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MILITARY USE OF ENVIRONMENTAL DEGRADATION BY ISLAMIC STATE, NORTHERN IRAQ

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Abstract

Members of the co-called Islamic State of Iraq and Syria (IS) took control of Qayyara and the surrounding oil fields in June 2014. They were expelled by Iraqi forces in August 2016, but as they withdrew north, they created a complex battlespace igniting fires at the Al-Mishraq sulphur plant and at oil wells, as well as allegedly using chemical weapons. The fires were originally intended to deter coalition airstrikes, but later became a ground tactic to thwart the advance of US-backed Iraqi government and Peshmerga forces. Oil wells in the Qayyara and Najma oil fields were intentionally set alight and it took on average 30 days to put out a single well. Plumes from oil fires were observed in satellite images over 267 days, and it is estimated that 1,33 million barrels of oil burned. The market value of the sour crude burned was between \$26,7 million and \$45 million. Additionally, the fires denied IS earning between \$105 000 and \$472 000 from road tankerage of oil to Syria. The sulphur piles ignited by IS at the Al-Mishraq sulphur plant generated plumes of sulphur dioxide (SO_2) and hydrogen sulphide (H_2S). Using ozone monitoring data, it is estimated that 83 461 metric tonnes (MT) of SO_2 were released into the atmosphere over six days. The market value of the combusted sulphur is estimated at \$6,1 million. The fires set at oil wells and sulphur piles by IS caused significant lost revenue to the 'caliphate' but also amplified an existing humanitarian crisis in an environmentally degraded region. This was caused by a toxic legacy from previous conflicts, coupled with desertification and unsustainable agricultural practices. The fires and areas affected continued to have real health effects on civilians even after IS had been defeated. For humanitarian aid and military personnel who were exposed by being in the areas, the severity of the effect was dependent upon the level of toxicity and length of exposure. This highlights the need to monitor environmental degradation in conjunction with accurate and timely health and environmental threat assessment in conflict areas. These must continue after the fighting ends if the true effects are to be understood.

Key words: Islamic State, Qayyara, oil wells, oil fires, sulphur fires, environmental degradation.

Introduction

In June 2014, the subdistrict of Qayyara (also known as Qayarah and Qayara 35°48′00″N 43°17′00″E) fell to the Islamic State of Iraq and Syria (IS) as it advanced to seize Mosul and Tikrit. In the wake of the IS advance into Mosul, two divisions of Iraqi soldiers (30 000 men) gave up their positions, weapons and bases. To consolidate control over the region, IS cut off water to surrounding villages and from Mosul's water purification plant.[2] On 7 August 2014, IS captured the Mosul Dam, giving them control over a large area of territory and prompting US action to address the threat. IS started a tactic of setting fire to oil wells to deter air strikes but on 17–18 August, Iraqi and Kurdish Peshmerga forces recaptured the dam with US air support. Military operations to take back the city of Qayyara from IS began on 23 August 2016, with air support from the Iraqi air force and the US-led coalition. It was at this time that IS increased the military use and scale of environmental degradation. Oil fires were started at wells in the Qayyara and Najma fields and oil was intentionally spilled onto the ground. The Qayyara air base was recaptured in July and Iraqi forces then retook the city on 24 August 2016. Shuttle diplomacy in August 2016, by a US envoy to the anti-IS coalition, brokered an oil revenue-sharing deal between Iraq and its Kurdish region vital to getting Peshmerga forces to advance on Mosul.[3] In October, Iraqi forces advanced to the Al-Mishraq sulphur plant while Peshmerga forces, on the other side of the Tigris, advanced west towards Mosul.[4] As US-backed Iraqi and Peshmerga forces advanced towards Mosul, IS created a complex battlespace with fires at Al-Mishraq sulphur plant combined with oil fires and the alleged use of chemical weapons. On 27 October 2016, UN Environment chief Erik Solheim called this crime "ecocide", and compared it to the environmental destruction caused by Saddam Hussein's wars.[5]

The history of the Qayyara oil field and Al-Mishraq sulphur plant

The Qayyara oil field was explored by the British Oil Development Company in 1927, and production commenced during the 1930s. The extracted oil is very heavy sour crude (American Petroleum Institute °API = Degrees API Gravity 15° C). The nearby Najma oil field is in the same geological structure as Qayyara. It was discovered by the British Petroleum Development Company in 1932, but because of its sour heavy oil (15 to 20 API gravity) production did not occur. The Najma field is 11 km (6,8 miles) long and 4,5 km (2,8 miles) wide. Extraction requires electricity and water as well as chemicals. Under the UN sanctions regime in the 1990s, oil industry maintenance standards fell due to a lack of spare parts, increasing the likelihood of pollution incidents. Prior to IS taking over the Qayyara and Najma oil fields, an Angolan company, Sonangol, had acquired a 75% stake, along with North Oil Company (25%), at a price of $6,00 per barrel. This contract was awarded in December 2009 but Sonangol pulled out in 2014 for security reasons. Reserves were estimated at 800 million barrels for Qayyara and 900 million for Najma.

To the north of Qayyara is the Al-Mishraq sulphur plant (35°58'50.76"N 43°18'45.85"E), which was established in 1969, with production starting in 1971. It covers an area of approximately 15 km^2 and contains the world's largest sulphur reserves estimated to be 544 MT. In 1990, the US-owned Freeport Company built a sulphur purification unit for $40 million that was damaged in the fighting in 2003. In 2013, under a $78,6 million award, the company Devco provided a complete purification facility with a capacity of 1 242 MT (1 370 tons) per day. The site includes a submerged combustion distillation system, sulphur recovery unit and sulphur filtration. The project was undertaken in coordination with CTI Consulting, River Consulting, ISTI Plant Services and Al Hawarth. Financing for the project came through JP Morgan Chase and Export–Import Bank of the United States. The Frasch process is used to exploit sulphur from underground deposits to depths of 120–200 m. The process depends upon water, electricity and chemicals.

