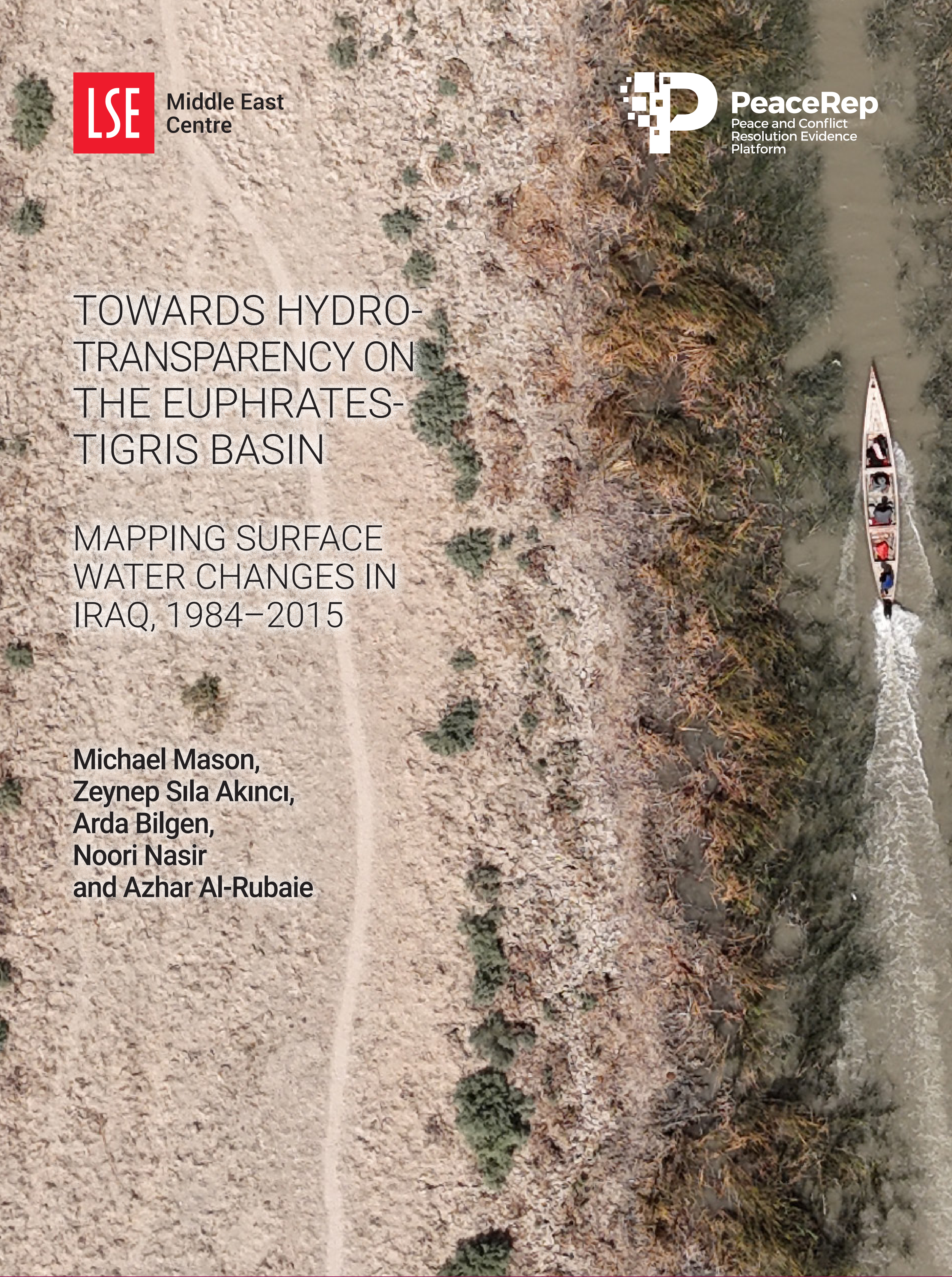

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TOWARDS HYDRO-TRANSPARENCY ON THE EUPHRATES-TIGRIS BASIN

MAPPING SURFACE WATER CHANGES IN IRAQ, 1984–2015

**Michael Mason,
Zeynep Sıla Akıncı,
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Abstract

This policy paper uses open-source software to examine surface water changes in the Euphrates-Tigris Basin from 1984–2015, focusing on Iraq – a downstream riparian state. The timeline captures the impact on Iraq of upstream dam construction, notably in Turkey and Iran, conflicts, and political transformations, and a period of protracted drought across the basin between 2007–18. Between 1984–2015, the area of permanent water in Iraq declined by a third, with greatest losses in the south. There was an 86 percent reduction in area of the Mesopotamian Marshes. In contrast, over the same period, the area of permanent water in Turkey increased by over a quarter.

Mapping long-term changes in the occurrence and variability of surface water is a necessary step in achieving greater hydro-transparency; that is, the open availability of information on the movement, storage and management of water within and across state borders. Increased hydro-transparency, through the public provision of evidence-based information, can build trust between the riparian states (Turkey, Syria, Iraq and Iran), informing options for more sustainable, equitable and reasonable utilisation of basin flows.

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Recommendations

- Increased hydro-transparency, through the public provision of evidence-based information, can initiate dialogue and build trust between riparian states, objectively informing options for more sustainable, equitable and reasonable utilisation of basin flows.
- User-friendly information on surface water changes should be used to guide open and inclusive deliberation in Iraq on the governance implications for water-sensitive sectors and regions.
- Validation and expert-review of Global Surface Water data from 2015, as applied to the Euphrates-Tigris Basin, should be commissioned. This would be of significant value to water use planning in Iraq, including in negotiations with Syria, Turkey and Iran over transboundary water flows as well as in talks between federal and subnational governments.
- Advanced analysis of water resources in Iraq would benefit from the adoption of combined terrestrial-hydrological modelling (e.g., NASA's Land Information System). This needs to be facilitated by scientific and financial support for increased ground-based data collection and modelling.

Introduction

This paper maps out changing surface water patterns in the Euphrates-Tigris Basin from 1984–2015 with a focus on Iraq – a downstream riparian state.[1] The timeline captures the impact on Iraq of upstream dam construction (notably in Turkey and Iran), wars, conflicts, and political transformations (particularly in Syria and Iraq), and a period of protracted drought (across the basin), especially between 2007–18. Mapping long-term changes in the occurrence and variability of surface water is a necessary step in achieving what we label 'hydro-transparency'; that is, the open availability of information on the movement, storage and management of water within and across state borders. Increased hydro-transparency, through the public provision of evidence-based information, can initiate constructive dialogue and build trust and confidence between the riparian neighbours, informing options for more sustainable, equitable and reasonable utilisation of basin flows.

The writing and publication of this paper is itself an exercise of hydro-transparency by promoting the democratisation of science, technology and expertise, particularly through the use of open-source water data and free access to, and dissemination of, research and policy findings on changes in surface water. For knowledge exchange and impact, a specific goal is the realisation of a hydro-transparency resource of value to policy practitioners and civil society actors in Iraq.

We first present our methodology and briefly outline the hydro-transparency deficit it seeks to respond to. Subsequent sections examine the dynamics of surface water changes in the Euphrates-Tigris Basin from 1984–2015 across three scales: basin-wide, Iraq, and the Mesopotamian Marshes. Finally, we offer concluding remarks, suggesting research and policy implications.

Methodology

Recent advances in optical remote sensing have improved the monitoring coverage and observed accuracy of surface water bodies. There are multiple methods, which are growing in sophistication with multisource satellite data (e.g., combining optical remote sensing imagery with radar data), integrated terrestrial and hydrological modelling (e.g., NASA Land Information System), and the use of machine learning (Huang et al. 2018). We selected the most comprehensive and detailed mapping of global surface water, as evaluated through scientific peer review (Pekel et al. 2016). This features an expert analysis and validation of all Landsat satellite data (over three million Landsat images) at monthly time-steps between March 1984 and October 2015, capturing any areas of water greater than $30m^2$ that are visible from space.

The dataset ('Asset ID 1984–2015') was validated by Pekel et al. (2016) through a web interface powered by Google Earth Engine.[2] It allows a mapping of surface water according to:

[1] According to FAO (2009, 1), the Euphrates-Tigris Basin has a total area of 879,790 km2 distributed between Iraq (46%), Turkey (22%), Iran (19%), Syria (11%), Saudi Arabia (1.9%) and Jordan (0.03%). The focus of the paper will be on Turkey, Syria and Iraq, as Iran contributes to around 10% of the Tigris flow by way of tributary rivers only, particularly through the Lesser Zab, Diyala, Kharkeh, and Karun rivers (Altınbilek 2004, 18).

[2] We selected the 1984–2015 database for its proven level of scientific validation: open-source data is also available until 2021.

- *Surface water occurrence*: the frequency with which water was present on the surface over a given time period (its location and persistence).
- *Surface water occurrence change intensity*: a comparison of two periods (March 1984 to December 1999 and January 2000 to October 2015) by averaging surface occurrence differences across the same months between these periods.
- *Surface water seasonality*: the *intra-annual* variability of surface water, which differentiates between 'permanent' (underwater throughout the year) and 'seasonal' (underwater for less than 12 months of the year) water for any given year.
- *Surface water recurrence*: the *inter-annual* variability of surface water, which describes the frequency with which water returned to a specific location from one year to another (expressed as a percentage).

The high policy significance of the work by Pekel et al. (2016) is that the dataset, with its thematic mapping function, is made freely available on a user-friendly interface, the Global Surface Water Explorer.[3] This opens up the possibility for anyone to explore surface water changes for a specific location without the need for complex remote sensing analysis (Yamazaki and Trigg 2016, 348). In this way, as a demonstration of hydro-transparency, we use the Global Surface Water Explorer to map the spatial and temporal changes in surface water in the Euphrates-Tigris basin from 1984–2015.[4]

The Global Surface Water dataset creates opportunities for researchers to observe and analyse the hydrological effects of key events in the political economy of the basin. This can include the clearer identification of the surface water impacts from important milestones, such as the launch of Turkey's South-eastern Anatolia Project (*Güneydoğu Anadolu Projesi*, GAP), which involves the construction of 22 dams, 19 hydroelectric power plants, and irrigation networks in south-eastern Turkey (Bilgen 2018) or the draining of the Mesopotamian Marshes in southern Iraq. Validation and expert-review of Global Surface Water data from 2015, as applied to the Euphrates-Tigris Basin, would be of significant value to water use planning in Iraq.

