 [300-mw-hydro-project-destroyed-in-a-bomb-attack/#gref](https://www.hydroreview.com/dams-and-civil-structures/was-ethiopias-tekeze-dam-and-300-mw-hydro-project-destroyed-in-a-bomb-attack/#gref), Accessed on 4 Mar 2022.
- 577 ICRC, 2021. Syria water crisis: Up to 40% less drinking water after 10 years of war,
578 International Committee of Red Cross, [https://www.icrc.org/en/document/syria-water-](https://www.icrc.org/en/document/syria-water-crisis-after-10-years-war)
579 [crisis-after-10-years-war](https://www.icrc.org/en/document/syria-water-crisis-after-10-years-war), Accessed on 4 Jan 2022.
- 580 Kifle, M., Gebremicael, T.G., Girmay, A., Gebremedihin, T., 2017. Effect of surge flow and
581 alternate irrigation on the irrigation efficiency and water productivity of onion in the semi-
582 arid areas of North Ethiopia. *Agricultural Water Management* 187: 69-76.
- 583 Médecins Sans Frontières (MSF), 2021. Tigray's cities fill with displaced people fleeing
584 insecurity and in need of aid, Voice from The field. Retrieved from
585 <https://www.msf.org/ethiopia-tigray%E2%80%99s-cities-fill-displaced-people-need-aid>,
586 Accessed on 26 Feb 2022.
- 587 Mwai, P., 2021. Ethiopia's Tigray crisis: Why it's hard getting aid into the region. BBC Reality
588 Check. Retrieved from <https://www.bbc.com/news/57929853>, Accessed on 5 Mar 2022.
- 589 OCHA, 2021. Libya Humanitarian Response Monitoring: Humanitarian Dashboard (Jan -
590 Mar 2021) (Issued May 2021), Reliefweb. Retrieved from
591 [https://reliefweb.int/report/libya/libya-humanitarian-response-monitoring-humanitarian-](https://reliefweb.int/report/libya/libya-humanitarian-response-monitoring-humanitarian-dashboard-jan-mar-2021-issued-may)
592 [dashboard-jan-mar-2021-issued-may](https://reliefweb.int/report/libya/libya-humanitarian-response-monitoring-humanitarian-dashboard-jan-mar-2021-issued-may), Accessed 12 August 2022.
- 593 OCHA, 2022a. Summary of Humanitarian Needs and Key Findings, Humanitarian Program
594 cycle, February 2021, Ukraine.

595 OCHA, 2022b. Afghanistan: Humanitarian assistance has saved lives, but immense needs
596 remain, United Nations: UN News - Global perspective Human stories. Retrieved from
597 <https://news.un.org/en/story/2022/08/1124522>, Accessed on 15 Mar 2022.

598 OCHA, 2022c. Summary of Humanitarian Needs and Key Findings, Humanitarian Program
599 cycle, December 2020, Libya.

600 OCHA, 2022d. Northern Ethiopia - humanitarian update situation report, April 7, 2022.

601 Oduor, M., 2021. UN report alleges Somalia troops fought in the Tigray war. African News.
602 Retrieved from [https://www.africanews.com/2021/06/09/un-report-alleges-somalia-troops-](https://www.africanews.com/2021/06/09/un-report-alleges-somalia-troops-fought-in-the-tigray-war/)
603 [fought-in-the-tigray-war//](https://www.africanews.com/2021/06/09/un-report-alleges-somalia-troops-fought-in-the-tigray-war/), Accessed on 22 April 2022.

604 Office for the Coordination of Humanitarian Affairs (OCHA), 2018. Israeli Forces Destroy
605 Wells, Public Infrastructure that is Indispensable to the Basic Needs of Protected Persons
606 in Gaza. Retrieved from [https://reliefweb.int/report/occupied-palestinian-territory/israeli-](https://reliefweb.int/report/occupied-palestinian-territory/israeli-forces-destroy-wells-public-infrastructure)
607 [forces-destroy-wells-public-infrastructure](https://reliefweb.int/report/occupied-palestinian-territory/israeli-forces-destroy-wells-public-infrastructure), Accessed on 21 Dec 2021.

608 Office for the Coordination of Humanitarian Affairs (OCHA), 2022a. Cluster Status: Water,
609 Sanitation and Hygiene (WASH) in Northern Ethiopia. Retrieved from
610 <https://reports.unocha.org/en/country/ethiopia/card/1WLAZPdZIo/>, Accessed on 27 April
611 2022.

612 Oyedotun, T.D.T., 2017. Ensuring water availability in Mekelle City, Northern Ethiopia:
613 Evaluation of the water supply sub-project. *Applied Water Science* 7(7): 4165–4168,
614 <https://doi.org/10.1007/s13201-017-0568-7>.

