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Research article

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ABSTRACT

Ongoing global change and its direct environmental impacts, in addition to securing economic transition to the post-oil era, could trigger complex socio-economic and political crises in oil-dependent economies of the Persian Gulf Region (PGR). To evaluate the role of climate change and related policies in degrading the environment and its socio-economic impacts in the PGR, we have used a variety of available global datasets and published data. The results show that the countries of the PGR pursue some types of socio-economic reforms to alleviate the impacts of climate change. However, it seems that these attempts are not compatible with the environment's capacity. The main problem stems from the fact that political differences between the PGR nations prevent them from managing the Persian Gulf environment as an integrated natural system and consequently they have to limit their efforts within their borders, regardless of what happens in other parts of the system. The shift to alternative revenue sources by the countries needs socioeconomic preparedness while there are environmental obstacles, political tensions and geopolitical rivalries. Unless there is a cooperative approach to mitigate the effects of climate change, accompanied by a reorientation of PGR economies, the situation is likely to worsen rather than improve. To address the challenges of climate change, integrated regional collaborations are needed. Collective action, such as more investment in regional research and development and education, is required if the PGR is to successfully transition from a commodity-based to a knowledge-based economy.

1. Introduction

A plethora of historical, archaeological and geological evidence evokes synchroneity between major palaeoclimatic changes and socio-economic/political crises in West Asia (Kaniewski et al. 2012, 2018, 2019; Sharifi et al., 2015). The timing of these events cannot be dismissed as simply pure coincidence and, regarding their geographical extent, the factors driving these changes were undoubtedly large scale (Kennett and Kennett 2007; Caspers 1971; Hole 1994; Gurjazkaite et al., 2018). The role of environmental shifts in shaping past societal changes may be explained by the vulnerability of some societies to extreme climatic conditions such as droughts and floods, with consequent impacts on food production (Kaniewski et al., 2015; Weiss 1997).

Climatic variability and its effects on human environments led our ancestors to consider different adaptation strategies, depending on their technical capabilities and the severity of the changes. In some cases, they migrated (Gupta et al., 2006) leading to de-urbanization and a shift from sedentary to nomadic lifestyles (Djamali et al., 2009; Kaniewski et al., 2012; Wright et al., 2003). In other cases, they innovated techniques to survive under new environmental conditions e.g. the invention of hydraulic structures (Madani et al., 2016) and transitioned to new agricultural products/methods (Djamali et al., 2016). Whatever the adaptation approach was, the new socio-economic conditions led to the legislation of new rules and new governing systems (DeMenocal 2001) that in turn created fresh sources of conflict or communication between the societies.

Given West Asia's long and complex environmental and social histories, it is not surprising that current climate change has also been advanced as a potential trigger for socio-economic and political problems (Scheffran and Battaglini 2011; Scheffran et al., 2012; Sowers et al., 2011). Unlike ancient societies, we know that the cause of present climate change is human-induced CO_2 emissions linked to the

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combustion of fossil fuels (Broecker 1975). Although there is a relationship between the amount of CO_2 emissions and economic growth in recent decades (Granados et al., 2012), the medium to long-term future of the world's economy depends on moving away from fossil fuels (Murray and King 2012). Socio-economic impacts of this global decision (e.g. 2015 United Nations Paris agreement on climate change) on oil producers such as Persian Gulf Region (PGR) countries, is a matter of concern. Furthermore, the environmental consequences of fossil-fuel combustion and its impact on climate could limit the scope of economic diversification policies and hamper long-term investment for economic diversification and a smooth transition into the post-oil era. At present, the PGR is faced with a dual dilemma relating to its role as a major supplier of fossil fuels and also its high sensitivity to the environmental impacts of global climate change for which those fuels are responsible (Zenghelis 2006).

As the PGR contributes significantly to current climate change, and also suffers deeply from the consequences, the region constitutes a key case study for understanding the environmental impacts of present global changes (Burt et al., 2013; Lelieveld et al., 2012; Parry et al., 2007). Moreover, international adaptation strategies (Parry et al., 2007) could directly and/or indirectly affect socio-economic, political and geopolitical conditions in the region (Goldthau 2017).

In this study, we focus on climatically-induced environmental changes as a threat to the economic prosperity and socio-economic development of PGR countries. Moreover, we examine the socio-economic capacity of the Persian Gulf (PG) countries to deal with the consequences of global climate changes. Finally, we probe to what extent national climate-oriented policies and adaptation plans could act as catalysts to conflicts in the PGR. In our study, we did not include ideological, international intervention or military factors.

2. Environmental framework

The PGR comprises eight countries that rim the PG: Bahrain, Iran, Iraq, the Kingdom of Saudi Arabia (KSA), Kuwait, Qatar and the United Arab Emirates (UAE) (Figure 1). The catchment basin of the PG extends from the low latitudes of 14° in Yemen to the higher latitude of 39° in Turkey and also includes Syria and Jordan (Figure 1).

2.1. Climate of the region

The PGR lies in a subtropical, hyper-arid zone that is generally characterized by high temperatures and low precipitation. The climate of the region is mainly governed by the Mediterranean systems although the eastern parts are influenced by the Indian Ocean Monsoon (Figure 1) (Walters Sr and Sjoberg 1988).

The average annual temperature and rainfall in the PGR varies significantly and is largely dependent on geography and orography. The average annual rainfall on the southern coasts and over the Gulf is less than 100 mm while the northern watershed areas (Iran and Iraq) receive, on average, 355 mm of precipitation annually (World-Bank 2019), largely due to the orography and higher latitudinal positions (Table 1).

Air temperature in lowland areas of the PGR can exceed 50 °C during summer (June to August), where the average monthly temperature in summer is $>$ 32 °C. In the highlands of the watershed area in Iran and Iraq, the average monthly temperature in winter and summer is usually $<$4 °C and $>$28 °C, respectively (World Bank, 2019). The low-lying areas of the PGR experience mild temperatures during winters and the most precipitation is received from November to March in the whole area.

Different seasonal winds blow over the PGR. The Shamal wind (Arabic word for north) is the most prolonged and intensive one to blow near the surface and transports around 90 million tons of dust per year into the Gulf region, mainly from the deserts of the Arabian Peninsula, Iraq and Syria (Giannakopoulou and Toumi 2012; Jish Prakash et al., 2015). The wind occurs in the region during winter and summer. The activity in summer reaches its maximum in June and July (Prospero et al., 2002) while in winter it is more active in November and March (Thoppil and Hogan 2010).

2.2. Marine environment

The PG is a semi-enclosed epicontinental water body that is located at the northwestern corner of the Indian Ocean. The basin is connected to the Gulf of Oman and the Arabian Sea via the Strait of Hormuz (Figure 1).

The average depth of the basin is around 35 m; the bathymetry increases eastward with a depth of $>$110 m at the Strait of Hormuz (Reynolds 1993). The bathymetry of the basin is complex. More than 60 islands exist in the PG. Their origin is mostly related to regional geological structures. Moreover, salt domes, the accumulation of sediments in shallow waters, and coral reefs construct other island types (Ross et al., 1986). The existence of these islands, along with the complicated bottom topography of the PG, limits maritime routes to just a few narrow waterways, closer to the Iranian coast.

The PG is a meso-tidal water body with maximum tidal range of more than 3.5 m in the northwest flank of the Gulf (Najafi and Noye 1997). The circulation of the water body is poorly understood but it is generally counterclockwise (Kämpf and Sadrinasab 2006) (Figure 1). The water residence time in the Gulf is around 2–5 years (Reynolds 1993).

Sea surface temperatures can exceed 35 °C in summer (Figure 2), while in winter they can fall to $<$10 °C (Vaughan et al., 2019). Water loss through evaporation (high temperatures and strong winds) exceeds the net freshwater input and increases the salinity of the water body to more than 39 grL^{-1} in most parts of the Gulf (Kämpf and Sadrinasab 2006) and even up to 70 to 80 grL^{-1} on the southern coast of the Gulf namely in coastal waters of Bahrain (Sheppard et al., 2010). The warm and more saline water of the PG exits through the Strait of Hormuz (Reynolds 1993) (Figure 1), where the outflowing plume of the warm and saline water extends into the Arabian Sea for a distance of around 1,700 km (Uchupi et al., 2002).

The main source of freshwater in the PG is Shatt-Al-Arab that is located at the northwest flank of the Gulf (Figure 1). The river system is formed by the confluence of the Euphrates and Tigris rivers in Iraq. Karun River from Iran joins the Shatt-al-Arab (SA) before discharging into the Gulf. The catchment basin of SA extends to higher latitudes in the highlands of Turkey, Iraq and Iran (Figure 1). The SA is the only navigable river in the PGR and the last 90 km of the river constitutes the border between Iran and Iraq. The SA river is vital for the economy of Iraq as it provides international access to open seas as well as the required water for irrigation and industry. There are no perennial rivers on the southern and eastern flanks of the PG.

Due to the orography and hydrogeological conditions of the region, numerous submarine springs exist in the PG. The water moves hundreds of kilometers from the Zagros Mountains and seeps into offshore areas in the northern part of the Gulf (Zektser et al., 2006). Springs on the southern coastal zone of the Gulf are mainly fed by Arabian Peninsula aquifers (Frenken 2009). However, very few scientific studies have been conducted on the magnitude and effects of groundwater flow on the Gulf environment (Farzin et al., 2017).

The biodiversity of the PG is limited by its harsh environmental conditions (Sheppard et al., 2010). Coral reefs and coral patches in hard-grounds, seagrass meadows and algal beds (Figure 3) are the most extensive high-diversity marine ecosystems in the Gulf (Sheppard et al., 2010). More than 600 fish species exist in the PG, whose spatial distribution is highly variable and depends on local marine conditions. The total area of mangrove forests in the PGR is estimated to be $275km^2$, and these are mostly situated in Iran, KSA and the UAE (FAO 2007). Coastal ecosystems, especially those in intertidal and subtidal zones, contain significantly higher biological diversity than terrestrial areas and their productivity is much higher than offshore ecosystems (Burt 2014). Economically, coastal ecosystems are the second most valuable resource in the PG, after oil (Burt 2014).

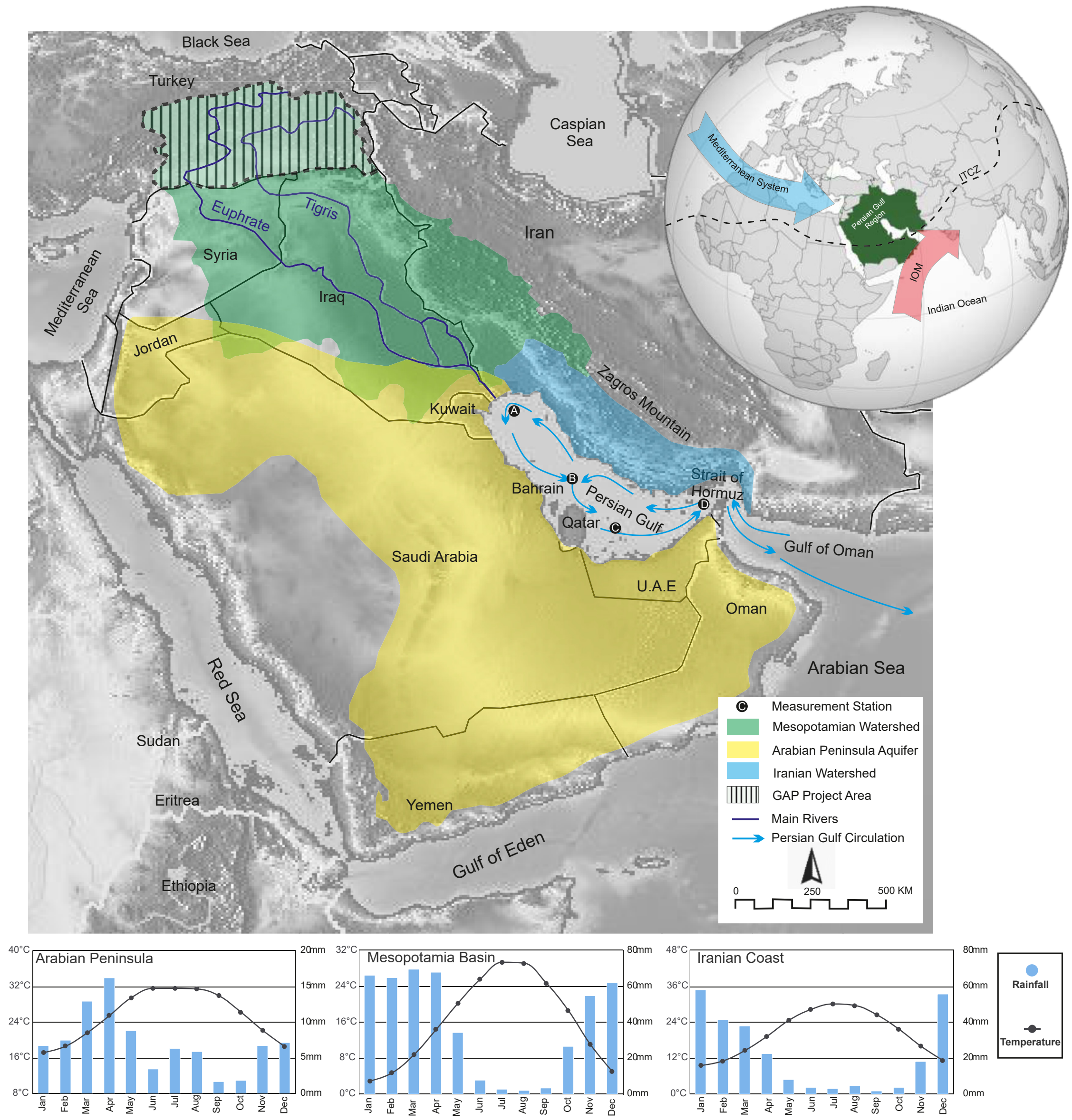

Figure 1. The Persian Gulf Region, its orography, international boundaries and the main trans-boundary water sources for the Gulf (adapted from Frenken, 2009). The position of the Persian Gulf Region and the main climate systems influencing the region are shown in an inset in the upright corner of the figure in which the position of the Intertropical Convergence Zone (ITCZ) for June is presented by a dashed line. Water circulation of the Persian Gulf (arrows) is adapted from Reynolds (1993). Average monthly precipitation and temperatures of the different watershed areas of the Persian Gulf since 1901 (World-Bank, 2019) are shown for each watershed area below the map (solid line represents temperature and the bars represent average rainfall per month). Four stations for measuring salinity and sea-level in the Persian Gulf are marked by black circles and labeled by A, B, C and D.