Context

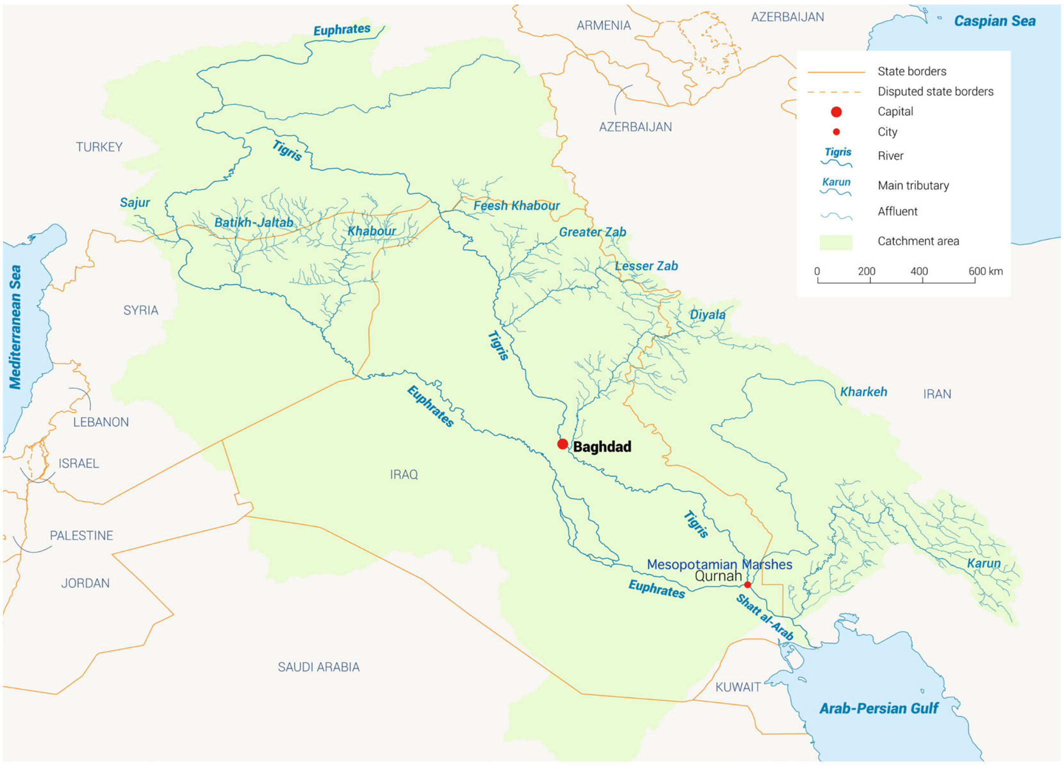
The Euphrates-Tigris Basin (Figure 1) is an engineered river system in which seasonality is heavily mediated by water extraction, regulated flows and reservoir releases. It provides critical resources of water, energy (hydropower) and food for the rapidly growing population of the basin. Since the early 1920s, the politics of water in the Euphrates-Tigris Basin has been marked by different periods of cooperation, confrontation and compromise between Turkey, Syria, Iraq and Iran.[5] The question of how much water is available in the basin is at the heart of this hydro-politics, which has featured disagreements on water withdrawals and even the hydrology of the constituent rivers – the Euphrates and Tigris – as they originate from the highlands of Turkey, follow distinct downstream trajectories, then merge together in southern Iraq as the Shatt al-Arab, which discharges into the Persian Gulf.

[3] Available at: https://global-surface-water.appspot.com/; though other tools are available – Al Sabeh et al. (2022), for instance, investigate the hydrology of the Yarmouk River Basin with the Water Evaluation and Planning (WEAP) tool, a model developed based on an integrated approach to water resources planning.

[4] We used ArcGIS Pro to generate the maps. The boundaries of the basin were delimited with the WWF HydroSHEDS Basins Level 9 dataset: see Lehner et al. (2008) and Lehner and Grill (2013). Country boundaries were delimited with FAO GAUL (2015).

[5] Following the disintegration of the Ottoman Empire, Turkey became independent in 1923 whereas Syria remained under French mandate from 1923–46 and Iraq remained under British mandate from 1920–32. Iran, formerly Persia, was ruled by the Pahlavi monarchy from 1925 until the Islamic Revolution in 1979.

Figure 1: Catchment Area of the Euphrates-Tigris Basin



Source map: Fanack.com

Monitoring the average monthly and annual flow data of the Euphrates and the Tigris at major points, including at shared borders, has been an integral part of each riparian country's water policy. Despite this, they have often released data in a restricted or selective manner, disseminating contradictory figures that only partially reflect the hydrological processes taking place in the basin. This is not uncommon as 'information on available resources can be a powerful bargaining chip in negotiations' (Elver 2002, 344). The securitisation of water data accounts for the lack of consensus on annual flows of the Euphrates and the Tigris issuing downstream from the Turkish border. From the mid-1960s when both upstream and downstream riparians began initiating water development projects in a 'competitive, uncoordinated and unilateral' manner (Kibaroğlu and Sayan 2021, 144), there is a trend of gradually declining water flows of both rivers, which has been attributed mainly to the upstream effects of large hydraulic infrastructure (Al-Ansari 2021; Jones et al. 2008; UN-ESCWA/BGR 2013, 58–59, 111). Other researchers, however, claim that climate change-related factors have a higher correlation with flow levels (Bozkurt et al. 2015, 145; Venturi and Capozzoli 2017, 255).

Differences between estimated flows, as well as observed changes in the flows, carry charged consequences for regional politics as there is neither a shared inventory of water and land resources of the basin nor a transboundary water treaty covering the whole basin. In domestic politics, the figures determine how riparian countries utilise water for irrigation, energy generation, and industrial and domestic use. In global politics, the figures inform how the countries develop their foreign policy towards each other and the international community. Therefore, the accuracy, comparability and transparency of hydrological data is of crucial importance for developing and maintaining cooperative relations on and through water (Bilgen 2023).

Surface Water Flows in the Euphrates-Tigris Basin

Surface water is the main water resource in Iraq (Republic of Iraq 2021, 4). According to the last comprehensive study of water resources in the country, 81.15 billion cubic metres (BCM) of freshwater was available in 2015 (Ministry of Water Resources 2014, 6). Of this total 88.9% (72.1 BCM) was surface water, 6.5% (5.2 BCM) was sustainable groundwater supplies and 4.6% (3.8 BCM) was drainage water. Of the total available surface water of 72.1 BCM, just over 60% (43.7 BCM) was received from riparian neighbours, with the most significant annual transboundary flows from the Euphrates (18.4 BCM; 25.5% of total available surface water) and Tigris (15.9 BCM; 22% of total available surface water), followed by three rivers – the Diyala (3.7 BCM), Greater Zab (3.4 BCM), Lesser Zab (2.3 BCM) – that join the mid-portion of the Tigris in Iraq (Ministry of Water Resources 2014, 6). As the Tigris receives a large amount of water from its major tributaries, there are significant differences in the discharge regime between the two rivers (Beaumont 1998, 169).

There are divergent calculations and estimates regarding surface flows in the Euphrates-Tigris Basin. The total flow of the basin is estimated to vary between 68 BCM to 84.5 BCM (Shareef and Maden 2021, 30). Nevertheless, it is possible to distinguish broadly between a pre-1973 'near-natural flow regime' and a post-1973 period characterised by the build-up of dams and other water control structures (UN-ESCWA and BGR 2013, 60, 110). Water use for human purposes (mainly irrigation and hydropower) increased sharply in the second half of the twentieth century, resulting in a reduction in stream-flows and major changes to the natural hydrological regime of the river.

Drawing mainly on data at Jarablus, on the Turkish-Syrian border, a report led by the UN Economic and Social Commission for Western Asia (ESCWA) calculated the mean annual flow volume of the Euphrates River as about 30 BCM for the pre-damming period (1930–1973) and approximately 25 BCM after damming (1974–): there were over 60 dams on the river by 2010 (UN-ESCWA and BGR 2013, 49). Other gauging stations also display lower mean annual flow volumes after 1974 compared to previous decades. However, there are wide variations in the scholarly literature on the post-1974 water potential of the Euphrates. These estimates range from about 30 BCM (Kolars and Mitchell 1991, 88; Özdemir et al. 2002, 27) to 35 BCM (Bilen 2000) and as high as 37 BCM (Öziş et al. 2020).

For the Tigris River, the ESCWA-led report drew on historical data (1931–2011) obtained from Iraqi gauging stations at Mosul and Kut. During the pre-damming period of near-natural flows (1931–73), the mean annual flow volumes were 21.3 BCM at Mosul and 32 BCM at Kut; and in the era of large-scale water infrastructure (1974–2005), the mean annual flow volumes had dropped to 19.5 BCM for Mosul and 16.7 BCM for Kut (UN-ESCWA and BGR 2013, 110). The decrease in annual flow volume on the Tigris is approximately 10 BCM between the 1953–84 period and the 1985–2005 period (UN-ESCWA and BGR 2013, 110–11). However, there are significant uncertainties over discharge data, in large part because of greater recording gaps and missing information at Kut. Between Mosul and Kut, the flow volumes on the Tigris are boosted by the merging of the major tributaries (the Greater Zab, Lesser Zab and, below Baghdad, the Diyala), but this estimated water input does not always match observed values on the Tigris. Generally, the data shows reduced high flows and increased low flows at Kut during the post-1973 period, which is likely to be associated with upstream damming and other flood control measures (UN-ESCWA and BGR 2013, 110–111).

Divergent data on Tigris discharges is mirrored in the scholarly literature which, for the post-1973 period has estimates that range from 16.8 BCM (Bilen 1994) to 21.3 BCM (FAO 2009, 4) and as high as 24 BCM (Özdemir et al. 2002, 31). The data timeline (1984–2015) for this report excludes the filling of Turkey's Ilısu Dam, the largest dam on the Tigris, a process that began in 2018. Even though the Ilısu Dam does not have an irrigation component, there is much concern in Iraq over the downstream impacts of the dam (and a linked dam planned at Cizre with both hydropower and irrigation components), notably projected negative impacts on the inflows for the reservoir of the Mosul Dam and further downriver effects on the Mesopotamian Marshes (Al-Madhhachi et al. 2020).

