Temporal trend of diarrhea morbidity rate with climate change: Egypt as a case study

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RESEARCH ARTICLE

Temporal trend of diarrhea morbidity rate with climate change: Egypt as a case study

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Abstract

Many studies have detected a relationship between diarrhea morbidity rates with the changes in precipitation, temperature, floods, droughts, water shortage, etc. But, most of the authors were cautious in their studies, because of the lack of empirical climate-health data and there were large uncertainties in the future projections. The study aimed to refine the link between the morbidity rates of diarrhea in some Egyptian governorates representative of the three Egyptian geographical divisions with the meteorological changes that occurred in the 2006–2016 period for which the medical data are available, as a case study. Medical raw data was collected from the Information Centre Department of the Egyptian Ministry of Health and Population. The meteorological data of temperature and precipitation extremes were defined as data outside the 10th–90th percentile range of values of the period of study, and their analysis was done using a methodology similar to the one recommended by the WMO and integrated in the CLIMDEX software. Relationships between the morbidity rates of diarrhea in seven Egyptian governorates and the meteorological changes that occurred in the period 2006 to 2016 were analyzed using multiple linear regression analysis to identify the most effective meteorological factor that affects the trend of morbidity rate of diarrhea in each governorate. Statistical analysis revealed that some meteorological parameters can be used as predictors for morbidity rates of diarrhea in Cairo, Alexandria, and Gharbia, but not in Aswan, Behaira, and Dakahlia where the temporal evolution cannot be related with meteorology. In Red Sea, there was no temporal trend and no significant relationships between the diarrhea morbidity rate and meteorological parameters. The predictor meteorological parameters for morbidity rates of diarrhea were found to be depending on the geographic locations and infrastructures in these governorates. It was concluded that the meteorological data that can be used as predictors for the morbidity rate of diarrhea is depending on the geographical location and infrastructures of the target location. The socioeconomic levels as well as the infrastructures in the governorate must be considered confounders in future studies.

Keywords Climate Change · Diarrhea · Meteorological parameters · Extreme atmospheric temperature · Extreme precipitation

Introduction

Climate change is an emerging public health emergency. The direct health impacts of climate change are associated with the increase in the frequency and intensity of heat waves, extreme precipitation events, floods, droughts, and fires. Attention has also been paid to indirect effects related to environmental disturbances such as crop failures, shifting patterns of disease vectors, and increases in the burden of diarrheal disease (Smith et al. 2014). Many national and international reports from the Egyptian Environmental Affairs Agency (EEAA), as well as international publications, proved that Egypt is vulnerable to climate change. Some predicted hazards related to climate change in Egypt include floods, droughts, and water shortage. The salinization of underground water and estuaries in coastal areas resulting from the rising of the sea level may cause contamination of public water supplies and encourage unhygienic

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practices (Egypt Third National Communication 2016). Moreover, considering both RCP4.5 and RCP8.5 scenarios, the daily maximal and minimal temperatures were increased by 1.3 ± 0.1 and 1.3 ± 0.3 °C, respectively, during the period 2006–2016, and about 80% of the days in a year would be hotter than the 90th percentile of the reference period (2006–2015), and the annual precipitation detected to have a significant decrease (Mostafa et al. 2019).

In a context of generalized climate warming, the Mediterranean and, particularly, its east basin are "hot spots" of climate change (Kim et al. 2019), which means that the surrounding countries will undergo in the next decade dramatic environmental changes to which they will have to adapt. In addition, the megacities of the area constitute hot spots of air pollution affecting air quality, climate, and ecosystems not only locally but also at the largest scale of the whole East Mediterranean region (Myriokefalitakis et al. 2011).

There is much evidence that the incidence of water- and foodborne illnesses can be affected by climate change, and this is linked to the fact that warm temperatures favor bacterial growth. Moreover, the WHO reported that diarrheal diseases are directly influenced by climate change due to the occurrence and the survival of bacterial agents, toxic algal blooms in water, and viral pathogens, in addition to lack of safe water that can compromise hygiene (WHO 2012).

Several studies have been carried out to identify how diarrhea rates change with the changes in precipitation, temperature, floods, droughts, water shortage, etc. Chou et al. (2010) found that changes in the maximum temperature and extreme rainfall were strongly related to diarrhea-associated morbidity, especially among children (0–14 years) and the elderly (40–64 years). A study in China revealed that diarrhea incidence increased with increase in temperature and relative humidity (Yang et al. 2021). The latter authors also found that a 1 °C rise in temperature increases the rates of diarrhea cases by 5.6%. A recent study in Nepal estimated an increased risk of 4.4% in diarrheal disease cases among children under 5 years of age per a 1 °C rise in mean temperature (Dhimal et al. 2022). Similar positive associations between temperature and diarrhea have been reported from Latin America and Africa (Musengimana et al. 2016; Thiam et al. 2017; Checkley 2000). Several previous studies considered weather variables only, although other factors such as water supply and sanitation, population density, socioeconomic status, and level of development may play an important role in predicting the occurrence of diarrhea (Gasana et al. 2022). Despite the published results, most of the authors were cautious in their studies. Because of the lack of empirical climate-health data, there were large uncertainties in the future projections.

This study aims to refine the link between the morbidity rates of diarrhea in some Egyptian governorates representative of the three Egyptian geographical divisions with the meteorological changes that occurred in the 2006–2016 period for which the medical data are available, as a case study. The specific objectives of the present study were to (1) quantify the annual trends of the diarrhea morbidity rate in Egypt for the period of the availability of the medical data (from the years 2006 to 2016) and (2) identify the most significant meteorological parameters affecting diarrhea in seven representative governorates.

Materials and methods

Study design

This study is a retrospective descriptive study of the diarrhea morbidity rate in some Egyptian governorates representative of the three Egyptian geographical divisions with the meteorological changes that occurred in the 2006–2016 period (Fig. 1).

Setting of the study

Egypt has around 27 governorates, themselves divided into 3 divisions according to climate and social criteria: Upper Egypt, Lower Egypt, and Frontier. Aswan is representing Upper Egypt; Behaira, Dakahlia, and Gharbia represent Lower Egypt; and Alexandria and the Red Sea represent Frontier. Greater Cairo consists of three governorates (capital Cairo, Giza, and Qalubia). Moreover, Greater Cairo is considered one of the most densely populated megacities in the world.

