Trends of climate with rapid change in Sinai, Egypt

Mohamed A. Dadamouny and Martin Schnittler

ABSTRACT

This study presents evidence for rapid climate change in the Sinai Peninsula, Egypt. Analyses of data for temperature and rainfall from 1970 to 2014 show a clear tendency towards decreasing rainfall and increasing average temperatures. This trend caused severe droughts for many years that were suddenly interrupted by high and unpredictable rainfall that fluctuated heavily in space and time. If this tendency continues, the population dynamics of many plant and animal species will be negatively affected, with many of them being important for local inhabitants. Detrimental effects can be expected in the coastal and tourist cities like Sharm El-Sheikh, Taba, El-Tor, St. Catherine, Ras Sedr and El-Arish. Conservation efforts should be directed to conserve the biological and natural resources and to keep pace with this environmental change.

Key words | aridity, climate, conservation, resources, Sinai, trends

Mohamed A. Dadamouny (corresponding author)
Martin Schnittler
Ernst Moritz Arndt University Greifswald, Institute of Botany and Landscape Ecology,
Soldmannstr. 15,
D-17487 Greifswald,
Germany
E-mail: *mohamed.dadamouny@uni-greifswald.de*

INTRODUCTION

The world's population is anticipated to increase from around 7.2 to 9.2 billion (10^9) within the period from 2014–2050. The monthly growth is estimated to be around 6 million (Lal & Stewart 2012). Most of it occurs in developing countries, where natural and biological resources are currently under considerable human pressure (El-Ramady *et al.* 2013). For this reason, changing climate affects human lives particularly severely in these regions of the world. However, climate change is a complex phenomenon, not easy to circumscribe. Commonly measured by meteorologists are daily weather data, air temperature, precipitation, atmospheric pressure, humidity, wind speed, sunshine, and cloud cover (Food & Agriculture Organization (FAO) 2008). Obviously, these parameters are not stable and can change within short periods of time. Scientists have not yet agreed upon an internationally accepted definition of climate change. According to FAO (2008), it can refer to: (1) long-term changes in average weather variables (World Meteorological Organization); (2) all changes in the climate system, involving the drivers of change and their impacts (Global Climate Observing System); and (3) just man-induced changes in the climate system (United Nations Framework Convention on Climate Change) (El-Ramady *et al.* 2013). This paper is describing climate trends at the Sinai Peninsula, Egypt. We will adopt the first definition since it is extremely difficult (and not the focus of this paper) to disentangle the drivers of climate change, especially if these drivers are natural processes or stem from human impacts. Only some causal explanations are well known. Irrespective of its prediction around 120 years ago by scientists studying CO_2, man-made climate change was formally approached first in 2007 by the Nobel Prize Committee (Lichtfouse 2009). Already, Svante Arrhenius (1859–1927) had estimated that the greenhouse impact, by doubling the concentration of the atmospheric CO_2, would cause a temperature rise of about $+5$ to $+6\,^{\circ}$C (Arrhenius 1896). Although his crude estimate is higher than most of today's scenarios, he is considered the first scientist to have predicted anthropogenic global warming (Arrhenius 1908, see Weart 2008). We know today that his pathway is one of many possible drivers of the climate. It included natural drivers (e.g. peatlands, where a significant part of the carbon held by the vegetation returns to the atmosphere due to plant and microbial respiration (Gorham 1991; Lappalainen 1996)). Also, it included

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anthropogenic (Kyoto Protocol) processes. Besides CO_2, methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride (SF_6) are greenhouse gases emitted by human activities (Chanton *et al.* 1995). Consequently, the Intergovernmental Panel on Climate Change (Intergovernmental Panel on Climate Change (IPCC) (2014), 5th Assessment Report) presented Representative Concentration Pathways (RCPs) referring to more than one possible scenario for future climate change (Meinshausen *et al.* 2011). RCPs were calculated up to the year 2100; with Extended Concentration Pathways describing extensions of the RCPs from 2100 to 2500. The increase in global mean surface temperature (2081–2100) relative to (1986–2005) is expected to be 0.3 to 1.7 °C under RCP2.6, 1.1 to 2.6 °C under RCP4.5, 1.4 °C to 3.1 °C under RCP6.0 and 2.6 °C to 4.8 °C under RCP8.5.

Egypt's contribution to global emissions of greenhouse gases is rather small (3.4% coal/peat in 2011) (Egyptian Environmental Affairs Agency (EEAA) 1999; International Energy Agency (IEA) 2013). However, the potential impacts (social and economic) of climate change could be harsh for the country's future (Egyptian Environmental Affairs Agency (EEAA) 1999; Comsan 2011). These effects are due to the steadily growing population of Egypt, its large proportion of deserts and limited fertile land, and the concentration of economic activities near the coastline. Egypt's climate is semi-arid and characterized by hot, dry summers, moderate winters, and very little rainfall (Dadamouny 2009). Therefore, most of the land can be classified as semi-desert or desert. The impacts of climate change, in particular warming, are reflected not only by changes in the water cycle (Howard *et al.* 2010). Climate change has also led to increasing desertification and higher mortality in many plant species that cannot tolerate high temperatures and severe droughts (Supplement, Figure S1(a)–(c); Figure S1 is available with the online version of this paper). Other risks are less predictable, including flash floods which may lead to unpredictable water flows and recharge (Supplement, Figure S1(d)), more frequent droughts, and changes in the capacity and nature of groundwater stores (Stern 2006; Xu *et al.* 2007; Bates *et al.* 2008). Also, a rise in sea level will increase the risks of permanent or seasonal saline intrusion into the groundwater in South Sinai and the Nile River, in its northern delta (Howard *et al.* 2010). This is affecting the quality and potential usability of water sources for domestic, agricultural and industrial uses. The consequences of climate change will impede all development sectors in Egypt. The most significant repercussions include impacts on the water resources of the Nile River and groundwater, agricultural output, coastal resources, and tourism. As the environmental conditions play a crucial role in defining the function and distribution of species, changes in these conditions will actively change plant diversity patterns in the future (Duraiappah 2006; Field *et al.* 2009). In the upcoming years, it is expected that climate change will be one of the main drivers of biodiversity patterns (Sala *et al.* 2000; Duraiappah 2006; Pressey *et al.* 2007; Ingole & Kakde 2013).

In this paper, we try to derive climate trends for the Sinai Peninsula. This region is located between the Mediterranean Sea and the Red Sea, including around 2,000 plant species and many hundreds of rare and endemic animals. Based on data available from weather stations recorded from 1970 to 2014, we calculate trends and briefly discuss their impacts on the status of natural and biological resources. Finally, we present some proposed solutions that may help to mitigate the effects of climate change in the near future.

STUDY AREA

Sinai lies in the arid to extremely-arid belt of North Africa, and belongs to the Saharan-Mediterranean climate region. Most of Sinai (excluding the mountains) is classified as extremely arid ($P/EP < 0.03$), where P is the annual precipitation and EP is the potential evapotranspiration, calculated according to Penman's formula (Ayyad & Ghabbour 1986). The mountains in the St. Catherine area, with their highest summits above 2,600 m above sea level (a.s.l.), receive higher amounts of precipitation, estimated to exceed 50 mm a year as rain and snow (Dadamouny 2009). We selected six regions for an analysis of climatic parameters (Figure 1). The first region is El-Arish, which is the capital and largest city of North Sinai. This lies on the Mediterranean coast of the Sinai Peninsula (31 °08′N, 33 ° 83′E) about 50 km from the Rafah border with the Gaza Strip and 344 km north-east of Cairo. Most prominent is a broad wadi known as W. El-Arish, which receives flash flood waters from north and central Sinai. Although the prevailing Mediterranean winds alleviate its high temperatures, as for