Military use of environmental degradation

Both Iraq and Syria experienced extreme environmental stress from a drought that lasted from 2007–2010.[6,7] Water scarcity played a significant but complicated role in creating the conditions that led to the political unrest and violent insurrection in Syria in the spring of 2011,[8] which spilled over into Iraq.[9] The high air temperatures associated with the drought caused an increased demand for fuel and electricity for air conditioning. In Syria, the drought created food insecurity and migration, which could not be addressed effectively by the government. This further deepened ethnic and socio-political fractures that IS was able to exploit.[10,11] IS actions demonstrated early that they understood the military significance of capturing and then operating, denying or destroying critical infrastructure such as electricity, fuel, food, water and transportation. This included the environmental resources that underpinned them. Once IS forces came under attack by anti-IS forces, they used tactics very similar to those used by Iraqi combat engineers in 2003 retreating from coalition forces. IS then attempted to delay the advancing force by damaging, denying or destroying natural resources and associated infrastructure.

Water

In Syria and Iraq, records of water being used as a weapon date back 4500 years.[12,13] In 1991, when the Shia Marsh Arabs rebelled against Saddam Hussein, in support of the US invasion, he used water as a strategic weapon against them by diverting water to the marshes. These marshes had not fully recovered[14,15] when IS considered the Marsh Arabs their enemies and used the Fallujah Dam to reduce flow to the marshes from the upper reaches of the Euphrates. In September 2014, IS inhibited the advance of Iraqi forces by using the Sudur mini-dam to flood villages in the Shirwain Basin area in Diyala Province.[16] Then, in October 2014, IS diverted the Khalis River, a tributary of the Tigris River, to flood part of the town of Mansouriya in Diyala Province causing hundreds of families to flee.[17] They also cut off the drinking water supply around Mansouriya, Slam and Sarajiq, which came from the Khalis River. Over the period August 2012 to July 2015, King (2016) identified 44 incidents of water manipulation in Iraq and Syria for political or military advantage.[18] Of these, 21 were attributable to IS showing its systematic use of water to achieve military, economic and political effect. Control of water has been significant in recruiting fighters locally and gaining legitimacy.[19]

Oil fields

The oil and gas sector has been used to achieve military effect by both state and non-state actors in the region. As the Iraqi Army retreated from Kuwait in February 1991, they damaged or destroyed 749 oil wells, storage tanks and refineries, 610 of which were set alight.[20] Uncontrolled releases of oil began in January 1991, and fires started in late February 1991. Iraqi forces also uncapped or damaged more than 130 wells and allowed crude oil to flow freely across the landscape, causing large numbers of livestock and other animals to die. The oil that entered into the Persian Gulf polluted more than 706 km (439 miles) of the Saudi Arabian coastline.

Within IS, the Shura council identified oil as fundamental to the survival of the insurgency, and critically, to finance their intent to create a caliphate.[21] IS created a foothold in Syria's oil-rich east that was used in conjunction with control of water to consolidate control over eastern Syria after the capture of Mosul in 2014 (Figure 1). Due to IS seizing control of oil fields, the Syrian government hydrocarbon production plunged from 383 000 barrels per day (bpd) in 2010 to 10 000 bpd in 2015 and 2016. When IS took over northern Iraq, it seized the Ajil and Allas fields in NE Kirkuk as well as Qayyara and Najma. Locals report that on the day of the takeover, IS secured the fields, and engineers were sent in to begin operations and start transporting oil to refineries and markets. At the Qayyara refinery, IS appointed an Egyptian engineer – who used to live in Sweden – as the new manager.[22]

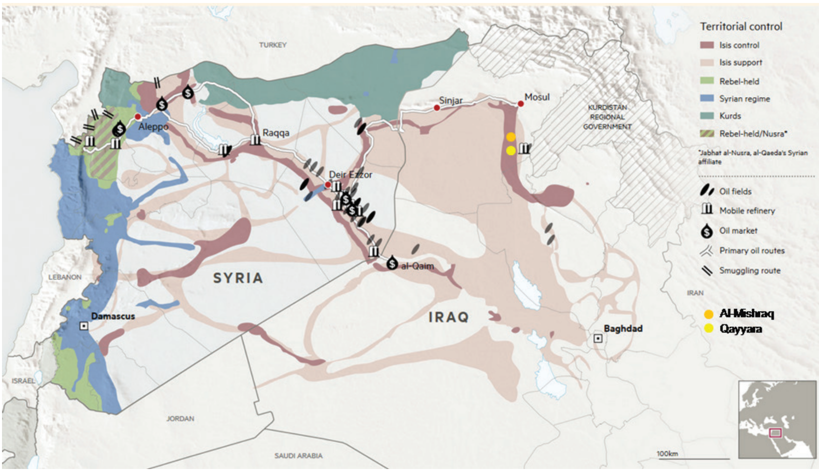

Fig 1. Control of oil field and territory by IS in February 2016.
Modified from Solomon et al., 2016.

In September 2104, US military forces and partner nations, including Saudi Arabia and the United Arab Emirates, attacked 12 IS-controlled modular oil refineries in eastern Syria in the vicinity of Al Mayadin, Al Hasakah and Abu Kamal.[23] The determination that these were legitimate military targets was that these small-scale refineries provided fuel to run IS operations, money to finance their continued attacks throughout Iraq and Syria, and they were economic assets. IS was earning $1,5 million per day in 2015 from all the fields it was operating in Syria and Iraq.[24] These attacks were stated to be strategic in nature. Russian airstrikes in Syria were reported to have been more aggressive in destroying oil infrastructure compared to the coalition approach which, after November 2016, focused on disrupting the extraction process rather than hitting actual wells.[25] In the summer of 2016, Iraqi media reported IS oil revenues were down by 90%.[26]

Sulphur

The Qayyara air base, 60 km south of Mosul, a hub for Mirage F1EQ, MiG-23 and 25sMLs, was captured from Iraqi forces on 23 May 2003. It became Forward Operating Base (FOB) Endurance or Q-West for coalition forces. On 25 June, retreating Iraqi forces started a fire at the Al-Mishraq sulphur plant (45 km from Mosul) using rocket-propelled grenades. Field samples of air in the vicinity of the fire detected SO_2 at levels immediately dangerous to health and life, and hydrogen sulphide (H_2S) was also released. The pollution in Mosul caused many people to be taken to hospitals and most vegetation was destroyed. Firefighters were primarily from FOB Endurance (Q-West) and included the 101st Airborne Division, 52nd Engineer Battalion, 326th Engineer Battalion, and the 887th Engineer Battalion. Many soldiers later reported a significant change in their ability to run two miles (3,2 km) on the Army Physical Fitness Test. A US Army Public Health Command study (2003) found 6 000 military personnel located within a 50 km radius of Mishraq during the 2003 fire but not all had been identified and tested.[27]

