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Climate change and temperature rise: Implications on food- and water-borne diseases

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HIGHLIGHTS

► Prediction of climate-induced increase in food- and water-borne morbidity in a semi-arid Eastern Mediterranean coastal city.
► Number of disease cases increases with temperature beyond a threshold of 19.2 °C.
► Expected increase in morbidity of 16 to 28% by year 2050.
► Up to 42% increase in morbidity anticipated by the end of the century.

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ABSTRACT

This study attempts to quantify climate-induced increases in morbidity rates associated with food- and water-borne illnesses in the context of an urban coastal city, taking Beirut-Lebanon as a study area. A Poisson generalized linear model was developed to assess the impacts of temperature on the morbidity rate. The model was used with four climatic scenarios to simulate a broad spectrum of driving forces and potential social, economic and technologic evolutions. The correlation established in this study exhibits a decrease in the number of illnesses with increasing temperature until reaching a threshold of 19.2 °C, beyond which the number of morbidity cases increases with temperature. By 2050, the results show a substantial increase in food- and water-borne related morbidity of 16 to 28% that can reach up to 42% by the end of the century under A1FI (fossil fuel intensive development) or can be reversed to ~0% under B1 (lowest emissions trajectory), highlighting the need for early mitigation and adaptation measures.

1. Introduction

There is a growing evidence of global climate change, whereby records have shown an increase in world temperature since 1970, as well as an exceedance of the upper limit of natural and historical temperature variability (WHO, 2002). Climate change in recent decades is suspected to have adverse human health impacts, with infants and elderly being the most vulnerable (Ebi and Paulson, 2010). In this context, it is estimated that climate change in 2000 was responsible for approximately 2.4% of worldwide diarrhea in some middle-income countries (WHO, 2002). Infectious (bacterial, viral and parasites) and non-infectious (food intolerances or intestinal diseases) diarrhea remains a major public health problem worldwide and a primary cause of increased morbidity and premature mortality globally, leading to 2 billion diarrheal cases and 2 million deaths each year (WHO, 2009). Studies have shown that climate factors such as increased temperature, relative humidity, and episodes of increased rainfall and runoff affect the incidence of diarrhea significantly (Chou et al., 2010; D'Souza et al., 2008; Hashizume et al., 2007; McMichael et al., 2004). Ambient temperatures were reported to be positively associated with the rates of replication and survival of diarrhea-causing bacteria, protozoa, and food-borne microorganisms (Black and Lanata, 1995; Semenza et al., 2012). According to Checkley et al. (2003), higher temperatures extend the survival of gastroenteritis causing bacteria, such as *Escherichia coli*, in contaminated food. Higher temperatures may also indirectly affect behavior patterns, such as increased consumption of water and lax hygiene, which may promote diarrhea transmission (Chou et al., 2010). Furthermore, reduced precipitation coupled with a decrease in water availability limits dilution effects and forces communities to use contaminated water resulting in a significant increase in water-borne illnesses (Hashizume et al., 2007). On the other hand, extreme rainfall or snowmelt events might also overload aging and poorly designed water treatment plants and sewage infrastructures and contaminate water distribution systems, leading to water contamination and increased diarrhea outbreaks (Patz et al., 2008; Zhang et al., 2010; Auld et al., 2004). Therefore, this paper investigates the correlation between climatic factors and the incidence of food and water-borne diarrhea using a