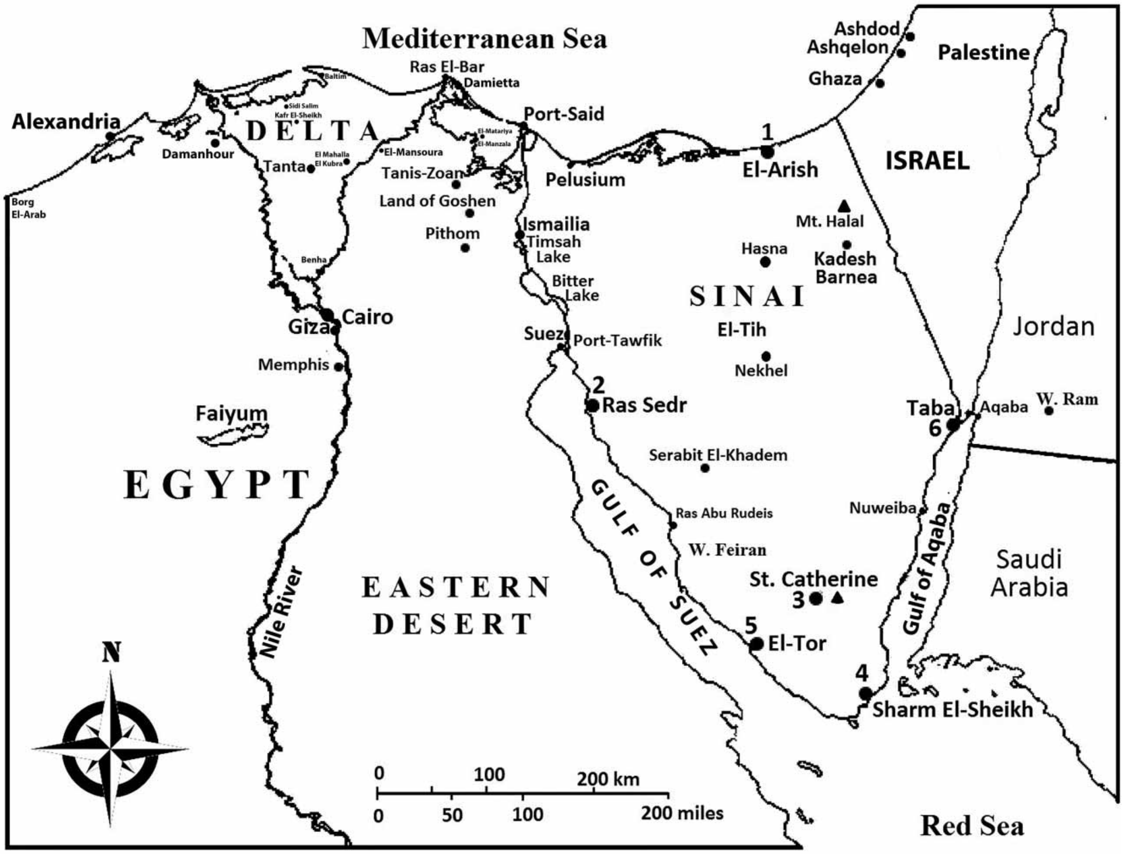

Figure 1 | Map of the Sinai Peninsula, Egypt, showing the locations of the weather stations at 1. El-Arish, 2. Ras Sedr, 3. St. Catherine, 4. Sharm El-Sheikh, 5. El-Tor, and 6. Taba.

the northern coast of Egypt, the region is classified as a hot desert. Its basin area, which drains into the Mediterranean Sea, covers about 19,500 km^2 (El-Bihary & Lachmar 1994; Klein 2000; Figure S2(a)) (Figure S2 is available with the online version of this paper). The coastline is rather straight, receiving sediment loads varying from 500,000 to 800,000 m^3/year, and the coastal sediment bar usually dams the Nile River outlet (Nir 1982, 1989).

The second region is Ras Sedr, also known by the name ‘Sudr’. It is located on the Gulf of Suez coast (29 °35′N, 32 ° 42′E) and belongs to the South Sinai Province, which consists of three areas: W. Sedr, Abu Sedr, and Soerp. Ras Sedr, as a tourist city, has a 95 km beach coastline. It lies 200 km from Cairo and approximately 60 km from the Ahmed Hamdi Tunnel crossing the Suez Canal. In the Köppen-Geiger climate classification system, the area is considered as a hot desert (Peel *et al.* 2007). It is also highly vulnerable to flash floods and drought that may be attributed to climate changes (Ahmed *et al.* 2014).

The third region is St. Catherine in the central part of South Sinai (28 °34′N, 33 °57′E). This mountainous region of Precambrian igneous and metamorphic rocks includes Egypt’s highest peaks (Mt. St. Catherine, 2,641 m a.s.l., Mt. Moussa 2,285 m, Mt. Serbal 2,070 m, Mt. Umm Shomer 2,586 m, and Mt. Tarbush 2,029 m). The Sinai massif contains some of the world’s oldest rocks and around 80% of these rocks are 600 million years old (Moustafa 1990; Said 1990; Dadamouny 2009). According to the Köppen-Geiger climate system, its climate is also a hot desert (Peel *et al.* 2007). However, St. Catherine city has the coldest nights in Egypt due to its high elevation (1,500 m a.s.l.); minimum temperatures can reach −15 °C. Among its high mountains, there are basins and many wadis (W. Al-Alarbaeen, Shrayj, Ferrah, Itlah, Raha, Tellaah, Naqb Hawa, Farsh El-Roumana, Farsh Mesaila, Safsafa, Tynia, Ahmar, Farsh El-Luza, Gebal, and W. el-Deir). Due to the rugged relief, weather conditions change locally and within a short time, including extreme weather events with snows on the summits. The region comprises two main wadis: W. Zaghra, situated north-east of St. Catherine (Figure S2(b)), and W. Watir (Figure S2(c)) near Nuweiba. The latter wadi is among the wadis in the Sinai hit most often by flash floods (Figure S2(c)), with a catchment of 3,580 km^2, which is considered to be a hyper-arid catchment (Lin 1999). A third wadi, W. Feiran, is the longest and broadest wadi in South Sinai. Its basin surface is 1,675 km^2, and covers a densely branched and widely distributed drainage system.

The fourth region is Sharm El-Sheikh at the southern tip of the Sinai Peninsula. It lies on the coastal strip along the Red Sea overlooking the Straits of Tiran at the mouth of the Gulf of Aqaba (27 °55′N, 34 °19′E). Its climate is a subtropical arid one. The Gulf of Aqaba coast is warmer than the Gulf of Suez (Abd El-Wahab 2003). The coastlines of the Red Sea and outlying reefs are increased at irregular intervals by creeks known as Sharms, which are typically drowned stream valleys. Near to Sharm El-Sheikh are two more wadis (W. Mandar and W. Lithi) and the National Park, Ras Mohamed (480 km^2), situated around 30 km south of Sharm El-Sheikh.

The fifth region is El-Tor at the Gulf of Suez, South Sinai (28 °14′N, 33 °37′E, Dadamouny 2009), known as well by the name Tur Sinai. W. Meir, situated north-east of El-Tor, is a prominent wadi. The sixth region is Taba, a small Egyptian town covering 1 km^2 near to the northern tip of the Gulf of Aqaba (29 °29′N, 34 °54′E), its protectorate south-west of Taba covers 3,590 km^2. The area within 40 km of its meteorological station is a hot desert (Peel *et al.* 2007) covered by shrubland (68%), oceans and seas (18%), and lakes and rivers (13%, Shokry & Ammar 2009).

MATERIALS AND METHODS

Data collection

Available meteorological data for the selected regions in Sinai were collected from six meteorological stations in June 2014. These stations are El-Arish, Ras Sedr, St. Catherine, Sharm El-Sheikh, El-Tor, and Taba, all governed by the Egyptian Meteorological Authority (EMA, established in 1898 in Cairo). Later, the data were updated up to December 2014. We collected the daily raw data for the parameters: minimum, maximum and mean temperatures, total precipitation (TP), relative humidity (RH), air pressure at sea level (PSL), and wind speed. A quality control has been set up by EMA for the studied stations since 1970. Data are double controlled, first by the observer and second by a supervisor who makes occasional visits at each station, checking records at different times of the day and repeating measurements. Results are submitted to EMA.

Data treatment

From 1970 to 2014, all years with daily records for less than eight months were considered as missing. For these years, we took the monthly and annual means from the unpublished data books prepared by the EMA. They prepared two books; the first includes data from 1945 to 1974 but has only one of the six studied stations (El-Tor). The second book contains the monthly and annual means from 1975 to 2005 for all locations. For St. Catherine and Sharm El-Sheikh, there were two stations in each location, but the data for one of them were missing for many years, therefore we considered only one station in our analysis. We completed the missing years not available in the stations' reports from EMA in Cairo. For the temperature, the missing data totaled 6.8% (37 out of 540 months). For the rainfall, the data for some years appear to be missing, but in certain cases this is because there were no rains. The missing rainfall data ranged from 4.4 to 13.3% (two, five, and six years were missing for El-Arish, Sharm El-Sheikh, and El-Tor and St. Catherine), respectively. The availability of data for Taba station was 99.2%. Rainfall records for Ras Sedr station before 1978 were also missing. To verify the equality of variance ($P > 0.05$) in the data (homogeneity), a non-parametric Leven's test was used according to Nordstokke & Zumbo (2010) and Nordstokke *et al.* (2011) using IBM SPSS Statistics version 22 (SPSS 2013).

Data analysis

First, from the daily records we calculated the monthly and annual means, minimum, maximum, standard deviation, and standard error (SE) values for all collected parameters through the descriptive statistics. Based on the analyses of climate records from 1970 to 2014, a linear regression equation between X (years) and Y (climate parameters) was used to forecast the trend of these parameters within future years. We used the software Minitab (2014) and SPSS (2013). For temperatures, alternatively, the pattern was visualized by the change in monthly means for the time intervals 1970–1984, 1985–1999, and 2000–2014. The total number of rainy days per year, a percentage of the highest three days to the total annual rainfall, highest daily records, and total annual rainfall were used to draw the trend of precipitation in the study area. Regression analysis was carried out for yearly minimum, mean, and maximum values to reveal the extremes and to forecast the tendency of each. For the same period (1970–2014), regression of the total rainfall was carried out for the studied six regions except Ras Sedr (from 1978 to 2014), due to the missing data for rainfall before 1978. Subsequently, regression for annual means of RH, air PSL, and mean and maximum wind speed was carried out using the available climate data for the six regions from 1970 to 2014.