Meteorological data

In this study, we use the assimilated ERA-Interim (Berrisford et al. 2011) daily data (maximal and minimal temperatures, precipitations) of the period 2006–2016 for which the parallel medical data are available. The meteorological observations have been performed routinely for decades by the EMA in its network of surface stations. As these data were not distributed to the large public and therefore rarely used, an effort was made recently to check the quality of the hourly meteorological measurements performed from 1 January 2004 to 31 December 2010 at 8 of the EMA stations (Korany et al. 2016). These high-quality data were then deposited in a public repository (https://www.pangaea.de/) from which they can be downloaded at no cost. The datasets contain the hourly values of the air temperature from which the maximum temperature (*Tmax*) and minimum temperature (*Tmin*) can be extracted, but not the precipitation. In this study, we have not retained the stations located in areas with a very low population density and only selected governorates. Note that this consistency is not ensured for variables

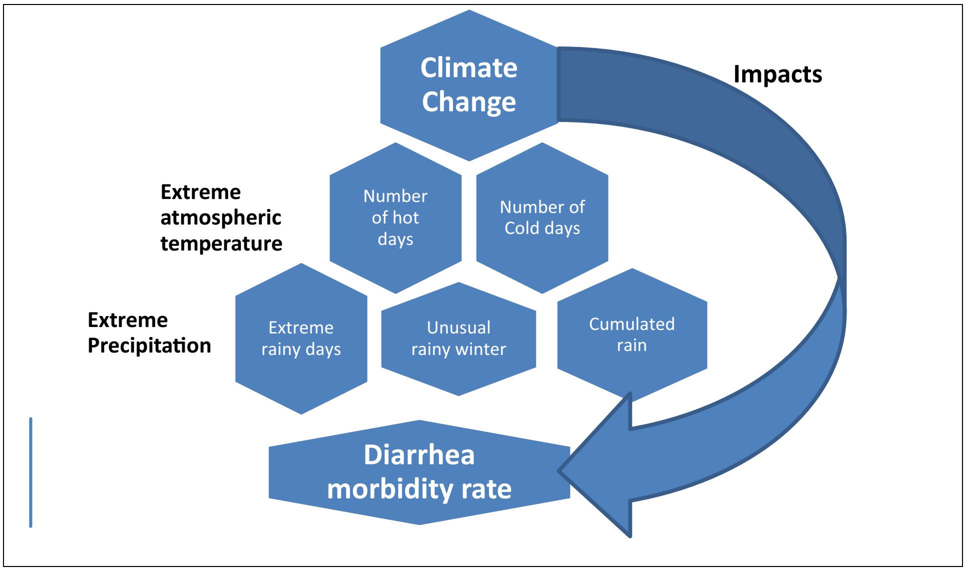


Fig. 1 Study design

that are not assimilated but modeled, such as temperature and precipitation extremes (Sillmann et al. 2013).

Therefore, reanalysis uses a forecast model to assimilate and compare observations of various types and from multiple sources, thus becoming able to extrapolate information from locally observed parameters to unobserved parameters at nearby locations (Dee et al. 2011). The daily precipitation and *Tmax* and *Tmin* at 2 m necessary for this study were extracted using the ECMWF web user interface (http://apps.ecmwf.int/datasets/data/interim-full-daily/levtype¼sfc/) for the included governorates from 2006 to 2016. As shown in a companion paper (Mostafa et al. 2019), sub-regional differences of climate variability can be evidenced in Egypt. Temperature and precipitation extremes are defined as data outside the 10th–90th percentile range of values of the period of study (Frich et al. 2002), and their analysis is done using a methodology similar to the one recommended by the WMO and integrated in the CLIMDEX software (Donat et al. 2013).

Medical data

The raw medical data for the 2006–2016 periods were collected from the Information Centre Department of the Egyptian Ministry of Health and Population (MOHP). The yearly population data for each governorate were obtained from the data published in the CAPMUS reports. The yearly diarrhea morbidity rates of each governorate were obtained by dividing the number of cases of diarrhea recorded by MOHP by the total population, and multiplying these results by 100,000 yields the yearly prevalence of diarrhea in 100,000 populations in each governorate. These calculated values of the diarrhea prevalence were verified by comparison with the data published for the whole Egypt in the WHO annual statistical reports.

Statistical analysis

The collected data and the calculated morbidity rates were digitalized. Statistical analysis was done through SPSS version 20. Pearson's correlation coefficient was used to quantify the temporal trend of the incidence of diarrhea and the relationships between this incidence and the meteorological parameters. The multiple linear regressions were used to identify the most effective meteorological parameters, in the form of the effects of time in years and the meteorological variables (extreme hot and cold days, unusual rainy winters, extreme rainy days, and cumulative rain), that affect the trend of the morbidity rate of diarrhea in each governorate (Fig. 2).

Results

Figure 3 shows the trend of the diarrhea morbidity rate in Egypt between 2006 and 2016, which was significantly increasing with the time during the period 2006–2016 in Egypt ($r = 0.4$, $P < 0.05$). It increased slowly from 2006 to 2011, reached a high point in 2012, and then markedly increased in the year 2016.

Figure 4 shows that the diarrhea morbidity rates were increased in most governorates, and suggests that, except in Aswan and the Red Sea, this increase was positively correlated with the cumulative rain, number of extreme rainy days, and number of extreme hot days.

The results of the statistical analysis (Table 1) show that there was a significant temporal increase of the number of