2.3. Hydrology

The PG catchment can be divided into three main sub-basins: (i) the SA basin (Tigris-Euphrates/Mesopotamian basin) in the northwest; (ii) the Iranian watershed in the north; and (iii) the Arabian Peninsula basin to the south (Figure 1). Following, the SA and Arabian Peninsula basins are discussed as trans-boundary basins.

Table 1. Mean annual temperature and precipitation and average high and low temperatures by country in the Persian Gulf Region.

Country	Mean Annual Temp. (°C)	Mean Annual Prec. (mm)	Average High Temp. (°C)	Average Low Temp. (°C)
Bahrain	27.04	73.61	29.4	23
Iraq	21.54	193.53	29	15.8
Iran	16.92	223.05	22.6	10.2
Qatar	27.09	65.15	31.5	22
KSA	24.70	74.03	30.4	18.6
Kuwait	25.17	114.30	32	19
UAE	26.82	64.84	32.8	21.2

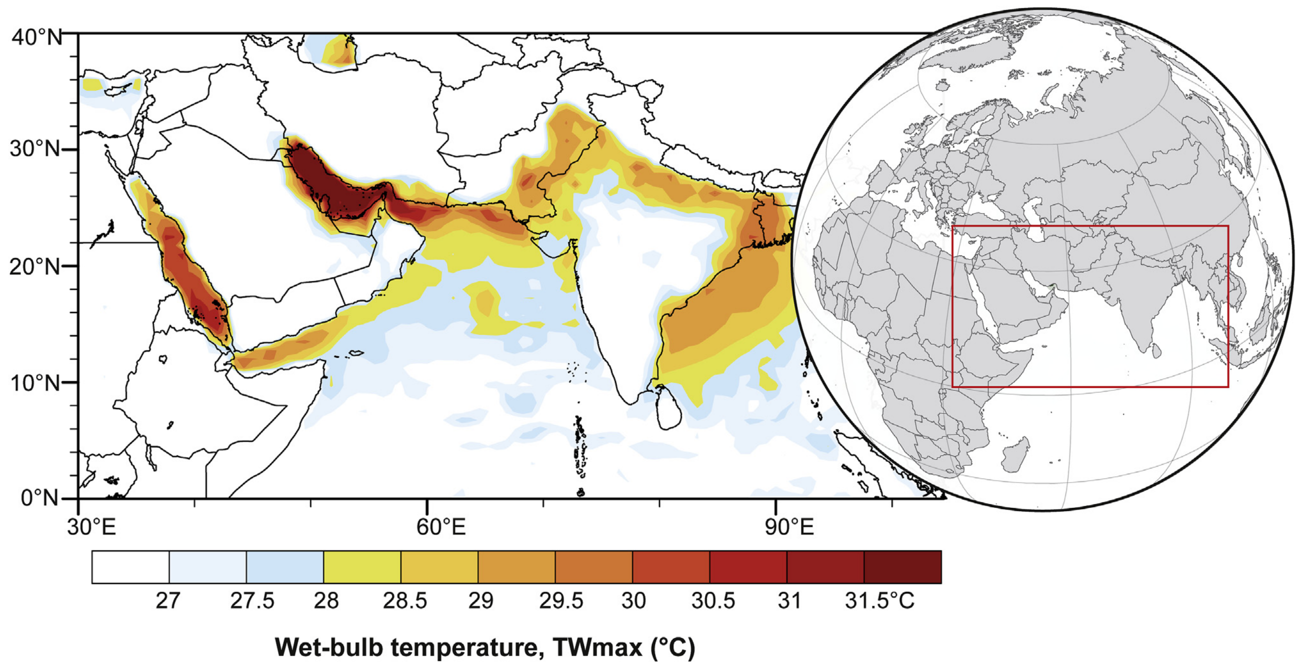

Figure 2. Spatial distribution of highest daily maximum wet-bulb temperature, TWmax (°C), in the modern record (1979–2015). Adapted from Im et al. (2017).

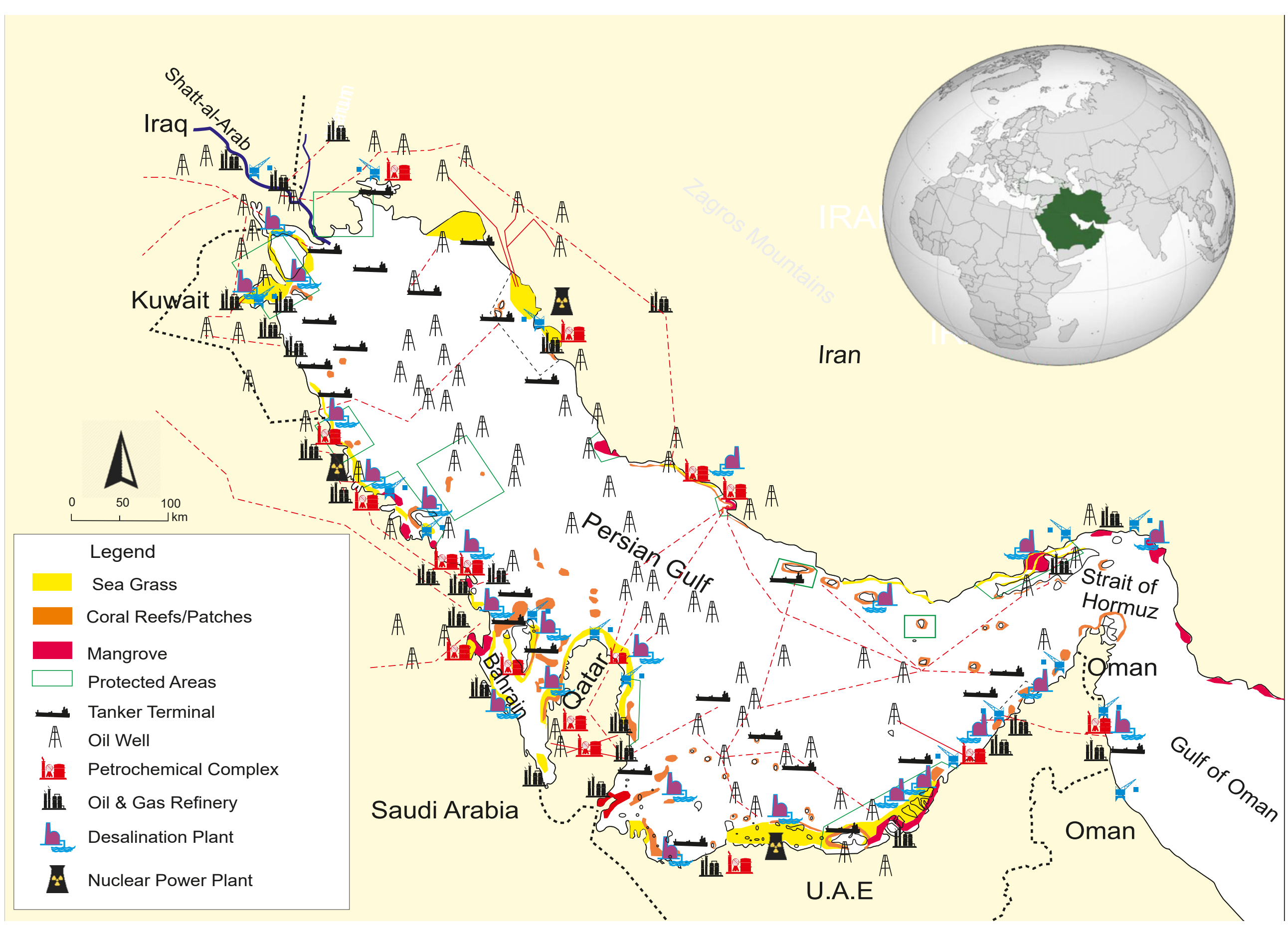

Figure 3. Major environmentally sensitive areas of the Persian Gulf (Sheppard et al., 2010), main oil and gas infrastructures (International Energy Agency, https://www.iea.org), major ports (Ardemagni 2018), desalination plants (Dawoud 2012) and nuclear energy facilities (World Nuclear Association 2019).

2.3.1. *Shatt-al-Arab basin*

The SA basin lies in Iraq, Turkey, Iran, Syria, KSA and Jordan. Almost all of the water is provided by highlands in Turkey, Iraq and Iran. Although around half of the basin is in Iraq, and almost completely covers the country, around 60 % of Tigris water and almost all Euphrates' water are furnished by tributaries located in other upstream countries (Issa et al., 2014) (Figure 1). Since a large share of the water is supplied by snowfall on highlands, especially in Turkey, the rivers' flow regime shows pronounced peaks related to snow melt (Beaumont 1998). The two rivers join in Iraq and continue their course as the SA for ~200 km before finally discharging into the PG. The estuary of the SA is tide dominated. Therefore, the salinity of the river mouth fluctuates between 0.7 psu to 40 psu (Abdullah et al., 2016).

2.3.2. *Arabian Peninsula sub-basin*

The southern catchment basin of the PG is characterized by limited renewable groundwater resources and the absence of any perennial rivers and/or lakes. Apart from localized aquifer systems reliant on drainage systems, the majority of renewable groundwater exists in permeable rock formations that are fed by sparse precipitation over the catchment basin (Frenken 2009).

3. Socioeconomic conditions

At present, more than 180 million people live in the PGR countries; more than 26 million of this population live in the coastal zone. Islam is the official religion in all countries of the PGR and is widely practiced by its citizens.

The PGR countries are well known for their role as the world's biggest energy providers and possess 40 % of the world's oil and 44 % of gas reserves. As a result, the oil and gas industries are currently the main economic drivers of PGR countries (El-Katiri and Fattouh 2017).

In addition to the oil and gas industries, the PGR has been a major trade route since at least the third millennium BC (Wilson 2012). Around 60% of the world's crude oil shipping occurs along PG maritime routes and the region is responsible for around 5.2 % of the world's container trade (World Bank 2019).

More than 98 % of the region's energy demands are met by oil and gas, with the remainder coming from renewable hydraulic energy provided by Iraq and Iran (World Bank 2019).

With the exception of Iran and Iraq, the region's other countries mainly rely on groundwater resources (Frenken 2009). In addition to more exploitation of ordinary sources of fresh water, the PGR relies heavily on desalination plants (Figure 3). Of the 15,900 operational desalination plants in the world, half of them are in the region (Frenken 2009).

4. Material and methods

We have used multidisciplinary data from different global, regional and national sources. Most of the socio-economic data were extracted from development data at the World Bank datacenter (https://databank.worldbank.org/home.aspx). Climate data were obtained from Global Historical Climatology Network–monthly (GHCNm) (https://www.ncdc.noaa.gov/ghcn-monthly) for 357 weather stations in the study area, in addition to other sources of climatological data e.g. Climate Change Knowledge Portal (CCKL) (https://climateknowledgeportal.worldbank.org/region/middle-east/climate-data-historical). Community Climate System Model 4 (CCSM4) was used to model the climatological data to provide an insight into precipitation and temperature trends.

The optimum interpolation sea surface temperature (OISST) values for the years between 1981 and 2019 were downloaded from the NOAA website (http://www.esrl.noaa.gov/psd/data/gridded/data.noaa.oisst.v2.html). The weekly SST datasets were prepared at $1^\circ \times 1^\circ$ spatial resolution in netCDF format and were adjusted for biases based on the methods described by Reynolds (1988) and Reynolds and Marsico (1993). The analyses of these data were combined with *in situ* data and NOAA-AVHRR SST (Reynolds et al., 2002). Maximum summertime temperature values were extracted from the long-term monthly mean SST dataset (between 1971 and 2000), available for each $1^\circ \times 1^\circ$ cell. The Degree Heating Weeks (DHW) values were determined from the SST data (Goreau and Hayes 1994; Gleeson and Strong 1995).

Four locations were considered in this study to monitor sea-level changes and sea surface salinity (SSS) change in different parts of the PG (Figure 1). Daily sea-level anomalies were downloaded for 1993 to mid-2019 from the Copernicus satellite altimetry data service (https://resources.marine.copernicus.eu/). This product is processed by the sea-level thematic assembly center multi-mission altimeter data processing system. The system processes the data from all altimeter missions: Jason-3, Sentinel-3A, HY-2A, Saral/AltiKa, Cryosat-2, Jason-2, Jason-1, T/P, ENVISAT, GFO and ERS1/2 (Copernicus 2020).

SSS data were downloaded from the above mentioned database (https://resources.marine.copernicus.eu/). SSS data is a part of the global SSS/SSD L4 reprocessed dataset that interpolated optimally from *in situ* observations.

Data on the environmental and socio-economic changes, especially data on hydrology and economy, were extracted from 35 published

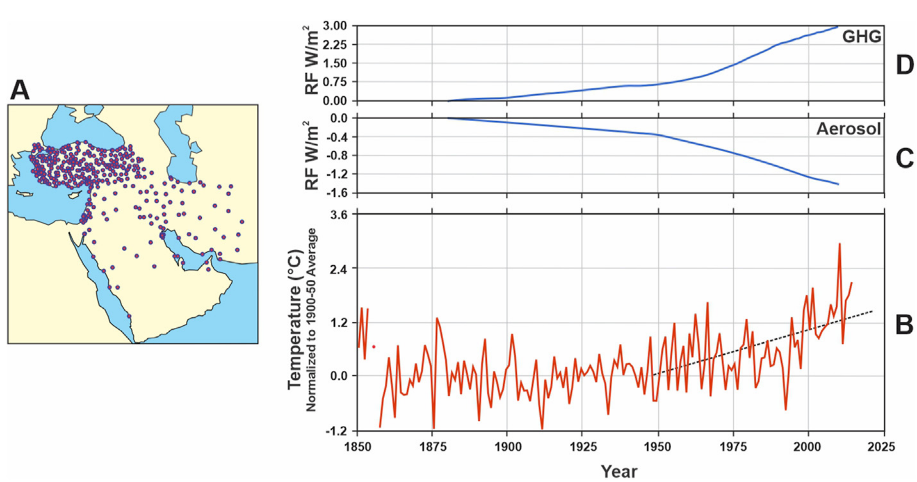

Figure 4. Environmental change across West Asia including the PGR since 1850. A) Location of 357 meteorological stations; B) temperature variation since 1850 normalized to the 1900–1950 average; C) radiative forcing (RF) in W/m^2 from aerosol scattering; D) Radiative forcing in W/m^2 from well-mixed greenhouse gases (GHG).