During the period of observation for this report (1984–2015), the largest, most permanent, water bodies on the basin map (see Map 1) are:[6]

- For Iraq: Razzaza Lake/Lake Milh (1,632 km^2) – a flood control reservoir 10km west of Karbala; and Lake Tharthar (1,627 km^2), a large artificial lake, 65 km northwest of Baghdad, that was created in 1956 to receive floodwaters from the Tigris and supply irrigation water.
- For Turkey: Lake Van (3,522 km^2), a large saline lake in north-east of the basin; and, in the north-west of the basin, the Atatürk Dam Reservoir (817 km^2) and the Keban Dam Reservoir (675 km^2).
- For Syria: Lake Assad (447 km^2), a water reservoir in central Syria created behind the Tabqa Dam (completed 1974).
- For Iran, which occupies less than a fifth of the basin area, there are no substantial bodies of (near) permanent water, though the Dez Dam reservoir (less than 70km^2), in Khuzestan province, is discernible in the south-eastern corner of the basin.

Iraqi government representations of the Euphrates-Tigris Basin tend to emphasise declining downstream flows. Recent studies support this narrative. In a US Geological Survey report, prepared in 2010 in cooperation with the Iraqi Ministry of Water Resources and the Iraqi Ministry of Agriculture Water Resources, Dina Saleh summarises streamflow data for all long-term gauging stations in the Euphrates-Tigris Basin in Iraq – three stations on the Euphrates and 20 stations on the Tigris. Declines in annual mean discharges are clearest for stations south of Baghdad, notably at Hit on the Euphrates (Saleh 2010, 133) and at Kut on the Tigris (Saleh 2010, 121). In another study, drawing on flow data from 15 gauging stations across Iraq (four on the Euphrates and eleven on the Tigris), Issa et al. calculate an annual reduction of 0.245 km^3/year on the Euphrates and of 0.1335 km^3/year on the Tigris corresponding to annual percentage reductions of 0.96% for the Euphrates and of 0.29% for the Tigris (Issa et al. 2014, 426–9).

[6] Area data for these water bodies are from Reimer et al. (2008) for Lake Van, Jones et al. (2007) for Lake Assad, NASA Earth Observatory (2003) for the Atatürk Reservoir, and Al-Muhamadi et al. (2019) for Lake Tharthar; and International Lake Environment Committee Foundation (2023) for the Keban Dam Reservoir.

The Tigris and the Euphrates are the main sources of water for the Mesopotamian Marshes. As discussed below, much attention in recent years has also been directed at the faltering restoration of the Mesopotamian marshlands, which historically depended on high spring flows and regular flooding, as a result of water shortages caused by upstream damming, water diversions and desiccation (Al Maarofi 2015; UN-ESCWA and BGR 2013, 119; Warner et al. 2011).

At least publicly, Turkish government representations of the Euphrates-Tigris Basin tend to emphasise high hydrological variability rather than declining downstream flows. This can be seen in scientific papers written by serving heads of the General Directorate of State Hydraulic Works (*Devlet Su İşleri Genel Müdürlüğü*, DSİ). For example, a chapter on the basin by Özden Bilen, the Director-General of DSİ from 1993–5, highlights the *high variance* of the annual flow both of the Euphrates – comparing, at Birecik (near the border in Turkey), a low of 14.9 BCM in 1961 and a high of 57.7 BCM in 1988 – and also the Tigris: the average annual flow of the river at Cizre (by the Turkey-Syria border) is calculated to range from a low of 9.6 BCM in 1973 and a high of 34.3 BCM in 1969 (Bilen 1994, 96–7). Doğan Altınbilek, the Director-General of DSİ between 1996–2001, also stresses high flow fluctuations in the basin, indicating that the average annual flow of the Euphrates at the Turkish-Syrian border ranges from 14 BCM (1961) to 57 BCM (1969) in the period 1946–94. The average annual flow of the Tigris at the Turkish-Iraqi border ranges from 7 BCM (1961) to 34 BCM (1969) in the same period (Altınbilek 2004, 19). He also states that the minimum and maximum monthly flows of both rivers significantly differ – almost 28-fold for the Euphrates and about 80 times for the Tigris – noting at the same time that the regulation of the basin waters through dams has made the flow pattern more uniform (Altınbilek 2004, 25–6).

Differences between flow estimates for the Euphrates-Tigris Basin, as well as any future decreases in the flows, carry far-reaching consequences for the utilisation of water for irrigation, energy generation, industrial use, and domestic use (Kibaroğlu 2021, 94). Climate change stresses in the basin, which are projected to become more significant over future decades, include decreasing river flows and evaporation, alongside an increasing frequency and severity of droughts (Arab Center for the Studies of Arid Zones and Dry Lands and United Nations Economic and Social Commission for Western Asia 2021; Mueller et al. 2021). Between 1984–2015, for instance, droughts in 1989, 1989–99, 1999–2001, 2008–9, 2010–11, 2012, and 2013–14 were particularly severe in Turkey (Su Yönetimi Genel Müdürlüğü 2022, 30). Research based on snowmelt data and streamflow records is so far inconclusive on climate change effects in the upper basin. Akyürek et al. (2011), examining the period 2000–9, noted a decrease in peak discharge amounts and an earlier snowmelt timing in both 2008 and 2009 (Akyürek et al. 2011, 3647). However, Şen et al. (2011), investigating changes in the discharges of the Euphrates and the Tigris, observed no statistically significant changes in the annual flow between the periods 1972–88 and 1990–2006 despite earlier spring melting of the snowpack (Şen et al. 2011, 4).

Projected climate change impacts for the basin include major reductions in water flows. Based on multiple model and scenario simulations, Bozkurt and Şen (2013) claim that the annual total surface runoff in the Euphrates-Tigris Basin will, by the end of this century, decline by 25–55% in the main headwaters of the basin in eastern Turkey (Bozkurt and Şen 2013, 159). These findings support earlier studies projecting reductions in flow, although with variations in the extent. Chenoweth et al. (2011) project a 9.5% decline in the average annual river discharge in the basin by 2040–2069 with further 10% decrease by 2070–2099, while Kitoh et al. (2008) project a 29–73% decline in the annual discharge of the Euphrates by the period 2080–2099. Turkey's General Directorate of Water Management also predicts a 60% decline in the gross water potential of the basin by 2041–2070, which amounts to an annual water deficit of around 23 BCM in the specified period (Su Yönetimi Genel Müdürlüğü 2020, 119).

More recent research has examined relationships between climatic stresses and water surface storage in the basin. The maximum storage capacity of the main dams in the basin is estimated at more than 144 BCM on the Euphrates and around 116.5 BCM on the Tigris (UN-ESCWA and BGR 2013, 62, 113), but there is no scientific consensus on the active storage capacity of all the reservoirs planned to be built on the rivers. Öziş et al. (2020) predict that the active storage capacity in Turkey will eventually reach 60–70 BCM on the Euphrates, which is approximately twice the average annual flow volume of the river in Turkey, and 20 BCM on the Tigris, which is about the average annual flow volume of the river at Mosul. For downstream users, they estimate potential active storage of around 15 BCM on the Euphrates (mainly in Syria), and 20 BCM on the Tigris (mainly in Iraq) (Öziş et al. 2020, 432). A satellite-based analysis of surface reservoirs in the basin found that major drought conditions were significantly correlated with absolute reductions in reservoir area since 1985 (Hasan et al. 2019). At the same time, large-scale storage capacity can modulate the impacts of droughts (and flooding). In 2019 an extreme precipitation event – the highest recorded in a century – dramatically increased storage across the Euphrates-Tigris Basin: Abdelmohsen et al. (2022) calculate that dam reservoirs across the basin captured water equivalent to 40% of the losses suffered during the protracted drought of 2007–18, thereby offsetting some of its hydrological impacts.

Surface Water Dynamics for the Euphrates-Tigris Basin and Iraq, 1984–2015

The maps presented below show various spatial and temporal facets of Iraq's surface water geography. Colour selections for surface water changes follow graphic conventions for the Global Surface Water Explorer as established by Pekel et al. (2016). For the Euphrates-Tigris Basin and Iraq, Maps 1 and 2 show surface water occurrence over 32 years (March 1984 to October 2015) in monthly time-steps. The legend moves from bright blue (100% of observations are classified as water) through decreasing blue (as water occurrence reduces) into red for fewer observations of water, fading into white for zero (0%) observations classified as water across the full time period. Maps 3, 4 and 7 show surface water occurrence change intensity across two separate 15-year periods (1984–99, and 2000–15) for the Euphrates-Tigris Basin, Iraq and the Mesopotamian Marshes. Here the use of green indicates locations where water occurrence increased and red indicates locations where surface water decreased: brighter tones of both green and red show, respectively, greater changes in the intensity of increase or reduction of surface water occurrence. Grey areas indicate locations for which there is no measurable change.

Temporal variations in surface water distribution are also mapped for Iraq (Maps 5 and 6) and the Mesopotamian Marshes (Map 8). Map 5 shows water seasonality for Iraq; that is, the *intra-annual* variability of surface water between 1984–2015. Seasonal water surfaces are those underwater for less than 12 months a year. The common map legend for both maps uses increasing intensity of blue to denote the number of months water is present in a year, from 0 months (white) to 12 months (dark blue) on average across the 32-year time period. Maps 6 and 8 show water recurrence for Iraq and the Mesopotamian Marshes; that is, the *inter-annual* variability of surface water between 1984–2015. The legend for these maps features a shift in colours corresponding to the average frequency with which surface water returns from year to year over the selected time period – from pure orange for zero (0%) frequency merging into blue for increasing recurrence to a pure blue for full (100%) frequency of return.

The maps are a visual resource that invite use alongside other hydrological data (e.g., reservoir discharges, groundwater flows, water quality measures) and related data (e.g., climatic variables, agricultural land use, demographic change): they provide one source of objective information that can be utilised for greater *hydro-transparency* on the movement, storage and management of water within the basin, including impacts on riparian states.