Analysis of Qayyara oil and sulphur fires

Daily visible images from the moderate-resolution imaging spectroradiometer (MODIS), visible infrared imaging radiometer suite (VIIRS) and operational land imager (OLI) passing over Southern Nineveh were examined for hotspots and plumes. The MODIS instrument on the NASA Terra and Aqua satellites captured data in 36 spectral bands ranging in wavelength from 0,4 μm to 14,4 μm. The VIIRS instrument on the Suomi National Polar-orbiting Partnership (Suomi NPP) can collect data in 22 different spectral bands of the electromagnetic spectrum, in wavelengths between 0,412 μm and 12,01 μm. The operational land imager (OLI) on Landsat 8 measures in the visible, near infrared, and short wave infrared portions of the spectrum. Fires east of Baiji were detected in MODIS and OLI images in early January 2016. Initially, around Mosul, one or two well fires were begun on 8 May 2016, lasting less than one day, and intermittently burned in June.[28,29,30] Another fire complex began on 3 July with daily fire detections occurring until about 12 July, when the fires greatly increased in number and continued to burn until gradual reductions occurred, starting in November 2016. On 20 October 2016, MODIS first detected a heat signature at Al-Mishraq and a large sulphur plume was observed. Figure 2 shows fire and thermal anomalies from Aqua and Terra MODIS instruments plus Suomi NPP VIRRS where a plume from the sulphur plant appears grey-white due to sulphate aerosols and droplets of sulphuric acid, which reflect light. Smoke plumes from the Qayyara oil field are black due to black carbon and other aerosols that absorb light. White plumes observed in Kuwait oil fires in 1991 were attributed to the majority of particles being salt (mostly NaCl) originating from oil-field brines expelled from wells together with oil.[31,32] At the Qayyara field, no white plumes were observed in MODIS associated with oil well fires.

In the Qayyara oil field, hotspots and plumes were observed on 267 days over the period 13 June 2016 to 27 March 2017 (Table 1). This included days with heavy cloud cover where plumes could be seen only partially. Plumes from the Al-Mishraq sulphur plant were observed on five days from 21 October 2016 to 26 October 2016. Plumes travelled most often to the south and southeast. Where there were multiple plumes on any given day, they could show variation in travel direction around a cardinal point, e.g. south or southwest.

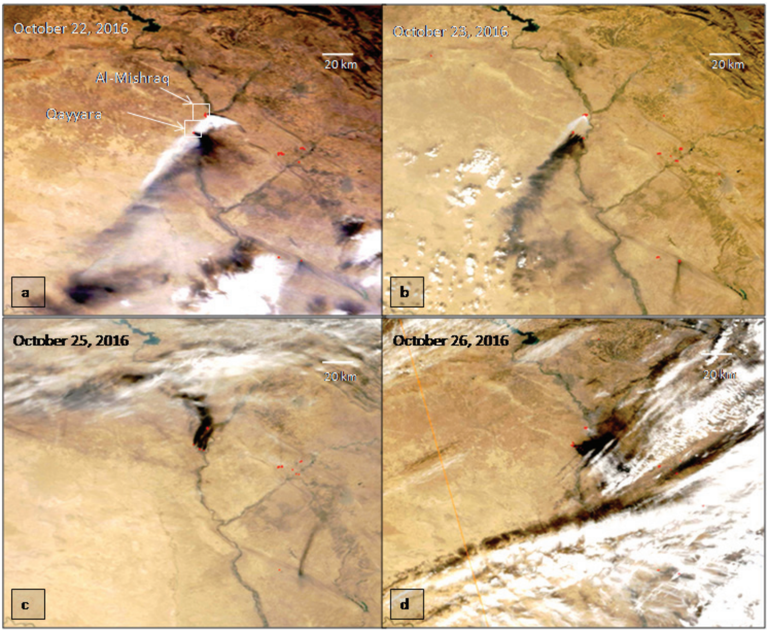

Figure 2. 4 MODIS observations with fire and thermal anomalies from Aqua and Terra/MODIS plus Suomi NPP/VIRRS. Heat signatures of fires are red spots. One at the Al-Mishraq Sulphur Plant was first detected on October 20, 2016. a. October 22nd and b. 23rd 2016 a plume of $S0_2$ (white) originated from a hotspot over Al-Mishraq traveled SW and merged with plumes from oil fires (black) from Qayyarah. c. On October 25th, 2016 $S0_2$ plume obscured by those from oil fires from Qayyara blown N. d. On October 26th, 2016 a small plume of $S0_2$ plume blew E. Cloud cover exists in all observations but the plumes can be distinguished.

Table 1. Number of days plumes from Qayyara and Al-Mishraq oil and sulphur fires were observed in MODIS images over the period of 13 June 2016 to 27 March 2017 and the direction of travel. Numbers in parentheses are for sulphur plumes.

Month	Days	Cloud	Plume	N	NE	E	SE	S	SW	W	NW
13 June 2016 to 27 March 2017	267	91	225	18	17 (1)	37 (1)	60 (1)	54	40 (3)	28	26

Oil plumes appeared confined to the troposphere with relatively short residence time due to removal by cloud and precipitation. Initially, the plumes of SO_2 and H_2S from Al-Mishraq remained in the lower troposphere but lofted to higher altitudes. Data from the ozone monitoring instrument (OMI) shows the plume of SO_2 and H_2S was over Baghdad by 24 October with concentrations of ten dobson units.[33] Using visible wavelength data, the number of days that plumes from the Qayyara oil field and Al-Mishraq sulphur plant travelled over surrounding urban centres was examined (Table 2).

Table 2. Number of days plumes and hot spots from Qayyara and Al-Mishraq oil and sulphur fires were observed in MODIS images over surrounding urban centres for the period of 13 June 2016 to 27 March 2017. Numbers in parentheses are for sulphur plumes.

Month	Over Qayyara air base	Over Erbil	Over Mosul	Over Mosul Dam	Over Kirkuk	Over Lake Tharthar	Over Baghdad	Over Mt Sinjar
13 June 2016 to 27 March 2017	103 (3)	6	8	1	11	2	1	2

At lower altitudes, oil plumes reached Mosul on eight different days, Irbil on six different days and Kirkuk on 11 different days. The winds were most often southerly in direction. Qayyara city and the air base had 103 days when oil plumes were over them (Figure 3). Sulphur plumes travelled over Qayyara and the air base on three days.