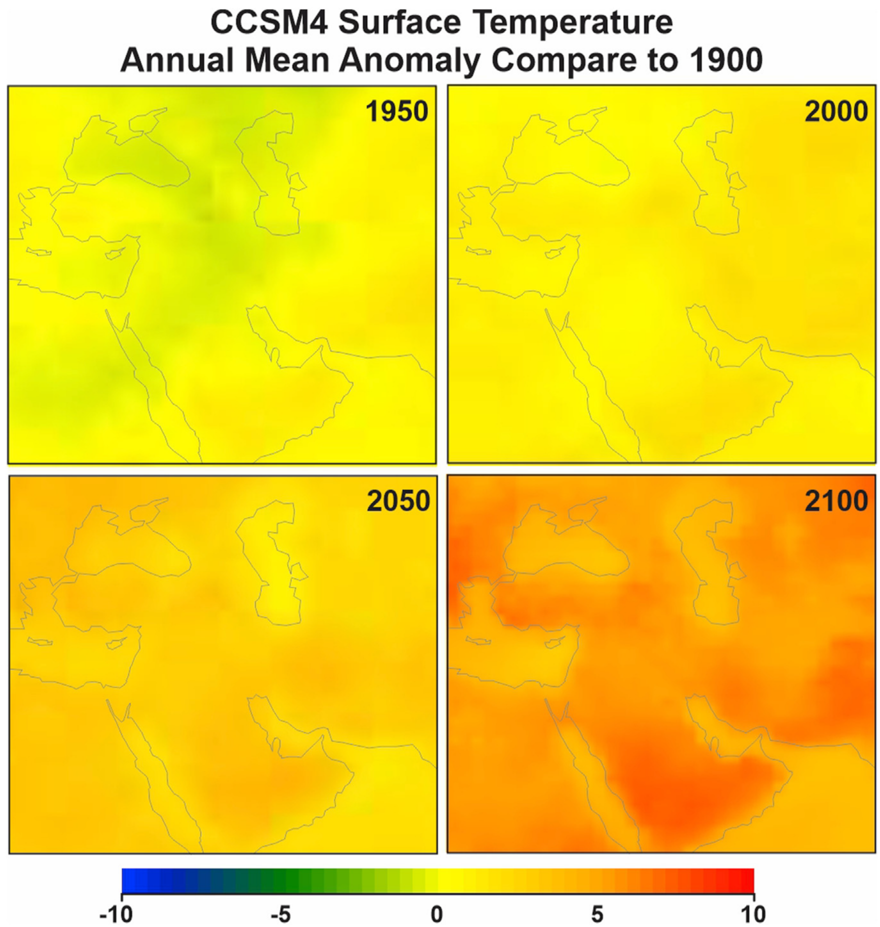

Figure 5. CCSM4 output for surface temperature anomalies in Southwest Asia for 1950, 2000, 2050 and 2100, compared to 1900.

papers and reports and were combined and summarized in tables and graphs.

5. Results and interpretation

5.1. Climate of the region

Temperature data from the Global Historical Climatology Network–monthly (GHCNm), for 357 weather stations across the region (Figure 4A), normalized to the 1900–1950 average, suggest the temperature over the region has increased by at least 2 °C since 1950 (Figure 4B). The observed increase in temperature follows the radiative forcing imposed by the emission of well-mixed greenhouse gases to the atmosphere of the region (Figure 4C).

The outputs of the Community Climate System Model 4 (CCSM4) for land surface temperature anomalies compared to 1900 over West Asia suggest that some regions will experience more than 5 °C temperature increase by 2100 (Figure 5).

Projected change in monthly precipitation of the Middle East for 2020–2099 (compared to 1986–2005) (Figure 6) shows that, under a high-emission scenario, the catchment basin of the SA will experience much drier conditions in the future (World Bank 2019).

5.2. Marine environment

The variations of SST values (Figure 7A) show that the Gulf's SST has increased by around 1 °C since 1981. Moreover, the determined DHW values for the same period (Figure 7b) show that the frequency and intensity of long-lasting hot periods have increased since 1981. Coral bleaching events are well correlated with DHW peaks (Figure 7b). For the 38 years of SST observations, the highest weekly value of ~35 °C was recorded for the week ending August 6, 2017, when the DHW value was >13 and constituted the highest positive thermal value for the year 2017. A similar study along the southern coast of the Gulf shows a higher weekly value of 37.7 °C for the same time period (Burt et al., 2019).

The results of sea-level monitoring show that the fitted trend from early 1993 to mid-2019 is positive for the selected stations (Figure 8). Moreover, the data suggest that the magnitude of sea-level is greater at stations to the east. On average, PG sea level has increased at a rate of 2.85 mm per year since 1993 that matches with the results of Prandi et al. (2021).

The results of SSS for the four aforementioned stations reveal no remarkable changes in the SSS time series (order of $\pm 10^{-5}$) (Figure 9).

5.3. Water

Data from NASA GRACE (Gravity Recovery and Climate Experiment) (Rodell et al., 2018) shows that the PGR is getting drier and constitutes a hotspot of water insecurity in the world (Figure 10).

The capacity of renewable groundwater resources in the Arabian Peninsula basin is less than 200 Billion Cubic Meter (BCM) (Table 2) (Odhiambo 2017). According to the World Bank (2019), the total exploitation of renewable water in the catchment basin in 2000 was around 22.6 BCM, which is about four times greater than the rate of groundwater recharge (See Table 3). To compensate for the scarcity of water, the Arabian Peninsula countries rely on desalination plants and fossil-water reserves, the latter having an estimated capacity of 2175 BCM (Odhiambo, 2017). Around 90 % of the reserve is located in the KSA

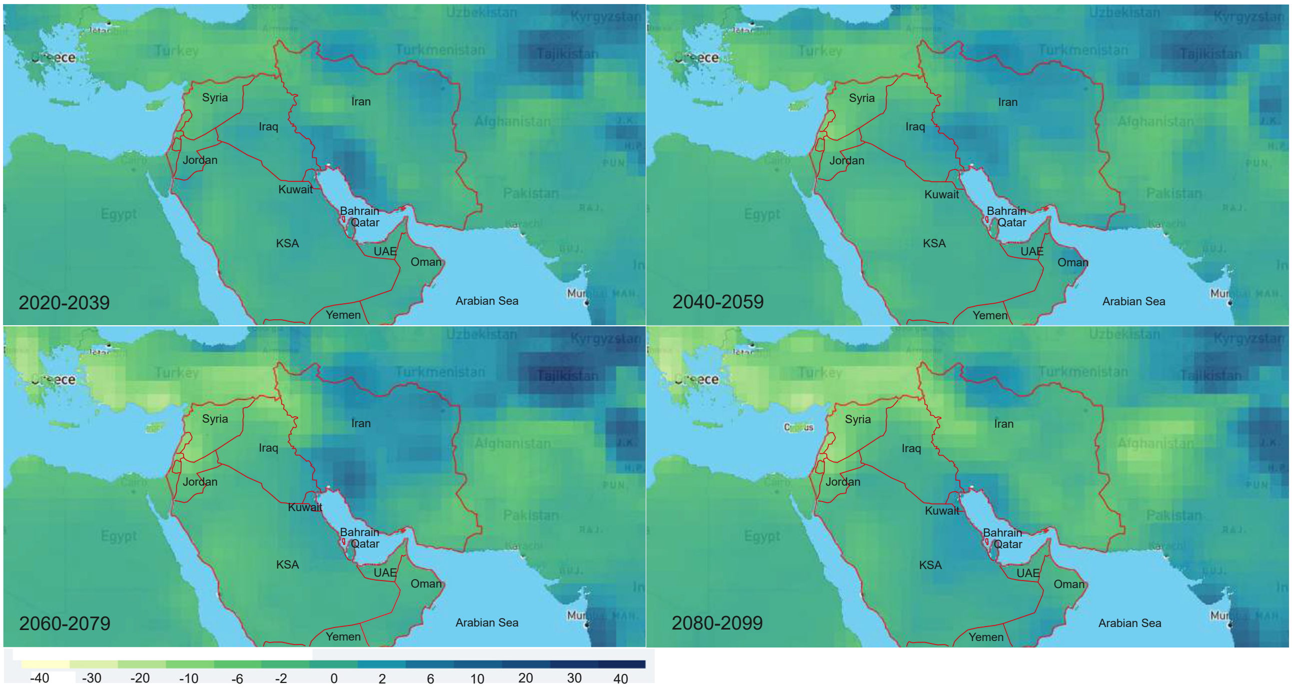

Figure 6. Projected change in monthly precipitation of the Middle East region for 2020–2039, 2040–2059, 2060–2079 and 2080–2099 (https://climateknowledgeportal.worldbank.org/).

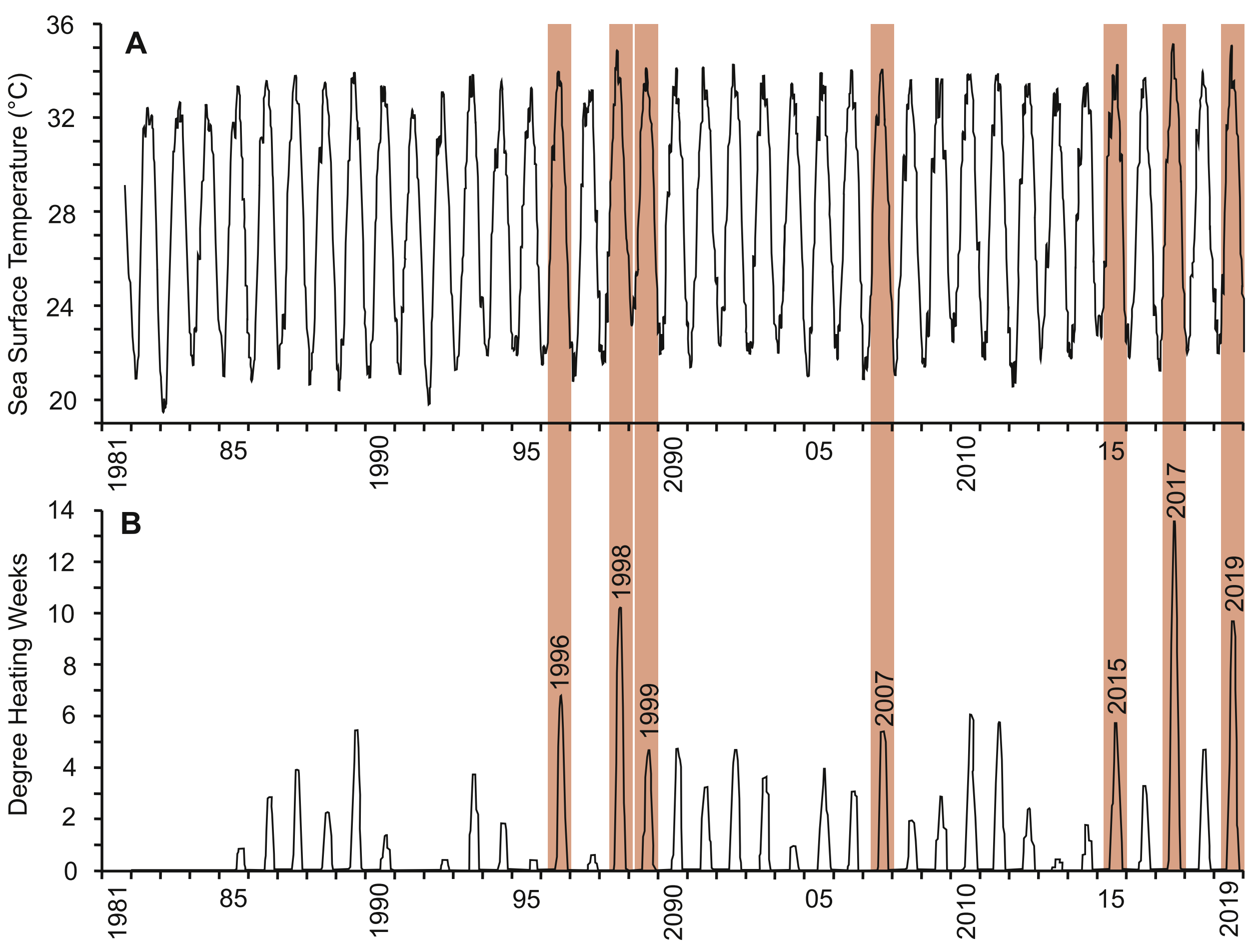

Figure 7. Weekly mean SST changes of the Persian Gulf since mid-1981 (a). The average is denoted by a red line. The Degree Heating Weeks (DHW) in Iranian waters of the Persian Gulf for the same period; (B) major coral bleaching incidents are marked by red circles.