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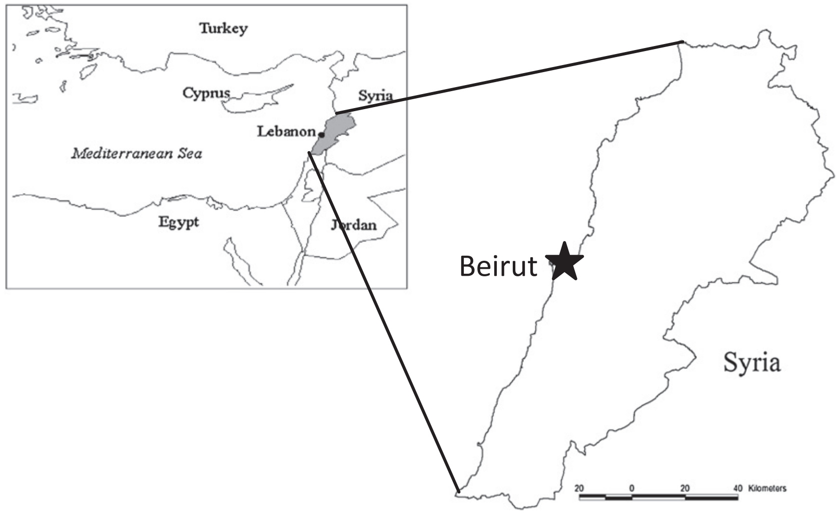

Fig. 1. Location of the study area.

Poisson generalized linear model and taking the coastal city of Beirut, Lebanon,[1] which encompasses around 2 million inhabitants, as a study area (Fig. 1). The derived relationship is relied upon to estimate the increase in food- and water-borne disease incidence for the 21st century. Adaptation measures are then proposed to face the climate-related increasing incidence of diarrheal diseases in the study area.

2. Methodology

2.1. Current climate and food- and water-borne disease incidence data

In an attempt to define a relationship between climate explanatory variables and food- and water-borne illness in the study area, the monthly data of cases of food- and water-related diseases in Lebanon (including Brucellosis, Cholera, Dysentry, food poisoning, Hydatic Cyst, parasitic worms, Trichinosis, Typhoid fever and viral Hepatitis A), between 2001 and 2010, were obtained from the Ministry of Public Health based on hospitalization records (MoPH, 2010). These records showed higher values toward the middle of the year (months 6 to 9) which coincides with the hot and water-scarce summer season (Fig. 2).

Climate data, including monthly average temperature and rainfall, were obtained from the Department of Meteorology at the Beirut International Airport and were used to correlate morbidity to climatic parameters through the development of a regression model. Note that spatial changes in climate parameters and disease were considered to be insignificant, due to the relatively small study area and therefore were not considered in the analysis.

2.2. Future climate and population projections

Population projections in Lebanon, up to year 2100, were adopted from the World Population Prospects (UN, 2010) with 44% (average of years 2000 to 2010) living in Beirut (World Bank 2012). Climate projections, as forecasted by two regional climate models (IPSL[2] and ENEA[3]), were used to predict the increase in daily temperature during the first half of the 21st century (2012–2050) under the A1B scenario, which assumes a balanced emphasis on all energy sources (Gualdi et al., 2012). The simulations were part of the CIRCE project funded by the European Commission under the Sixth Framework Programme. The main characteristic of the CIRCE models is their capacity to simulate influencing climatic features of the region, mainly the Mediterranean Sea. They allow high-resolution simulations of relatively small-scale geographic features, while also coupling the atmospheric modeling components to a specific model of the Mediterranean Sea (Table 1).

While this study aims at examining the food- and water-related morbidity impact of climate change over the whole 21st century, the CIRCE project covers simulations from 1950 to 2050 only. Therefore, the range of temperature increase beyond 2050 was defined based on: (1) expected increase in temperature for the Middle East, with respect to the 2000–2009 reference period, as predicted by 18 Global Climate Models (GCMs) under the A2 scenario (Evans, 2009), and (2) forecasted increase in temperature for West Asia, with respect to the 1961–1990 baseline period, as provided in IPCC-AR4 (Pachauri and Reisinger, 2007) under the A1FI and B1 scenarios. A2 was selected because it is the closest to the “business as usual” scenario, while B1 and A1FI were chosen to account for the highest and lowest emission trajectories, respectively.[4] It was assumed that the climate is evolving slowly and continuously and that the increase in average yearly temperature is linear within the simulation period. Thus, the average increase in decadal temperatures from 2010 to 2095 was linearly interpolated (Dessai, 2003).