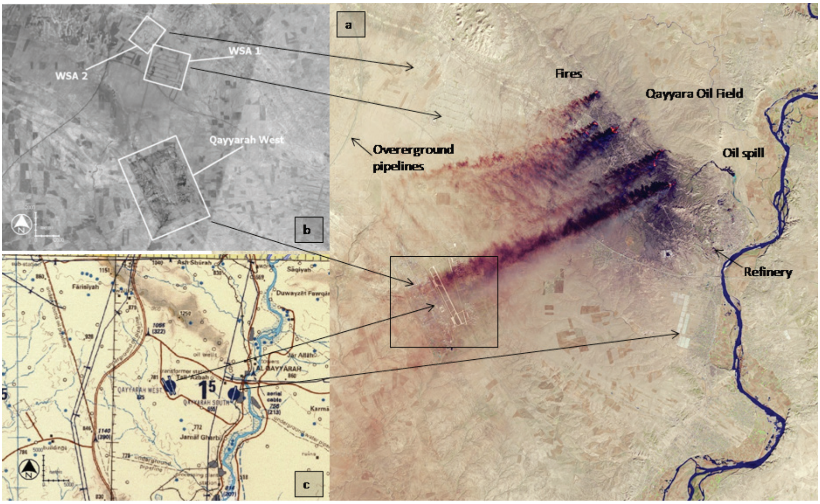

Fig. 3. a. Operational Land Imager (OLI) on Landsat 8 false-color images acquired Jan 24, 2017. Shortwave-infrared, near-infrared, and green light (OLI bands 6-5-3) show active fires (bright red) from well fires and plumes extending SW over Qayyara West Air Base. b. CNES/SPOT image showing from 1995 showing the air base and two weapons storage areas. WSA 2 measured 800 acres and contained 42 munitions igloos. WSA 1 measured over 1640 acres and contained 30 munitions storage igloos. c. NIMA Tactical Pilotage Chart 1:50,000.

Market value of combusted oil

Of the 50 wells in the Qayyara field, between 18 and 34 are reported to have been set on fire by IS.[34] Estimates from the Iraqi Oil Ministry were that 5 000 barrels of oil were burned per day. Using this figure, first-order calculations were undertaken to determine the total number of barrels burned over the 267 days that plumes were observed and the range of market values (Table 3). Using a figure of 42 gallons per barrel (pb), 1,3 million barrels (56 million gallons or 212 million litres) were burned at the Qayyara oil field. This represented a value of between $26,7 million and $45 million at $20 pb and $45 pb respectively. This was a loss to IS oil revenues but also to the regional economy. In production yields, this represented a 62% loss at the Qayyara field of pre-IS daily peak production of 8 000 bpd and a 45,7% loss of peak production over the year.

Table 3. Estimates of the amount of oil burned at the Qayyara oil field by IS and its market value calculated at $20 and $45 per barrel.

Month	Fire days	Barrels burned	Gallons burned	Litres burned	Price $20 per barrel (pb)	Price $45 pb
13 June 2016 to 27 March 2017	267	1 335 000	56 070 000	212 265 000	26 700 000	60 075 000

This loss of production yield and market value due to fires also resulted in a loss in revenue from road tankerage to refineries and the onward sale of products. It was assessed by security sources from the Iraqi ministry of oil that IS moved 50 tanker loads per day (tlpd) from Qayyara and Najma oil fields to refineries along the Iraq–Syria border and then on to Syrian cities, e.g. Aleppo, 550 km west of Qayyara.[35,36,37] In a highly organised system, Syrian and Iraqi buyers went directly to the oil fields with their tankers to buy crude.[38] This often resulted in tanker lines that became targets of airstrikes. IS responded by making tanker drivers register outside an oil field where they received the time to return to be filled. In this way, lines of tankers were reduced. Numbers of between 50 and 25 tlpd were used to estimate the number of tanker loads that were forgone (tlf) from Qayyara due to the 267 fire days and their value (Table 4). The fires at Qayyara resulted in IS losing between $210 000 and $472 000 in revenue from road tankerage (50 tanker loads per day) to Syria using $20 pb and $45 pb respectively.

Table 4. Estimates of tanker loads per day (tlpd) from Qayyara that were forgone (tlf) due to the 267 fire days and the monetary value.

tlpd	Total tlpd (barrels)	Total tlpd (gallons)	Total tlpd (litres)	Total tlf due to 267 fire days	Total tlf due to 267 fire days (barrels)	Total tlf due to 267 fire days (gallons)	Total tlf due to 267 fire days (litres)	$20 pb	$45 pb
50	10 500	440 000	1 669 500	13 350	28 03 500	117 480 000	445 756 500	210 000	472 500
25	5 250	220 000	834 750	6 675	1 401 750	58 740 000	222 878 250	105 000	236 250

Market value of combusted sulphur

The fire at Al-Mishraq in October 2016 was started by IS reportedly putting explosives in sulphur piles, which covered an area of approximately 0,16 km^2. Over six days of observation using MODIS and OMI data, 83 461 MT of SO_2 were released into the atmosphere.[39] This was smaller than the fire in June 2003, which released roughly 544 312 MT of SO_2 over 30 days.[40] Using the figure for SO_2 as a proxy for the tonnage of sulphur burned and the 2016 sulphur world price for September of $74 per MT, the market value of combusted sulphur was $6,1 million (Table 5). By comparison, the value of combusted sulphur from the 2003 fires, at September 2016 prices, was $40,2 million.

Table 5. Estimates of the amount of SO_2 released from sulphur fires at the Al-Mishraq sulphur plant (by IS in 2016 and Iraqi Forces in 2003) and the market value of sulphur.