RESULTS

Changes in climate parameters over time

Table 1 lists the figures for linear trends calculated from annual records of minimum, maximum and mean temperatures, annual precipitation, RH, air pressure and maximum and mean wind speed. Table 2 gives the respective data for the years 1995 to 2014.

Temperature

From 1970 to 2014, the average annual mean temperature of the six studied regions in Sinai increased by +2.3 °C (20.3 to 22.6 °C). Figure 2 displays the increase of monthly mean temperature during the timespans of 1970–1984, 1985–1999, and 2000–2014 in each region. From the first time interval (1970–1984) to the last (2000–2014), the highest increase in the annual mean temperature (+2.8 °C) was at Taba on the Gulf of Aqaba, while the lowest increase in the annual mean (+1.2 °C) was in El-Arish on the Mediterranean Sea. The extreme values of maximum and minimum temperatures are shown in Figure 3. During the last 20 years (1995–2014), the maximum recorded temperatures were 46 °C for Sharm El-Sheikh (22 and 23 June 2010 then 2 and 3 June 2013). Then 45 °C was recorded at El-Arish (29 May 2003, 25 June 2007, and 4 March 2013), Ras Sedr (30 July 2002), El-Tor (2 July 1995 and 20 August 2010), and Taba (2 July 1996, Table 2). Absolute minimum temperatures were −6 °C, recorded at El-Arish on 8 January 1994, and at St. Catherine on 1 February 2008 (Figure 3). Moreover, Sharm El-Sheikh is the warmest region in our study area, its minimum temperature was 4 °C on 5 February 2003 and at El-Tor it was 1 °C on 1 January 2003.

Maximum temperatures tend to rise in all studied regions (Figure 2). The regression coefficients for the maximum and mean temperatures in all stations are positive. If this trend continues in a linear fashion, maximum temperatures may reach 52 °C at El-Arish, 53 °C at Ras Sedr, 49 °C at St. Catherine, 54 °C at Sharm El-Sheikh, 55 °C at El-Tor, and 46 °C at Taba by 2050. At the same time, the mean temperature is increasing and may exceed 30 °C at Sharm El-Sheikh. The changes are much less pronounced for minimum temperatures, which tend to rise in all studied regions except for St. Catherine, where the regression coefficient is low (0.24, Table 1). According to the linear trends, minimum temperatures may reach 15 °C at Sharm El-Sheikh, 10 °C at El-Tor, 8 °C at Ras Sedr and Taba, and 2 °C at El-Arish by 2050. In St. Catherine, the minimum temperature may be lower than −3 °C in the upcoming years. A stronger fluctuation in temperature is one indication of climate change. Extreme temperatures seem to occur more often in recent years, especially for maximum temperatures (Figure 3).

Annual TP

Data for TP from 1970 to 2014 are shown in Figure 3. Single, comparatively wet years with rainfall peaks were 1975 (271.9 mm), 2002 (205.5 mm), and 2008 (142.7 mm) at El-Arish, 1978 (64.4 mm), 1987 (41.1 mm), and 2006 (94.5 mm) at Ras Sedr, 1975 (97.5 mm), 1976 (126.5 mm) 1991 (68 mm), and 2010 (44.1 mm) at St. Catherine, 1975 (48.3 mm), 1990 (19 mm), and 2010 (34.4 mm) at Sharm El-Sheikh, 1975 (47.5 mm), 2002 (82.6 mm), and 2011 (18.6) at El-Tor, and 1978 (150 mm), 1988 (51.6), and 2010 (61.5 mm) at Taba. However, like the average amounts of

Table 1 | Intercept (*a*) and slope (*b*) of a linear regression as well as the regression coefficient (R^2) for eight climate parameters (maximum, mean, and minimum temperature, annual precipitation, mean RH, mean PSL, and maximum and mean wind speed) measured at six stations of the Sinai Peninsula (1970–2014)

	Max. temperature (°C)			**Mean temperature (°C)**			**Min. temperature (°C)**			**Total annual rainfall (mm)***		
	a	***b***	***R^2***	***a***	***b***	***R^2***	***a***	***b***	***R^2***	***a***	***b***	***R^2***
El-Arish	– 445.1	0.243	0.71	– 54.5	0.038	0.32	– 32.4	0.017	0.02	6027.9	– 2.96	0.38
Ras Sedr*	– 462.4	0.251	0.77	– 129.4	0.076	0.62	– 142.8	0.073	0.27	657.4	– 0.319	0.04
St. Catherine	– 602.9	0.318	0.66	– 118.1	0.068	0.42	125.3	– 0.063	0.24	2280.7	– 1.128	0.31
Sharm	– 477.9	0.259	085	– 145.6	0086	0.75	– 314.2	0.161	0.53	736.7	– 0.364	0.14
El-Tor	– 539.4	0.289	0.79	– 152.7	0.088	0.43	– 199.5	0.102	0.41	431.2	– 0.210	0.03
Taba	– 151.9	0.096	0.27	– 171.1	0.096	0.36	– 210.9	0.107	0.22	1852	– 0916	0.14

	Mean RH (%)			**Mean sea level pressure (hPa)**			**Max. wind speed (km/hr)**			**Mean wind speed (km/hr)**		
	a	***b***	***R^2***	***a***	***b***	***R^2***	***a***	***b***	***R^2***	***a***	***b***	***R^2***
El-Arish	– 17.2	0.042	0.06	1,792.0	– 0.393	0.02	370.5	– 0.157	0.03	73.0	– 0.033	0.05
Ras Sedr*	103.4	– 0.026	0.02	1,374.0	– 0.180	0.65	207.9	– 0.082	0.02	44.2	– 0.016	0.03
St. Catherine	– 1,112.2	0.5721	0.30	3,155.6	– 1.068	0.103	– 916.5	0.505	0.01	154.4	– 0.068	0.08
Sharm	640.8	– 0.300	0.37	1,514.1	– 0.251	0.86	1,841.8	– 0.884	0.12	632.5	– 0.306	0.65
El-Tor	550.7	– 0.247	0.20	1,134.9	– 0.062	0.12	1,490.8	– 0.702	0.06	98.4	– 0.037	0.03
Taba	46.5	– 0.268	0.2	1,014.1	– 0.075	0.18	2450	– 1.193	0.48	412.4	– 0.198	0.26

*Regression for total rainfall at Ras Sedr is based on data from 1978 to 2014.

Table 2 | Annual data for seven climate parameters recorded at six weather stations in the Sinai Peninsula during the last 20 years (1995–2014). Climate parameters are maximum, mean and average temperature (°C), total rainfall (mm), and means for RH (%), wind speed (km/hr), and air PSL (hPa). Means are based on daily records

El-Arish

	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Max. Temp.	41.0	44.0	42.0	43.0	42.0	39.0	40.0	42.0	45.0	43.0
Mean Temp.	20.2	20.1	18.4	20.8	20.5	19.7	20.7	21.1	20.3	20.2
Min. Temp.	0.0	1.0	3.0	0.0	2.0	1.0	1.0	1.0	2.0	0.0
T. Rainfall	9.2	46.76	116.4	143.8	13.98	107.2	79.75	205.5	75.97	139.96
Humidity	65.9	66.8	68.1	67.0	68.6	70.6	68.2	67.9	66.6	67.6
Wind Speed	11.0	7.4	8.2	7.4	6.1	6.6	7.7	7.1	8.5	7.9
Air pressure	1,015.1	1,012.9	1,015.3	1,013.4	1,013.7	1,014.0	1,013.8	1,013.9	1,013.2	1,014.0
	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Max. Temp.	39.4	42.0	45.0	42.0	39.0	41.0	40.0	39.0	45.0	44.0
Mean Temp.	21.4	23.2	20.4	20.6	20.7	21.7	22.8	20.3	20.4	20.7
Min. Temp.	2.0	2.0	3.0	−3.0	2.0	3.0	3.0	2.0	4.0	4.0
T. Rainfall	33	150.89	121.17	142.72	33.52	119.2	62.0	44.68	47.7	48.25
Humidity	66.5	76.0	70.2	66.7	66.7	54.7	65.1	69.7	69.0	73.3
Wind Speed	8.8	7.6	6.8	7.0	9.4	8.8	7.6	7.7	8.3	5.4
Air pressure	1,014.0	1,016.9	1,012.8	1,013.2	1,012.7	842.5	1,010.9	1,012.7	1,013.0	1,013.8