Key Patterns and Changes at Basin and Country-level

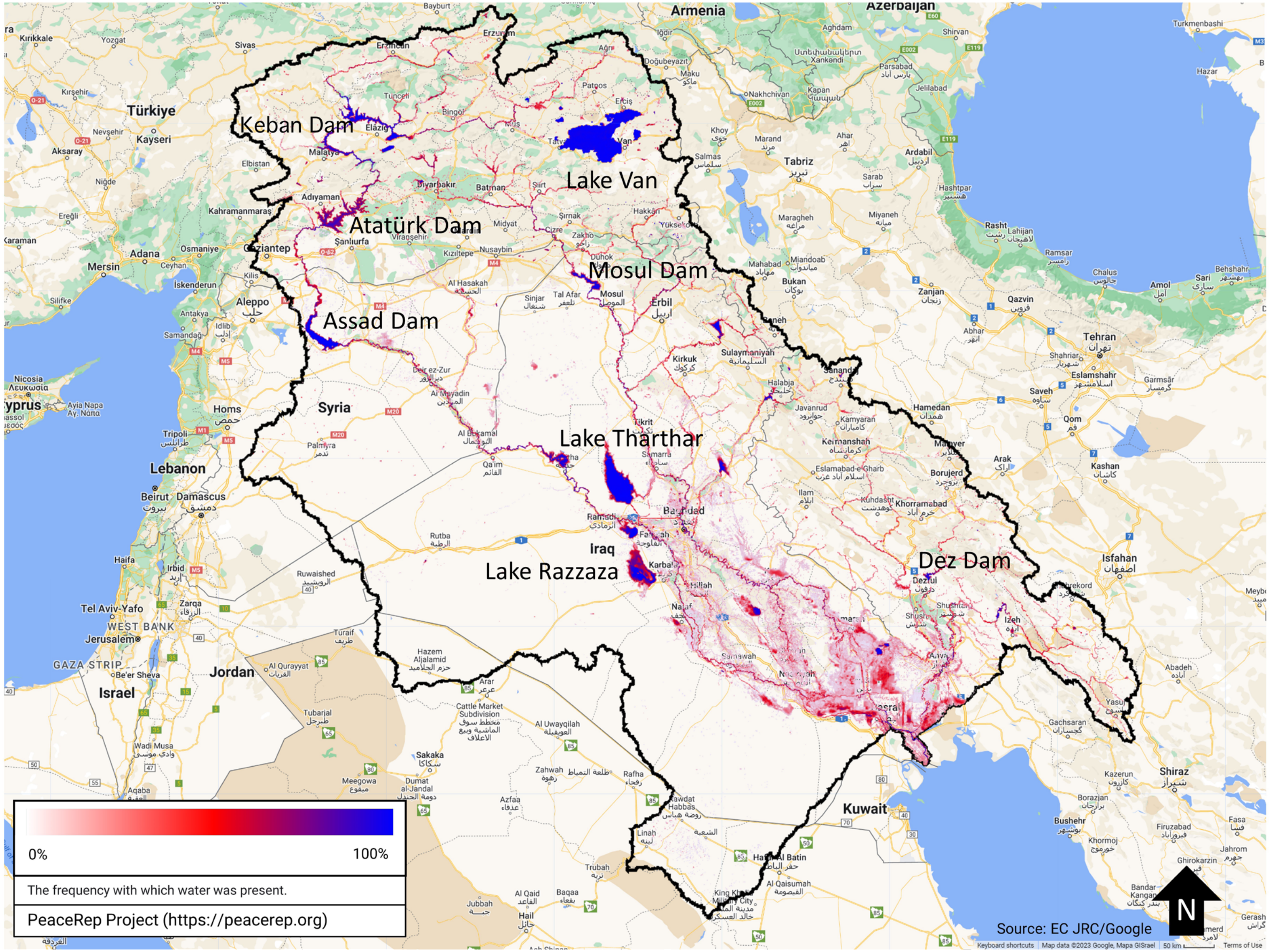
Basin-wide changes in surface waters across the Euphrates-Tigris Basin are especially important for Iraq. In contrast to Turkey and Iran, Iraq's surface water inflows are overwhelmingly from the Euphrates-Tigris Basin. Iraq occupies 46.4% (407,880 km2) of the total area (879,790 km2) of the basin, but that basin coverage is over 93% of the total area of the country: to recap, just over 60% of Iraq's renewable water resources originate outside its border (FAO 2009, 1; Shamout and Lahn 2015, 11). While the Global Surface Water database does not include water area statistics for transboundary river basins, we draw on data available at the national level (Pekel et al. 2016, supplementary table 2).

From 1984–2015, the area of permanent water in Iraq declined from 5,684 km^2 to 3,779 km^2 – a reduction of a third (33.5%). On the water occurrence maps (Maps 1 and 2), lower frequencies of water occurrence are most salient in southern Iraq, although there is a revealing geography of non-permanence attached to the overall network of basin waterways. As highlighted before, the issue of seasonality is largely moderated through water abstraction, flow regulation and reservoir releases. Map 5 illustrates the extensive seasonality of surface water in Iraq, with a visible tendency moving southwards (downstream) for water to be present fewer months in a year. From 1984–2015, seasonal surface water in Iraq declined from 4,323 km^2 to 3,971 km^2 – a reduction of 8%. Map 6 on surface water recurrence in Iraq from 1984–2015 shows an overlapping pattern of inter-annual variability, with lower frequencies of return more observable along southern water bodies and the lowest percentages (bright orange tones) concentrated in the Mesopotamian Marshes.

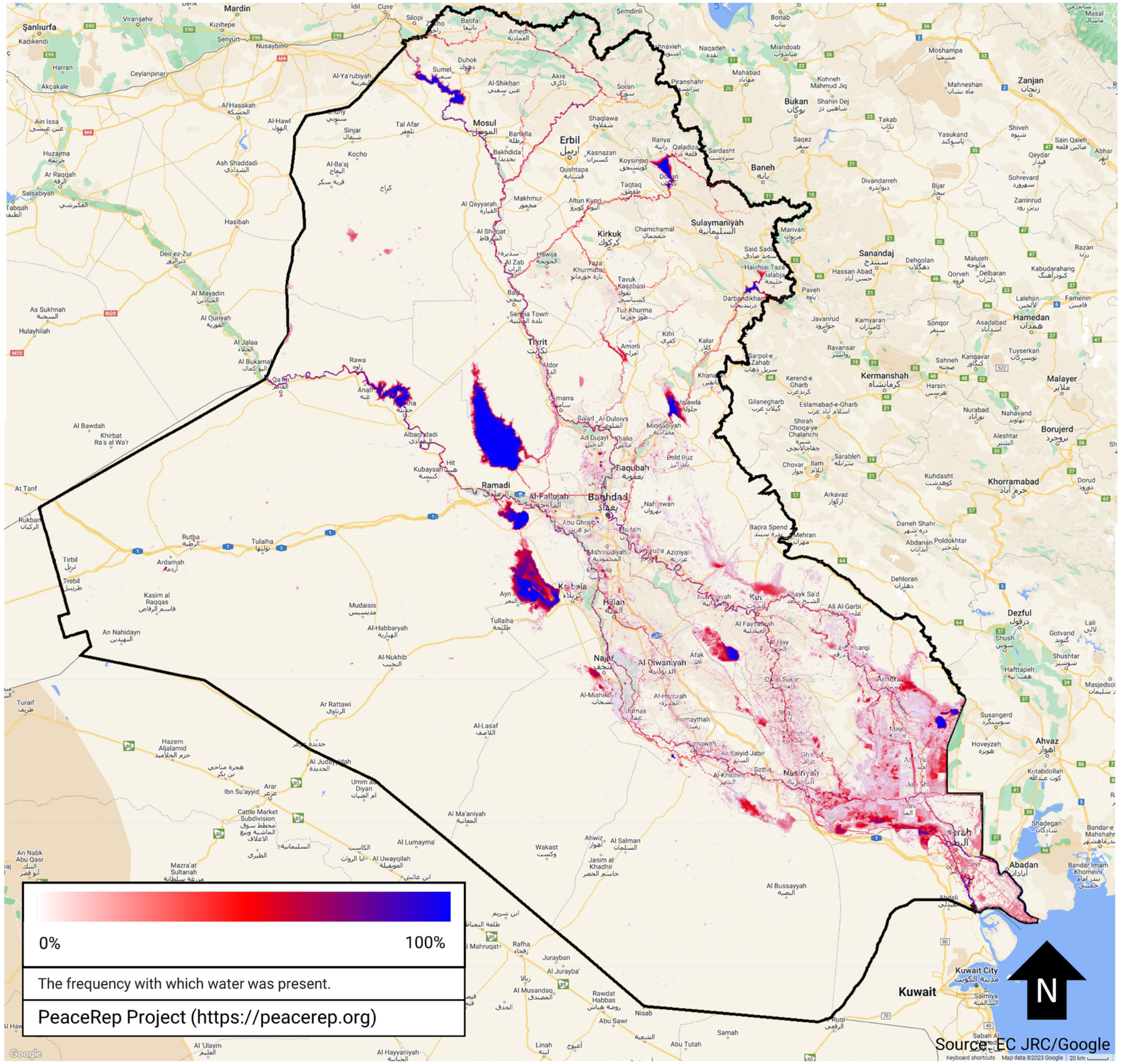
Between 1984–2015, the area of permanent water in Turkey increased from 8,667 km^2 to 10,875 km^2 – an increase of over a quarter (25.5%). While this data applies to *all* of Turkey, its 21.8% share (192,190 km^2) of the Euphrates-Tigris Basin occupies 24.5% of the country (FAO 2009, 1). While Turkey is reported to experience the impacts of climate change more intensely than the other riparian countries in the basin (Bozkurt and Şen 2013, 159), Turkey still benefits from high levels of surface water relative to its downstream neighbours. Over the same period, the area of permanent water across Syria increased over 30% (from 753km² to 982km²), and the area of permanent water across Iran fell 56% (from 7,167km² to 3,146km²) (Pekel et al. 2016, supplementary table 2). Accounting for these changes would require analysis of the full hydrological profile of each country.

Temporal shifts in frequency counts on Maps 1 and 2 are captured by Maps 3 and 4 on the change intensity of surface water occurrence. These maps show a significant decrease in downstream water occurrence between the periods of comparison (1984–99 and 2000–15), with the starkest reductions south of Baghdad, notably in the Mesopotamian Marshes. In this part of southern Iraq, the low frequencies (receding red tones) of surface water occurrence in the maps of the basin (Map 1) and Iraq (Map 2) largely correspond with the bright reds of change intensity in Maps 3 and 4, meaning that these locations have concentrated reductions in surface water (see next section). The most striking decrease outside the southern marshlands is the substantial reduction of surface water on Lake Razzaza, south-west of Baghdad and 10km west of Karbala city. Al-Razzaza is an artificial lake created in the late 1970s to receive Euphrates floodwater via Habbaniya Lake. Between 1989 and 2015, the surface area of the lake declined by 73.5% – from 1632 km² to 433 km², reflecting reduced flows from Habbaniya Lake (a major source of water for irrigation) and drought conditions from 2007 (Jumaah et al. 2022, 318–20).