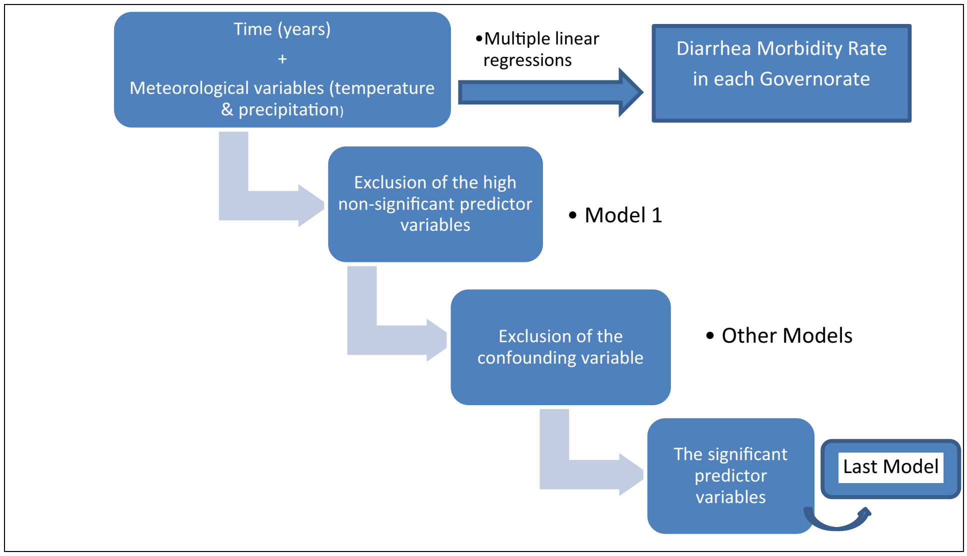


Fig. 2 Statistical analysis

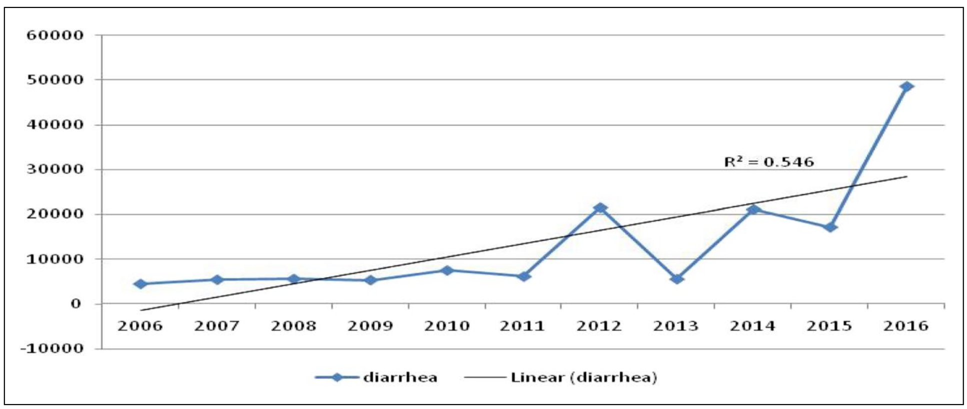


Fig. 3 Trend of diarrhea morbidity rate in Egypt during the period 2006–2016

extreme rainy days in Greater Cairo and of the number of hot days in Alexandria, Dakahlia, Behaira, and Gharbia, and a decrease of the number of cold days in Greater Cairo, Dakahlia, Behaira, and Gharbia. Conversely, there was no significant correlation between time and meteorological variables in Aswan and Red Sea Governorates.

Table 2 shows that the incidence of diarrhea in Greater Cairo Governorate was significantly correlated with years, extreme rainy days, and unusual rainy winters in the statistical model (2 and 3). After the removal of the effects of the numbers of extreme cold and hot days (model 4), it becomes clear that the morbidity rate of diarrhea was significantly affected by the extreme rainy days and the number of unusually rainy winters.

In Alexandria (Table 3), the morbidity rate of diarrhea was significantly affected by the number of extreme hot days, and this significance increases after exclusion of the effects of the other meteorological factors and of time (model 6).

In Aswan (Table 4), the morbidity rate of diarrhea was significantly affected by years only in all the models (models 1–5), and this significance increases with the removal of the meteorological factors. Therefore, there was no significant effect of the meteorological parameters on the incidence of diarrhea at this location.

In Behaira also (Table 5), the morbidity rate of diarrhea was significantly affected by years only (models 5 and 6), and this effect became significant only after removal of the effects of the meteorological parameters. Thus, there was no significant effect of the meteorological parameters on the incidence of diarrhea.

Table 6 shows that the morbidity rate of diarrhea was significantly affected by years only in all models (models 1–5) in Dakahlia Governorate, and this significant effect was increased with the removal of the effects of the meteorological parameters. Here also, there were no significant effects of the meteorological parameters on the incidence of diarrhea.

In Gharbia Governorate, the morbidity rate of diarrhea was significantly positively correlated with the number of extreme hot days (model 6), after exclusion of the statistical effects of the years and other meteorological factors (Table 7).

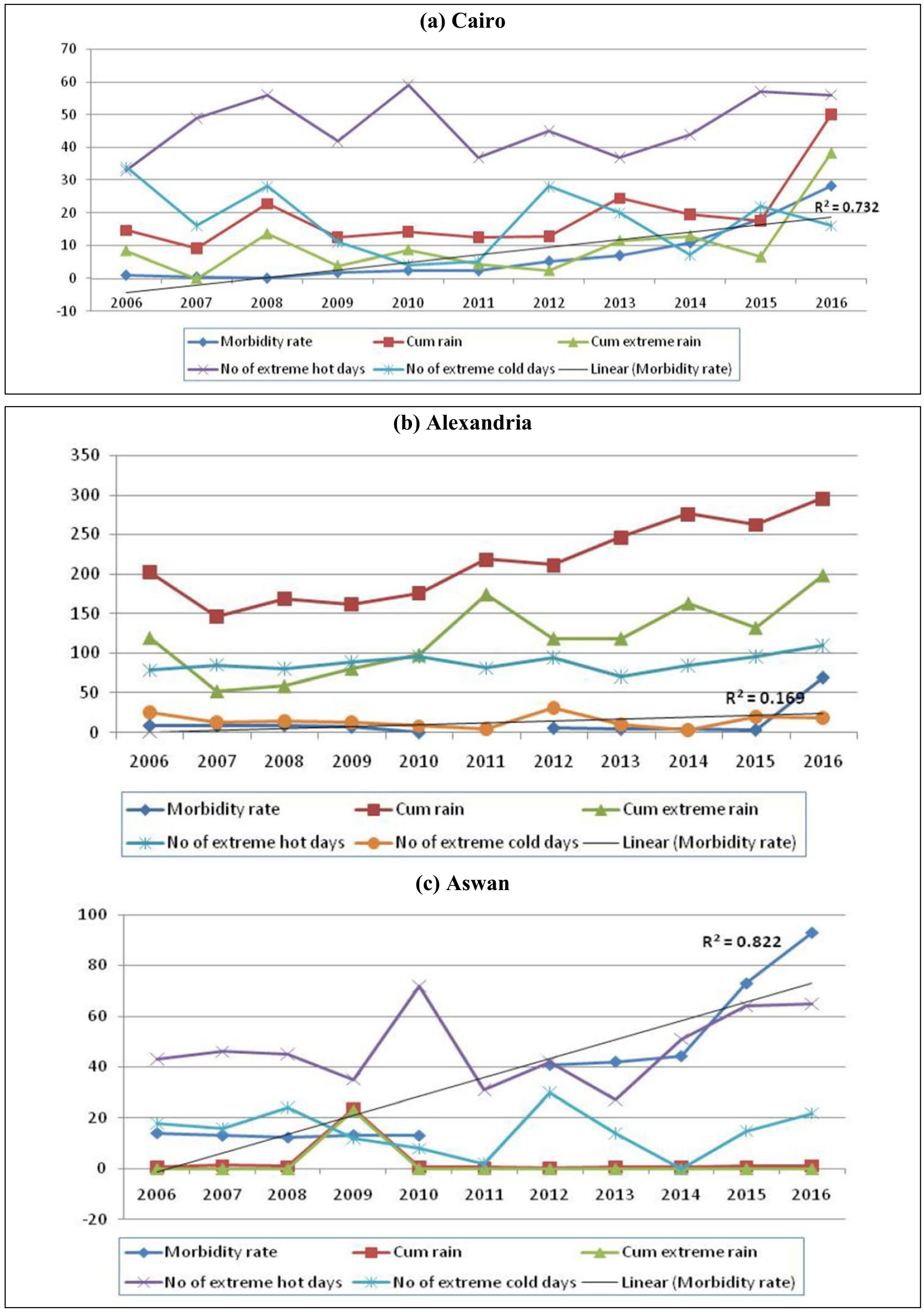


Fig. 4 Trends of diarrhea morbidity rate and some meteorological factors in a selection of Egyptian governorates. **a** Cairo. **b** Alexandria. **c** Aswan. **d** Behaira. **e** Dakahlia. **f** Gharbia. **g** Red Sea