Ras Sedr

	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Max. Temp.	38.0	39.0	39.0	40.0	41.0	43.0	41.0	45.0	41.0	41.0
Mean Temp.	22.6	21.4	21.7	21.4	21.8	22.3	21.5	23.1	24.1	22.8
Min. Temp.	2.0	3.0	1.0	5.0	3.0	4.0	6.0	5.0	3.0	8.0
T. Rainfall	37.1	23.4	28.5	21.7	24	11.44	6.61	14.2	11.18	31.75
Humidity	57.7	56.2	54.8	55.1	56.8	55.0	52.6	53.3	52.0	52.4
Wind Speed	12.8	12.5	12.1	11.6	12.6	13.4	11.1	11.2	10.3	10.0
Air pressure	1,015.6	1,013.4	1,014.1	1,014.2	1,015.1	1,013.4	1,013.0	1,013.0	1,012.5	1,012.6
	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Max. Temp.	44.0	43.0	44.0	42.0	43.0	43.0	41.0	41.0	42.0	42.0
Mean Temp.	22.5	22.8	23.2	23.1	23.4	24.4	22.6	23.4	23.2	25.4
Min. Temp.	5.0	5.0	2.0	2.0	6.0	4.0	1.0	4.0	6.0	7.0
T. Rainfall	11.2	94.5	2.79	11.42	1.78	6.4	10.7	6.9	1.0	16.8
Humidity	52.8	52.7	51.8	48.8	48.8	50.2	50.1	49.6	49.2	42.7
Wind Speed	10.7	8.0	12.0	12.1	12.0	12.9	11.5	11.4	11.8	9.7
Air pressure	1,013.0	1,012.1	1,012.2	1,012.1	1,011.6	1,010.8	1,011.7	1,011.0	1,011.5	1,011.3

(*continued*)

Table 2 | continued

St. Catherine

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Max. Temp.	32.0	29.0	28.0	26.0	30.0	26.0	31.0	35.0	36.0	34.0
Mean Temp.	16.40	18.10	17.85	16.55	15.70	16.65	18.50	17.50	19.00	17.58
Min. Temp.	1.0	1.5	0.0	3.0	1.4	1.0	0.0	0.0	2.0	0.0
T. Rainfall	22	25	38	14.6	nd	nd	nd	nd	nd	27.0
Humidity	31.0	30.9	32.4	25.1	22.3	25.2	27.3	37.5	28.4	39.4
Wind Speed	12.4	11.3	9.8	9.3	8.6	11.4	10.1	8.7	9.8	8.6
Air pressure	1,021.7	1,019.5	1,020.3	1,021.4	1,018.9	1,020.5	1,020.6	1,019.3	1,021.2	1,018.6

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Max. Temp.	38.0	35.0	39.0	38.0	43.0	42.0	39.0	37.0	37.0	35.0
Mean Temp.	18.06	16.54	20.71	18.17	17.92	20.17	16.92	20.67	17.92	17.75
Min. Temp.	−1.0	−2.0	1.0	−6.0	−3.0	−1.0	1.0	1.0	−3.0	0.0
T. Rainfall	25.6	8.6	17.4	4.0	7.6	44.1	1.2	20.1	16.6	4.5
Humidity	40.5	41.6	20.7	36.7	40.2	38.0	42.9	34.5	40.6	41.0
Wind Speed	8.3	7.9	8.4	7.8	8.6	9.2	6.9	11.5	10.7	10.4
Air pressure	1,020.3	1,016.5	994.8	1,020.2	1,020.0	1,020.3	1,019.6	934.1	1,020.0	1,020.7

Sharm El-Sheikh

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Max. Temp.	39.0	40.0	43.0	43.0	42.0	44.0	42.0	45.0	42.0	43.0
Mean Temp.	24.5	25.7	25.2	26.0	26.1	25.5	26.5	26.3	26.1	26.8
Min. Temp.	7.0	3.0	6.0	12.0	12.0	5.0	10.0	9.0	4.0	5.0
T. Rainfall	nd	17.0	0.4	nd	nd	9.0	6.5	8.1	12.1	18.3
Humidity	44.8	41.7	39.5	40.2	40.6	39.8	40.6	37.4	42.3	36.6
Wind Speed	21.5	22.1	20.8	18.6	21.3	19.3	18.7	19.6	18.5	19.4
Air pressure	1,015.2	1,013.9	1,013.7	1,014.5	1,013.2	1,012.0	1,012.9	1,012.3	1,013.8	1,011.6

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Max. Temp.	42.0	43.0	43.0	41.0	41.0	46.0	43.0	43.0	46.0	45.0
Mean Temp.	25.9	25.6	25.9	26.2	26.1	27.6	25.8	26.7	27.4	28.1
Min. Temp.	10.0	8.0	10.0	10.0	11.0	12.0	8.0	9.0	9.0	5.0
T. Rainfall	5.4	6.0	0.8	0.3	0.0	34.4	12.3	0.0	0.6	0
Humidity	37.8	36.5	37.2	34.5	35.1	36.8	38.5	35.6	34.5	41.8
Wind Speed	19.3	18.9	17.8	18.4	16.0	17.3	16.6	14.7	15.3	18.7
Air pressure	1,011.3	1,011.1	1,010.8	1,010.9	1,010.9	1,010.2	1,010.4	1,010.0	1,010.2	1,009.8

(*continued*)

Table 2 | continued

El-Tor

	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Max. Temp.	45.0	40.0	41.0	39.0	42.0	41.0	42.0	43.0	43.0	42.0
Mean Temp.	22.9	23.2	22.9	23.7	23.1	22.0	23.3	23.6	23.3	22.9
Min. Temp.	7.0	4.0	5.0	7.0	6.0	2.0	4.0	5.0	1.0	2.0
T. Rainfall	29.7	13.5	1.0	3.1	8.3	11.4	11.9	82.6	3.1	5.4
Humidity	54.3	55.4	52.5	54.8	57.7	58.2	56.7	56.5	55.0	55.8
Wind Speed	24.8	24.5	22.4	22.9	23.9	24.2	25.7	25.7	24.8	25.1
Air pressure	1,010.5	1,009.6	1,011.0	1,010.3	1,010.6	1,010.7	1,010.9	1,011.3	1,010.9	1,011.3

	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Max. Temp.	42.0	44.0	43.0	42.0	41.0	45.0	41.0	43.0	43.0	42.0
Mean Temp.	23.8	27.0	27.6	28.8	25.8	25.8	23.5	22.3	23.7	25.1
Min. Temp.	3.0	6.0	4.0	6.0	8.0	6.0	4.0	10.0	5.0	8.0
T. Rainfall	2.0	0.8	4.9	2.5	0.0	17.4	18.6	7.5	5.3	18.6
Humidity	56.3	54.9	54.5	54.5	58.6	56.5	52.8	56.7	44.4	43.8
Wind Speed	25.0	24.4	23.6	23.5	21.7	22.5	24.1	25.7	23.1	23.0
Air pressure	1,011.6	1,011.1	1,011.0	1,011.1	1,009.3	1,009.1	1,011.1	1,010.9	1,010.8	1,010.2

Taba

	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Max. Temp.	40.0	45.0	42.0	40.0	41.0	41.0	41.0	44.0	40.0	41.0
Mean Temp.	21.0	21.1	20.9	20.6	20.8	23.3	23.1	23.1	23.3	18.9
Min. Temp.	3.0	0.0	5.0	3.0	4.0	4.0	5.0	4.0	4.0	0.0
T. Rainfall	13.3	15.2	3.3	8.6	6.9	11.3	13.4	9.8	4.4	10.2
Humidity	62.0	61.8	50.8	59.0	57.8	51.6	46.8	45.7	57.4	51.4
Wind Speed	21.6	19.1	20.2	19.3	18.4	16.5	18.9	16.4	15.4	16.7
Air pressure	1,021.5	1,020.2	1,018.9	1,020.5	1,020.2	1,018.9	1,017.6	1,019.3	1,019.2	1,018.0

	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Max. Temp.	40.0	39.0	41.0	43.0	39.0	43.0	38.0	41.0	40.0	42.0
Mean Temp.	23.0	23.5	22.5	18.9	20.4	23.5	17.7	23.0	23.4	23.6
Min. Temp.	0.0	0.0	0.0	0.0	−1.0	4.0	2.0	2.0	6.0	1.0
T. Rainfall	2.9	6.3	12.0	13.5	2.3	61.5	2.1	5.8	23.2	23.9
Humidity	50.2	65.3	49.7	43.5	43.8	43.7	46.4	43.0	42.0	53.9
Wind Speed	15.5	16.6	15.0	15.5	14.7	10.8	13.0	10.1	9.9	17.6
Air pressure	1,017.7	1,020.6	1,017.2	1,017.7	1,016.9	1,015.5	1,015.4	1,015.4	1,015.8	1,017.0