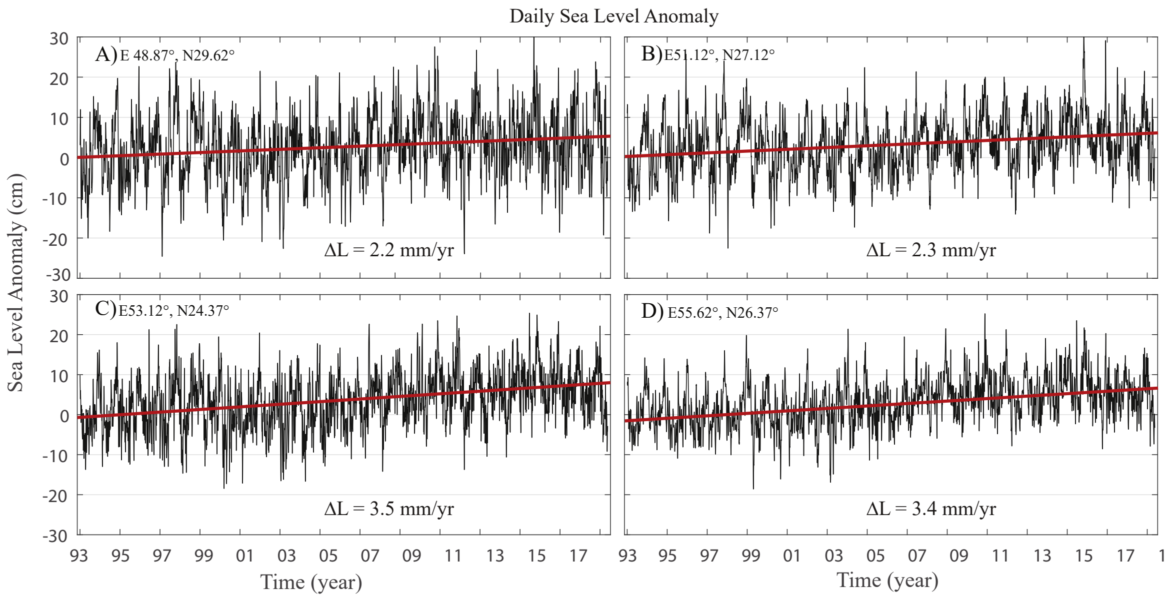

Figure 8. Time series of daily sea-level changes at four different measurement stations A, B, C and D in the Persian Gulf. The position of the stations is denoted in Figure 1 and the coordinates of each station are presented in decimal degrees in the insets. The horizontal axis shows time from 1993 to 2019 and the vertical axis shows sea-level changes in centimeters. Δ L represents average mean annual sea-level rise in millimeters for each station. The westernmost measurement station (A) has the lowest rate of sea-level rise with a Δ L = 2.2 mmy^{-1} and station C, in southern coastal waters of the Gulf, has experienced the highest rate with Δ L = 3.5 mmy^{-1} during the measurement period. Generally, the stations of C and D, in the eastern part of the Gulf, show a higher rate of sea-level rise than the stations A and B in western part of the Gulf.

and the country sources a third of its water from fossil-water reserves (World Bank 2019).

In the northern part of the PG, where SA and its tributaries flow into the Gulf, the average annual discharge is extremely variable and ranged from <30 to >84 BCM during the 1960s and 1970s (Frenken 2009). The long-term mean annual discharge at its mouth is estimated to be > 73 BCM (Abd-El-Mooty et al., 2016). Until 2008, 56 large dams had been constructed by Iran, Iraq, Syria and Turkey on the tributaries of the basin that traps more than 244 BCM of water (Table 3). While average annual demand for water in Iraq has grown 1.42 % since 1930, water availability and inflow has diminished by 1.25 % per year during the same period

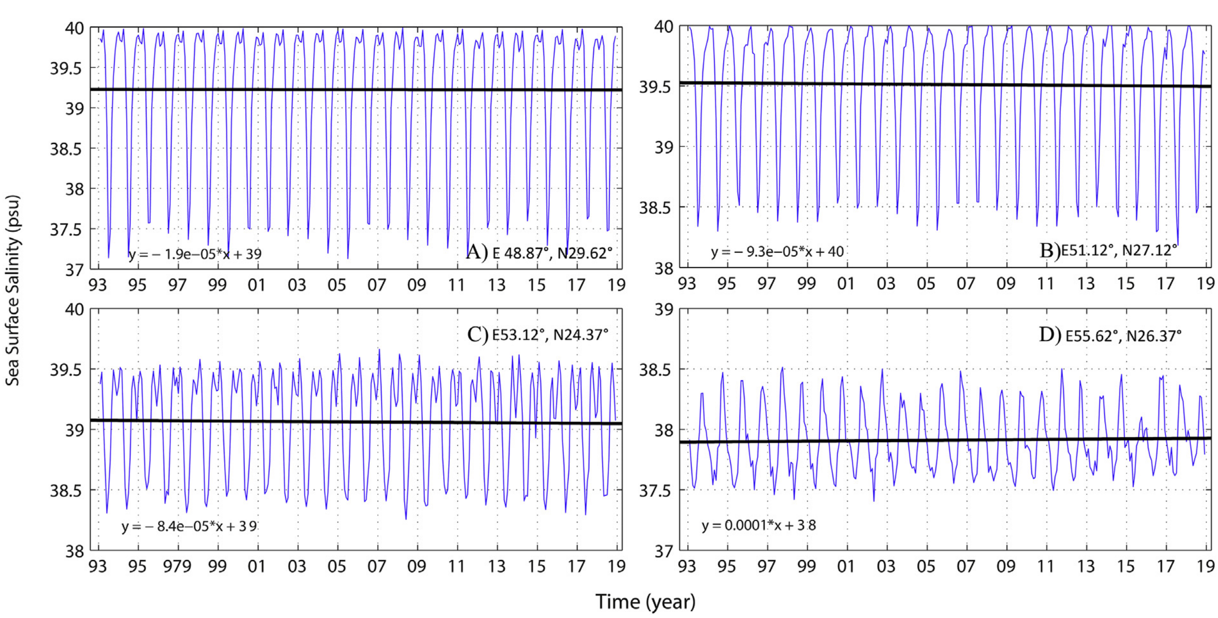

Figure 9. Time series of daily changes in sea surface salinity in four different measurement stations of A, B, C and D in the Persian Gulf. The position of the stations is denoted in Figure 1 and the coordinates of each station are presented in decimal degrees in the insets. The horizontal axis shows time from 1993 to 2019 and the vertical axis is the sea surface salinity in Practical Salinity Unit (PSU). The overall changes of sea surface salinity from 1993 to 2019 are presented by "y" for each station. Generally, the salinity change in the Persian Gulf is negligible for the given period. However, the value of "y" for stations A, B and C is negative and shows very slight decline in sea surface salinity while the value of "y" for the easternmost station (station D at the Strait of Hormuz) is positive and shows negligible increase in sea surface salinity.

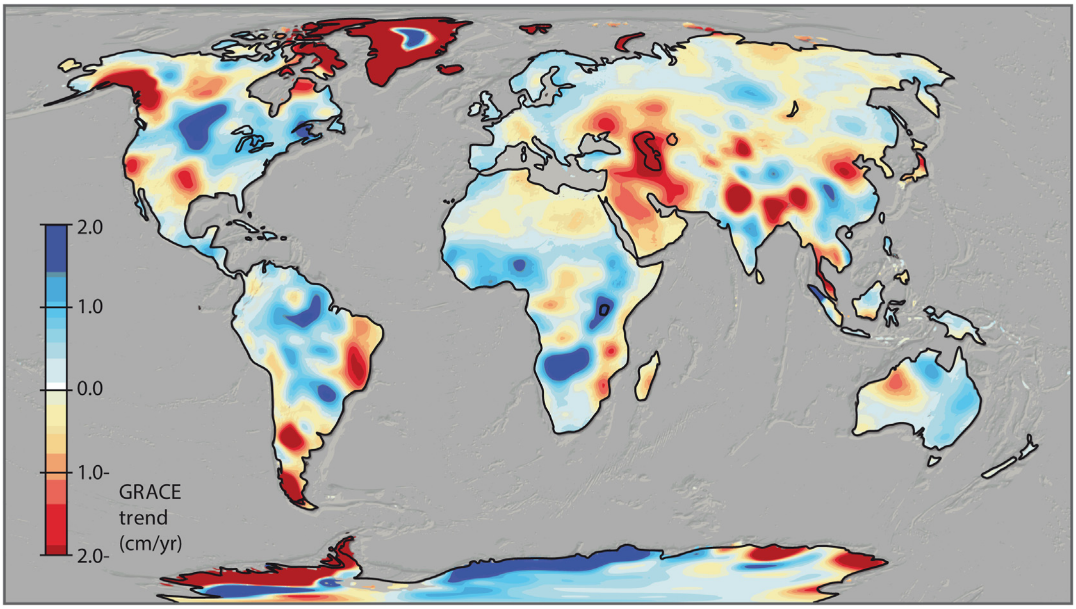

Figure 10. NASA GRACE (Gravity Recovery and Climate Experiment) data quantifying the rates of Total Water Storage at the global scale, from April 2002 to March 2016. The map shows which regions on Earth are gaining or losing fresh water. The results clearly demonstrate that the PGR is getting drier and constitutes a hotspot of water insecurity. The decline is the result of prolonged regional drought and a consequent increase in demand for non-renewable groundwater. Map adapted from Rodell et al. (2018).

Table 2. Groundwater recharge, non-renewable water availability and water demand (Billion Cubic Meters) in the Arabian Peninsula for 2000 and forecasts for 2025 (Odhiambo 2017).

Country*	Groundwater Recharge	Non-renewable Reserve	Water Demand in 2000	Water Demand in 2025
Bahrain	0.11	~0	0.32	0.57
Kuwait	0.16	No data	0.59	0.97
Oman	0.9	102	1.53	2.4
Qatar	0.5	~0	0.29	0.5
KSA	3.85	428.4	17.8	24.2
UAE	0.19	No data	2.2	3.2

(Issa et al., 2014) (Table 2). Moreover, it is estimated that underground reserves in Iraq have dropped by 27 % since 2007 (Jongerden 2010).

5.4. Socio-economic results

5.4.1. Population

The population of PGR has grown annually at a rate of 4.64% since the 1950s (Figure 11) which is more than double the global average (Van Lavieren et al., 2011). Within the PGR countries, the UAE (8%) and Iran (2.3%) have the highest and the lowest average annual growth rates over the period 1955–2015, respectively (World-Bank 2019).

Immigration has played an important role in population size in the Gulf countries (Roudi-Fahimi and Kent 2007). On average, more than 50 % of the population in the southern countries of the PG (Bahrain, Qatar, KSA and UAE) are immigrants (Kapiszewski 2004; Baldwin-Edwards 2005), mostly coming from south, east and west Asia (Kapiszewski 2004).

More than 87 % of the people in PG countries have basic literacy and around 12 % of them have higher educations (Table 4). According to the World Bank (2019), the share of the population with Masters and Doctorate degrees in most PGR countries is around 2 % (Table 4). Compared to some developed countries, e.g. Sweden (12%) and Norway (11%), these numbers are low for the PGR countries (World Bank 2019).

Unemployment rates are highly disparate in the region. Iran and Iraq have the highest unemployment rates and Qatar has the lowest rate amongst the eight countries (Figure 12). Around 20 % of the labor force

Table 3. The share of West Asian countries by total area and water supply of the Tigris & Euphrates rivers and their share of water exploitation by dams until 2008 (Frenken 2009; Issa et al., 2014).

countries	As % of total area of the basin	As % of total of water supply	No. of large dams	Capacity (BCM)
Iraq	46.4	20	7	110.3
Turkey	21.8	70	34	99.6
Iran	18.9	6	14	23.7
Syria	11	4	1	11.2
KSA	1.9	0	0	0
Jordan	0.03	0	0	0
Total	**100**	**100**	**56**	**244.8**

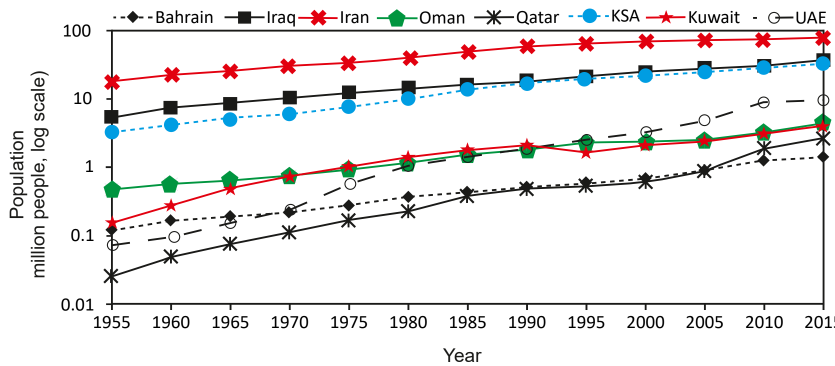

Figure 11. Population size and growth (logarithmic scale) of countries rimming the Persian Gulf since 1955 (World Bank 2019).

Table 4. Education in Persian Gulf countries (World Bank 2019).

	Literacy rate (%)	BSc	MSc and Higher	Gov. expenditure on education (% of GDP)	Labor force with basic education
Bahrain	94.6	9.5	1.2	2.3	ND
Iran	87.2	6.1*	3.5*	4	25.9*
Iraq	74.1	ND	ND	ND	ND
Kuwait	94.5	9.6	0.8	6	ND
Oman	86.9	12.5	2.3	6.7	ND
Qatar	ND	15.8	ND	4	ND
KSA	79.4	ND	ND	7.5	ND
UAE	ND	ND	2.5	ND	80.6

* Data from www.amar.ir.

in Iran and Iraq works in the agricultural sector, this number is <5 % in other neighboring countries (World Bank 2019). The industry and services sectors play major roles in the economy of the PG countries and most of the labor force is employed in these sectors (Figure 12).

According to Le Mouël and Schmitt (2018), the region is notably dependent on agricultural imports and the dependency for the entire region is >50%, which has grown in recent decades. This figure is much higher for the countries of the Arabian Peninsula.