615 Pertile, M., & Faccio, S. (2020). Access to water in Donbass and Crimea: Attacks against water
616 infrastructures and the blockade of the North Crimea Canal. *Review of European, Comparative &*
617 *International Environmental Law*, 29(1), 56–66. DOI: 10.1111/reel.12316.

618 Reuters, 2021a. Key events in a year of war in northern Ethiopia. Retrieved from
619 [https://www.reuters.com/world/africa/key-events-year-war-northern-ethiopia-2021-11-](https://www.reuters.com/world/africa/key-events-year-war-northern-ethiopia-2021-11-01/)
620 [01/](https://www.reuters.com/world/africa/key-events-year-war-northern-ethiopia-2021-11-01/), Accessed on 11 Jan 2022.

- 621 Reuters, 2021b. Dam down, water supplies failing in Ethiopia's conflict-hit Tigray. News
622 report. Retrieved from [https://www.reuters.com/article/uk-ethiopia-conflict/dam-down-
623 water-supplies-failing-in-ethiopias-conflict-hit-tigray-idUSKBN29P10G](https://www.reuters.com/article/uk-ethiopia-conflict/dam-down-
623 water-supplies-failing-in-ethiopias-conflict-hit-tigray-idUSKBN29P10G), Accessed on 11
624 April 2022.
- 625 Reuters, 2021c. United Nations (U.N) warns catastrophe looms in Ethiopia's north, urges
626 government to end de facto aid blockade. News. Retrieved from
627 [https://www.reuters.com/world/un-warns-catastrophe-looms-ethiopias-north-urges-
628 government-end-de-facto-aid-2021-09-02/](https://www.reuters.com/world/un-warns-catastrophe-looms-ethiopias-north-urges-
628 government-end-de-facto-aid-2021-09-02/), Accessed on 12 Feb 2022.
- 629 Reuters, 2021d. Ethiopia denies bombing Tigray's Tekeze power dam. Report. Retrieved from
630 [https://www.reuters.com/article/us-ethiopia-conflict-dam/ethiopia-denies-bombing-
631 tigrays-tekeze-power-dam-idUSKBN27T1HM](https://www.reuters.com/article/us-ethiopia-conflict-dam/ethiopia-denies-bombing-
631 tigrays-tekeze-power-dam-idUSKBN27T1HM), Accessed on 22 April 2022.
- 632 Reuters, 2022. Blockade killing hospitalized children in Ethiopia's war-torn Tigray, doctors
633 say. NBC News. Retrieved from [https://www.nbcnews.com/news/world/ethiopian-tigray-
634 blockade-killing-hospitalized-doctors-say-rcna10994](https://www.nbcnews.com/news/world/ethiopian-tigray-
634 blockade-killing-hospitalized-doctors-say-rcna10994), Accessed on 29 May 2022.
- 635 Reliefweb, 2021. Syria Water Crisis: Up to 40% less drinking water after 10 years of war,
636 OCHA Services. Retrieved from [https://reliefweb.int/report/syrian-arab-republic/syria-
637 water-crisis-40-less-drinking-water-after-10-years-war](https://reliefweb.int/report/syrian-arab-republic/syria-
637 water-crisis-40-less-drinking-water-after-10-years-war), Accessed 2 September 2022.
- 638 Schillinger, J., Azerol, G.O., Sermin, G.G., Heldeweg, M., 2020. Water in war:
639 Understanding the impacts of armed conflict on water resources and their management.
640 WIREs Water, 2020;e1480, doi:10.1002/wat2.1480.
- 641 Schillinger, J., Özerol, G., & Heldeweg, M. (2022). A social-ecological systems perspective on the
642 impacts of armed conflict on water resources management: Case studies from the Middle East.
643 Geoforum, 133(2–3), 101–116. DOI: 10.1016/j.geoforum.2022.05.001.
- 644 Shiferaw, H., Gebremedhin, A., Gebremicael, T.G., Zenebe, A., 2018. Modelling
645 hydrological response under climate change scenarios using SWAT model: the case of Ilala
646 watershed, Northern Ethiopia. Modeling Earth Systems and Environment 4: 437-449.