Location	Month	Metric ton	Sulphur price Sept 2016 $
Al-Mishraq	October 2016	83 461	6 176 113,71
Al-Mishraq	June 2003	544 310,8	40 279 002,46

Air pollution from oil and sulphur fires

Using the calculations of the amount of oil burned at Qayyara (212 265 million litres) over 267 days (Table 3), emission estimates for selected pollutants (nitrogen dioxide [NO_2], particulate matter 10 micrometres [PM_{10}], particulate matter 2,5 micrometres [$PM_{2,5}$] and carbon monoxide [CO]) were calculated by multiplying the quantity of oil burned by a pollutant emission factor. Qayyara oil is heavy sour crude with a sulphur level > 5% and the full suite of pollutants released would have included SO_2, NO_2, CO, polycyclic aromatic hydrocarbon (PAHs) and lead (Pb).[41] The factors used are for 'open-burning' of crude oil fires, and were obtained from a number of sources shown in Table 6 along with estimates derived from the 2005 Buncefield oil fires[42]. The latter fire burned an estimated 105 million litres of oil, petrol and kerosene.[43] The emission estimates indicate that PM_{10} (31 172 MT using an emission factor of 170 000 mg/kg) and $PM_{2,5}$ (18 703 MT using an emission factor of 102 mg/kg) were the greatest relative proportion of the output of the Qayyara fires. This is similar to the analysis conducted after the Buncefield oil fires (Table 6). However, the dominant contributions of PM_{10} and $PM_{2,5}$ are reversed with PM_{10} being higher at Qayyara and $PM_{2,5}$ being higher at Buncefield. A total of 119 MT of NO_2 (calculated using an emission factor of 651 mg/kg) and 5 501 MT of CO were emitted over the 267 days. Proportionally, the emission estimates from Qayyara for NO_2 and CO are similar to those for Buncefield. The reason for the high PM_{10} at Qayyara and observations of black plumes could be related to the efficiency of the combustion.[44,45,46] Temperatures at well fires were reported to be 700 °C or 1292 °F.[47]

Table 6. Estimates of pollution emission from Qayyara from 267 fire days.

Pollutant	Emission factor mg/kg	Metric tonnes from fires at Qayyara	Buncefield* 100% loss assumed	Reference *Targa et al. (2006).
NO_2	651	119	54,6	Derived from Lemieux *et al*. (2004) CO emission factor[48] and ratio of NOX to CO reported by Evans *et al*. (1987).[49]
PM_{10}	170 000	31 172	12 109,6	Lemieux *et al.* (2004)[50] and US Dept of Defence range of PM_{10} in total PM.
$PM_{2.5}$	102	18 703	72 65,7	From 60% $PM_{3,5}$ figure of Ross *et al*. (1996).[51]
CO	30 000	5 501	2 514,1	Lemieux *et al.* (2004) for crude oil.[52]

Carbon dioxide emissions per barrel of crude oil were determined by multiplying heat content by the carbon coefficient by the fraction oxidised times the ratio of the molecular weight of CO_2 to that of carbon C (44/12):

5,80 mmbtu per barrel × 20,31 kg C per mmbtu × 44 kg CO_2/12 kg C × 1 MT/1,000 kg
= 0,43 MT CO_2 per barrel.

0,43 MT CO_2 per barrel x 1 335 000 barrels = 574 050 MT of CO_2 emitted over the 267 days of the Qayyara fires.

Estimating that a typical passenger vehicle emits 4,7 MT of CO_2/yr,[53] the amount of CO_2 released at Qayyara is equivalent to the emissions from 122 138 passenger cars in one year. Passenger vehicles are defined as two-axle four-tyre vehicles, namely passenger cars, vans, pickup trucks, and sport utility vehicles (SUVs).

The 83 461 MT of SO_2 emissions from the fires at Al-Mishraq in 2016 (Table 5) were equivalent to a small volcanic eruption. In comparison with eruptions in 2016, this was one of the largest releases of SO_2 that year.[54]

Fighting fires

After the Iraqi Army had retreated from Kuwait in 1991, it took 200 days and a massive response of some 10 000 engineers, firefighters, equipment operators and support personnel from around the world to extinguish the oil fires. The cost of fire fighting has been estimated at up to \$2,5 billion, and \$20 billion for repairs to the damaged oil wells and infrastructure, according to US government sources. Fighting the fires at the wells in the Qayyara oil field was left to the Northern Oil Company with military forces by-passing and moving north towards Mosul. Firefighting involved removing improvised explosive devices (IEDs), placed there by IS, from the wells, putting out the fires, controlling the gas release and preventing crude oil from moving into the water systems. Over 120 IEDs were found around the burning wells. On average, it took a team of 70 firefighters 30 days to extinguish one fire, working mostly without breathing equipment, or even face masks.[55] In aggregate, this took 1 020 fire days for 34 wells (30 days x 34 wells) and 70 firefighters per well, a total of 71 400 person days. Excavators dumped load after load of damp sand onto the flames, while firefighters with high-pressure water hoses struggled to keep the machinery cool enough to function. At times, explosives were used to starve the fire of oxygen, and chemicals were also injected into the well pipe to smother flames. Once the source of the fire could be reached, a mixture of water and salt was injected into the pipe to stop the gas from coming up.[56] Water usage was calculated for 300 gallons per minute (gpm) (1 135,62 litres) hoses using the reported average fire extinguishing times of 30 days per fire (Table 7). One 300 gpm hose pumped 18 000 gallons (68 137 litres) in one hour, so 432 000 gallons (1,63 million litres) in 24 hours. Over 30 days, this amounted to 311 million gallons (1,17 billion litres).

Table 7. Estimates of water usage at one well from a 300 gpm fire hose over one hour, 24 hours and 30 days.

Number of 300 gpm hoses	**Gallons in 1 hour**	**Litres in 1 hour**	**Gallons in 24 hours**	**Litres in 2 4 hours**	**Gallons in 30 days**	**Litres in 30 days**
1	18 000	68 137	432 000	1 635 297	311 040 000	1 177 413 926
5	90 000	340 687	2 160 000	8 176 486	1 555 200 000	5 887 069 632

It is not known how many hoses were used per fire but images show a range of one to five. These observations have been used to estimate the total amount of water pumped over 30 days at each of the 34 wells (Table 8). One hose running continuously for 30 days pumped 10 billion gallons (40 billion litres). Five hoses pumped 52 billion gallons (200 billion litres). The water from one hose pumping over 30 days is equivalent to filling 16 013 Olympic swimming pools (OSPs) equal to an area coverage of 20 km^2. Over 30 days, the amount of water pumped by five hoses filled 80 064 OSPs equal to an area coverage of 100 km^2.