[1] Lebanon is situated along the Eastern Mediterranean coast at 33.0° latitude and 35.5° longitude with a temperate to semi-arid climate. The country does not fall within high-risk regions of vector-borne diseases, such as Malaria and Dengue, which makes health impacts of climate change unperceivable to the non-expert stakeholder. However, it suffers from a significant burden of food- and water-borne diseases, reaching 257 DALYs (Disability-adjusted life year) per 100,000 persons according to the 2004 statistics of the World Health Organization (WHO, 2004), which is high with respect to other Mediterranean countries (104 DALYs in Cyprus, 38 in Israel, 32 in France, 26 in Spain, and 23 in Greece and Italy). The diarrheal burden of disease is by far the highest among all infectious and parasitic diseases in the country. Also, diarrhea contributes 10% of premature mortality among children aged less than 5, resulting in 420 deaths in the country in the year 2008 (UNICEF, 2010). The overall cost of water-borne diseases was estimated at 0.2 to 6.1% of GDP for the year 2000 (El-Fadel et al., 2003). Current and projected climate change is expected to exacerbate the diarrheal burden of disease and the associated health costs (Haines et al., 2006).

[2] Institut Pierre Simon Laplace Des Sciences de l'Environnement; http://igcmg.ipsl.jussieu.fr/.

[3] Ente per le Nuove Tecnologie l'Energia e l'Ambiente (Italian National Board for New Technology, Energy and the Environment); http://clima.casaccia.enea.it/PROTHEUS/.

[4] A1 storyline represents a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and rapid introduction of new and more efficient technologies. A1FI characterizes fossil fuel intensive development. The B1 scenario represents a convergent world with the same global population as in the A1 storyline but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies.

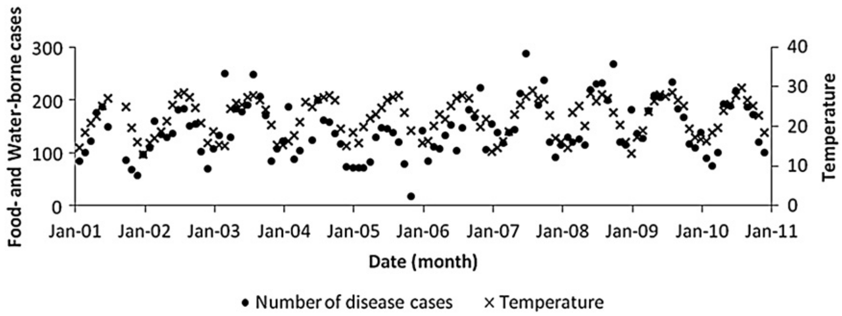

Fig. 2. Variations in mean monthly temperatures and food- and water-borne cases between 2001 and 2010.

2.3. Model development

A Poisson generalized linear model was developed to quantify the relationship between climatic parameters and the number of reported food- and water-borne disease cases. The potential effects of seasonality and the presence of an annual trend were also assessed. Since the population in the study area is changing over time, the number of reported cases was modeled as a fraction of the exposed population. This was accommodated in the modeling framework through the introduction of an offset (Cameron and Trivedi, 1998; Qian, 2010) as expressed in Eqs. (1) to (3):

$$Y_i \sim Pois\ (u_i\lambda_i) \tag{1}$$

$$\log(u_i\lambda_i) = \log(u_i) + \log(\lambda_i) \tag{2}$$

$$\log(\lambda_i) = X_i\beta \tag{3}$$

where u_i is the exposed population at time i; λ_i is the expected number of cases as a fraction of the exposed population; X_i is the regression matrix; and β is the vector of model coefficients. Note that for a Poisson model the mean and the variance are one and the same. While problems with overdispersion are common in Poisson regressions, an assessment of model residuals did not show any signs of the phenomena in our case. Regression analyses for this study were conducted using the statistical software R (R Development Core Team, 2009). Note that only the impact of moderate year-round increases in average temperatures on public health was considered, since systematic data on the impacts of heat waves in Lebanon do not exist and since extreme events are, by definition, rare and case-specific, making inference from studies conducted in other countries difficult. Furthermore, the analysis considered the pooled health impacts, instead of individual effects such as Salmonella, Rotavirus and other pathogens (Checkley et al., 2000; Fleury et al., 2006; Hashizume et al., 2007, 2008; Kovats et al., 2004; Singh et al., 2001), which is easier to assimilate by the non-expert stakeholder and policy maker (compared to the common medical-oriented approach of addressing individual diseases or pathogens), thus, improving the dissemination of the results and the general perception of the climate effect on future health trends and hazards.