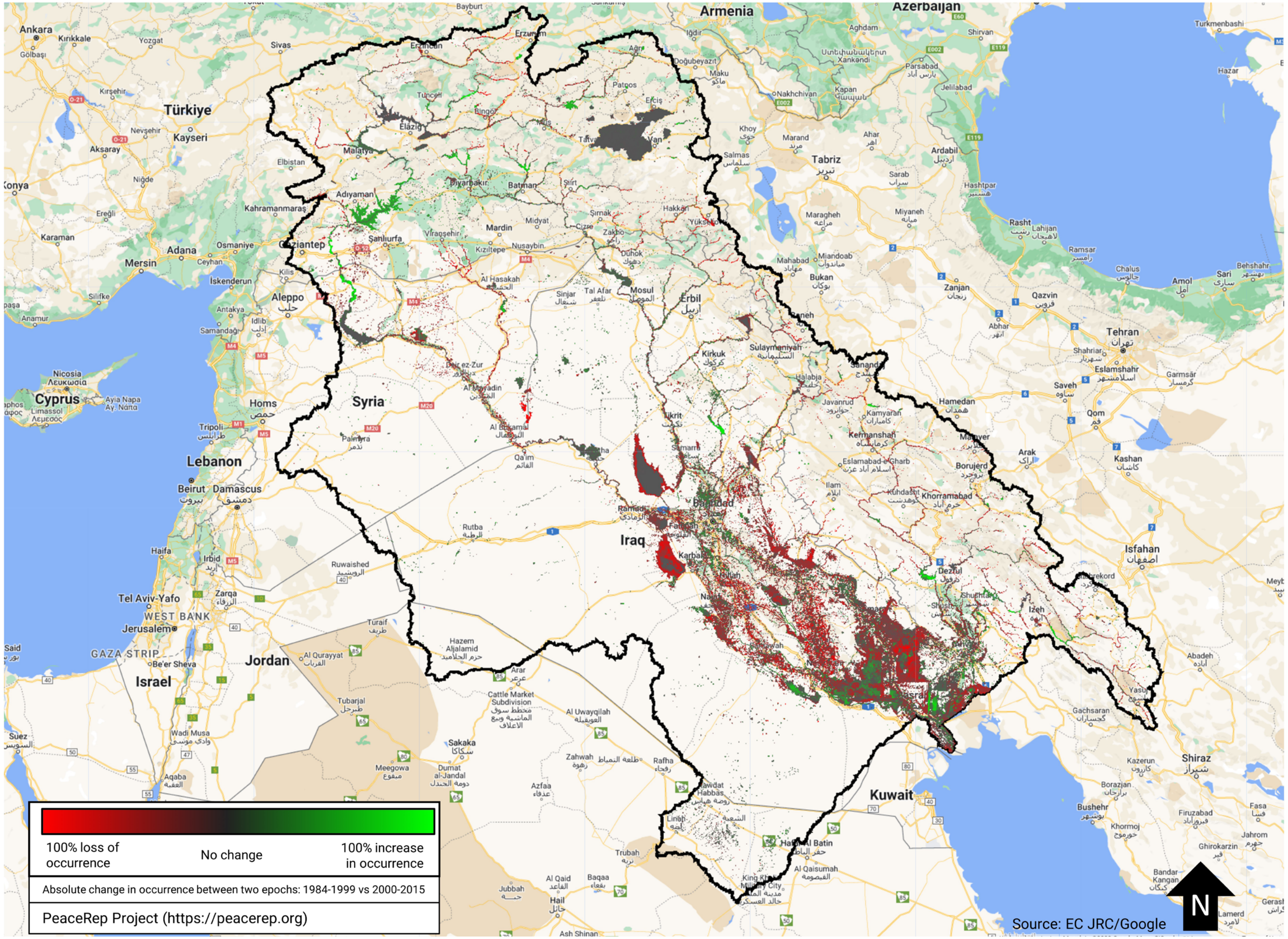
In the top-left (north-west) of Map 3, we can observe increases in the frequency of surface water, which demonstrates Turkey's growing hydrological take from the Euphrates-Tigris Basin. The clearest spatial manifestation is the Atatürk Dam Reservoir – the large body of water (capacity 48.7 BCM) in south-east of Adıyaman that was filled in 1990–2 [hence the intense green on Map 3] following the completion of the Atatürk Dam, the centre-piece of GAP (Tortajada 2000, 454). While Map 3 reveals evidence of other GAP projects coming onstream (e.g., the Batman Dam reservoir from 1999), the data timeline (1984–2015), as mentioned earlier, excludes the filling of the reservoir of the Ilısu Dam (capacity 10.4 BCM). As of 2023, 91% of the energy projects and 60% of the irrigation projects under GAP have been completed (DSİ 2023, 51). When fully operational, it is estimated that GAP will annually divert about 22.5 BCM including reservoir evaporation (Altınbilek 1997, 312) – 18.42 BCM from the Euphrates and 6.87 BCM from the Tigris (Devlet Planlama Teşkilatı 1997, 28–9).



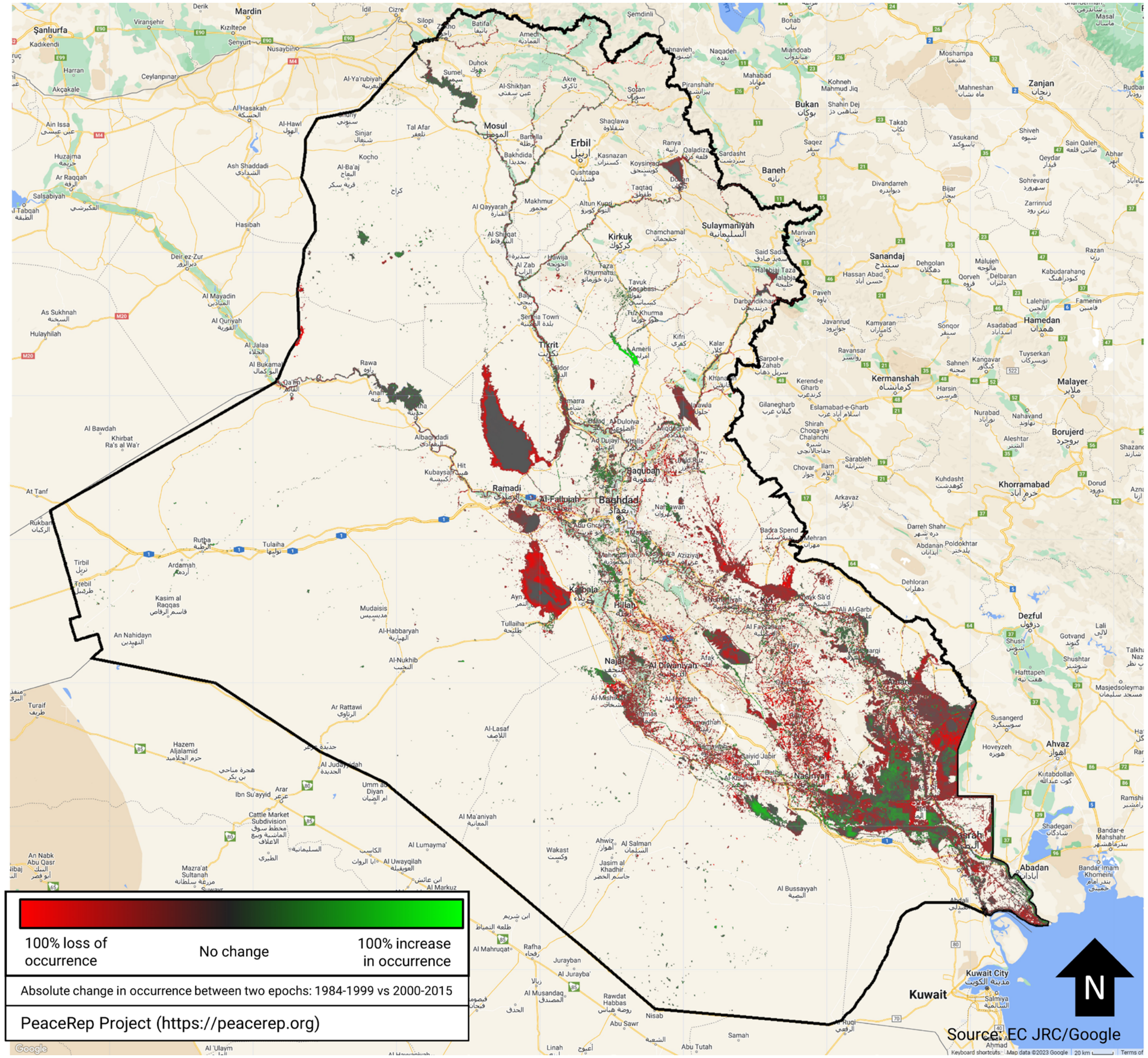
Map 1: Water Occurrence in Euphrates-Tigris Basin (1984–2015)



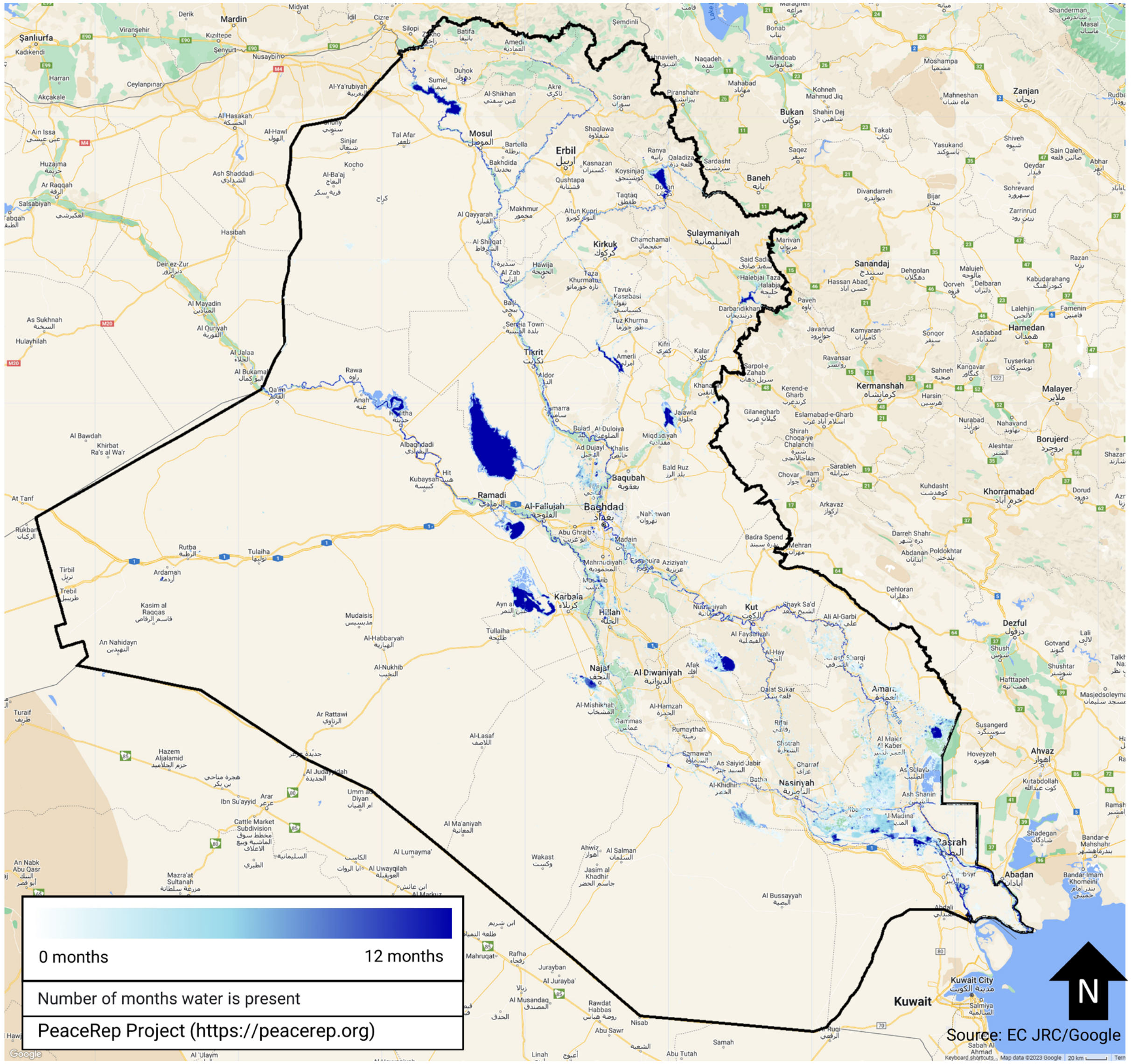
Map 2: Water Occurrence in Iraq (1984–2015)