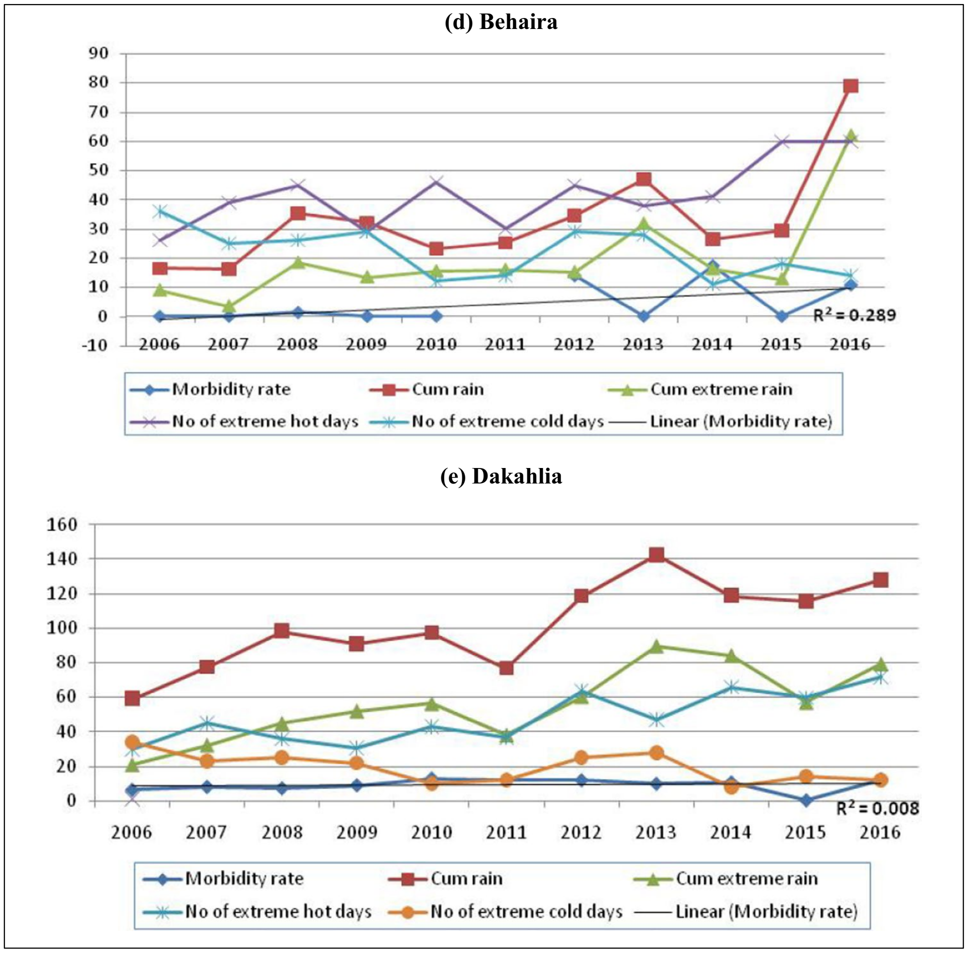
Finally, in Red Sea Governorate, there was no significant correlation between the morbidity rate of diarrhea and either the years or the meteorological parameters (Table 8).

Table 9 summarizes the relationships of the diarrhea morbidity rate and the meteorological parameters. Extreme rainy days and the unusual rainy winter were significant predictors for the diarrhea morbidity rate in Cairo, while the number of hot days was a significant predictor for the morbidity rate in Alexandria and Gharbia Governorates. There were no meteorological predictors for diarrhea morbidity in the other governorates, while the time factor was a significant predictor for the morbidity rate of diarrhea in Aswan, Behaira, and Dakahlia.

Discussion

Climatic change and the increased number of associated extreme weather events have been shown to affect significantly seasonal diarrhea in susceptible populations. For

Fig. 4 (continued)



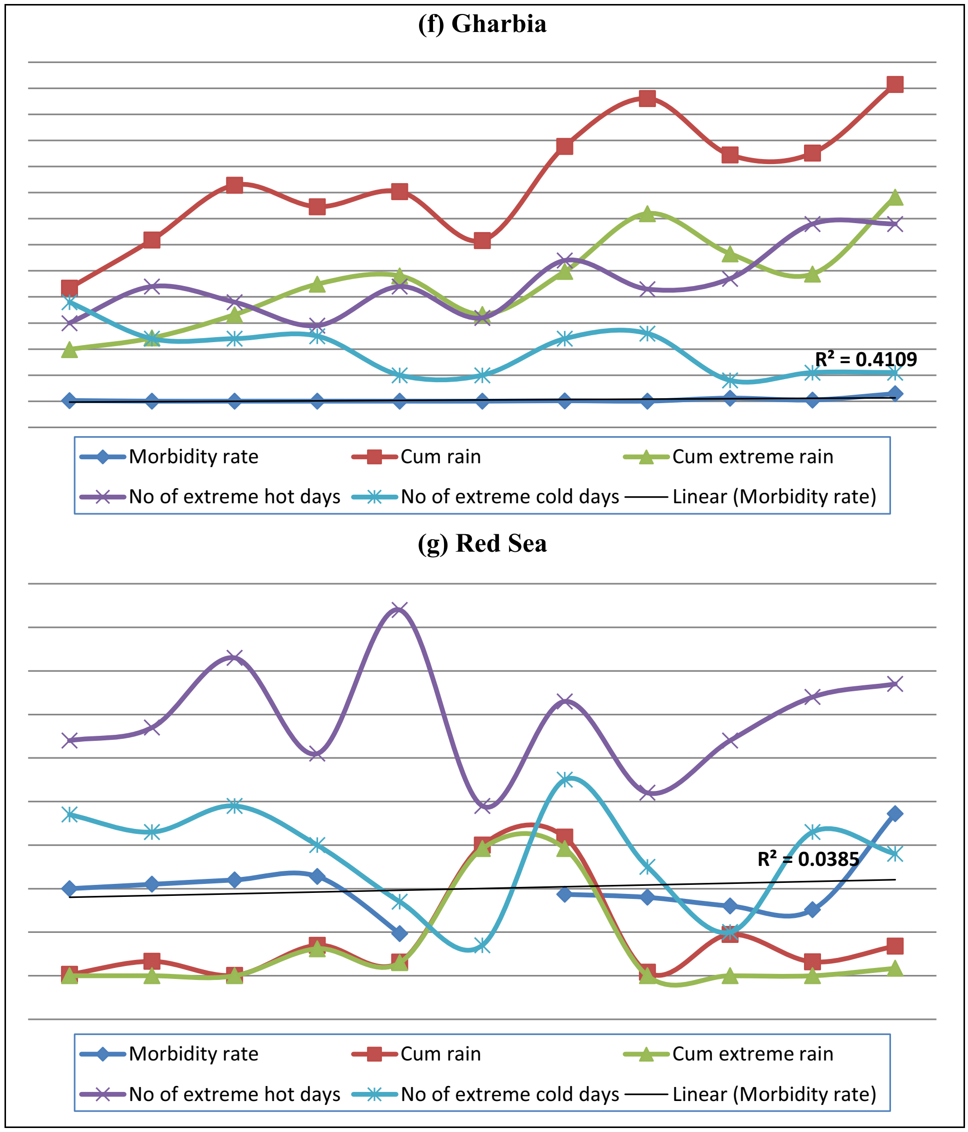
instance, Hashizume et al. (2007) studied the association between climate variability and hospital visits for non-cholera diarrhea in Bangladesh and they found evidence that there was a relation between the frequency of the visits and climatic variations. Moreover, they expected that future climate change would exacerbate diarrhea. Diarrhea is a climate-sensitive health problem, and therefore expected to become worse in a changing climate (WHO Fact Sheet No. 266 2012; Egypt Third National Communication 2016).