Table 8. Estimates of water usage from a 300 gpm fire hose over 30 days at 34 well sites. These totals are then expressed as being equivalent to water held in an Olympic swimming pool (2 500 m^3) and as their area (0,00125 km^2).

Number of 300 gpm hoses	**Gallons in 30 days for 34 wells**	**Litres in 30 days for 34 wells**	**Equivalence to water in an OSP**	**Equivalent OSP area km^2**
1	10 575 360 000	40 032 073 498	16 013	20
5	52 876 800 000	200 160 367 488	80 064	100

Once an oil fire at a well head was extinguished, concrete was poured down the pipe to seal it. The total number of wells where this occurred is unknown but a total of 6 MT of concrete was used at well number 60 and the process took seven days. Using this figure, 204 MT of concrete and 238 worker days would have been required to seal 34 wells.

Similar to the oil fires, the response to fires at the Al-Mishraq sulphur plant was left to civilian responders. Military forces by-passed this and continued to advance on Mosul. Similar to the oil fires, firefighting involved removing IEDs from around the plant, moving sulphur piles away from the reach of the fire using earth movers and trucks, putting out the fires with water, controlling the gas release and preventing secondary fires. Analysis of thermal anomalies in MODIS data shows the fires were controlled within six days. Again, firefighters worked mostly without breathing equipment or even face masks. The numbers of firefighters and machines and the quantity of water used are unknown but media images show large numbers. Using figures in Table 7, the estimate of water usage from one to five 300 gpm fire hoses used over six days was 62,2 million gallons (235,48 million litres) and 311 million gallons (1,17 billion litres) respectively (Table 9). The water from one hose pumping for six days is equivalent to filling 94 OSPs equal to an area coverage of 0,12 km^2. Over the same period, the amount of water pumped by five hoses could fill 471 OSPs equal to an area coverage of 0,59 km^2.

Table 9. Estimates of water usage from a 300 gpm fire hose over six days at Al-Mishraq sulphur plant. These totals are then expressed as equivalent to water held in an Olympic swimming pool (2 500 m^3) and as their area (0,00125 km^2).

Number of 300 gpm hoses	Gallons in 6 days	Litres in 6 days	Equivalence to water in an OSP	Equivalent OSP area km^2
1	62 208 000	235 482 785	94	0,12
5	311 040 000	1 177 413 926	471	0,59

Water contamination

The water used to fight the fires would have been contaminated with firefighting products, fuels and fuel-related products. Estimates of the combined water usage to fight the oil fires (30 days each at 34 wells) at Qayyara and the sulphur fires (six days) at Al-Mishraq are shown in Table 10 to be 10,64 billion gallons (40,27 billion litres) from one hose and 53,19 billion gallons (201,34 billion litres) from five hoses. The water from one hose would have been equivalent to filling 16 107 OSPs and 80 535 OSPs from five hoses. This is equal to an area coverage of 20,13 km^2 and 100,67 km^2. This water was not captured or contained and so would have contaminated groundwater and entered into the Tigris River. This will need to be monitored in boreholes and by digging trial pits to monitor contamination of the land in the Qayyara and Al-Mishraq areas.

Table 10. Estimates of combined water usage from using 300 gpm fire hoses over 30 days at Qayyara and six days at the Al-Mishraq sulphur plant. These totals are then expressed as equivalent to water held in an Olympic swimming pool (2 500 m^3) and as their area (0,00125 km^2).

Number of 300 gpm hoses	Gallons of water used for oil and sulphur fires over 36 days	Litres for water used for oil and sulphur fires over 36 days	Water used for oil and sulphur expressed as OSP	Water used for oil and sulphur expressed as OSP area km^2
1	10 637 568 000	40 267 556 283	16 107	20,13
5	53 187 840 000	201 337 781 414	80 535	100,67

Damage to oil infrastructure

In response to the degradation and destruction of oil and gas infrastructure in Syria and along the Syria–Iraq border by US military forces, partner nations and the Russians, IS constructed open ditches or pits for storing crude. They then used portable metal furnaces to distil raw petroleum from these pits into fuel (Figure 4). Over 1 600 furnaces were identified in northern Iraq, with 600 between Qayyara and Hawija.[57] When heated in a furnace, crude oil produces various oil products depending on the temperature. The hydrocarbons evaporate and flow through a pipeline at the top of the furnace. The vapour in the pipe is cooled while flowing through a pipeline into a water basin. The vapour condenses, and the liquid is collected at the end of the pipe. These makeshift refineries work at a fraction of the output of pre-conflict refineries but IS took advantage of fuel shortages to raise prices.

Many of these distilleries were worked by children. The portable metal furnaces were susceptible to accidents and spills, particularly where they had been damaged. This caused significant local environmental damage. Uncontrolled burning of crude oil released dangerous levels of pollutants. Many of the children who worked the distilleries incurred skin and respiratory diseases and severe burn injuries that will impede future livelihoods.[58] Communities living in proximity to the sites were likely affected, and the effect on health and the environment should be investigated.

Fig 4. a. Aerial photo of multiple makeshift refineries around Mosul. b. A boys controlling the temperature of a portable metal furnace. c. View from the furnace through the water basin back to the collection point. From Oilprice.com.

Hazards on the ground related to oil

Under IS control and the subsequent fighting, oil fields have been targeted and have not had proper maintenance while under their control. This resulted in increased numbers of spills and leaks due to infrastructure damage and destruction, a lack of technology for leak detection and prevention, environmentally unacceptable disposal of drill cuttings and tank bottom sludge, flaring off gas, little or no protection of aquifers and disposal of oil-contaminated water to shallow aquifers, to the Tigris or to land. On 28 August 2017, as Iraqi forces entered Qayyara, IS reportedly opened up oil pipes in the town and flooded the streets with crude. UNICEF arrived the next day and found oil spilling into the Tigris River, the town's main source of drinking water. This is on top of the significant degradation of soil and groundwater, and air pollution that occurred in the 1990s and during the Second Gulf War.[59]