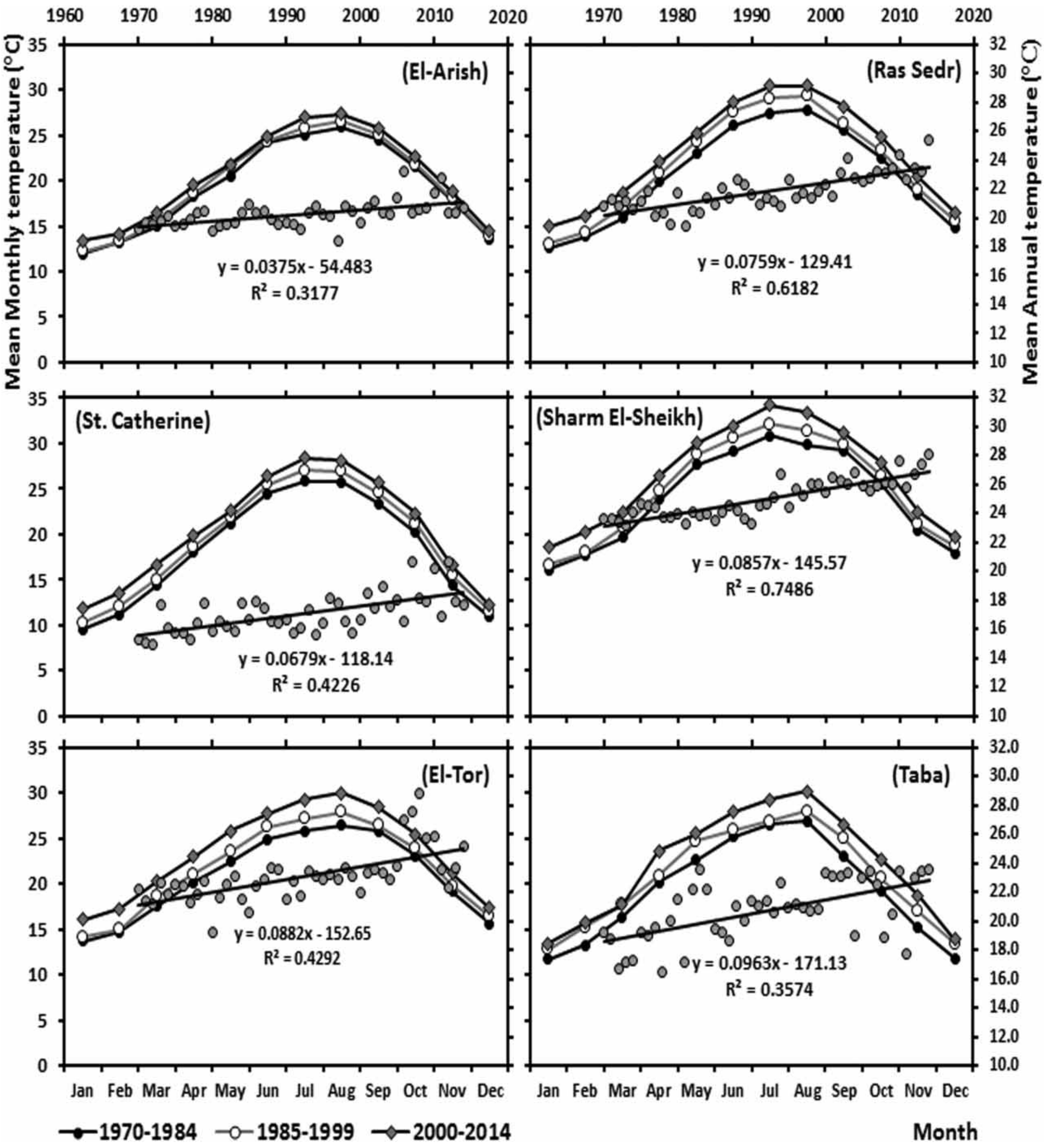

Figure 2 | Trend of mean temperatures (°C) in the studied six regions based on monthly means between 1970 and 2014. Regression is for the annual means on secondary Y (right) and time (years).

precipitation, these peaks also tend to decrease. The average of total annual rainfall ± SE (1970–2014) was 119.8 ± 9.7 (El-Arish), 35.3 ± 4 (St. Catherine), 10.8 ± 2 (Sharm El-Sheikh), 13 ± 2.6 (El-Tor), 26.6 ± 4.7 (Taba), and 19.7 ± 3 (Ras Sedr, 1978–2014). Within the time span of 1970 to 2014, the most striking trend is the severe decline in precipitation (both rain and snow, Figure 4). Based on the analysis of total rainfall during this period, the trend for rainfall is different from that recorded for temperature. In particular, severe declines were recorded for South Sinai, except for one or two wet years (Figure 4; Figure S3, available with the online version of this paper). The slopes of the regression equations and their coefficients are shown in Table 1. The latter values are negative, indicating the decline of total rainfall year after year. On 19 and 20 February 1975, an extreme rainfall event occurred in the El-Arish drainage basin,

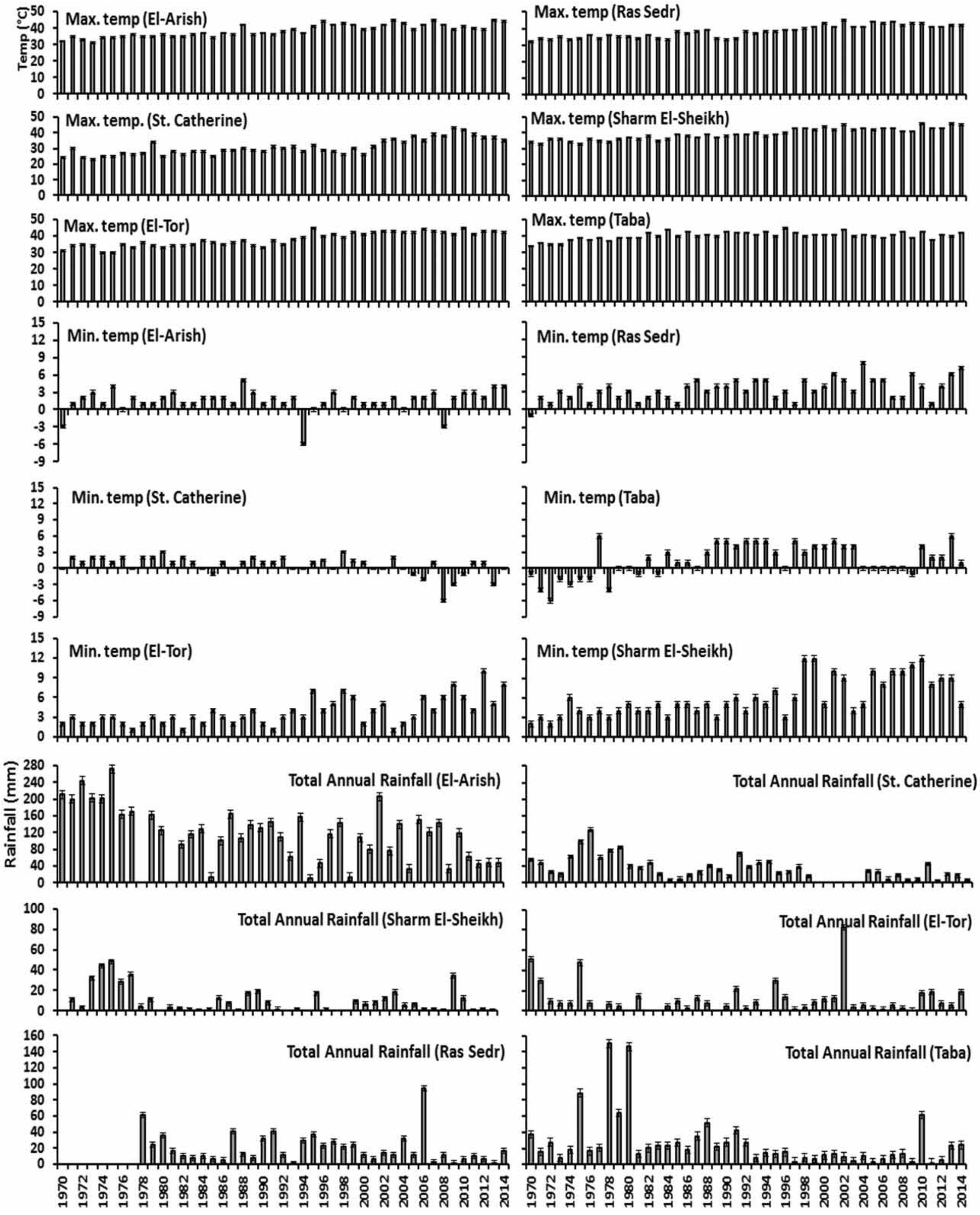

Figure 3 | Extreme values of absolute maximum and minimum temperature and total annual rainfall from 1970 to 2014.

causing an extreme flood flow throughout the Sinai Peninsula except for its northern part. Table 2 shows the total annual rainfall during the last 20 years (1995–2014). Years with unusually high precipitation stick out, like the 205.5 mm measured in 2002 at El-Arish, which is located on the Mediterranean Sea. This is followed by Ras Sedr, where 94.5 mm was recorded in 2006, and 82.6 mm was recorded at El-Tor during 2002. High annual rainfall was