5.4.2. Economy

Thanks to oil and gas reservoirs, the region has experienced rapid economic growth that is manifested in the states' intensive coastal urbanization and development of offshore oil and gas extraction (Burt,

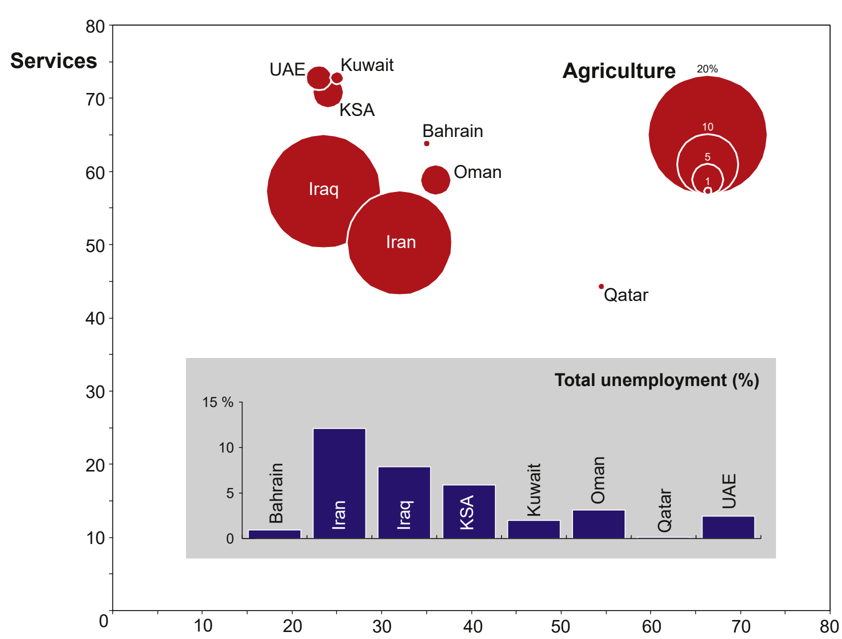

Figure 12. Employment in different economic sectors for PGR countries in 2017 (World Bank 2019).

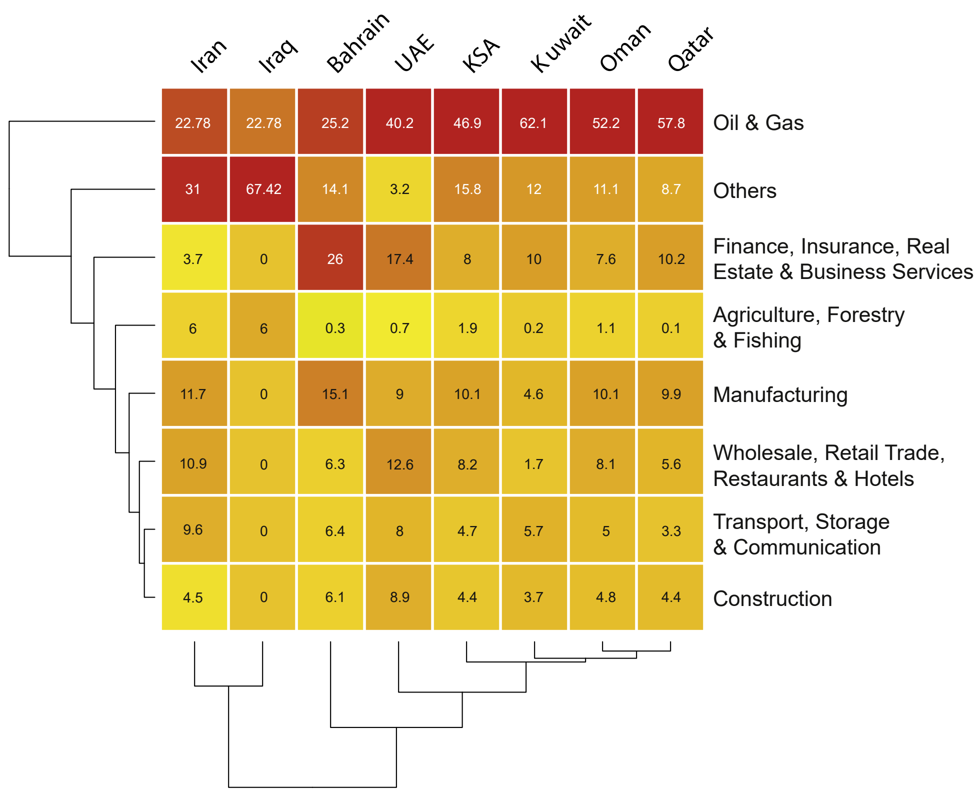

Figure 13. Share of GDP by sector for Persian Gulf countries (World Bank 2019).

2014; Sheppard et al., 2010; Vaughan et al., 2019) (Figure 3). The other major economic sectors of the Gulf countries are also largely dependent on oil and gas incomes e.g. petrochemical industries in addition to transport, storage and communications (Figure 13).

5.4.3. CO_2 emissions

The PG countries emit ~5.5 % of global CO_2, a figure that has doubled since the 1980s (Figure 14). Amongst them, Iran and the KSA are the major gas-emitting countries of the region, producing 650 and 600 billion tons of CO_2 emissions per annum, respectively (World-Bank 2019). KSA is the world's sixth largest consumer of oil and gas and Iran imports natural gas despite hosting the world's largest natural gas reserve (El-Katiri 2014).

5.4.4. Energy

The energy consumption of the PGR has grown considerably since the mid-20th century and regional energy demand will continue to grow at high rates (World Bank 2019). The share of hydroelectric sources for Iran and Iraq has declined dramatically since 1970 (Figure 15) and the share of fossil fuels has increased in recent decades (World-Bank 2019). While the PGR has increasingly relied on fossil fuels as its energy source, global reliance on fossil fuels has gradually been declining since the 1960s (Figure 16).

With the exception of Iran, which produces around one percent of its required energy from nuclear power, this energy type has yet to be harnessed by other countries of the Gulf region. However, countries such as the UAE and KSA have invested heavily in nuclear energy (Figure 3). The UAE has built commercial nuclear power reactors on the PG coast with an aim to provide 20 % of its energy requirements by the end of 2020. Iran plans to develop more commercial nuclear power plants with an aim to triple the share of nuclear energy by 2028 (World Nuclear Association 2019). KSA also plans to source more than 20 % of its energy demand from nuclear energy by 2040 (Ahmad and Ramana 2014). Other sources of renewable energy such as wind, tide and solar energy are also available in the region. The KSA plans to provide 50% of its required energy by 2040 and the UAE plans to obtain 75% of its electricity from solar energy by 2050 (Almasoud and Gandayh 2015; Nematollahi et al., 2016).

6. Discussion

6.1. The changing environment

The temperature data demonstrate that figures have gradually climbed in the region (Figure 4), concurrent with the rapid economic development of the region since the 1950s. Many studies have confirmed that the region has experienced a warming trend in recent decades, as the frequency of warm days has significantly increased whereas the frequency of cold days has notably declined (Zhang et al., 2005). Alternative extreme temperature records and heat waves have been observed in the region (Nasrallah et al., 2004) and have led some researchers to postulate that heat waves in the PGR will exceed the critical threshold for human adaptability in coming decades (Pal and Eltahir 2016). This is a threat for the economic development of the region and will certainly have severe economic consequences. For instance, some reports show that the number of fire incidents at oil and gas plants have increased during heat waves since 2005 (Nojoumi et al., 2015).

The results of the model, used in this study, shows that in the near future the region will experience a slight increase in precipitation due to the Northward movement of the ITCZ (Evans 2009) but, at longer timescales, dry conditions will be dominant (Figure 6). This projection is corroborated by other researchers e.g. Chao et al. (2018) and Voss et al. (2013). Evans (2009) predicted that, by the 2050s, Syria and Turkey will experience a >25 % decrease in precipitation. Construction of numerous dams by countries (in particular Turkey) on the main water sources of the Mesopotamian basin (Al-Ansari 2013) will exacerbate the impacts of the climatic changes. Turkey has constructed 22 dams on the upstream portions of the Tigris and Euphrates Rivers, which have significantly

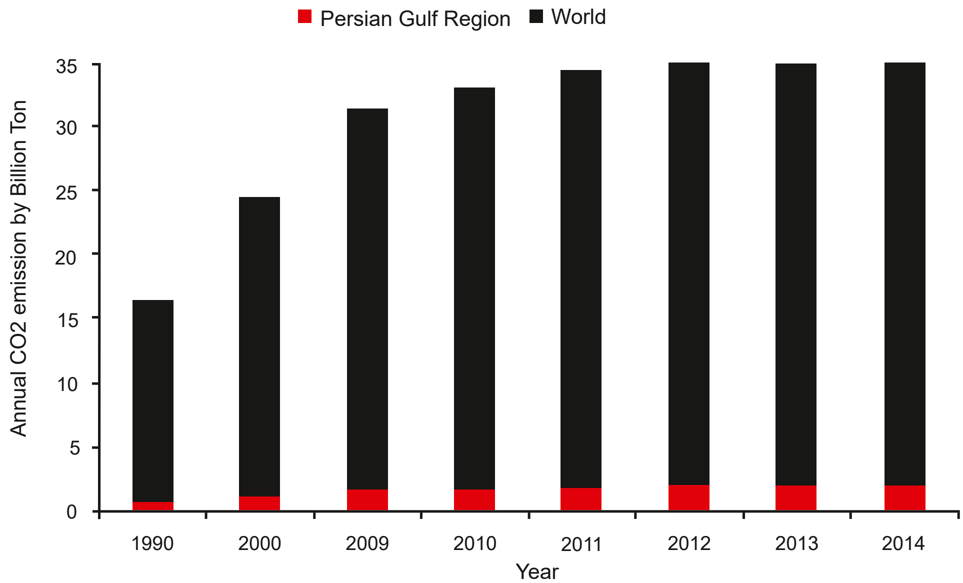

Figure 14. Total annual CO_2 emissions (Gt) for the Persian Gulf Region and the world (World-Bank, 2019).

diminished water flow into Iraq and Syria. Growing water shortages due to climate change, in addition to water overexploitation, has led to the loss of 30 % of SA's capacity since 1980 (Beaumont 1998). It is forecasted that the river system will be completely dry by 2040 (Al-Ansari 2013; Beaumont 1998; Issa et al., 2014). Because the SA is the main source of freshwater for the PG, dramatic changes in the river's discharge have serious implications for the PG's environment and could, for instance, increase the salinity of the water in the river's estuary by at least 40 grL^{-1} in the northwestern part of the PG.

Drought in West Asia since 1971 (Gleick 2014), in addition to the construction of dams to combat water scarcity (Berkun 2010), has led to desertification and a sharp rise in dust sources in the Mesopotamian Basin (Zoljoodi et al., 2013). Furthermore, the region has experienced an increase in the frequency of dust storms. The sediment sink for the dust storms has expanded from the Mesopotamian Basin in the west to central parts of Iran and even to the northern coasts of Iran along the Caspian Sea (Hamidi et al., 2013). Since 1950, radiative forcing reduction by aerosol scattering over the region (Figure 4D) indicates the increases in dust emission from existing dust pools as well as from newly introduced sources such as dried-up wetlands and abandoned farmlands (Zoljoodi et al., 2013). The immediate economic impact of the dust storms on Iranian and Iraqi infrastructure is huge e.g. the temporary closure of power plants, repeated closure of public sectors in affected areas and aviation problems. Furthermore, frequent dust storms cause health problems (Schweitzer et al., 2018; Goudarzi et al., 2017; Thalib and Al-Taiar 2012), crop damage and inefficiency in solar devices (Furman 2003). Dust storms are detrimental to coral communities due to increasing water turbidity (Riegl 2003).

The increasing temperature along with dust storms threatens snow reserves of the SA catchment basin and could change the hydrological regime of the river. In tandem with the long-term regional drought, this has engendered over-reliance on groundwater for industrial, agricultural and domestic needs (Voss et al., 2013). The depletion of the surface and groundwater resources will probably continue in the future, particularly during drought years (Chao et al., 2018).

In the PG, the global change is reflected mainly in increasing SSTs (Figure 7) and sea-level rise (Figure 8). The mean sea surface temperature of the PG has warmed by about 1 °C since the 1980s that is much higher than the estimations of Shirvani et al. (2015) who demonstrated 0.57 °C since 1950. Our finding is supported by the work of Lachkar et al. (2020) who demonstrated that the fast rise in SST is responsible for deoxygenation in the Arabian Sea. The rate of PG sea-level rise has been increasing by 2.85 mm/y since 1993 that is supported by the work of Hassanzadeh et al. (2007). Global average sea-level is rising at an average rate of 3.36

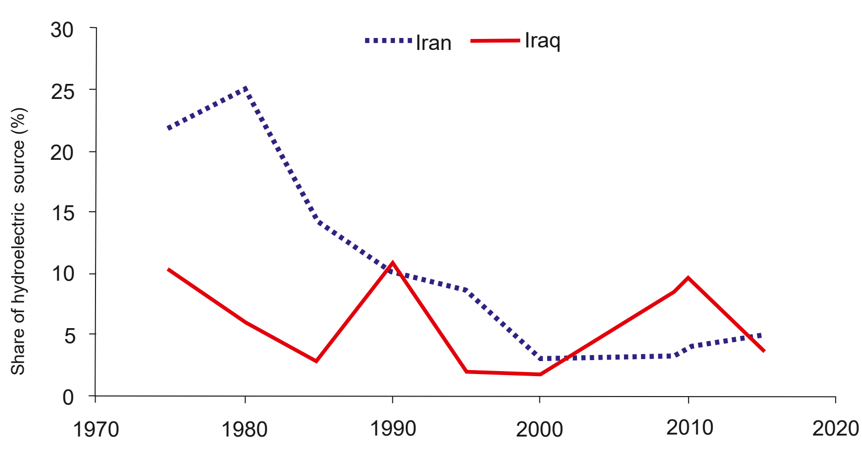

Figure 15. Evolution of electricity production from hydroelectric sources (% of total) in Iraq and Iran since 1970 (World Bank 2019).