Oil products are a mixture of many different chemicals, making predicting their environmental fate and effects difficult.[60] Spills of heavy crude at the Qayyara oil field will partially degrade, a fraction will volatilise, while the remainder will adhere to soil and sediments. Little evaporation or dissolution will occur and it will weather very slowly. Generally, short-chained aromatic compounds such as benzene, toluene, ethylene and xylene (BTEX) are highly mobile and volatilise easily. Longer-chained compounds (large alkanes) have very low solubility, often remaining attached to local soil and sediments.[61] Large-scale releases of PAHs could potentially have severe long-term environmental impact. PAHs are very persistent organic compounds, some of which are potential carcinogens and/or could cause respiratory problems. When released by fires, they can be transported over a large area before deposition in soils.[62]

The short-chained and aromatic compounds pose a greater threat as they move into soil and air, exposing people via inhalation. The threat is related to the quantity released, the composition of the oil and the age of the released oil products. Long-term exposure to some of the oil-related substances (BTEX and PAHs) is associated with various health problems, such as respiratory disorders, liver problems, kidney disorders and cancer, depending on the duration and intensity of exposure.[63] Due to their prolonged exposure with minimal protection, the firefighters from Iraq's North Oil Company are at high risk as are civilians living in Qayyara. Aid workers and military personnel would have spent less time in these hazardous environments but the impact on them individually would be dependent upon their level of toxicity and length of exposure.

Oil pollution can be especially problematic for local ecological receptors, as certain animals, such as birds, are very sensitive to exposure to petroleum compounds.[64] Nitrogen (N) and sulphur (S) compounds are associated with acid rain, which negatively affects vegetation and causes acidification of soils. The soils around Qayyara have already been degraded by previous conflict, desertification and unsustainable agricultural practices. Groundwater pollution must be anticipated to have occurred where oil was released onto the soil surface[65] and additionally from contaminated water from firefighting. This will affect agricultural land and those using ground and surface water for irrigation, drinking and domestic purposes. This poses a long-term vulnerability to health, livelihoods and societal stability as it does in Syria[66] and must be understood if it is to be addressed.

Medical effects of oil and sulphur fires

Some health effects associated with air pollution are well recognised, such as increases in hospital admissions and deaths from cardiovascular diseases, respiratory diseases and lung cancer.[67] People with pre-existing cardiovascular and respiratory diseases and older people are particularly at risk. However, researchers around the world are finding that air pollution may be associated with a much wider range of health conditions. The Royal College of Physicians has collated evidence on the effects of air pollution on diabetes and neurological diseases, as well as the way exposure during pregnancy may be associated with low birth weight and pre-term births.[68]

Even without the effects of fires, ambient temperatures in and around Qayyara and Al-Mishraq during the summer 2016 and 2017 were 49 °C (120 °F). Due to the drought, IS control and conflict, people were malnourished and physically as well as mentally stressed. Civilians displaced by fighting were severely affected by the fires, plumes and fallout.[69,70] Thick smoke blocked out the sun, reducing temperatures locally. Fallout of oil, soot, sulphur and acid rain affected areas under the path of plumes (Figure 5).

Fig 5. View of the Qayyara oil field with a fire in the near ground having been extinguished using pipes, earth moving and shelter boxes in the near and mid ground. Another fire still burns in the distance with the plume rising near vertically to join a layer of soot particles spread over the whole horizon. Note the oil and soot on the desert floor. Photo from Kate Geraghty.

Those in the path of plumes and fallout were constantly exposed to numerous substances from multiple sources. Most risk assessment approaches and procedures evaluate risks on a substance-by-substance basis and not the combined health effects of exposure to multiple chemicals.[71] Analysis of the wind direction and plume incidence (Table 2) shows that civilians around Qayyara as well as military and humanitarian personnel experienced high exposure to oil and sulphur fire toxins.[72] Qayyara's roughly 20 000 residents remained after IS had started the fires and were exposed for over 267 days. For 103 days, people south of oil wells in the Qayyara field were enveloped in the combined plumes from all the fires. Medical facilities reported immediate severe short-term health effects, especially to people with pre-existing respiratory problems.[73] Doctors in a hospital in Qayyara district reported patients who claimed that they had never smoked in their lives come in with their lungs coated in tar. A 1,9-km (1,2-mile) stretch of hastily erected plastic tarp tents that made up the Qayyarah Airstrip Internally Displaced Peoples (IDP) camp housed approximately 50 000 IDPs. Doctors reported on 21 April 2017 that almost everyone was coughing, sick or complaining about smoke. Dr Tayseer Alkarim, an oncologist from the France-based group called Women and Health Alliance International (WAHA), reported, "people usually came to our health center seeking treatment for symptoms like fever, coughing, respiratory problems, diarrhea and asthma complications".[74]

Inhaled SO_2 readily reacts with the moisture of mucous membranes to form sulphurous acid (H_2SO_3), which is a severe irritant. People with asthma can experience increased airway resistance with SO_2 concentrations of less than 0,1 parts per million (ppm) when exercising. Healthy adults experience increased airway resistance at 5 ppm, sneezing and coughing at 10 ppm, and bronchospasm at 20 ppm.[75] SO_2 is heavier than air; thus, exposure in poorly ventilated, enclosed or low-lying areas could result in asphyxiation. Respiratory protection is required for exposures at or above 20 ppm. Exposures of 50 to 100 ppm may be tolerated for more than 30 to 60 minutes, but higher or longer exposures could cause death from airway obstruction. Iraqi army officials reported that the sulphur cloud from Al-Mishraq spread over 5 km^2, forcing the evacuation of about 200 families. Two people were reported dead and up to 1 000 people were treated for breathing problems. The United Nations Environment Programme (UNEP) reported that the Directorate of Health and the World Health Organization (WHO) treated over 1 000 persons for suffocation symptoms in the cities of Qayyara, Makhmour and Ijhala.[76] The effects on military personnel are unknown but the Combined Joint Task Force Operation Inherent Resolve (CJTF-OIR) provided more than 24 000 protective chemical masks to Iraqi and Peshmerga forces during training in preparation for the Mosul offensive. As learned in Kuwait[77] and at Al-Mishraq in 2003,[78] if military forces do not use their personal protective equipment (PPE), or use it improperly, the severity of effect would be dependent upon the level of toxicity and length of exposure.

When SO_2 meets water, it instantly dissolves to form sulphuric acid (H_2SO_4) and when this gets into soil by merging with water, it could persist for years, leaching out minerals, compromising agriculture, and harming nearby aquatic life through runoff. The effects on soils, aquifers and drinking water will need to be monitored.