- 647 Shishaye, H.A., Tait, D.R., Befus, K.M., Maher, D.T., Reading, M.J., Jeffrey, L., Tewelde,
648 T.G., Asfaw, A.T., 2020. Development of an improved hydrogeological and hydro-
649 geochemical conceptualization of a complex aquifer system in Ethiopia, *Hydrogeology*
650 *Journal* 28 (8): 2727-2746.
- 651 Sowers, J., Weinthal, E., 2021. Humanitarian challenges and the targeting of civilian
652 infrastructure in the Yemen war. *International Affairs* 97(1): 157–177.
- 653 Spiegel et al., 2019. Responding to epidemics in large-scale humanitarian crises: a case
654 study of the cholera response in Yemen, 2016–2018 *BMJ Glob Health*, 4 (2019),
655 Article e001709, [10.1136/bmjgh-2019-001709](https://doi.org/10.1136/bmjgh-2019-001709).
- 656 Stoddard, A., Harvey, P., Czwarno, M., Breckenridge, M.J., n.d.-a. Humanitarian Access
657 SCORE Report: Iraq. 22.
- 658 Talhami, M., & Zeitoun, M. (2021). The impact of attacks on urban services II: Reverberating effects
659 of damage to water and wastewater systems on infectious disease. *International Review of the Red*
660 *Cross*, 16. DOI: [10.1017/S1816383121000667](https://doi.org/10.1017/S1816383121000667).
- 661 Tafesse, N., 2006. Surface Waters Potential of the Hantebet Basin, Tigray, Northern Ethiopia.
662 *Agricultural Engineering International: The CIGR e-Journal*.
- 663 Tigray Water Resources Bureau, 2020. Annual water resources and irrigation bureau report,
664 Office of the Water Supply and Irrigation, pp. 1-80.
- 665 Tigray Water Resources Bureau, 2021. Annual water resources and irrigation bureau report,
666 Office of the Water Supply and Irrigation, pp. 1-95.
- 667 Tuncok, I.K., Mays, L.W., Briscoe, J, 1999. Water Resources Management in Developing
668 Countries and the Role of World Bank. In *WRPMD'99: Preparing for the 21st Century*, 1–
669 16). doi:[10.1061/40430\(1999\)116](https://doi.org/10.1061/40430(1999)116).
- 670 Woldearegay, K., Tamene, L., Mekonnen, K., Kizito, F., Bossio, D., 2018. Fostering Food
671 Security and Climate Resilience Through Integrated Landscape Restoration Practices and

- 672 Rainwater Harvesting/Management in Arid and Semi-arid Areas of Ethiopia Rainwater-
673 Smart Agriculture in Arid and Semi-Arid Areas, Springer: 37-57).
- 674 UN, 2018. Yemen: attacks on water facilities, civilian infrastructure, breach' basic laws of
675 'war' says UNICEF, United Nations (2018).
- 676 UN Water, 2015. International Decade for Action “Water for Life”, 2005 – 2015, Retrieved
677 from https://www.un.org/waterforlifedecade/water_and_sustainable_development.shtml,
678 Accessed on 26 Dec 2021.
- 679 Walsh, D., Abdi, D.A., 2022. Why Is Ethiopia at War With Itself?. The New York Times.
680 Retrieved from <https://www.nytimes.com/article/ethiopia-tigray-conflict-explained.html>,
681 Accessed on 27 May 2022.
- 682 Weinthal, E., & Sowers, J. (2019). Targeting infrastructure and livelihoods in the West Bank and
683 Gaza. *International Affairs*, 95(2), 319–340. DOI: 10.1093/ia/iiz015.
- 684 World Food Program (WFP), 2022. Emergency Food Security Assessment in Tigray Region,
685 Ethiopia, 1-34.
- 686 World Health Organization (WHO), 2022. Blockade creates "'hell' in ' Ethiopia's Tigray:
687 Aljazeera English News. Retrieved from
688 <https://www.aljazeera.com/news/2022/1/12/blockade-creates-hell-in-ethiopias-tigray-who>,
689 Accessed 23 may 2022.
- 690 Wu, X., Jeuland, M., Whittington, D., 2016. Does political uncertainty affect water resources
691 development? The case of the Eastern Nile. *Policy and Society*,
692 S1449403516300169, doi:10.1016/j.polsoc.2016.07.001.
- 693 Yemane A., Teka H. Tesfay F., Gidey H., Tekle A., Tadesse Y., Yahiya M., Tadesse
694 H., Amare B., Gebru F., G/Her M., Hailay S., G/Mariam T., Berhe Y., Wall L.L., 2022.
695 Obstetrics and gynaecology in an Ethiopian war zone, 1-5, DOI: 10.1111/1471-0528.17238.

696 Zeitoun, M., & Talhami, M. (2016). The impact of explosive weapons on urban services: Direct and
697 reverberating effects across space and time. *International Review of the Red Cross*, 98(901), 53–70.
698 DOI: 10.1017/S1816383117000157.

699 Zeitoun, M., Eid-Sabbagh, K., & Loveless, J. (2014). The analytical framework of water and armed
700 conflict: A focus on the 2006 Summer War between Israel and Lebanon. *Disasters*, 38(1), 22–44.
701 DOI: 10.1111/disa.12039.

702 Zelalem, Z., 2021. A year on, Ethiopia decimated by civil war. Retrieved from
703 <https://www.aljazeera.com/news/2021/11/4/a-year-on-ethiopia-decimated-by-civil-war>,
704 Accessed on 13 Feb 2022.

705 Zwizwai R., 2022., Humanitarian crisis in Tigray amidst civil war,
706 www.thelancet.com/infection, Vol. 22, 1-2.

707

708