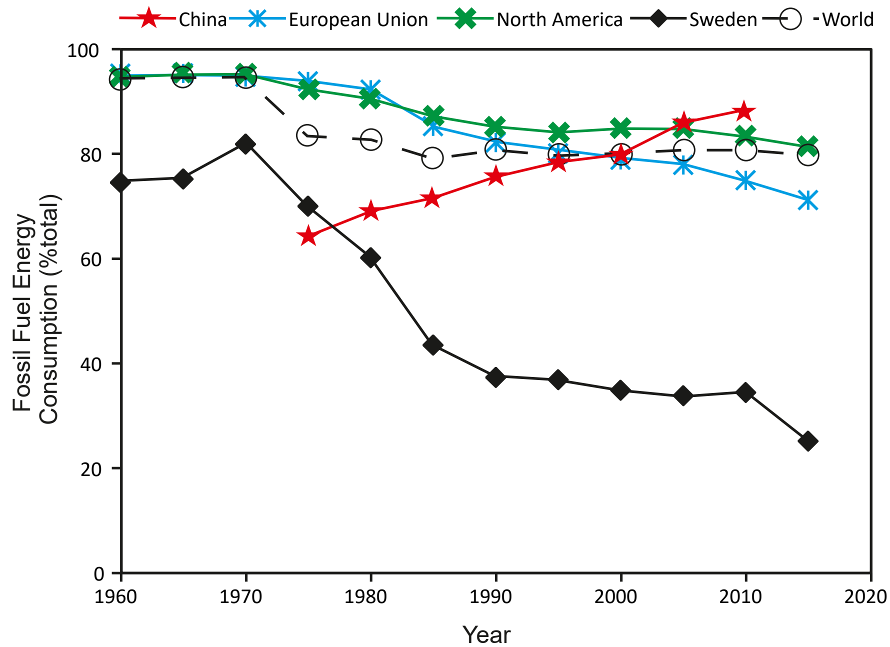

Figure 16. Fossil fuel consumption (% total) since 1960 for chief energy consumers, the world and representative countries China and Sweden (World Bank 2019).

$\pm$ 0.4 mm yr^{-1} and PG sea-level rise more or less is the same (Church and White 2006; Hereher 2020). The combined impact of sea-level rise and increasing temperatures has negatively impacted the sensitive ecosystems of the Gulf i.e. the coral reefs, with coral bleaching and death being reported (Kabiri et al., 2012; Hereher 2020; Riegl 2003). Long lasting high SST in the PG is the cause of coral bleaching incidents in 1996, 1998, 2002, 2007, 2015, 2017, and 2019 (Figure 7b). Paparella et al. (2019) have shown that the hot years are always associated with low Shamal wind conditions during the summer. According to Riegl (2003), Shamal winds will be weaken in the coming decades, under ongoing climate change. As a result, it is suggested that the coral reefs of the PG will vanish by the end of the current century (Riegl 2003). The loss of habitats has significant impacts on fisheries and economic activities (Wabnitz et al., 2018).

In spite of the increasing temperature and water over-exploitation of the PG catchment basin, the results show that the salinity of the PG has not changed since 1993 (Figure 9), an observation supported by Mogaddam et al. (2020). The apparently steady evolution of salinity could be related to the compensation of the PG water through the Strait of Hormuz by less saline water from the global ocean (Campos et al., 2020). Although it needs detailed studies, the compensation of the PG salinity could accelerate the water circulation and decrease the residence time that alternatively affects the sedimentation regime of the Gulf (Campos et al., 2020). In addition to global change, the desalination

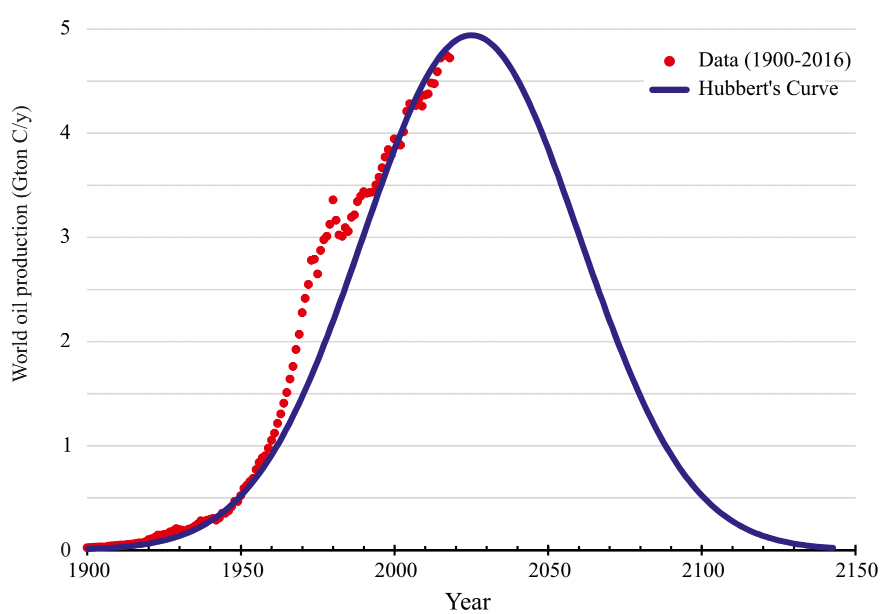

Figure 17. Annual world oil production since 1900 fitted to Hubbert's curve. The data of global oil production were extracted from the data bank of the International Energy Agency (https://www.iea.org/data-and-statistics). Hubbert's curve shows that the peak for global oil production will happen around 2027.

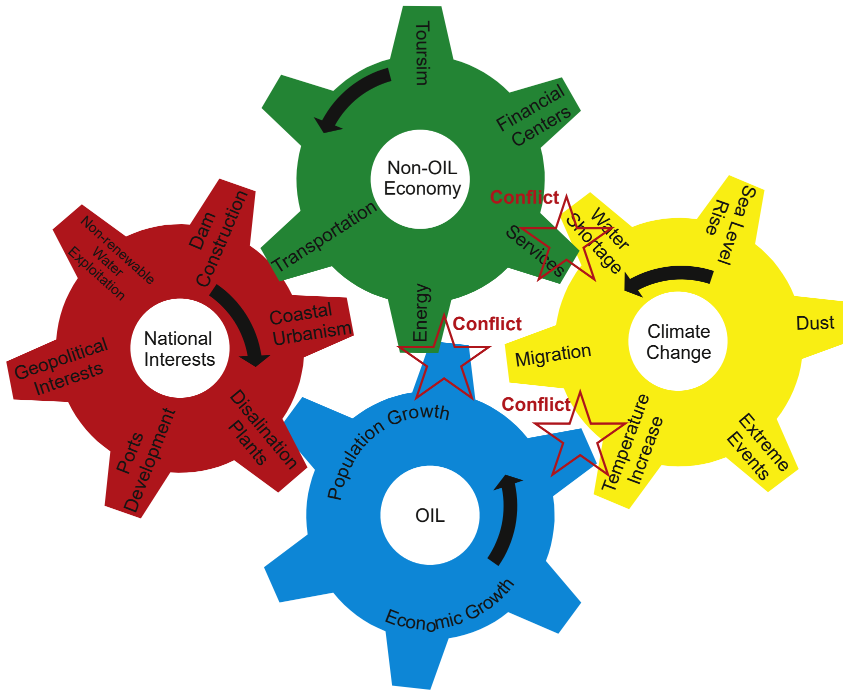

Figure 18. Conceptual model of potential areas of conflicts in the transition to a non-oil economy in Persian Gulf countries.

plants annually discharge 3 BCM of brine production into the Gulf (Jones et al., 2019; Lee and Kaihatu 2018) and could impact environmentally sensitive areas e.g. estuaries, mangrove forests and coral reefs at a local scale (Figure 3).

6.2. Socio-economic changes

The coastal area of the Gulf, especially the southern coast, was sparsely populated for hundreds of years before the mid-20th century. The discovery of oil, along with improvements in human survival (Roudi-Fahimi and Kent 2007), has sparked rapid population growth in this region since the mid-20th century (Figure 4). The high rate of population growth, urbanization and industrial development in the PG countries, especially the countries belonging to the Arabian Peninsula, is not compatible with the available water resources (Frenken 2009). Water insecurity is one of the main environmental obstacles for future economic development and could be a major source of conflict in the PGR (Alterman and Dziuban 2010).

In line with declining precipitation (Figure 6), agricultural productivity is expected to drop by around 30–60 % due to increasing water scarcity and higher temperatures (World Bank 2019). A corollary is that food security will be seriously compromised in coming decades. Alterman and Dziuban (2010) believe that long-lasting scarcity of water could trigger political turmoil and social unrest in the region. For instance, some studies have argued that the Syrian civil war is rooted in climate change and water problems (Abel et al., 2019) that were compounded by dam constructions in Turkey and socio-economic tensions in Syria (Gleick 2014). Another example of water related conflict is Iraq. Iraq, with its 58 km coastline on the PG, has the least marine territories in the region and is heavily dependent on SA for its maritime trade. Iranian control over Shatt al-Arab (Entessar 1984) and Kuwaiti control over the islands at its river mouth (Horner 1992) were the main geopolitical underpinnings for armed conflicts in 1981 and 1990, between Iraq-Iran and Iraq-Kuwait, respectively (Nonneman 2004). The projected situation of SA is worse than previously thought, and it is seen as a potential source of future conflict (Beaumont 1998). The construction of large dams in upstream areas, along with agricultural activities and municipality uses of water, have significantly changed the water quality and hydrology of the river since the mid-20th century. The quantity of water trapped in dams in Turkey and Iran is several times greater than the annual discharge of SA River and overexploitation of water in the river's catchment basin, coupled with declining precipitation, threatens Iraq's agricultural sector (World-Bank 2019). Moreover, losing the capacity of SA for navigation (Al-Ansari 2013) has the potential to undermine Iraq's seafaring trade. Despite several bilateral and multilateral water-management agreements between Iraq and its neighbors (Frenken 2009), there is no comprehensive water resources agreement between the countries aimed at sustaining the environment. Furthermore, increasing dust sources in Iraq and southwest Iran, due mainly to water management problems, are compounded by consequent environmental degradation that in turn have engendered depopulation of southwest Iran at a rate of 1.2 % per year since 2011 (Amar 2019). Numerous political negotiations have been conducted between Iran and Iraq but without tangible results (Madani 2014).

In addition to the fluvial systems, trans-boundary underground water is of great concern (Alterman and Dziuban 2010). The “green revolution” of the Middle East was mainly based on the exploitation of renewable and non-renewable underground water resources that led to a degradation of both the quantity and quality of the reservoirs (Frenken 2009). The alternative desalinization of seawater is not a sustainable solution. The KSA and the UAE alone spend $6 billion per year on water desalination and more than 60 % of domestic oil use in the KSA is consumed by desalinization and power plants (Alterman and Dziuban 2010). The cumulative effects of global warming on sea water temperature and salinity, brine discharge from desalination plants, decreasing freshwater input from the SA and overexploitation of groundwater (Frenken 2009) hamper freshwater supply to the Gulf and compromise the marine environment as a reliable water resource for desalinization.

Sea-level rise is hazardous for low-lying areas of the PG and threatens significant parts of the Gulf, with important implications for its smallest countries in particular. According to IPCC scenarios, Irani et al. (2017) suggested that sea-level in the PG could rise by up to 186 cm in worst-case scenarios and would rise by at least 84 cm by 2100. Sea-level rise, in addition to modifications in precipitation regimes and sediment supply, will lead to changes in the nature of disputed borders in north-western parts of the Gulf where Iran, Iraq and Kuwait are located

(Schofield 2018). In addition to the impacts on sedimentary islands of the Gulf, changes in sea-level, along with changes in sedimentation regime due to general circulation changes, have the potential to affect heavy investments in coastal urbanization and industrialization (Donchyts et al., 2016).

6.3. Adaptation plans

Due to the strategic position of West Asia, including the PGR, in global trading routes, PG countries have invested heavily in maritime infrastructure and ports with an eye to economic diversification for the post-oil era and as a reliable path for economic development (Ardemagni 2018). For instance, the PGR has a central role in the Chinese "One Belt One Road" project in international trade and economy (Lin 2011). The rapid development of ports along the PG coast shows that PG countries have invested heavily in this economic sector. The rivalry to control the region's main ports and trading routes has acted as a source of conflict between the northern and southern countries of the PG (Ardemagni 2018). The economic shifts forecasted under climate change could intensify competition. At present, rivalry is compounded by geopolitical instability in Bab-el-Mandeb Strait and the Strait of Hormuz (Ardemagni 2018) (Figure 1).

The tourism industry, which is also an alternative source of revenue to oil, faces significant cultural barriers in the PGR. The contribution of travel and tourism to the economy of PG countries averages <5 % of their GDP (Henderson 2006). In fact, the region constitutes one of the least developed tourism regions in the world (Sharpley 2002). In spite of this, revenues from travel and tourism have increased dramatically from around 2 billion dollars in 1995 to around 59 billion dollars in 2017 and these are predicted to swell to >190 billion dollars by 2026 (World Bank 2019). Despite disparities between Islamic traditions and tourism, some of the countries in the region are changing their regulations so as to be compatible with international tourism, in addition to developing tourist infrastructure (Henderson 2006). However, climate change (e.g. extreme temperatures and dust storms), along with environmental degradation, especially in attractive areas (e.g. coral reefs), could seriously affect the future of tourism in the region.

More investment in hydropower energy by Iran and Iraq is risky, based on future climate scenarios (Jamali et al., 2013), although they are concerned about the impacts of eventual flash floods e.g. the March 2019 flood that affected two thirds of Iran. However, the PGR has considerable potential for other types of renewable energies (Nematollahi et al., 2016). For example, wind energy could be harnessed in countries such as Iran and Oman (Nematollahi et al., 2016). Exploitation of tidal energy is possible for countries in the northwest and southeast of the Gulf. Solar energy could be exploited throughout the region (Almasoud and Gandayh 2015), although the increasing frequency of dust storms and high temperatures could hamper this.

Although nuclear energy could play an important role in meeting the world's energy demands, especially in developing countries where future energy demands will be high (Vaillancourt et al., 2008), it is the most controversial source of alternative energy sources. Iran's nuclear program, for instance, has triggered a series of international crises since 2002 (Özcan and Özdamar 2009). Furthermore, in addition to the political obstacles in using nuclear energy, the environmental impacts of the power plants on the PG's environment are considerable. In fact, the warm water outflow from planned nuclear reactors, in addition to PG desalination plants, will further accentuate thermal anomalies in the Gulf, at least at local scales, and intensify negative impacts on the sensitive environments.