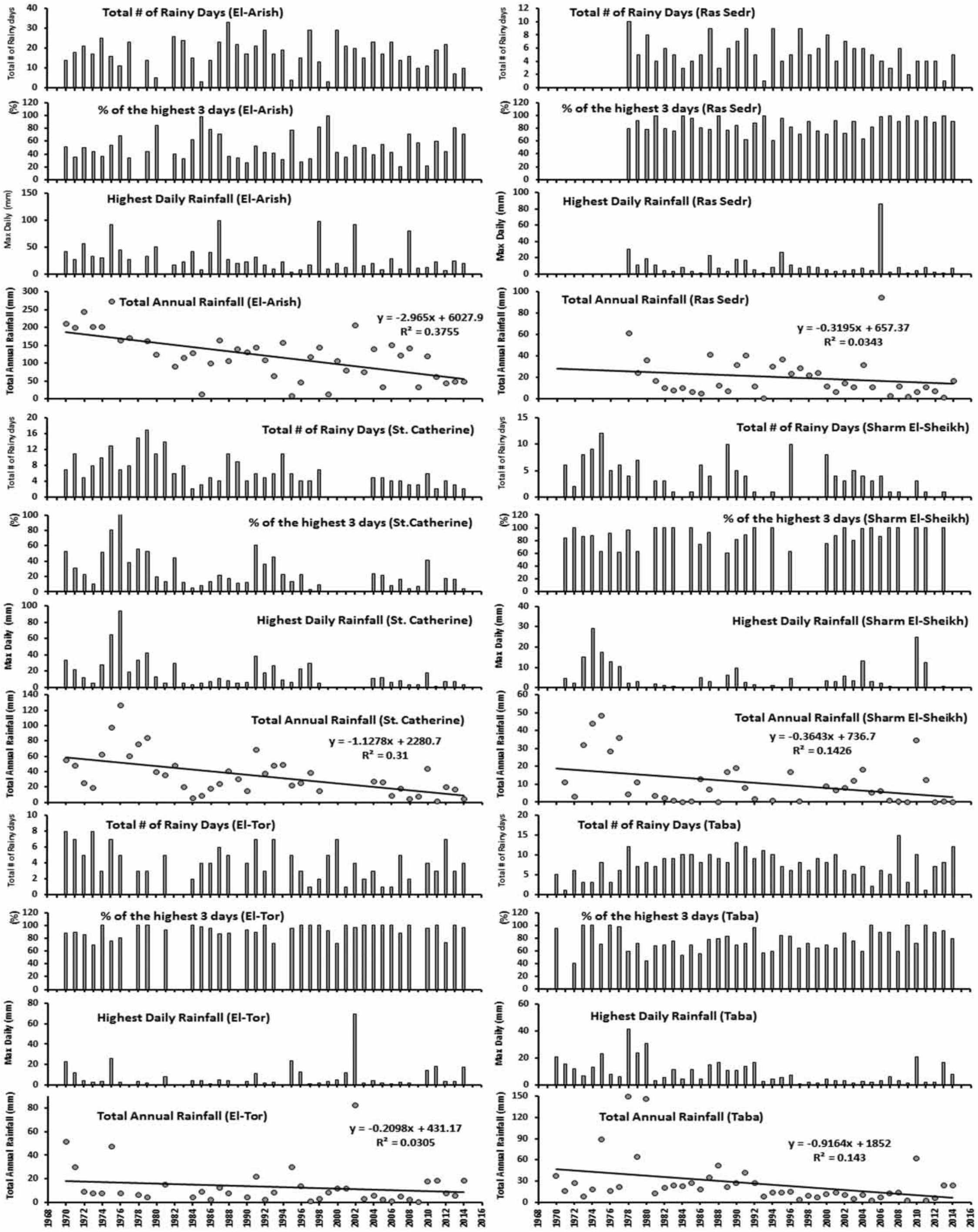

Figure 4 | Trend of annual precipitation (mm) and maximum daily rainfall (mm) from 1970 to 2014 for the stations El-Arish, St. Catherine, Sharm El-Sheikh, El-Tor, Taba, and from 1978 to 2014 for Ras Sedr station, change in the rainfall pattern through decrease in the number and amount of rainy days interrupted by the highest amount of rainfall in one to three days.

also recorded for St. Catherine (44.1 mm) and Sharm El-Sheikh (34.4 mm, both in 2010, Table 2). Based on analyses of daily precipitation, maximum daily figures during the period from 1995 to 2014 were 91.9 mm (18 February 2002, El-Arish), followed by 86.1 mm (1 April 2006, Ras Sedr) and 70.1 mm (3 September 2002, El-Tor).

Moreover, our available few years before 1970 showed that the precipitation was distributed in the months of winter and spring (October to March or April). But, during the years from 1970 to 2014, we reported a change in rainfall pattern as the maximum daily amounts of rainfall are received in one to three days of the year. Figure 4 shows the total number of rainy days. Previously, in El-Arish, the total annual rainfall in 1963 was 163.58 mm, recorded in 20 days, and the highest daily rainfall was 36.07 mm in December. At the same station, the total rainfall/ number of rainy days/ maximum daily record were 117.87 mm/ 27/ 41.91 mm (21 April) in 1964, 171.70 mm/ 23/ 35.05 (12 January) in 1965, and 77.98/ 22/ 20.7 (23 March) in 1966.

RH

Trend for annuals means of RH declined for all regions except in two stations. These stations were El-Arish, which shows a slight increase, and St. Catherine, which is the coldest region in Egypt due its high elevation (Table 1). Highest annual means of RH were recorded at El-Arish in 2006 (76%, Table 2), followed by 65.3% at Taba in the same year. The annual means range between 49 and 58% at Ras Sedr, 21 and 43% at St. Catherine, 35 and 49% at Sharm El-Sheikh, and 43 and 59% at El-Tor as shown in Table 2.

Air PSL

With increasing temperature, the mean air PSL seems to decline (Table 1). During the investigation period (1970–2014), the lowest/highest annual means were around 843/1017 hectopascals (hPa) at El-Arish. They were 1011/1016 at Ras Sedr, 934/1022 at St. Catherine, 1009/1015 at Sharm El-Sheikh, 1009/1012 at El-Tor, and 1015/1022 at Taba (Table 2).

Wind speed

Increasing annual temperatures seem to be followed by a decline in maximum wind speed. Maximum figures (226 km/h) were recorded on 29 December 2010 at St. Catherine, followed by 115 km/h at El-Tor on 6 June 1996, then 108 km/h at Sharm El-Sheikh on 21 July 2000. The extremes of wind speed are usually accompanied by rains with sudden gusts on these days. The maximum wind speed was 85 km/h at El-Arish (23 February 2000). This is followed by 70 km/h at Taba (21 April 2004), and 57 km/h at Ras Sedr (7 March 1996). Much lower maxima were recorded for El-Tor (25.7 km/h), Sharm El-Sheikh (22.1 km/h), and Taba (21.6 km/h, Table 2).

Impact of climate change on biological and natural resources

Although we have data only for single species, the trends in temperature and rainfall are likely to have an adverse impact on vitality and population size of many rare plant and animal species in Sinai (Figure S1). Often, this is overlaid by anthropogenic impact, most prominently overgrazing, the collection of fuelwood and fodder, and fire. Based on global positioning system records, there are numerous coastal regions that may be flooded if the water levels of the Mediterranean and the Red Sea rise in future. One of these regions is Nuweiba, located on the Red Sea coast (Figure 5) at the mouth of W. Watir (Figure S2(d)–(g)). Based on a satellite image, a possible increase in the Red Sea level (according to different scenarios anticipated as around 30 cm, 50 cm, and 1 m) may lead to the disappearance of Nuweiba Port and its surrounding vast floodplain (around 40 km^2). Moreover, saline water may mix with groundwater and reach the water drainage of W. El-Arish (Figure S2). Similar scenarios pose a threat to many coastal cities (Baltim, Damietta, Ras El-Bar, Port Said, El-Manzala,

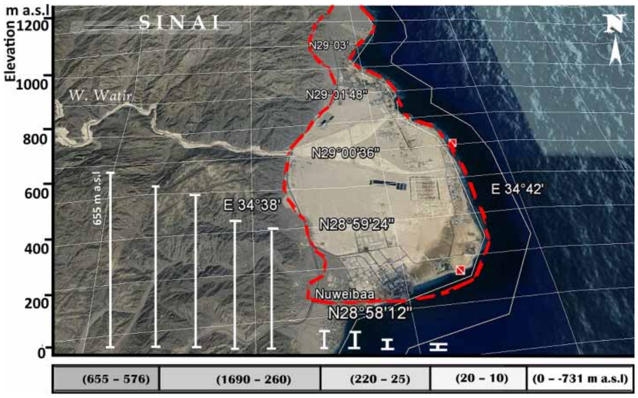

Figure 5 | Satellite image for Nuweiba showing a coastal region that may be affected by an increase in sea level of the Red Sea and flash flooding of W. Watir.

Borg El-Arab, and Alexandria). According to a worst-case scenario, the water may move through the northern delta upwards to reach Damanhour city, El-Mansoura, Shirbin, Kafr El-Sheikh, El-Mahalla El-Kubra, and Tanta.

DISCUSSION

Currently, the human contribution to climate change is a topic of intense debate among scientists. Most researchers believe that climate changes as well steadily due to natural processes, and untangling the complex natural and anthropogenic drivers of climate change is one of the most challenging tasks of future research. One of the main questions is if the anthropogenic causes, like the CO_2-mitigated greenhouse effect, will become the core drivers of future changes. Many other drivers of climate change should be considered, including the increase in the anthropogenic heat fluxes from cities (González-Aparicio *et al.* 2014) and energy balance on the earth. According to the IPCC (1990), an early study declares that the year of 1988 was the warmest year within the last 100 years. Similarly, 1989 was the fifth warmest year in the 134 years with records of global temperature, and six of the ten warmest years on record occurred in the 1980s (Kerr 1990). Climatologists have different opinions on whether the observed increase in average annual global surface temperature (about $+0.6\,^{\circ}C$) over the last century is already a clear indication of greenhouse warming or not (IPCC 1990). Otherwise, is it still within the natural variability of climate or not? There seems little dispute among climatologists that mankind has already significantly influenced the earth's climate (Golitsyn 1989). This influence is through such factors as the urban heat-island impact, intensification of desertification through land degradation, deforestation and stratospheric ozone depletion (IPCC 1990). Some studies assume that global warming will become more severe at higher latitudes, affecting winters to a greater degree than summers (Golitsyn 1989; Schneider 1989). A warmer atmosphere contains more water vapor and upturns the intensity of the entire hydrological cycle, but precipitation trends are likely to change homogeneously in time and space (Golitsyn 1989). Widely discussed, but statistically even harder to ascertain, is the question of whether global warming will increase the likelihood of floods and droughts, and whether it causes stronger storms or typhoons, and severe heat waves (Golitsyn 1989; Hansen *et al.* 1989).