The statistical analysis of the Egyptian medical data shows that the morbidity rate of diarrhea among children under 5 years decreased between 2000 and 2008 as a result of the application of the rehydration health campaign program (El-Zanaty and Way 2009; Mansour et al. 2013). However, there have been suggestions that climate change in Egypt would make this reduction in diarrhea morbidity rate difficult to maintain (Egypt Third National Communication 2016), and this particularly after the stop of the rehydration health campaign program. This may already explain the increase in the morbidity rate of diarrhea detected in the present study, and there is an expectation that this increase will continue as climate change proceeds.

There is much evidence that climate change has already affected Egypt, but its impacts differ from one Egyptian governorate to the other (Mostafa et al. 2019). These spatial differences are confirmed by the present study. In Greater Cairo, a significant increase of the number of extreme rainy days and a decrease of the number of cold days have been detected. The number of hot days was also found to increase significantly in Alexandria, Dakahlia, Behaira, and Gharbia, and the number of cold days to decrease in Dakahlia, Behaira, and Gharbia. However, there was no significant temporal trend of the meteorological variables in Aswan and Red Sea Governorates.

The hazards related to climate change in Egypt include floods, droughts, water shortage, and an increased salinity of groundwater and estuaries in coastal areas due to the sea level rise (SLR). This may cause contamination of public water supplies and encourage unhygienic practices (Egypt Third National Communication 2016). From Fig. 4, it can be seen that diarrhea morbidity rates have increased with the increase in cumulative rain, number

Fig. 4 (continued)



of extreme rainy days, and number of extreme hot days in most governorates, except in Aswan and the Red Sea. This could be attributed to a climate effect because meteorological parameters did not change significantly in these two governorates.

In order to achieve the objective of our current study, backward linear regression models were applied to disentangle the effects of the climate variables on the diarrhea morbidity rate. The proposed models include a variety of climate factors (numbers of extreme hot, cold, and rainy days; unusual rainy winters; and cumulated rainfall per year) that have a potential influence on the time trends of diarrhea morbidity rates in our selection of Egyptian governorates.

The results of Chou et al. (2010) indicate that maximum temperature and extreme rainfall days have the strongest effect on diarrhea-associated morbidity. In the present study, the effects of meteorological factors on the diarrhea morbidity rate were found to be varied with the geographic location of the governorate. *In Greater Cairo*, the morbidity rate was significantly affected by the cumulative extreme rain and number of unusually rainy winter days after the removal of the effect of numbers of extreme cold and hot days (Table 2). Extreme events of unusual rainy winters may result in accumulation of water especially if there is no well-prepared infrastructure to manage it. These cumulative extra rains may lead to contamination of the sources of drinking water. Wolf et al. (2014) reported that extreme events of floods may flush contaminations into drinking water, deteriorating the quality of local water sources and increasing diarrheal risk. Moreover, Liu et al. (2018) defined that

Table 1 Relationship of the temporal trends of some meteorological variables in a selection of Egyptian governorates (the period considered is 2006–2016)

Gov.	Statistical test	Cumulated rain (mm)	Extreme rainy days (days/year)	Unusual rainy winter (days/year)	No. of hot days (days/year)	No. of cold days (days/year)
Cairo	Pearson Correlation *(r)*	.286	0.8	.025	.445	-.642
	Sig. (2-tailed)	> 0.05	< 0.001	> 0.05	> 0.05	.005
Alexandria	Pearson Correlation *(r)*	.540	.413	.000	.647	-.439
	Sig. (2-tailed)	> 0.05	> 0.05	> 0.05	.005	> 0.05
Aswan	Pearson Correlation *(r)*	-.054	.015	.140	.243	-.212
	Sig. (2-tailed)	> 0.05	> 0.05	> 0.05	> 0.05	> 0.05
Behaira	Pearson Correlation *(r)*	.454	.440	-.169	.679	-.801
	Sig. (2-tailed)	> 0.05	> 0.05	> 0.05	.003	< 0.0001
Dakahlia	Pearson Correlation *(r)*	.464	.429	-.466	.753	-.729
	Sig. (2-tailed)	> 0.05	> 0.05	> 0.05	< 0.0001	.001
Gharbia	Pearson Correlation *(r)*	.492	.488	-.301	.709	-.798
	Sig. (2-tailed)	.05	.05	> 0.05	.001	< 0.0001
Red Sea	Pearson Correlation *(r)*	.363	.264	-.221	.010	-.190
	Sig. (2-tailed)	> 0.05	> 0.05	> 0.05	> 0.05	> 0.05

economic levels were modifiers for the impact of floods on diarrhea in the regions with low economic levels.

But, in *Alexandria* (Table 3) and *Gharbia* (Table 7), morbidity rates of diarrhea were significantly affected by the number of extreme hot days, and the significance of the correlation was increased after exclusion of the effects of the other meteorological factors as well as the time trend (model 6). This was explained by WHO Fact Sheet No. 266 (2012). It was reported as a fact that diarrheal diseases due to water- and foodborne diseases are directly affected by the rise in temperature due to climate change, which will affect the occurrence and the survival of bacterial agents, toxic algal blooms in water, and viral pathogens, and the lack of safe water for domestic uses and hygiene.