According to the Paris Agreement on climate action, countries are committed to keeping global temperature increases less than 2 °C above pre-industrial levels, by the end of the 21st century (United Nations 2015). This temperature threshold has already been broken in the PGR. G20 countries, as the main greenhouse gas emitters and the chief customers of PG oil, have to cut their greenhouse gas emissions notably by 2050 (Goldthau 2017). In the short to medium term, PG countries have to combat the direct impacts of global warming, but they must also continue to supply oil and gas to the global economy. At longer timescales, however, they have to accept the reality of replacing fossil fuels with cleaner energies (Covert et al., 2016). Clean energy sources require heavy capital investment and technological capabilities that are mostly hosted in developed countries. The commodity-based economies of the PG countries have to reduce their dependency on fossil fuels and find new revenue sources (Goldthau 2017) as global oil production may have reached its peak (Figure 17).

While climate is changing fast, and the environment is being degraded, options for economic diversification remain limited for PG countries. A transition from commodity-dependent economies to a sustainable knowledge-based economy is difficult due to low numbers of educated/qualified people, compounded by the "brain drain" that also affects the region (Özden 2006). Of course, it is possible for PG countries to transition to a technology-based economy, in collaboration with developed countries, but more industrialization of the region will increase the present anthropogenic pressures on the environment with wider societal consequences (Sale et al., 2011). Moreover, political tensions and cultural barriers in the region threaten long-term foreign investment (Burt and Bartholomew, 2019).

Notwithstanding the fact that oil has been the main economic driving force in the PGR since mid-20th century, climate change impacts and international mitigation/adaptation policies have reduced the importance of oil for the long-term development of the countries (Figure 18). The countries have to be more dependent on oil to provide financial resources to transition to a non-oil economy but, by contrast, the environmental impacts of climate change make it difficult to transition to a non-oil economy. In the current situation, PGR countries must avoid regional rivalries and conflicts and invest more to educate the people to combat the effects of climate change. Moreover, these countries must work together to find regional solutions to save the environment as the main reliable source of sustainable development (Figure 18) while local technical capacity has been identified as a major obstacle for improved environmental regulation and management (Sale et al., 2011; van Lavieren et al., 2011).

7. Conclusion

The PGR faces two major problems regarding global climate change: (i) direct impacts of climate change and environmental degradation; and (ii) securing the economic transition/diversification to the post-oil era. While rapid environmental changes have attracted less attention from government authorities in littoral countries of the PG, they will nonetheless be important in economic diversification (e.g. focusing on maritime development) and controlling water resources. In this regard, it seems that both extremities of the PG, the Strait of Hormuz and the Shatt-al-Arab, constitute hotspots for regional rivalries. While national rivalries continue to dominate the region's geopolitical context, the environment is being rapidly degraded and endangering sustainable development of the region. Although the economic activities of the littoral countries are restricted to national boundaries, the environmental impacts of these activities are felt in all coastal countries, even 1700 km away in the Arabian Sea. Environmental degradation will limit the scope of economic diversification policies and hinder long-term investment e.g. for the tourism and travel industries. Countries should learn that they have limited time to educate their societies to tackle the direct and indirect impacts of climate change and to increase technological and scientific capabilities to change their economic paths. For instance, investing in renewable energy sources and developing new revenue streams requires reducing political tensions, developing regional cooperation, and adopting integrated environmental policies by all regional countries. These attempts should be integrated, planned regionally and undertaken collaboratively. Although cooperation and partnerships between PGR countries is urgently needed, the outlook is not promising. In this regard, the role of scientific communities and international bodies is important to focus the attention of political leaders on the impacts of climate change for regional stability and long-term prosperity.

Declarations

Author contribution statement

Abdolmajid Naderi Beni: Analyzed and interpreted the data; Wrote the paper.

Nick Marriner and Morteza Djamali: Contributed reagents, materials, analysis tools or data.

Arsah Sharifi: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Alan Kirman, Jafar Azizpour and Keivan Kabiri: Analyzed and interpreted the data.

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Data availability statement

Data associated with this study has been deposited at the below repositories: 1- Development data at the World -Bank datacenter: https://databank.worldbank.org/home.aspx. 2- Global Historical Climatology Network–monthly (GHCNm): https://www.ncdc.noaa.gov/ghcn-monthly. 3- Climate Change Knowledge Portal (CCKL): (https://climateknowledgeportal.worldbank.org/region/middle-east/climate-data-historical. 4- The optimum interpolation sea surface temperature (OISST): http://www.esrl.noaa.gov/psd/data/gridded/data.noaa.oisst.v2.html. 5- Daily sea-level anomaly: https://resources.marine.copernicus.eu/. 6- Daily Sea Surface Salinity: https://resources.marine.copernicus.eu/.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

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References

Abd-El-Mooty, M., Kansoh, R., Abdulhadi, A., 2016. Challenges of water resources in Iraq. Hydrol. Curr. Res. 7 (4), 1–8.
Abdullah, A.D., Gisen, J.I., Zaag, P.v. d., Savenije, H.H., Karim, U.F., Masih, I., et al., 2016. Predicting the salt water intrusion in the Shatt al-Arab estuary using an analytical approach. Hydrol. Earth Syst. Sci. 20 (10), 4031–4042.
Abel, G.J., Brottrager, M., Cuaresma, J.C., Muttarak, R., 2019. Climate, conflict and forced migration. Global Environ. Change 54, 239–249.
Ahmad, A., Ramana, M., 2014. Too costly to matter: economics of nuclear power for Saudi Arabia. Energy 69, 682–694.
Al-Ansari, N., 2013. Management of water resources in Iraq: perspectives and prognoses. Engineering 5 (6), 667–684.
Almasoud, A., Gandayh, H.M., 2015. Future of solar energy in Saudi Arabia. J. King Saud Univ.-Eng. Sci. 27 (2), 153–157.
Alterman, J.B., Dziuban, M., 2010. *Clear Gold: Water as a Strategic Resource in the Middle East: a Report of the CSIS Middle East Program*: Center for Strategic and International Studies.
Amar, 2019. Statistic Center of Iran. https://www.amar.org.ir.
Ardemagni, E., 2018. Gulf Powers: Maritime Rivalry in the Western Indian Ocean.
Baldwin-Edwards, M., 2005. Migration in the Middle East and Mediterranean: A Regional Study Prepared for the Global Commission on International Migration.
Beaumont, P., 1998. Restructuring of water usage in the Tigris-Euphrates basin: the impact of modern water management policies. In: Coppock, J., Miller (Eds.), JA Transformation of Middle Eastern Natural Environments: Legacies and Lessons, pp. 168–186.
Berkun, M., 2010. Hydroelectric potential and environmental effects of multidam hydropower projects in Turkey. Energy Sustain. Dev. 14 (4), 320–329.
Broecker, W.S., 1975. Climatic change: are we on the brink of a pronounced global warming? Science 189 (4201), 460–463.
Burt, J.A., 2014. The environmental costs of coastal urbanization in the Arabian Gulf. City, 18, 760–770.
Burt, J.A., Bartholomew, A., 2019. Towards more sustainable coastal development in the Arabian Gulf: opportunities for ecological engineering in an urbanized seascape. Mar. Pollut. Bull. 142, 93–102.
Burt, J.A., Feary, D.A., Van Lavieren, H., 2013. Persian Gulf reefs: an important asset for climate science in urgent need of protection. Ocean Chall. 20, 49–56.
Burt, J.A., Paparella, F., Al-Mansoori, N., Al-Mansoori, A., Al-Jailani, H., 2019. Causes and consequences of the 2017 coral bleaching event in the southern Persian/Arabian Gulf. Coral Reefs 38, 567–589.
Campos, E.J., Gordon, A.L., Kjerfve, B., Vieira, F., Cavalcante, G., 2020. Freshwater budget in the Persian (Arabian) Gulf and exchanges at the Strait of Hormuz. PloS One 15, e0233090.
Caspers, E.C.D., 1971. New archaeological evidence for maritime trade in the Persian Gulf during the Late Protoliterate period. East W. 21 (1/2), 21–44.
Chao, N., Luo, Z., Wang, Z., Jin, T., 2018. Retrieving groundwater depletion and drought in the tigris-euphrates basin between 2003 and 2015. Groundwater 56 (5), 770–782.
Church, J.A., White, N.J., 2006. A 20th century acceleration in global sea-level rise. Geophys. Res. Lett. 33.
Covert, T., Greenstone, M., Knittel, C.R., 2016. Will we ever stop using fossil fuels? J. Econ. Perspect. 30 (1), 117–138.
Dawoud, M.A., 2012. Environmental impacts of seawater desalination: Arabian Gulf case study. Int. J. Environ. Sustain. 1 (3).
DeMenocal, P.B., 2001. Cultural responses to climate change during the late Holocene. Science 667–673.
Djamali, M., de Beaulieu, J.-L., Andrieu-Ponel, V., Berberian, M., Miller, N.F., Gandouin, E., et al., 2009. A late Holocene pollen record from Lake Almalou in NW Iran: evidence for changing land-use in relation to some historical events during the last 3700 years. J. Archaeol. Sci. 36 (7), 1364–1375.
Djamali, M., Jones, M.D., Migliore, J., Balatti, S., Fader, M., Contreras, D., et al., 2016. Olive cultivation in the heart of the Persian Achaemenid Empire: new insights into agricultural practices and environmental changes reflected in a late Holocene pollen record from Lake Parishan, SW Iran. Veg. Hist. Archaeobotany 25 (3), 255–269.
Donchyts, G., Baart, F., Winsemius, H., Gorelick, N., Kwadijk, J., Van De Giesen, N., 2016. Earth's surface water change over the past 30 years. Nat. Clim. Change 6 (9), 810.
El-Katiri, L., 2014. A Roadmap for Renewable Energy in the Middle East and North Africa. Oxford institute for energy studies.
El-Katiri, L., Fattouh, B., 2017. A brief political economy of energy subsidies in the Middle East and North Africa. In: Combining Economic and Political Development. Brill Nijhoff, pp. 58–87.
Entessar, N., 1984. External involvement in the Persian Gulf conflict. J. Conflict Stud. 4 (4).
Evans, J.P., 2009. 21st century climate change in the Middle East. Climatic Change 92 (3-4), 417–432.
FAO, 2007. The World's Mangroves 1980-2005. FAO Forestry Paper 153.
Farzin, M., Nazari, S., Amani, A., Feiznia, S., Kazemi Azemi, G.-A., 2017. Determination of Submarine Groundwater Discharge Probable Areas into the Persian Gulf on Coastlines of Bushehr Province Using Standard thermal Anomaly Map.
Frenken, K., 2009. Irrigation in the Middle East region in figures AQUASTAT Survey-2008. Water Rep. (34).
Furman, H.K.H., 2003. Dust storms in the Middle East: sources of origin and their temporal characteristics. Indoor Built Environ. 12 (6), 419–426.
Giannakopoulou, E., Toumi, R., 2012. The Persian Gulf summertime low-level jet over sloping terrain. Q. J. R. Meteorol. Soc. 138 (662), 145–157.
Gleeson, M., Strong, A., 1995. Applying MCSST to coral reef bleaching. Adv. Space Res. 16 (10), 151–154.
Gleick, P.H., 2014. Water, drought, climate change, and conflict in Syria. Weather Clim. Soc. 6 (3), 331–340.
Goldthau, A., 2017. The G20 must govern the shift to low-carbon energy. Nature News 546 (7657), 203.
Goreau, T.J., Hayes, R.L., 1994. Coral bleaching and ocean" hot spots. Ambio-J. Hum. Environ. Res. Manag. 23 (3), 176–180.
Goudarzi, G., Daryanoosh, S., Godini, H., Hopke, P., Sicard, P., De Marco, A., et al., 2017. Health risk assessment of exposure to the Middle-Eastern Dust storms in the Iranian megacity of Kermanshah. Publ. Health 148, 109–116.
Granados, J.A.T., Ionides, E.L., Carpintero, Ó., 2012. Climate change and the world economy: short-run determinants of atmospheric CO2. Environ. Sci. Pol. 21, 50–62.

Gupta, A.K., Anderson, D.M., Pandey, D.N., Singhvi, A.K., 2006. Adaptation and human migration, and evidence of agriculture coincident with changes in the Indian summer monsoon during the Holocene. Current Sci.-Banglore 90 (8), 1082.

Gurjazkaite, K., Routh, J., Djamali, M., Vaezi, A., Poher, Y., Beni, A.N., et al., 2018. Vegetation history and human-environment interactions through the late Holocene in Konar Sandal, SE Iran. Quat. Sci. Rev. 194, 143–155.

Hamidi, M., Kavianpour, M.R., Shao, Y., 2013. Synoptic analysis of dust storms in the Middle East. Asia-Pac. J. Atmos. Sci. 49 (3), 279–286.

Hassanzadeh, S., Kiasatpour, A., Hosseinibalam, F., 2007. Sea-level response to atmospheric forcing along the north coast of Persian Gulf. Meteorol. Atmos. Phys. 95 (3-4), 223–237.

Henderson, J.C., 2006. Tourism in Dubai: overcoming barriers to destination development. Int. J. Tourism Res. 8 (2), 87–99.

Hereher, M.E., 2020. Assessment of climate change impacts on sea surface temperatures and sea level rise—the Arabian Gulf. Climate 8, 50.

Hole, F., 1994. Environmental instabilities and urban origins. In: Chiefdoms and Early States in the Near East: The Organizational Dynamics of Complexity, 18, p. 121.

Horner, J., 1992. The Iraq-Kuwait Border dispute. J. Borderl. Stud. 7 (1), 1–18.

Im, E.-S., Pal, J.S., Eltahir, E.A., 2017. Deadly heat waves projected in the densely populated agricultural regions of South Asia. Sci. Adv. 3 (8), e1603322.

Irani, M., Massah Bavani, A., Bohluli, A., Lahijani, H.A.K., 2017. sea level rise in Persian Gulf and Oman sea due to climate change in the future periods. Phys. Geogr. Res. Q. 4 (4), 603–614.

Issa, I.E., Al-Ansari, N., Sherwany, G., Knutsson, S., 2014. Expected future of water resources within Tigris–Euphrates rivers basin, Iraq. J. Water Resour. Protect. 6 (5), 421–432.