IS tactics of setting fires

The military concept for IS setting fires appears originally intended to deter coalition airstrikes, but later became a ground tactic to thwart the advance of US-backed Iraqi government and Peshmerga forces. The military effect IS achieved on the ground by setting the fires at Qayyara and Al-Mishraq was localised and variable. It was a tactic for attempting some air defence when IS had no air assets other than unmanned aerial vehicles (UAVs). Fires achieved low-level atmospheric obscuration deterring airstrikes and artillery fire, which required visible alignment, aiming and battle damage assessments. This was overcome by either aircraft or by anti-IS ground forces moving out of the path of the plumes or with sensors using other parts of the electromagnetic spectrum. Fire and oil spills caused some route denial to the advancing anti-IS forces but, as in the previous Gulf wars, this was quickly overcome with mechanised forces by-passing and continuing the advance on Mosul. Some success was had by IS trading space and resources for time but advancing anti-IS forces did not expend their resources to deal with the fires. The fires at Al-Mishraq caused delay to advancing forces by forcing them to wear PPE or move out of the impact area. In addition to the challenges of wearing PPE in the desert, it produced tensions within the anti-IS force due to very different scalings of equipment within different fighting units. This ranged from full chemical, biological, radiological and nuclear (CBRN) capability in main battle tanks through to no PPE (Figure 6). This in turn caused some reconfiguration of the order of battle within anti-IS forces, but the advance continued.

Fig 6. a. A U.S. Army M109A6 Paladin howitzer conducts a fire mission at Qayyara West Airfield, Iraq, in support of the Iraqi forces' push toward Mosul, Oct. 17, 2016. Army photo by Spc. Christopher Brecht. b. Iraqi forces wear a range of protective equipment after winds brought fumes from a nearby sulfur plant set alight by Islamic State militants, at south of Mosul in Qayyara, Iraq, October 22, 2016. REUTERS/Alaa Al-Marjani.

The fires affected the use of the Qayyara air base by anti-IS forces after it had been recaptured from IS on 9 July 2016. The base became the headquarters for the Battle of Mosul, and work immediately began on repairs to the runway, which was reopened on 22 October 2016. From 13 June 2016 to 27 March 2017, the 103 days with oil plumes and three days with sulphur plumes affected the air quality but did not stop air or artillery strikes being launched. It did however affect the health of anti-IS forces deployed there, necessitating protective measures.

Civilians in the areas of the fires and plumes had no protection from exposure, with the resulting medical and environmental consequences. Causing fires was therefore effective as a terror weapon but was unlikely to have gained IS support for their cause in the longer term.

By taking over and operating oil fields and the Al-Mishraq sulphur plant, IS achieved financial strength. They held a monopoly of an essential commodity in a captive market in Syria and Iraq. This strength and the accompanying revenue were lost when IS set these fires. This raises questions as to whether this was a tactical decision within IS, supported at strategic level. The evidence does not support IS having been ready to put out the oil fires they themselves had set so they could resume raising revenue from oil and sulphur if the advancing anti-IS forces had been stopped. There is also no evidence that IS had the medical capability to deal with the negative health consequences for which they were responsible either in the short or long term.

The production and refining of oil and the sulphur purification process have key dependencies and interdependencies, especially around water, chemicals, power, transport and communication. As an example, flooding down the Tigris due to failure of the Mosul Dam would likely destroy the pump facility critical to the Al-Mishraq sulphur plant. Without water from the Tigris, the plant would have to cease operations. It appears that IS had capability to assess dependencies and interdependencies as part of their planning. They used this knowledge to understand criticality and vulnerability. This in turn was used to seize, operate, control or destroy physical infrastructure in territory they captured. Once they were losing ground to anti-IS forces, this same understanding was used to damage, destroy or booby-trap this infrastructure systematically as they retreated. The willingness to use environmental degradation appears to have scaled from destroying individual pumps and wells to breaching dams. However, the evidence does not support IS having the ability to repair or replace these should the advancing anti-IS forces be stopped. This again raises the question whether this was a tactical decision supported at strategic level by the IS Shura council. Implied by these actions is a fundamental weakness in the strategic management and sustainability of the environment by the caliphate. Without provision of environmental infrastructure and health care, the legitimacy of IS in the eyes of the population under its control would diminish. Water, food and health insecurity compounded by climate change and further drought also could not have been addressed effectively, further weakening loyalty to IS. It is important to understand whether this was due to losses caused by anti-IS forces or whether this was the result of political, economic and military actors within IS being unable to co-operate to sustain the caliphate over the long term.

Conclusion

Although essentially forbidden by the Geneva Conventions,[79] attacks on industrial infrastructure,[80] including oil facilities, have been commonplace in armed conflict[81,82] and IS have systematically carried them out. Fires amplified the existing humanitarian crises in an environment degraded with a toxic legacy from previous conflicts, coupled with desertification and unsustainable agricultural practices. Like protection from torture and religious persecution, a healthy environment is a human right that is getting greater scrutiny in conflict-affected countries.[83] The wider issue of the environmental footprint of conflict and the way it affects populations is gaining a strong legal framework to address liabilities and provide timely support to those affected.[84] King (2017) notes that the best possible international diplomatic response to the growing capacity of hostile non-state actors to use water as a weapon, is to legitimise state power.[85] This can be extended to using environmental degradation as a weapon[86] and can be achieved by nations supporting international agreements and facilitating co-operation among the governments of Turkey, Iraq and possibly Syria as well as the Kurdistan Region.[87] Nations could use diplomatic leverage in the United Nations and other bodies to support the application and enforcement of an existing body of international law that prohibits using environmental destruction and degradation as a weapon.

Critical is the documentation of environmental destruction and attribution. However, in the case of the conflicts in Syria and Iraq, it has become increasingly apparent that fewer humanitarian organisations are working in these conflict zones than before, as they too have become targets of violence. Examination here has shown that remotely identifying environmental degradation caused by IS at Qayyara and Al-Mishraq is possible and it can be quantified. This enables attribution of IS actions assisting in prosecution of IS and messaging against ideology. Such examinations could also help identify environmental hazards and protect civilians from exposure over either the short or the long term to the worst health effects. Vital to effective recovery and reconstruction is communicating risk to civilians to prevent exposure to hazardous materials. This contributes further considerations for post-conflict environmental remediation and protection of natural resources getting increased support and scrutiny globally.

Endnotes

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