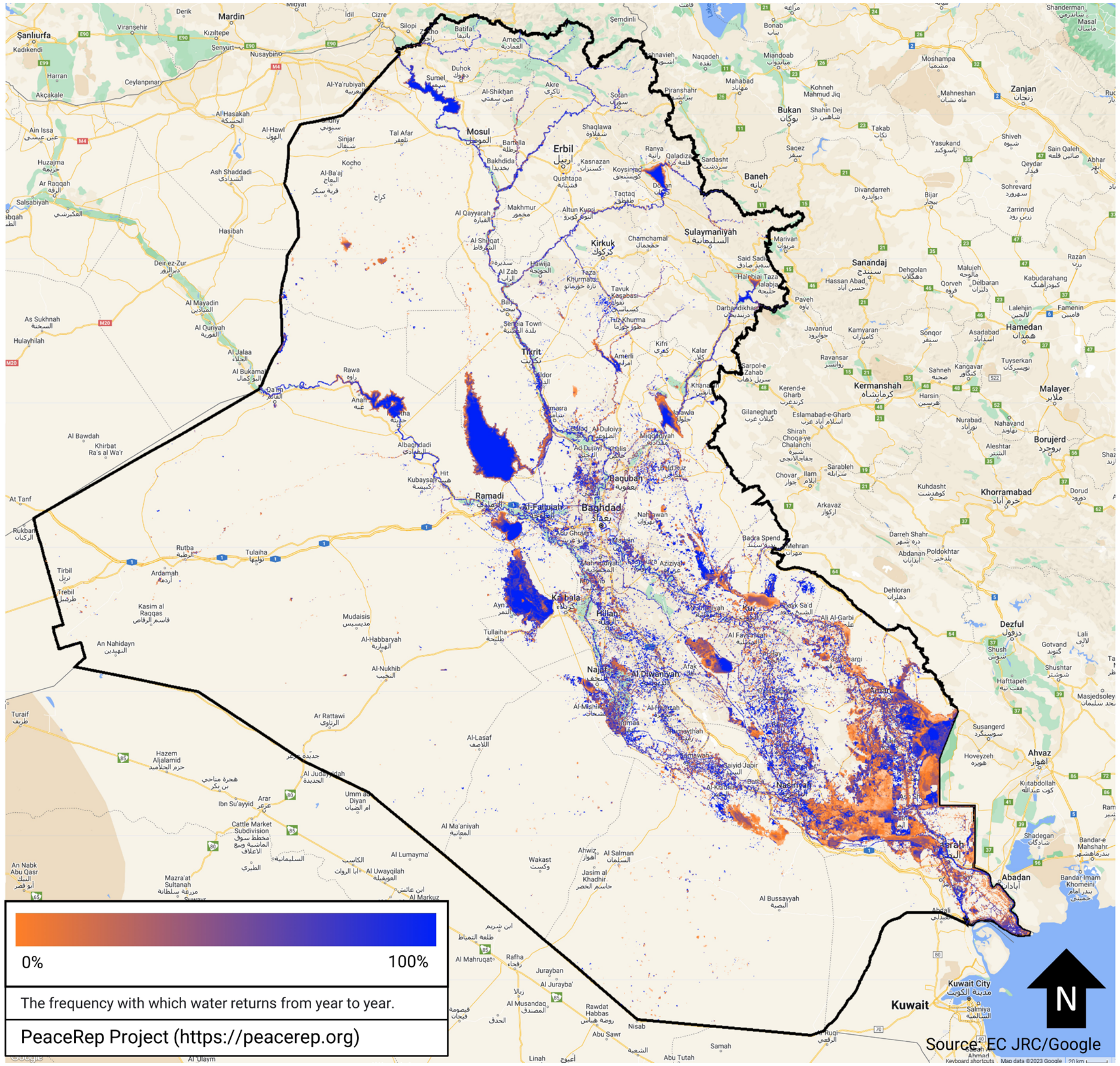
Map 3: Water Occurrence Change Intensity in Euphrates-Tigris Basin (1984–2015)



Map 4: Water Occurrence Change Intensity in Iraq (1984–2015)



Map 5: Water Seasonality in Iraq (1984–2015)



Map 6: Water Recurrence in Iraq (1984–2015)

Patterns and Changes for the Mesopotamian Marshes

The Mesopotamian Marshes, situated along the confluence of the Tigris and Euphrates Rivers, historically formed the largest wetland ecosystem in the Middle East. They cover three main areas: the Hammar Marshes located south of the Euphrates, the Hawizeh Marshes east of the Tigris River and the Central (Qurnah) Marshes situated between the two rivers (Map 7). Water supply to the marshes has varied with discharge flows from the upper basin, but prior to large-scale damming and drainage projects from the 1970s, they were annually recharged during spring (March to May) by a major freshwater pulse (AlMaarofi 2015, 5–7). Historically the marshes covered over 20,000 km^2 in high-flow periods and in 1970 they fluctuated in area between 15,000–20,000 km^2 (Ministry of Water Resources 2014, 111; UNEP 2001, 11). In 2016 the marshes were accepted for UNESCO World Heritage listing under the Government of Iraq nomination, *The Ahwar of Southern Iraq: Refuge of Biodiversity and Relict Landscape of the Mesopotamian Cities* (UNESCO 2016). This featured protective designation for 2,109 km^2 for nominated marsh components and 2,076 km^2 of buffer zone areas proposed for reflooding (Republic of Iraq 2014, 27).

During the observation period of the study (1984–2015), there was a dramatic reduction in area of the marshes. From Landsat images taken in 1984–5, the peak area of the marshes was 19,400 km^2. For 2015 the total area was 2,736 km^2 (Chen et al. 2011, 1083; Al-Azzawi 2022, 20), an 86% reduction (16,664 km^2) in marshland area between 1984–5 and 2015. This spatial decline is captured by Map 7, which shows changes in water occurrence intensity between 1984–99 and 2000–15. The first period corresponds with a series of major drainage projects: in the mid-1980s, at least 800 km^2 of the northeast corner of Hammar Marsh was drained to facilitate exploitation of the West Qurna oilfield (Chen et al. 2011, 1084); and in 1988, largely for political and military reasons, the government initiated a massive water diversion scheme to drain the marshes, which continued into next decade. By 2000 the marshland area was only 1,297 km^2, with the Central and Hammar Marshes almost completely drained (Partow 2001; Republic of Iraq 2014, 121–2). From 2003, under the new political system, there were national and international efforts to restore the southern marshes, alternating between early gains and later reversals (Jawad 2022; Warner et al. 2011). Under its *Strategy for Water and Land Resources in Iraq*, the Ministry of Water Resources (2014) estimates that a minimum of 5.825 BCM freshwater consumption is needed per year under average hydrologic conditions to maintain a restoration of 50% of historic marshland area as determined by the Center for Restoration of Iraqi Marshes and Wetlands (Ministry of Water Resources 2014, 2).[7]

Map 7 reveals that the greatest losses over the three decades are in the Hawizeh Marshes, the eastern section of the Hammar Marshes, and the western half of the Central Marshes, though there are also localised gains. Iraqi environmental engineer, Souad Al-Azzawi, argues in a recent assessment that the principal reason for long-term marshland decline is upstream damming. For the Hawizeh Marshes, the loss is mainly attributed to Turkey's construction and operation, during the 1990s, of nine dams and hydroelectrical power