Jamali, S., Abrishamchi, A., Madani, K., 2013. Climate change and hydropower planning in the Middle East: implications for Iran's Karkheh hydropower systems. J. Energy Eng. 139 (3), 153–160.

Jish Prakash, P., Stenchikov, G.L., Kalenderski, S., Osipov, S., Bangalath, H.K., 2015. The impact of dust storms on the Arabian Peninsula and the red sea. Atmos. Chem. Phys.

Jones, E., Qadir, M., van Vliet, M.T., Smakhtin, V., Kang, S.-m., 2019. The state of desalination and brine production: a global outlook. Sci. Total Environ. 657, 1343–1356.

Jongerden, J., 2010. Dams and politics in Turkey: utilizing water, developing conflict. Middle East Pol. 17 (1), 137–143.

Kabiri, K., Pradhan, B., Rezai, H., Ghobadi, Y., Moradi, M., 2012. Fluctuation of sea surface temperature in the Persian Gulf and its impact on coral reef communities around Kish Island. In: 2012 IEEE Colloquium on Humanities, Science and Engineering (CHUSER). IEEE, pp. 164–167.

Kämpf, J., Sadrinasab, M., 2006. The circulation of the Persian Gulf: a numerical study. Ocean Sci. 2 (1), 27–41.

Kaniewski, D., Guiot, J., Van Campo, E., 2015. Drought and societal collapse 3200 years ago in the Eastern Mediterranean: a review. Wiley Interdiscipl. Rev.: Clim. Change 6 (4), 369–382.

Kaniewski, D., Marriner, N., Cheddadi, R., Guiot, J., Van Campo, E., 2018. The 4.2 kaBP event in the Levant. Clim. Past 14 (10).

Kaniewski, D., Marriner, N., Cheddadi, R., Morhange, C., Bretschneider, J., Jans, G., et al., 2019. Cold and dry outbreaks in the eastern Mediterranean 3200 years ago. Geology 47 (10), 933–937.

Kaniewski, D., Van Campo, E., Weiss, H., 2012. Drought is a recurring challenge in the Middle East. Proc. Natl. Acad. Sci. Unit. States Am. 109 (10), 3862–3867.

Kapiszewski, A., 2004. Arab Labour Migration to the GCC States. In: Arab Migration in a Globalized World. International Organization for Migration, Geneva, pp. 115–133.

Kennett, D.J., Kennett, J.P., 2007. Influence of Holocene marine transgression and climate change on cultural evolution in southern Mesopotamia. In: Climate Change and Cultural Dynamics. Elsevier, pp. 229–264.

Lachkar, Z., Mehari, M., Al Azhar, M., Levy, M., Smith, S., 2020. Fast local warming of sea-surface is the main factor of recent deoxygenation in the Arabian Sea. Biogeosci. Discuss. 1–27.

Le Mouël, C., Schmitt, B., 2018. Food Dependency in the Middle East and North Africa Region: Retrospective Analysis and Projections to 2050. Springer.

Lee, W., Kaihatu, J.M., 2018. Effects of desalination on hydrodynamic process in Persian Gulf. Coastal Eng. Proc. (36), 3.

Lelieveld, J., Hadjinicolaou, P., Kostopoulou, E., Chenoweth, J., El Maayar, M., Giannakopoulos, C., et al., 2012. Climate change and impacts in the eastern mediterranean and the Middle East. Climatic Change 114 (3-4), 667–687.

Lin, C., 2011. China's new silk road to the Mediterranean: the Eurasian land bridge and return of Admiral Zheng He. ISPSW Strategy Ser.: Focus Defense Int. Sec. 165, 1–23.

Madani, K., 2014. Water management in Iran: what is causing the looming crisis? J. Environ. Soc. Sci. 4 (4), 315–328.

Madani, K., AghaKouchak, A., Mirchi, A., 2016. Iran's socio-economic drought: challenges of a water-bankrupt nation. Iran. Stud. 49 (6), 997–1016.

Mogaddam, S.F., Bidokhti, A., Givi, F.A., Ezam, M., 2020. Evaluation of physical changes (temperature and salinity) in the Persian Gulf waters due to climate change using field data and numerical modeling. Int. J. Environ. Sci. Technol. 17 (4), 2141–2152.

Murray, J., King, D., 2012. Climate policy: oil's tipping point has passed. Nature 481 (7382), 433.

Najafi, H.S., Noye, B.J., 1997. Modelling Tides in the Persian Gulf Using Dynamic Nesting.

Nasrallah, H.A., Nieplova, E., Ramadan, E., 2004. Warm season extreme temperature events in Kuwait. J. Arid Environ. 56 (2), 357–371.

Nematollahi, O., Hoghooghi, H., Rasti, M., Sedaghat, A., 2016. Energy demands and renewable energy resources in the Middle East. Renew. Sustain. Energy Rev. 54, 1172–1181.

Nojoumi, A., Nikdel, S., Haidaripour, S.M., 2015. A review of the oil, gas and petrochemistry fire incidents during the last two years. In: Process Engineering Conference, Iran.

Nonneman, G., 2004. The Gulf states and the Iran-Iraq war: pattern shifts and continuities. In: Iran, Iraq, and the Legacies of War. Springer, pp. 167–192.

Odhiambo, G.O., 2017. Water scarcity in the Arabian Peninsula and socio-economic implications. Appl. Water Sci. 7 (5), 2479–2492.

Özcan, N.A., Özdamar, Ö., 2009. Iran's nuclear program and the future of US-Iranian relations. Middle East Pol. 16 (1), 121–133.

Özden, Ç., 2006. Brain drain in Middle East and North Africa: the Patterns under the Surface. United Nations Population, EGM/2006/10, New York, NY.

Pal, J.S., Eltahir, E.A., 2016. Future temperature in southwest Asia projected to exceed a threshold for human adaptability. Nat. Clim. Change 6 (2), 197.

Paparella, F., Xu, C., Vaughan, G.O., Burt, J.A., 2019. Coral bleaching in the Persian/ Arabian Gulf is modulated by summer winds. Front. Mar. Sci. 6, 205.

Parry, M., Parry, M.L., Canziani, O., Palutikof, J., Van der Linden, P., Hanson, C., 2007. Climate Change 2007-impacts, Adaptation and Vulnerability: Working group II Contribution to the Fourth Assessment Report of the IPCC, 4. Cambridge University Press.

Prandi, P., Meyssignac, B., Ablain, M., Spada, G., Ribes, A., Benveniste, J., 2021. Local sea level trends, accelerations and uncertainties over 1993–2019. Sci. Data 8, 1–12.

Prospero, J.M., Ginoux, P., Torres, O., Nicholson, S.E., Gill, T.E., 2002. Environmental characterization of global sources of atmospheric soil dust identified with the Nimbus 7 Total Ozone Mapping Spectrometer (TOMS) absorbing aerosol product. Rev. Geophys. 40 (1), 2-1–2-31.

Reynolds, R.M., 1993. Physical oceanography of the Gulf, Strait of Hormuz, and the Gulf of Oman—results from the Mt mitchell expedition. Mar. Pollut. Bull. 27, 35–59.

Reynolds, R.W., 1988. A real-time global sea surface temperature analysis. J. Clim. 1 (1), 75–87.

Reynolds, R.W., Marsico, D.C., 1993. An improved real-time global sea surface temperature analysis. J. Clim. 6 (1), 114–119.

Reynolds, R.W., Rayner, N.A., Smith, T.M., Stokes, D.C., Wang, W., 2002. An improved in situ and satellite SST analysis for climate. J. Clim. 15 (13), 1609–1625.

Riegl, B., 2003. Climate change and coral reefs: different effects in two high-latitude areas (Arabian Gulf, South Africa). Coral Reefs 22 (4), 433–446.

Rodell, M., Famiglietti, J., Wiese, D., Reager, J., Beaudoing, H., Landerer, F.W., et al., 2018. Emerging trends in global freshwater availability. Nature 557 (7707), 651.

Ross, D.A., Uchupi, E., White, R.S., 1986. The geology of the Persian Gulf-Gulf of Oman region: a synthesis. Rev. Geophys. 24 (3), 537–556.

Roudi-Fahimi, F., Kent, M.M., 2007. Challenges and opportunities: the population of the Middle East and north Africa. Popul. Bull. 62 (2), 24.

Sale, P.F., Feary, D.A., Burt, J.A., Bauman, A.G., Cavalcante, G.H., Drouillard, K.G., Kjerfve, B., Marquis, E., Trick, C.G., Usseglio, P., 2011. The growing need for sustainable ecological management of marine communities of the Persian Gulf. Ambio 40, 4–17.

Scheffran, J., Battaglini, A., 2011. Climate and conflicts: the security risks of global warming. Reg. Environ. Change 11 (1), 27–39.

Scheffran, J., Brzoska, M., Brauch, H.G., Link, P.M., Schilling, J., 2012. Climate Change, Human Security and Violent Conflict: Challenges for Societal Stability, 8. Springer Science & Business Media.

Schofield, R., 2018. International boundaries and borderlands in the Middle East: balancing context, exceptionalism and representation. Geopolitics 23 (3), 608–631.

Schweitzer, M.D., Calzadilla, A.S., Salamo, O., Sharifi, A., Kumar, N., Holt, G., et al., 2018. Lung health in era of climate change and dust storms. Environ. Res. 163, 36–42.

Sharifi, A., Pourmand, A., Canuel, E.A., Ferer-Tyler, E., Peterson, L.C., Aichner, B., et al., 2015. Abrupt climate variability since the last deglaciation based on a high-resolution, multi-proxy peat record from NW Iran: the hand that rocked the Cradle of Civilization? Quat. Sci. Rev. 123, 215–230.

Sharpley, R., 2002. The challenges of economic diversification through tourism: the case of Abu Dhabi. Int. J. Tourism Res. 4 (3), 221–235.

Sheppard, C., Al-Husiani, M., Al-Jamali, F., Al-Yamani, F., Baldwin, R., Bishop, J., et al., 2010. The Gulf: a young sea in decline. Mar. Pollut. Bull. 60 (1), 13–38.

Shirvani, A., Nazemosadat, S., Kahya, E., 2015. Analyses of the Persian Gulf sea surface temperature: prediction and detection of climate change signals. Arabian J. Geosci. 8 (4), 2121–2130.

Sowers, J., Vengosh, A., Weinthal, E., 2011. Climate change, water resources, and the politics of adaptation in the Middle East and North Africa. Climatic Change 104 (3-4), 599–627.

Thalib, L., Al-Taiar, A., 2012. Dust storms and the risk of asthma admissions to hospitals in Kuwait. Sci. Total Environ. 433, 347–351.

Thoppil, P.G., Hogan, P.J., 2010. Persian Gulf response to a wintertime shamal wind event. Deep Sea Res. Oceanogr. Res. Pap. 57, 946–955.

Uchupi, E., Swift, S., Ross, D., 2002. Morphology and late quaternary sedimentation in the Gulf of Oman Basin. Mar. Geophys. Res. 23 (2), 185–208.

United-Nations, 2015. Paris Agreement. In: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement.

Vaillancourt, K., Labriet, M., Loulou, R., Waaub, J.-P., 2008. The role of nuclear energy in long-term climate scenarios: an analysis with the World-TIMES model. Energy Pol. 36 (7), 2296–2307.

Van Lavieren, H., Burt, J., Feary, D.A., Cavalcante, G., Marquis, E., Benedetti, L., Trick, C., Kjerfve, B., Sale, P.F., 2011. Managing the Growing Impacts of Development on Fragile Coastal and marine Ecosystems: Lessons from the Gulf. A Policy Report. UNU-INWEH, Hamilton, ON, Canada.

Voss, K.A., Famiglietti, J.S., Lo, M., De Linage, C., Rodell, M., Swenson, S.C., 2013. Groundwater depletion in the Middle East from GRACE with implications for

transboundary water management in the Tigris-Euphrates-Western Iran region. Water Resour. Res. 49 (2), 904–914.
Vaughan, G.O., Al-Mansoori, N., Burt, J., 2019. The Arabian Gulf. In: Sheppard, C. (Ed.), World Seas: an Environmental Evaluation, second ed. Elsevier Science, Amsterdam, NL, pp. pp1–23.
Wabnitz, C.C., Lam, V.W., Reygondeau, G., Teh, L.C., Al-Abdulrazzak, D., Khalfallah, M., Pauly, D., Palomares, M.L.D., Zeller, D., Cheung, W.W., 2018. Climate change impacts on marine biodiversity, fisheries and society in the Arabian Gulf. PloS One 13, e0194537.
Walters Sr, K., Sjoberg, W., 1988. The Persian Gulf region: a climatological study. In: USAF Environmental Technical Applications Center, Scott Air Force Base, Illinois, pp. 62225–65438. USA. Technical report No. USAFETAC/TN–88/002 (AD–A222 654).
Weiss, H., 1997. Late third millennium abrupt climate change and social collapse in West Asia and Egypt. In: Third Millennium BC Climate Change and Old World Collapse. Springer, pp. 711–723.
Wilson, A., 2012. The Persian Gulf (RLE Iran A). Routledge.
World Bank, 2019. Development Data. World Bank. https://databank.worldbank.org/home.aspx.
World-Nuclear-Association, 2019. Nuclear Power in Iran. http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/iran.aspx.
Wright, H., Thorpe, J.L., Mackay, A., Battarbee, R., Birks, J., Oldfield, F., 2003. Climatic change and the origin of agriculture in the Near East. Glob. Change Holocene 49–62.
Zektser, I.S., Everett, L.G., Dzhamalov, R.G., 2006. Submarine Groundwater. CRC Press.
Zenghelis, D., 2006. Stern Review: the Economics of Climate Change. HM Treasury, London, England.
Zhang, X., Aguilar, E., Sensoy, S., Melkonyan, H., Tagiyeva, U., Ahmed, N., et al., 2005. Trends in Middle East climate extreme indices from 1950 to 2003. J. Geophys. Res.: Atmosphere 110 (D22).
Zoljoodi, M., Didevarasl, A., Saadatabadi, A.R., 2013. Dust events in the western parts of Iran and the relationship with drought expansion over the dust-source areas in Iraq and Syria. Atmos. Clim. Sci. 3 (3), 321–336.