Chou et al. (2010) noted that the impact of the maximum temperature on diarrhea-associated morbidity was prominent among children (0–14 years) and older adults (40–64 years). These age groups are generally considered being the most vulnerable to climate change (Egypt Third National Communication 2016), but further investigation is still needed to determine exactly which age classes are the most at risk in Egypt.

In *Aswan* (Table 4), the diarrhea morbidity rate increased significantly with time only in all the models, from model 1 to model 5, and the significance was increased with the removal of the meteorological factors. Therefore, the meteorological parameters in this governorate proved to have no particular role on the morbidity rate of diarrhea, but this could be due simply to the fact that no significant change of these parameters was detected during the studied period.

In *Behaira*, the time trend was the only significant predictor to the morbidity rate of diarrhea in model 5 and model 6, and this significance was not detected in models 1 to 4 after the removal of the effects of the meteorological variables (Table 5). Therefore, climatic variables were considered confounders decreasing the significant predictor effect of the time trend for the morbidity rate of diarrhea in *Behaira*. Therefore, the significant increase of extreme hot days and the significant decrease in the extreme cold days are not the main predictor for diarrheal morbidity rates in this Egyptian governorate. Other confounders, such as the availability of health facilities in the form of stopping of rehydration program, sanitation, hygiene, and illiteracy, may have a significant role

Table 2 Multiple regression between diarrhea and climate factors in Greater Cairo (the period considered is 2006–2016)

Gov.	Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
			B	Std. Error	Beta		
Cairo	1	(Constant)	-140178.846	77607.707		-1.806	.101
		Year (years)	68.490	38.722	.312	1.769	.107
		Cumulated rain (mm)	27.382	64.799	.244	.423	.682
		Extreme rainy days (days/year)	79.461	69.285	.635	1.147	.278
		Unusual rainy winters (days/year)	610.126	148.536	.547	4.108	.002
		No. hot days (days/year)	14.755	15.737	.119	.938	.371
		No. cold days (days/year)	24.874	17.562	.237	1.416	.187
	2	(Constant)	-153157.114	68559.148		-2.234	.047
		Year (years)	75.042	34.132	.342	2.199	.050
		Extreme rainy days (days/year)	107.950	15.374	.863	7.021	.000
		Unusual rainy winters (days/year)	600.700	141.263	.539	4.252	.001
		No. hot days (days/year)	15.079	15.120	.122	.997	.340
		No. cold days (days/year)	26.981	16.199	.257	1.666	.124
	3	(Constant)	-171744.754	65962.173		-2.604	.023
		Year (years)	84.631	32.742	.386	2.585	.024
		Extreme rainy days (days/year)	109.867	15.250	.878	7.204	.000
		Unusual rainy winters (days/year)	601.329	141.229	.539	4.258	.001
		No. cold days (days/year)	25.856	16.156	.246	1.600	.135
	4	(Constant)	-101519.068	52124.237		-1.948	.073
		Year (years)	49.967	25.988	.228	1.923	.077
		Extreme rainy days (days/year)	110.993	16.123	.887	6.884	.000
		Unusual rainy winters (days/year)	522.169	140.004	.468	3.730	.003

in the significant trend of diarrhea ($R^2 = 0.289$) (Fig. 4d). These factors could be of great effect in this governorate, but this study was unable to include this data due to the lack of proper reporting and recording of such variables, which can be collected by surveys in further studies.

Although the diarrhea morbidity rate seemed to be related to cumulative rain, extreme rainy days and extreme hot days in Dakahlia (Fig. 4e), multiple linear regression revealed that the time trend was the only significant predictor for the diarrhea morbidity rate in all the models (Table 6). From model 1 to model 3, the significance of the correlation increased with the removal of the statistical effect of the meteorological parameters: cumulative extreme rain, unusual rainy

Table 3 Multiple regression between diarrhea and climate factors in Alexandria (the period considered is 2006–2016)

Gov	Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
			B	Std. Error	Beta		
Alexandria	1	(Constant)	13098.939	117361.125		.112	.913
		Year (years)	-8.905	59.254	-.055	-.150	.884
		Cumulated rain (mm)	1.659	9.194	.099	.180	.860
		Extreme rainy days (days/year)	5.553	9.976	.291	.557	.590
		Unusual rainy winters (days/year)	236.386	219.129	.247	1.079	.306
		No. hot days (days/year)	45.160	22.050	.591	2.048	.068
		No. cold days (days/year)	5.926	18.806	.075	.315	.759
	2	(Constant)	-4536.925	1471.601		-3.083	.010
		Cumulated rain (mm)	.914	7.389	.055	.124	.904
		Extreme rainy days (days/year)	6.068	8.944	.318	.678	.512
		Unusual rainy winters (days/year)	236.448	209.167	.247	1.130	.282
		No. hot days (days/year)	43.062	16.291	.563	2.643	.023
		No. cold days (days/year)	7.363	15.456	.094	.476	.643
	3	(Constant)	-4463.073	1288.536		-3.464	.005
		Extreme rainy days (days/year)	7.036	4.132	.369	1.703	.114
		Unusual rainy winters (days/year)	240.895	197.414	.252	1.220	.246
		No. hot days (days/year)	43.070	15.609	.563	2.759	.017
		No. cold days (days/year)	7.346	14.808	.093	.496	.629
	4	(Constant)	-4220.557	1157.118		-3.647	.003
		Extreme rainy days (days/year)	7.079	4.009	.371	1.766	.101
		Unusual rainy winters (days/year)	246.597	191.280	.258	1.289	.220
		No. hot days (days/year)	41.662	14.897	.545	2.797	.015
	5	(Constant)	-4165.597	1183.357		-3.520	.003
		Extreme rainy days (days/year)	4.835	3.696	.253	1.308	.212
		No. hot days (days/year)	46.273	14.799	.605	3.127	.007
	6	(Constant)	-4103.664	1210.122		-3.391	.004
		No. hot days (days/year)	52.396	14.368	.686	3.647	.002

Table 4 Multiple regression between diarrhea and climate factors in Aswan (the period considered is 2006–2016)