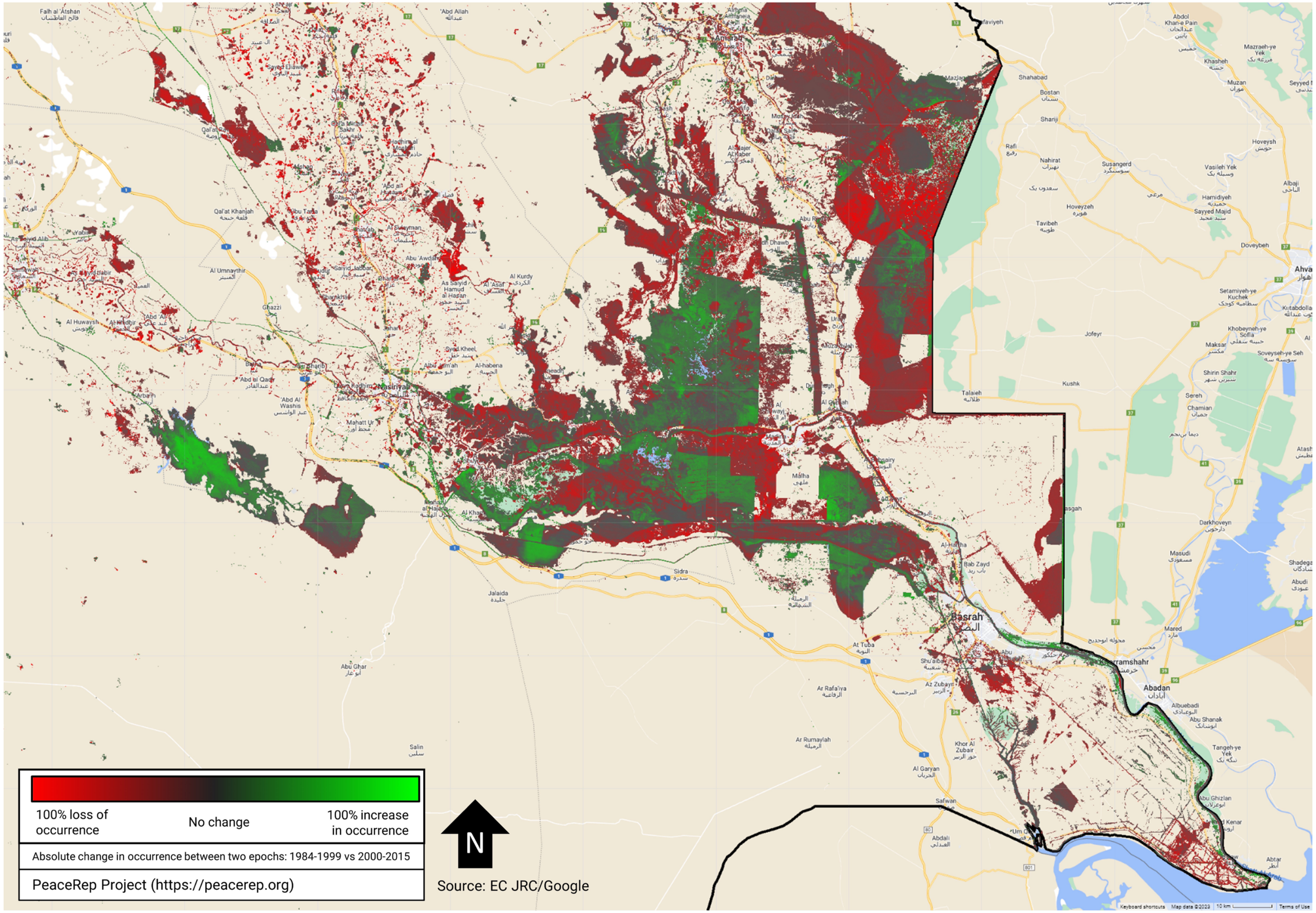
[7] This 5.825 BCM minimal consumption figure is based on inflow minus losses (outflow + evaporation) across all four marshes; Abu Zirig Marshes (0.18 BCM); Central Marshes (2.328 BCM); Hammar Marshes (2.064 BCM) and Hawizeh Marshes (1.253 BCM) (Ministry of Water Resources 2014, 19).

stations on the Tigris River with a total storage capacity of 6.38 BCM (Al-Azzawi 2022, 16–17). Iranian damming of the Karkheh River is separately threatening the integrity of the eastern Hawizeh Marshes. Map 9, covering the full extent of the Hawizeh Marshes, shows even greater reductions in water occurrence on the Iranian side. Similarly, the sharp reduction in the area of the Hammar and Central Marshes is principally attributed to the construction and operation of dams on the Euphrates, accelerating from the 1980s and 1990s with nine new Turkish dams, but also the Baath Dam (1986–) and Tishreen Dam (1999–) in Syria and the Qadisiyah (Haditha) Dam (1987–) in Iraq (Al-Azzawi 2022, 14–16). Turkey's high-level water bureaucrats and diplomats, on the other hand, point to issues related to Iraq's domestic politics as the major reasons for the decline, such as Saddam Hussein's regime, war-related degradation of water infrastructure over time, the mismanagement of water resources, the lack of economic and social capital, and systemic, widespread corruption.[8]

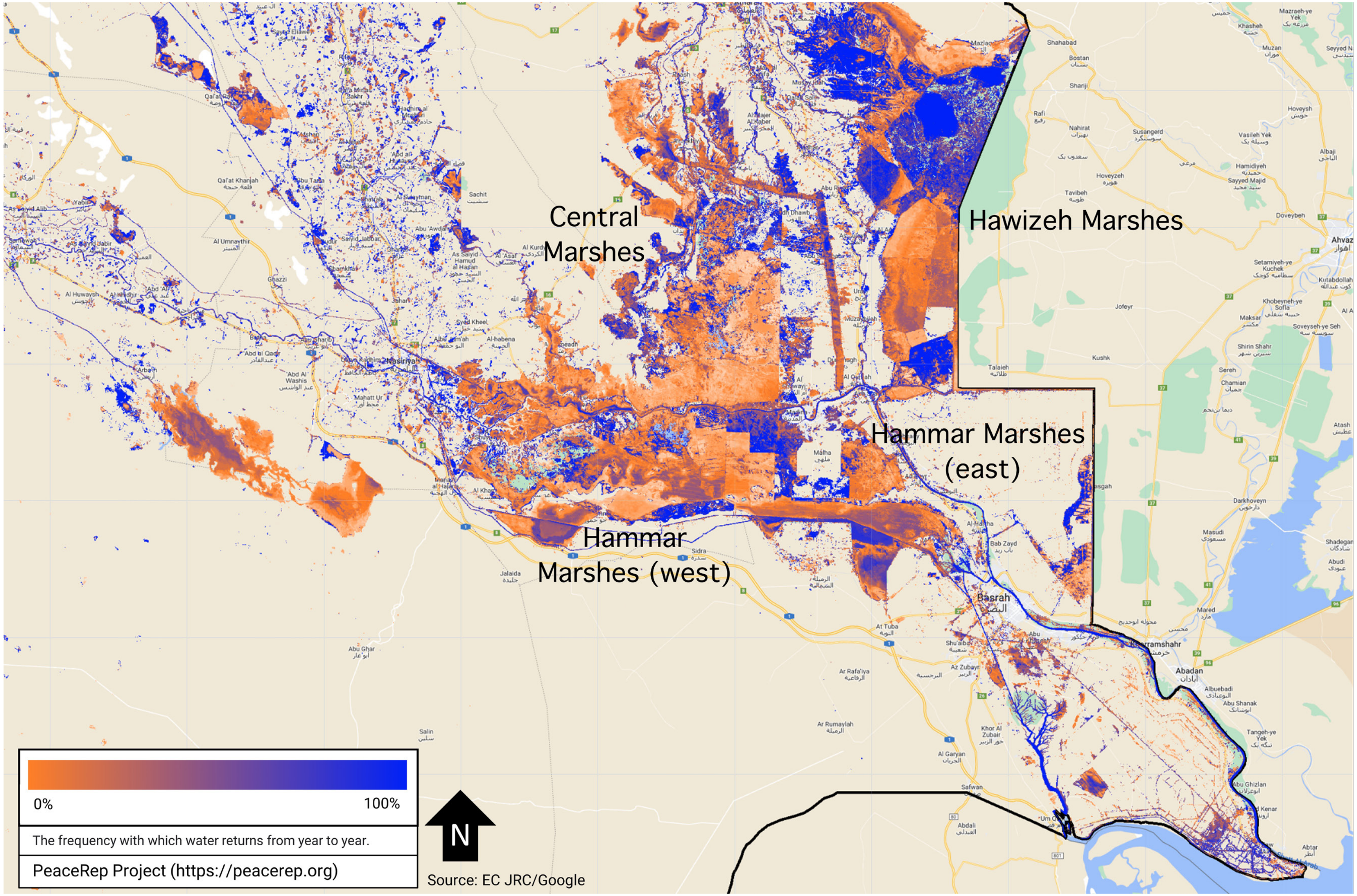
There is an overlap between Map 7, illustrating the water decline between two 15-year epochs, and Map 8 on surface water recurrence, which reveals the high inter-annual variability of surface for the Mesopotamian Marshes between 1984–2015. The majority of water return frequencies are low (below 50%), with some correlation between areas of lowest frequency of surface water return and areas of greatest spatial loss on Map 7. This is most marked for the Hammar Marshes and the Hawizeh Marshes. Map 10, on surface water recurrence across the Hawizeh Marshes, indicates a prevalence of very low return frequencies (compounding the reductions in water occurrence shown in Map 9). This is even more marked on the Iranian side of the border, providing evidence of deliberate, systematic drainage which, in the absence of publicly-available data from the Iranian government, has been attributed to new border security measures (e.g., dykes and other physical barriers) and drainage for oil exploration (Shapland 2023, 14–15).

Aggregate flow data since 2015 also reveal high inter-annual variability of surface water across the marshes. Since World Heritage Convention listing in 2016, the UNESCO-approved management plan for maintenance of the Mesopotamian Marshes has adopted the 5.8 BCM minimum flow requirement from the *Strategy for Water and Land Resources in Iraq* (Ministry of Water Resources 2014, 19). According to recent conservation assessments by UNESCO, only 3.15 BCM reached the marshlands both in 2017 and 2018 – the last years of the protracted drought that started in 2007 (UNESCO 2019). In 2019 there was a substantial inflow of 12.3 BCM as a result of heavy rains and flooding of the Tigris, but in 2020 the inflow dropped to 4.8 BCM. The World Heritage Committee has expressed concern over the threat posed to the outstanding ecological value of the marshes by non-fulfilment of minimum water requirements, which are likely to be exacerbated by ongoing upstream dam development and climate change (UNESCO 2021).