Trends in the climate of the Sinai region

Climate change in our study area does not only affect water resources but may increase the aridity of the area as well by increased evaporation. It will increase desertification; arid and semi-arid environments already occupy around 37% of the earth's surface (United Nations Environment Programme (UNEP) 1992). Around 64% of the arid regions and 97% of hyper-arid deserts are concentrated within Africa and Asia (Dadamouny 2009). The Sinai region, especially its southern part, is now extremely hyper-arid, with a long hot and rainless summer and mild winters. Its climate is affected by the orographic and the tropical impacts of the mountains and the two gulfs (Suez and Aqaba) (see Migahid *et al.* 1959; Zohary 1973; Batanouny 1981; Issar & Gilad 1982; Danin 1983, Danin 1986). Orographic precipitation predominates in southern Sinai, with clouds caught mainly by summits and cliffs. Gorges in the mountains help transport the water to upstream tributaries of the wadi system (Kassas & Girgis 1970). For the duration of this analysis (1970–2014), we reported a trend of decreasing annual precipitation overlaid by extreme events causing unpredictable flash floods. Klein (2000) stated that extreme flood events may occur once in a century or even less frequently. We recorded the first severe flood in North Sinai at El-Arish in 1975 and this was repeated in 1987, 1998, 2002, and in 2008. In South Sinai, although the amount of rainfall is lower than in the north, few extreme days were recorded for the years 1975, 76, 79 and 84 in St. Catherine, or 2002 in El-Tor. During most rainy days, we observed a high wind speed or even storms. A typical front progresses from South Sinai to the northeast. In accordance, our results reveal extreme wind speeds in the southern part of Sinai; particularly around St. Catherine. A single rainstorm contributed the following amounts of rain in the El-Arish drainage basin in 1975: 73 mm at St. Catherine Monastery (south of the basin), and 48 mm at Nakhl (in the central part of the basin, Gillad 1975). It is estimated that the average annual rainfall over the basin was 40–50 mm in this year. Although the northern part of El-Arish basin did not receive significant precipitation (8 mm), the total volume of the flood flow in the basin was estimated at 8×10^8 m^3 in 1975 (Smith *et al.* 1997; Klein 2000). North Sinai, especially the delta of Wadi El-Arish, depends on groundwater as a core resource for drinking water, industrial, and agricultural use. Here, climate change may have a direct impact on groundwater availability (Abdelaziz & Bakr 2012). Extreme rainfall has been recorded as well in earlier years: Dames & Moore (1982) stated one rainy day delivering 76.2 mm in November 1937. However, the average rainfall during the last 30 years did not exceed 44.1 mm at St. Catherine. As such, extreme events contribute a significant amount of the annual precipitation. During the time interval of the current study (1970–2014), the extreme events became more frequent. In agreement with Jay & Naik (2011), the rainfall trend has decreased, and this rainfall pattern behavior may be another indication of climate change. It seems to be a big part of the problem: a few days with extreme rains or flash floods, and most of the water is lost instead of being absorbed by the soils. Abdel-Wahab (2003) and Dadamouny (2009) stated that rainfall at St. Catherine decreased from 60.4 mm in the 1930s to 42.6 mm in the 1990s. But at least the rainfall amount was distributed in the winter and spring months. Thus, the trend for rainfall reflects a change in rainfall pattern, where the majority of the rainfall on Sinai, mostly in the south, is recorded over one to three days only.

In Sinai, increasing temperature coupled with drought are likely to affect plants, wild animals, and Bedouin populations, similar to the expected impacts of rising global temperatures on human health, lifestyles, food production, economic activity, residential and migration patterns (IPCC 1990). Combined with the associated general increase in temperature, changes in atmospheric circulation patterns and the water cycle may affect water availability, agricultural activity, flood protection practices, infrastructure planning, and natural habitats. Since the Sinai Peninsula is neither heavily industrialized nor populated, human influences are most likely to come from the outside, which invokes the full complexity of climate modeling to estimate human effects. Disturbance of the Sinai Peninsula groundwaters and drainage cycles or coastal erosion along the Red and Mediterranean Seas is feared. Many studies (such as Jay & Naik 2002, 2011) have shown a rise in the range of tides throughout most of the eastern Pacific as a result of global climate change and human activities. Human interference through flood control of rivers, water withdrawal, hydropower generation, navigational development, and changes in land use have led to changes in hydrologic trends (Naik & Jay 2011). Another fear is a higher frequency of extreme weather events like droughts, floods, and tropical cyclones. Doubling the effective CO_2 may increase the intensity of tropical cyclones or hurricanes by as much as 40% (Emanuel 1987). Further studies may provide a more reliable estimate of impacts of global warming on tropical cyclone activity (Henderson-Sellers & Blong 1989). Also, a significant rise in global mean sea levels can be expected from the thermal expansion of the upper layers of the ocean and meltdown of glaciers (Howard *et al.* 2013). IPCC scenarios forecast a rise of 9–29 cm over the next 40 years, or 28–98 cm by 2090 (IPCC 1990). An increase of only 25 cm or more in relative sea level would displace many residents of the delta regions of the Nile from their homes and livelihoods (Tickell 1989). This projected sea-level rise will also cause widespread coastal erosion, especially on shallow coasts (Titus 1988; Murday 1989). For a region like Sinai, where most human activities center around the coast and in a few big wadis, this might become a catastrophe.

For the average temperature trend, Sinai increased +2.3 °C based on our analysis of data (1970–2014) (20.3 to 22.6 °C). The same pattern is obtained by applying the General Circulation Model at the Environment & Climate Changes Research Institute in Egypt on the Nile Delta (Equatorial plateau), but with different scenarios. Change in temperature for the Nile Delta (2000–2100) is calculated with various models to be +3.2 °C (CSIRO), +4.3 °C (GFDL), +3.8 °C (GISS), and +4 °C (NCAR) (Abdel-Aziz 2011). As St. Catherine has a more changeable and unique climate than other regions of Sinai, a lot of studies have been concerned with its climate. According to Dadamouny *et al.* (2012), during the period 1979–1992 the lowest monthly mean minimum temperature at St. Catherine ranged from 1.4 in January to 17.5 °C in July. St. Catherine and Nekhel are considered to be the coldest towns in Egypt, together with some settlements in mountainous Sinai. Snowfalls in St. Catherine take place regularly in the winter months (December to February) and occasionally in autumn and spring. From 1934 to 1937, the lowest monthly mean temperature was recorded as −15 °C (Dadamouny 2009), while the highest mean maximum temperature for the same period was 25.8 °C (in August). It then increased during 1979–1992 to 30.8 and 31.8 °C in June and July, respectively (Abd El-Wahab 2003), and to 34.3 °C during 1970–2014. Moreover, the mean annual temperature in St. Catherine during the period 2004–2007 ranges from 16.5 to 18.1 °C (Dadamouny 2009). Within the mountains that surround St. Catherine there are many wadis subjected to climate change (e.g., Feiran, Zaghra, El-Arbaen). The annual rainfall in W. Feiran was recorded as around 50 mm until the end of the 1970s, but from 1980 until now, the wadi has become more arid and annual precipitation has decreased (Dadamouny 2009). The cumulative rainfall during extreme events from the summits draining into W. Feiran causes the most severe floods in Sinai (Abd El-Wahab 1995). For some time, the dry valley becomes a mighty river carrying boulders and gravel. In contrast, W. Feiran is the hottest wadi in southern Sinai, especially in June to August (maximum monthly temperature was 42 °C in June). In winter, temperatures stay well above zero (7 °C, Ramadan 1988). The potential evapotranspiration of St. Catherine was calculated as around 1,750 mm yr^{-1} (Tolba & Gaafer 2003; Cools *et al.* 2012). Finally, humidity or the amount of water vapor in the air is one of the major factors, since the RH has a great impact on the growth performance of many plant and fungal species. It is also an indicator of the probability of precipitation, dew, or fog, and therefore one can use the RH in weather forecasts.