Gov	Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
			B	Std. Error	Beta		
Aswan	1	(Constant)	-180423.176	46742.533		-3.860	.003
		Year (years)	89.407	23.155	.857	3.861	.003
		Cumulated rain (mm)	105.688	155.382	1.118	.680	.512
		Extreme rainy days (days/year)	-111.270	155.806	-1.174	-.714	.491
		Unusual rainy winters (days/year)	134.712	150.004	.203	.898	.390
		No. hot days (days/year)	14.083	8.887	.342	1.585	.144
		No. cold days (days/year)	18.079	11.515	.308	1.570	.147
	2	(Constant)	-165114.111	39953.771		-4.133	.002
		Year (years)	81.878	19.834	.784	4.128	.002
		Extreme rainy days (days/year)	-6.031	17.898	-.064	-.337	.742
		Unusual rainy winters (days/year)	88.332	130.305	.133	.678	.512
		No. hot days (days/year)	12.361	8.308	.300	1.488	.165
		No. cold days (days/year)	19.553	11.029	.334	1.773	.104
	3	(Constant)	-166360.105	38284.706		-4.345	.001
		Year (years)	82.474	19.012	.790	4.338	.001
		Unusual rainy winters (days/year)	83.591	124.667	.126	.671	.515
		No. hot days (days/year)	13.035	7.760	.317	1.680	.119
		No. cold days (days/year)	20.027	10.527	.342	1.902	.081
	4	(Constant)	-168844.909	37289.531		-4.528	.001
		Year (years)	83.761	18.510	.803	4.525	.001
		No. hot days (days/year)	11.267	7.142	.274	1.578	.139
		No. cold days (days/year)	21.432	10.096	.366	2.123	.054
	5	(Constant)	-154333.543	38010.059		-4.060	.001
		Year (years)	76.816	18.910	.736	4.062	.001
		No. cold days (days/year)	21.396	10.619	.365	2.015	.064

winters, and extreme cold days. Cumulative rain and extreme hot days in model 4 and cumulative rain in model 6 did not change the level of significant level of time trend on the diarrhea. The same results were detected by Bhandari et al. (2012), who found that atmospheric temperature was not a predictor of diarrheal occurrence in time series analysis, although they observed that higher cases of diarrhea were recorded

Table 5 Multiple regression between diarrhea and climate factors in Behaira (the period considered is 2006–2016)

Gov.	Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
Behaira	1	(Constant)	-43435.029	61916.963		-.702	.499
		Year (years)	21.811	30.794	.349	.708	.495
		Cumulated rain (mm)	-22.891	29.085	-1.090	-.787	.450
		Extreme rainy days (days/year)	27.173	31.585	1.127	.860	.410
		Unusual rainy winters (days/year)	-132.682	118.940	-.400	-1.116	.291
		No. hot days (days/year)	4.362	10.335	.150	.422	.682
		No. cold days (days/year)	-1.403	13.996	-.044	-.100	.922
	2	(Constant)	-47638.021	43466.241		-1.096	.297
		Year (years)	23.886	21.753	.383	1.098	.296
		Cumulated rain (mm)	-23.438	27.254	-1.116	-.860	.408
		Extreme rainy days (days/year)	27.702	29.708	1.148	.932	.371
		Unusual rainy winters (days/year)	-132.222	113.377	-.399	-1.166	.268
		No. hot days (days/year)	4.544	9.707	.156	.468	.649
	3	(Constant)	-60958.188	31769.259		-1.919	.079
		Year (years)	30.577	15.856	.490	1.928	.078
		Cumulated rain (mm)	-20.059	25.411	-.955	-.789	.445
		Extreme rainy days (days/year)	24.017	27.699	.996	.867	.403
		Unusual rainy winters (days/year)	-117.916	105.568	-.356	-1.117	.286
	4	(Constant)	-59260.673	31233.555		-1.897	.080
		Year (years)	29.584	15.575	.474	1.899	.080
		Extreme rainy days (days/year)	2.694	6.033	.112	.447	.663
		Unusual rainy winters (days/year)	-60.619	75.536	-.183	-.803	.437
	5	(Constant)	-65099.919	27540.871		-2.364	.033
		Year (years)	32.519	13.710	.521	2.372	.033
		Unusual rainy winters (days/year)	-64.717	72.801	-.195	-.889	.389
	6	(Constant)	-69293.824	26943.387		-2.572	.021
		Year (years)	34.581	13.418	.554	2.577	.021

during the hot periods. They attributed the misleading results to the presence of other confounders not related to climatic factors, such as sanitation, hygiene, availability of health facilities, and illiteracy.

These factors could also play a role in the present study. They will definitely need to be investigated further on.

In *Red Sea* Governorate, neither the time trend nor the meteorological parameters proved to be significant predictors

Table 6 Multiple regression between diarrhea and climate factors in Dakahlia (the period considered is 2006–2016)

Gov.	Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
Dakahlia	1	(Constant)	-127674.943	46311.913		-2.757	.020
		Year (years)	64.046	23.139	1.065	2.768	.020
		Cumulated rain (mm)	-6.645	6.400	-.650	-1.038	.324
		Extreme rainy days (days/year)	5.867	7.489	.462	.783	.451
		Unusual rainy winters (days/year)	29.780	83.288	.089	.358	.728
		No. hot days (days/year)	-6.144	6.364	-.274	-.965	.357
		No. cold days (days/year)	-1.239	9.557	-.039	-.130	.899
	2	(Constant)	-131427.417	34496.074		-3.810	.003
		Year (years)	65.912	17.288	1.096	3.813	.003
		Cumulated rain (mm)	-6.939	5.709	-.679	-1.215	.250
		Extreme rainy days (days/year)	6.096	6.945	.480	.878	.399
		Unusual rainy winters (days/year)	25.601	73.283	.076	.349	.733
		No. hot days (days/year)	-6.218	6.049	-.277	-1.028	.326
	3	(Constant)	-129917.977	32948.632		-3.943	.002
		Year (years)	65.190	16.524	1.084	3.945	.002
		Cumulated rain (mm)	-7.181	5.456	-.703	-1.316	.213
		Extreme rainy days (days/year)	5.978	6.678	.471	.895	.388
		No. hot days (days/year)	-6.473	5.781	-.288	-1.120	.285
	4	(Constant)	-132217.002	32596.655		-4.056	.001
		Year (years)	66.285	16.353	1.102	4.053	.001
		Cumulated rain (mm)	-2.613	1.920	-.256	-1.361	.197
		No. hot days (days/year)	-7.165	5.685	-.319	-1.260	.230
	5	(Constant)	-102545.551	23013.425		-4.456	.001
		Year (years)	51.354	11.506	.854	4.463	.001
		Cumulated rain (mm)	-2.438	1.955	-.239	-1.247	.233
	6	(Constant)	-89437.020	20846.778		-4.290	.001
		Year (years)	44.703	10.382	.743	4.306	.001

for diarrhea morbidity rate (Table 8). It is clear that apart from a severe increase in diarrhea cases in 2015/2016 (Fig. 4g), there were no variations in the morbidity rate of diarrhea in Red Sea Governorate between 2006 and 2016. Moreover, in the same period, there was no significant temporal trend of the meteorological parameters but only huge variations (Table 1). This could explain the absence of any predictor for the diarrhea morbidity rate in this governorate.