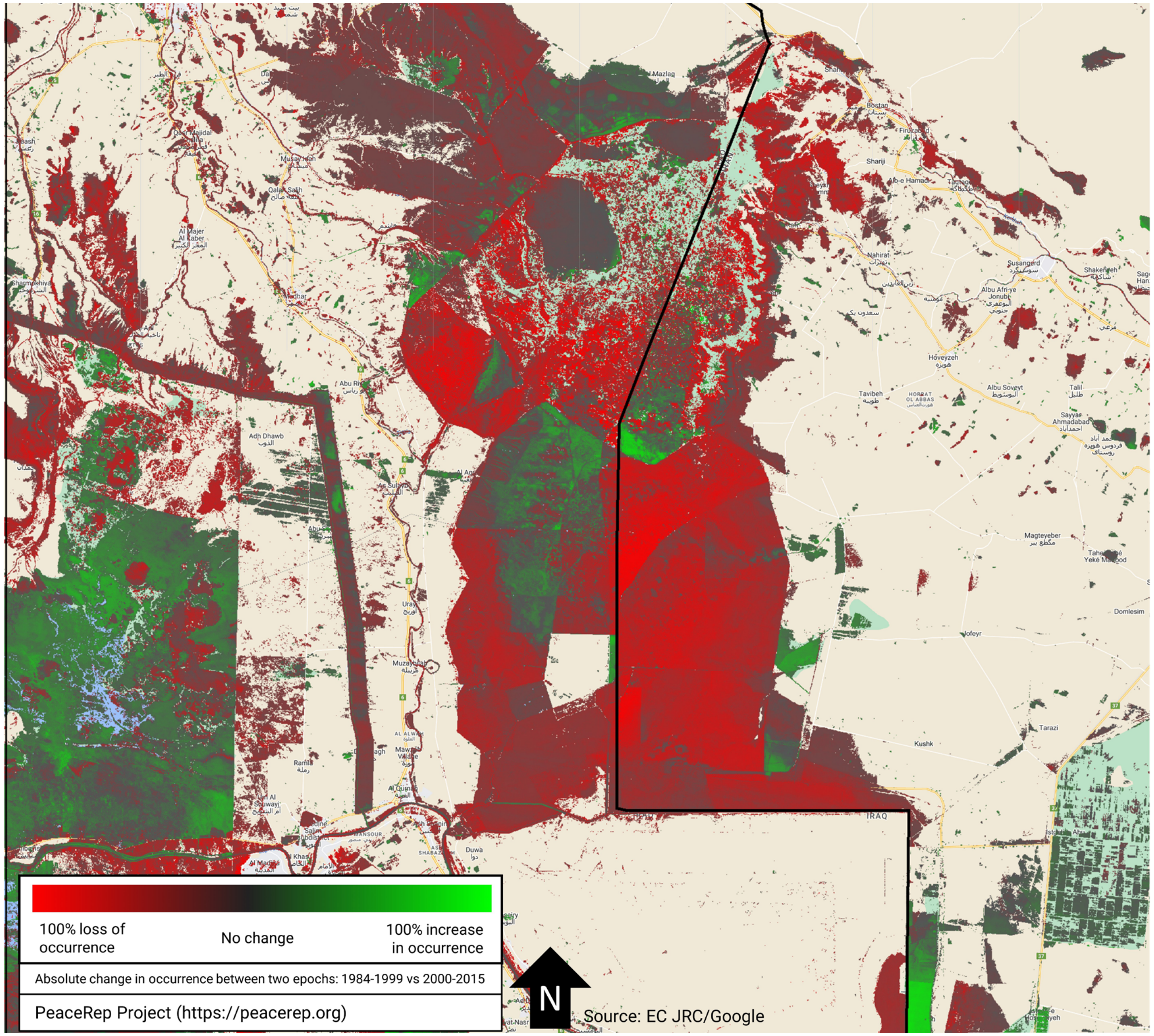
[8] Personal interview on 24/02/2023 on Zoom, 28/02/2023 in Ankara (Turkey), 16/03/2023 in İstanbul (Turkey).



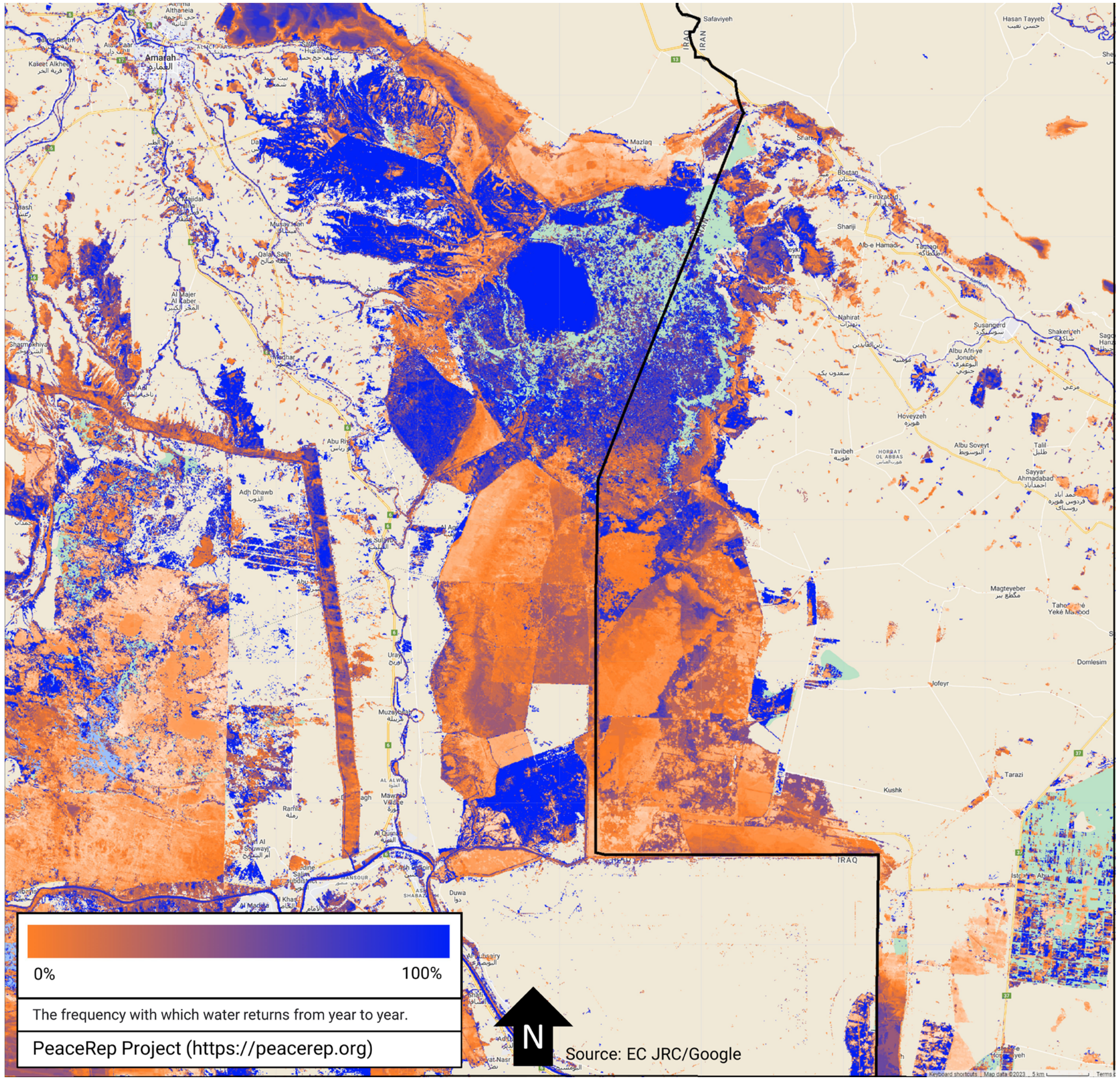
Map 7: Water Occurrence Change Intensity in Mesopotamian Marshes (1984–2015)



Map 8: Water Recurrence in Mesopotamian Marshes (1984–2015)



Map 9: Water Occurrence Change Intensity in the Hawizeh Marshes (1984–2015)



Map 10: Water Recurrence in the Hawizeh Marshes (1984–2015)

Conclusion

In April 2023, at a meeting of the state commission responsible for coordination between governorates in Iraq, Prime Minister Mohammed Shia al-Sudani directed governors not to publicise information about water problems in the country. This followed political pressure on the government to seek international legal redress against Turkey for, it was claimed, not releasing sufficient water upstream from the Tigris and Euphrates (Salih 2023). Negotiations with Turkey had resulted in an agreement (March 21) from President Recep Tayyip Erdoğan to double water releases to Iraq from the Tigris for the period of a month, but complaints continued about severe impacts from water shortages on food security, livelihoods and public health (Mahmoud 2023). Restricting information about water supplies in unlikely to lessen grievances in Iraq: greater *hydro-transparency* is one means by which the government could 'de-securitise' its use of water data.

Regionally, the securitisation of water data is a symptom of what has aptly been labelled the 'imperfect peace' of interactions between riparian states in the Euphrates-Tigris Basin against a background of political instability and conflict (Kibaroğlu and Sayan 2021). There remains no comprehensive basin-wide water treaty. State actors have generated mechanisms for limited cooperation – joint technical committees, bilateral protocols, high-level strategic cooperation councils, and memoranda of understanding – and non-state actors, including epistemic communities and international organisations, have simultaneously established more flexible and less formal mechanisms such as track II initiatives to broaden and deepen the level of cooperation. These institutions have created a legacy of modest cooperation, though not one that has delivered sustainable, equitable and reasonable use in the basin.

Iraq's water vulnerability is not determined by its downstream position, for there are legal and political-economic strategies that can strengthen interests of a co-riparian (Daoudy 2009), e.g., the appointment of envoys on bilateral water relations (Taştekin 2019), the recent accession of Iraq to the 1992 UN Water Convention (UNECE 2023), and persistent mutual interdependencies between Turkey and Iraq in the fields of security, development, energy, trade, and so on.

Overcoming the problem of contradictory, ambiguous and missing data on the surface flows of the Euphrates and the Tigris is a necessary but not sufficient condition for improved transboundary water relations in the basin. In this regard, Global Surface Water data can serve to validate or debunk the claims made by upstream and downstream countries about: how much surface water is present in their territories, changes in surface water occurrence over time, and what the basin-wide impacts are of hydraulic infrastructures of various scales and complexities. Such *hydro-transparency* can create an informational setting conducive to good faith negotiations on scenarios for water- and benefit-sharing (Zawahri 2023, 210–12).

The opposite can happen too: continued secrecy or opacity on shared waters can fuel mistrust and prevent cooperation. Within Iraq, the provision of user-friendly information on surface water changes can guide open and inclusive deliberation on the governance implications for water-sensitive sectors (e.g., agriculture) and regions (e.g., Mesopotamian Marshes).

More advanced analysis of water resources would benefit from the adoption of terrestrial-hydrological modelling (e.g., NASA's Land Information System), combining satellite data with ground-based observations. Such an integration of in-situ water data would also allow a systematic consideration of *water quality* as it relates to surface water. The long-term decline of water quality is of great concern in Iraq.[9] Recent technical advances in remote sensing are significantly improving the capacity to retrieve water quality variables (Yang et al. 2022): this opens up new possibilities for surface water mapping.

[9] Water drawn from the Euphrates is widely considered too saline for drinking before it crosses the Iraqi border, while Tigris water downstream of Baghdad is unacceptable for drinking. On the critical situation in southern Iraq, see Mason (2022).

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Cover Image
Drone photo of the Mesopotamian Marshes, southern Iraq, 29 September 2023.
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