Impact of climate change on biological and natural resources

Obviously, a lack of precipitation has great, difficult impacts on the natural vegetation of South Sinai, where many plant species have disappeared or remain as older individuals only (like the trees *Acacia tortilis*, *Crataegus* × *sinaica* and *Moringa peregrina*) which show low vitality and often lacking recruitment (loss of the ability to establish new, surviving individuals) (Dadamouny 2009). Also, this hampers recruitment (Dadamouny *et al.* 2012). According to Greenwood (1997), the number of species in Sinai deserts is further influenced by the steepness of climatic gradients. To assess the biodiversity response to climate change, Hannah *et al.* (2002) emphasized the need to apply simulation models operating at a regional scale. Moreover, species respond differently to climate change because of different adaptations to their environment (Erasmus *et al.* 2002). As a consequence, single-species models with a regional focus are essential (Tews & Jeltsch 2004) to entirely understand the manifold impacts of global climate change. This is what we want to achieve by recording and forecasting the population size of *Moringa peregrina* as one of the rare plant species in Sinai. However, even though recent simulation tools have occasionally been applied to climate-sensitive animal species (Forchhammer *et al.* 1998; Peterson & Kwak 1999; Saether *et al.* 2000; Wang *et al.* 2002; Wichmann *et al.* 2003), spatial plant population models are extremely rare (Kickert *et al.* 1999). As climate change may put half of the North American bird species at risk of extinction (Shea 2014), the same situation may occur in Sinai. Conservation efforts should be directed to conserve biological resources, and use them in a sustainable way to generate a constant income for local inhabitants. The responses of organisms towards climate change include phenotypic plasticity, genetic adaptation, and dispersal, migration or range shifts (Valladares *et al.* 2014), and these responses need further studies.

Precautionary measures should include the establishment of institutional coastal and biodiversity monitoring capabilities as recommended by El-Raey (2011), and enforcing laws and regulations (El-Raey 2010). Also, consistent coastal zone controlling, raising public awareness of climate risks, and adaptation plans are needed. Based on the first scenario that the sea level may rise around 30 cm, Egypt may lose some parts of its coasts, which extend over 3,500 km. One-third of this distance runs along the Mediterranean Sea from Rafah city in the east to Salloum in the west, and two-thirds along the Red Sea and the coasts of the Sinai Peninsula. This risk would induce a severe economic crisis, considering that about 53% of Egypt's population lives within 100 km of the coasts (EEAA 2006). Also, Egypt has a large number of inland lakes such as Lake Nasser (the largest freshwater lake) and Qarun (the saline lake) in Fayyoum. Already a modest rise in sea level will severely affect most of the people along the coasts of the Mediterranean Sea in Egypt, as expected also in China, particularly in the Pearl River Deltas plain containing the city of Guangzhou (Han 1989). Another problem is the water supply for the local inhabitants in North Sinai and the coastal area of the Suez Gulf. In general, Sinai has three indigenous water sources: rainfall, surface water and groundwater (Anonymous 1985; Zahran & Willis 2009). Most of the water comes from the Nile, which is treated at Port Said. However, the city of El-Tor and most of South Sinai depend on groundwater. The coastal area of the Gulf of Aqaba depends on desalinated water. At the same time, the northern strip of Sinai has received the highest amount of rainfall (300 mm/yr, Abdel-Wahab 2003). According to Hammad (1980), the amount of rainfall southward was (25 mm/yr). With the increase in the sea level, the amount of groundwater is subject to decline, and this is the minimum impact of climate change. Without an effective program for coastal protection, a minimal sea-level rise is likely to affect many coastal cities (Port Said, Damietta, and Alexandria) and those of the northern delta (Kafr El-Sheikh, Tanta, and El-Mahalla El-Kubra). Unfortunately, Egypt is thought of as one of the countries most susceptible to the pronounced adverse impacts of climate change (El-Raey 2010). Recent efforts to understand and mitigate the enormous impacts of climate change involve the development of Egypt's climate change action plan. This also includes Egypt's national communication on climate change and seeking support from international donor authorities and organizations (Egyptian Environmental Affairs Agency (EEAA) 1999). Moreover, an early warning system for flash floods has been developed for parts of the Sinai Peninsula to understand the response of the wadi to rainfall and observed flash flood events by Cools *et al.* (2012) and Eissa *et al.* (2014). A key factor is protective dams in wadis to protect settlements from flooding, mudflows from sediments and rubble supplied by intense physical weathering in the deep gorges. It is reported that scant rainfall on the mountains is one of the main water resources in southern Sinai, which runs over the slopes and collects in narrow-deep wadis forming perpetual streams and rivulets (Zahran & Willis 2009). But the excess water in the rainy years could percolate and store in rock crevices (Abd El-Ghani & Amer 2002). Outside of the focus of this study are possible impacts on the delta of the Nile River by sea-level rise and saltwater intrusion. Scenarios of sea-level rise by one meter by 2050 as a result of global warming are estimated to extinguish about one-third of the Nile Delta (Tsimplis & Shaw 2010; Calafat *et al.* 2012; IPCC 2013).

Proposed solutions

Egypt has ratified a number of multilateral environmental agreements and already has certain national level environmental plans that intersect with responses that might be required to manage climate variability and long-term climate change. We would like to emphasize the following points. (1) Public awareness and concern for environmental problems are growing, but the complexity of the problems and the uncertainty about many basic data quite often make discussions inconclusive; even indications issued by scientific authorities are sometimes misleading, and the problems are exacerbated by the frequent influence of ideological positions (Wu & Sardo 2010). Therefore, we recommend increasing public awareness in dealing with climate change issues. (2) To keep pace with the requirements of population growth, agricultural production has to increase by 70% by 2050 as recommended by El-Ramady *et al.* (2013). The big challenge will be to reconcile this growth with the conservation of the environment, simultaneously reducing the risks associated with increasing emissions of greenhouse gases and pollution with heavy metals (Aune 2012). (3) Egypt is a sunny country. Thus, solar energy has a high potential for use in water desalination, air conditioning, refrigeration and other requirements of life. (4) The increase in wind speed on the coastal line and in South Sinai (El-Tor, Sharm El Sheikh, and St. Catherine) is another source of renewable energy (windmills). (5) The dykes and protective measures on the sea coasts may help to overcome the sea-level increase, but could cause groundwater salination. (6) Establishing a number of desalination stations along the coasts of the Mediterranean Sea and Red Sea should be considered. (7) Economic development may be fostered by establishing the New Suez Canal. This is a proposed waterway parallel to the existing Suez Canal, which is the shortest shipping route between Europe and Asia (164 km long in 1869 and 193.3 km long in 2010). The New Suez Canal is expected to be only 72 km long, but requires 35 km of new trenches, 37 km of expansion, and deepening of the existing canal. Also, it requires the widening of the Great Bitter Lakes bypasses and Ballah bypass. The new canal between the Red Sea and the Mediterranean Sea may be a measure to accommodate the increase in sea level on both coasts.

CONCLUSION

Sinai is characterized by an extremely arid climate, with pronounced extremes in both temperature and rainfall, sparse vegetation, rare fauna, and precious natural resources. Our study evaluated daily weather records between 1970 and 2014 in six regions in Sinai (El-Arish, Ras Sedr, St. Catherine, Sharm El-Sheikh, El Tor, and Taba). As the climate model is based on many mathematical equations controlled by physical laws, it shows more detailed specifications on the climate of a particular location with lower errors. However, here we simply used the actual trend based on the datasets measured by authorized stations, to reveal the previous and the current status of Sinai climate. Based on the regression equations, we found trends of decreasing precipitation combined with increasing temperature (an average increase of $+2.3\,^{\circ}\mathrm{C}$ from 1970 to 2014), which will increase the level of aridity. In addition, extreme events, like flash floods, seem to become more frequent and unpredictable after long years of drought, carrying a significant amount of TP. These events occur in an unpredictable manner, and vary locally as convective rains. These pathways could continue within the same trend to reach the forecast values in the upcoming years (for example, temperature in 2050) or could be interrupted by a new change that could return the weather parameters to the normal pathways (less frequent). Not only our study area, but also the whole of Egypt requires more studies to build an appropriate model that could match the global pathways, or at least differ locally in space and time. Based on the extreme values during recent decades, the trend of temperature in Egypt and the Arabian Peninsula could exceed our forecasting. Also, scarcity of rainfall for many years could negatively affect the growth of wild and medicinal vegetation. During recent decades, we recorded unusually high rainfall (like 205.5 mm in 2002) at El-Arish on the Mediterranean Sea. This is followed by Ras Sedr (94.5 mm in 2006) and El-Tor (82.6 mm in 2002). These amounts are recorded for one to three days of the year, demonstrating another problem: that a high amount of rainfall in Sinai doesn't normally distribute across the months of the winter season. Extreme rainfalls or flash floods could harm important locations in Sinai, like the flood of February 1975 at El-Arish drainage basin and the flood of 2010 at St. Catherine. Therefore, it is important to establish protective dams in many areas of the Sinai, like the Watir, Zaghra, and El-Arbaeen wadis, to protect settlements and also natural and biological resources. As a result of an expected increase in the sea level, parts of the Egyptian coasts with low elevation above sea level may be lost. This may include the Nuweiba area on the Red Sea, and many cities on the Mediterranean Sea and in the north of the delta. Consequently, a second canal between the Red Sea and the Mediterranean Sea at an appropriate depth could help to accommodate the increase in sea levels, and more studies on this are recommended. Care efforts should be directed to conserving biological and natural resources and keeping pace with climate change.

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