The resulting exposure–response relationship between temperature and the total number of disease cases was applied to average monthly temperatures predicted by IPSL and ENEA under the A1B scenario. As to the remaining three scenarios (A2, B1 and A1FI), the average predicted yearly increase in ambient temperatures was assumed to be uniform over the 12 months of the year. While this assumption might be a simplification of the actual monthly dynamics, it is necessary given the coarse temporal resolution of the GCM data. A similar assumption of constant temperature increase throughout the year was adopted by El-Zein et al. (2004).

Temperature–morbidity relationships are highly dependent on socio-economic development and the ecological evolution of disease-causing micro-organisms. Indeed, attempts have been made to incorporate social and ecological changes in forecasting models (McMichael et al., 2004); however these changes proved to be difficult to predict and their parameterization is still highly uncertain. Therefore, we assumed that the exposure–response relationship will remain unchanged over the forecast period.

Table 1
Main characteristics of the CIRCE models in terms of model components and resolution (Gualdi et al., 2012).

Model	Atmospheric component and resolution	Mediterranean Sea model and resolution
ENEA (PROTEUS)	REG-CM3 30 km, 19 vertical levels	MIT-gcm 1/8° (9–12 km), 42 vertical levels
IPSL (IPSL-Reg)	LMDZ regional 30 km, 19 vertical levels	MED8 (OPA9) 1/8° (9–12 km), 43 vertical levels

3. Results and discussion

3.1. Quantifying the environmental impacts on food- and water-borne diseases

Exploratory data analysis revealed a high level of collinearity between rainfall and temperature. As such, only one of these two predictors can be used to ensure model stability (Qian, 2010). In this study, temperature was selected for this purpose because precipitation is highly seasonal with long dry spells between June and September, typical of Mediterranean climates. Note that the role of precipitation with respect to water-borne diseases (namely diarrhea) is driven either by flooding or through water contamination by overflowing wastewater. The Beirut area is seldom prone to floods and sewage outlets are usually directed to the sea rather than to fresh water (groundwater or surface water) resources.

Another known climate-related driver of water-related diseases is air humidity which can contribute 10 to 45% of predicted diarrhea morbidity, depending on the target age group (Chou et al., 2010). Yet, the effect of humidity on diarrheal incidence is strongly linked to the numbers of extreme rainy days (Chou et al., 2010) or to ambient temperature (Checkley et al., 2000), and thus cannot be considered independently. Therefore, water-borne diseases, specifically diarrheal illnesses, are often addressed as a function of temperature (Table 2). In our study, seasonality and the existence of a long-term annual trend were considered as potential predictors in the development of the Poisson regression model.

The preliminary assessment of the quality of the data resulted in the exclusion of two records. The cases reported for August 2007 were excluded from the analysis as the reported number of cases (1847 cases) is suggestive of an outbreak. Similarly, the occurrence of only 1 disease case on December 2005 seemed questionable and was also omitted.

The model results revealed a statistically significant nonlinear relationship (Eq. (4)) between temperature and the rate at which the morbidity cases were reported. This nonlinearity is captured through

Table 2
Examples of reported linear relationships between temperature and diarrhea incidence.