Table 7 Multiple regression between diarrhea and climate factors in Gharbia (the period considered is 2006–2016)

Gov.	Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
Gharbia	1	(Constant)	-1684.385	6723.295		-.251	.807
		Year (years)	.819	3.350	.117	.244	.812
		Cumulated rain (mm)	.146	1.127	.106	.129	.900
		Extreme rainy days (days/year)	.485	1.301	.280	.373	.717
		Unusual rainy winters (days/year)	9.755	12.516	.249	.779	.454
		No. hot days (days/year)	.724	.950	.255	.762	.464
		No. cold days (days/year)	-.690	1.318	-.211	-.523	.612
	2	(Constant)	-1656.494	6412.470		-.258	.801
		Year (years)	.808	3.196	.115	.253	.805
		Extreme rainy days (days/year)	.641	.467	.370	1.372	.197
		Unusual rainy winters (days/year)	8.796	9.624	.225	.914	.380
		No. hot days (days/year)	.746	.892	.263	.836	.421
		No. cold days (days/year)	-.678	1.255	-.207	-.540	.600
	3	(Constant)	-36.206	49.190		-.736	.476
		Extreme rainy days (days/year)	.692	.404	.400	1.714	.112
		Unusual rainy winters (days/year)	8.939	9.225	.228	.969	.352
		No. hot days (days/year)	.846	.768	.298	1.101	.292
		No. cold days (days/year)	-.884	.914	-.271	-.967	.353
	4	(Constant)	-73.557	30.379		-2.421	.031
		Extreme rainy days (days/year)	.713	.402	.412	1.773	.100
		Unusual rainy winters (days/year)	6.579	8.874	.168	.741	.472
		No. hot days (days/year)	1.278	.622	.451	2.055	.061
	5	(Constant)	-62.570	26.088		-2.398	.031
		Extreme rainy days (days/year)	.612	.372	.353	1.644	.123
		No. hot days (days/year)	1.242	.610	.438	2.035	.061
	6	(Constant)	-46.344	25.481		-1.819	.089
		No. hot days (days/year)	1.524	.618	.537	2.465	.026

Therefore, the geographic location of the different governorates was identified as an effective parameter for the impact of climate change on the morbidity rates of diarrhea in Egypt. Moreover, the impact of climate change in governorates with low socioeconomic levels could not be evidenced, probably because of such confounders as the lesser availability of health facilities, safe water supply, and sanitation.

Table 8 Multiple regression between diarrhea and climate factors in Red Sea (the period considered is 2006–2016)

Gov	Model		Unstandardized coefficients		Standardized coefficients	*t*	Sig
			B	**Std. error**	**Beta**		
Red Sea	**1**	(Constant)	− 14,016.617	9577.823		− 1.463	.174
		Year (years)	6.990	4.785	.446	1.461	.175
		Cumulated rain (mm)	2.349	12.086	.286	.194	.850
		Extreme rainy days (days/year)	− 3.620	11.616	− .436	− .312	.762
		Unusual rainy winters (days/year)	− 19.854	30.232	− .238	− .657	.526
		No. hot days (days/year)	.040	2.169	.006	.019	.985
		No. cold days (days/year)	.857	2.346	.109	.365	.722
	2	(Constant)	− 14,040.004	9053.634		− 1.551	.149
		Year (years)	7.003	4.515	.447	1.551	.149
		Cumulated rain (mm)	2.297	11.220	.280	.205	.841
		Extreme rainy days (days/year)	− 3.581	10.894	− .432	− .329	.749
		Unusual rainy winters (days/year)	− 20.060	26.824	− .241	− .748	.470
		No. cold days (days/year)	.868	2.158	.111	.402	.695
	3	(Constant)	− 14,736.461	8048.523		− 1.831	.092
		Year (years)	7.355	4.005	.469	1.836	.091
		Extreme rainy days (days/year)	− 1.395	2.068	− .168	− .674	.513
		Unusual rainy winters (days/year)	− 22.987	21.773	− .276	− 1.056	.312
		No. cold days (days/year)	.796	2.041	.101	.390	.704
	4	(Constant)	− 14,432.029	7744.824		− 1.863	.085
		Year (years)	7.213	3.856	.460	1.871	.084
		Extreme rainy days (days/year)	− 1.472	1.991	− .177	− .739	.473
		Unusual rainy winters (days/year)	− 20.049	19.749	− .241	− 1.015	.329
	5	(Constant)	− 12,898.078	7339.897		− 1.757	.101
		Year	6.447	3.654	.411	1.765	.099
		Unusual rainy winters (days/year)	− 20.809	19.400	− .250	− 1.073	.302
	6	(Constant)	− 14,656.196	7190.335		− 2.038	.060
		Year (years)	7.314	3.581	.466	2.042	.059

Table 9 Summary of the results of multiple regression between diarrhea and climate factors the different governorates (the period considered is 2006–2016)

Gov.	Time (years)	Cumulated rain (mm)	Extreme rainy days (days/year)	Unusual rainy winter (days/year)	No of hot days (days/year)	No of cold days (days/year)
Cairo	-	-	+++	++	-	-
Alexandria	-	-	-	-	++	-
Aswan	++	-	-	-	-	-
Behaira	++	-	-	-	-	-
Dakahlia	++	-	-	-	-	-
Gharbia	-	-	-	-	++	-
Red Sea	-	-	-	-	-	-

Conclusion

Therefore, it was concluded that the meteorological data that can be used as predictors for the evolution of diarrhea morbidity rate differ with the geographic location of the governorate in Egypt. Moreover, the socioeconomic levels as well as the infrastructures in the governorate will need to be considered confounders in the following studies.

Since climatic changes have contributed to the occurrence of diarrhea in some Egyptian governorates, it is necessary to develop an early warning system based on climate change information to manage disease control. A retrospective longitudinal study is recommended including primary data for drinking water sources, sanitation, sociocultural factors, availability of health services, and diarrhea control programs, as well as climatic variables.

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Author contribution A.S–H. and S.C.A. shared the idea of the project. A.S–H. analyzed the medical data in relation to the meteorological data in the different governorates, and wrote the manuscript. M.A.H. and L.S.E. shared in obtaining the medical data. S.C.A. with A.W., M.E., A.N.M., G.S., A.B., and M.A.W. obtained and prepared the meteorological data. All the authors revised the manuscript after it had been written, and the notes were corrected by A.S–H.

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Data availability The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate The project obtained the approval of the ethical committee of the National Research Centre, number 17084.

Consent for publication Informed consent was obtained from all individual participants included in the study.

Competing interests The authors declare no competing interests.

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