Reference	Diarrhea type (population)	Country	Increase in diarrhea cases per 1 °C temperature rise
Hashizume et al. (2008)	Rotavirus infection (*All*[a])	Bangladesh	40.2% above threshold (29 °C)
Hashizume et al. (2007)[b]	Non-cholera diarrhea hospitalization (*All*[a])	Bangladesh	5.6% (CI, 3.4–7.8)
Kovats et al. (2004)	Salmonella caused food poisoning (*All*[a])	Poland	8.7% above threshold (6 °C)
		Scotland	4.7% above threshold (3 °C)
		Denmark	1.1% above threshold (15 °C)
		England and Wales	12.4% above threshold (5 °C)
		Estonia	18.3% above threshold (13 °C)
		The Netherlands	9.3% above threshold (7 °C)
		Czeck Republic	9.5% above threshold (−2 °C)
		Switzerland	8.8% above threshold (3 °C)
		Slovak Republic	2.5% above threshold (6 °C)
		Spain	4.9% above threshold (6 °C)
Singh et al. (2001)[b]	All-cause diarrhea (*All*[a])	Pacific Islands	3% (CI, 1.2–5%)
Checkley et al. (2000)[b]	All-cause diarrhea (*children <10 yrs*)	Peru	8%

CI = confidence interval.
Threshold = temperature above which the number of illness cases increases with temperature.
[a] Applies to all age groups and both sexes.
[b] Studies considered relevant to this study.

the introduction of a quadratic term with a change point between temperature and rate of morbidity occurring at 19.2 °C. While no statistical significant support was discerned for a long-term annual trend, the data supported the inclusion of a seasonality term. The lack of an annual trend is not surprising given that the model accounts for annual changes in the exposed population through the inclusion of an exposure term (u_i). On the other hand, seasonality in the reported number of food- and water-borne disease cases is accounted for to a large extent by changes in monthly temperatures (Fig. 2); but the fact that seasonality still explains some of the variability in the data hints at the presence of other pathways. One possible pathway could be related to seasonal changes in the dietary intake. Note that seasonality was captured through the use of a cosine function. Other forms of Fourier series were also assessed. The final model structure is presented in Eqs. (4) and (5). A summary of the model coefficients and their respective standard errors are presented in Table 3 and Fig 3 compares the model predictions with the observed number of cases.

$$\log(\lambda_i) = -7.86 - 0.27T_{mean} + 0.007T_{mean}^2 - 0.11\cos(2\pi Month/12) \quad (4)$$

$$Reported\ \ Cases_i = u_i e^{-7.86 - 0.27T_{mean} + 0.007T_{mean}^2 - 0.11\cos(2\pi Month/12)} \quad (5)$$

Table 3
Estimated model coefficients and confidence intervals.

Coefficients	Model value	Standard error	P-value
Intercept	−7.86	0.21	$<2\times10^{-16}$
Slope T	−0.27	0.02	$<2\times10^{-16}$
Slope on T^2	0.007	0.0004	$<2\times10^{-16}$
Slope on cos(2π*Month*/12)	−0.11	0.015	7×10^{-15}

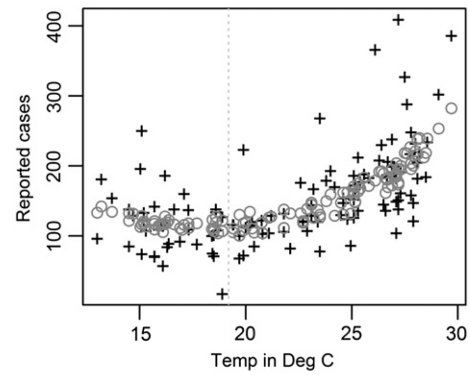

Fig. 3. Number of reported food- and water-borne cases as a function of temperature. The gray open circles represent model predictions. The black crosses represent the number of reported cases. The gray dotted vertical line represents the identified temperature threshold (19.2 °C).

The effect of the seasonality term was found to be significant and is shown in Fig. 4, while fixing the average ambient temperature to 20 °C. The seasonal trend indicates a rise in the rate of morbidity cases between January and June followed by a drop during the summer and fall seasons. This seasonal pattern is distinct from the observed seasonal pattern in temperature (Fig. 2), which further reinforces the presence of a different pathway.

Commonly, low temperatures have a negative impact on the number of water-related infections. However, when the temperature increases beyond a defined threshold, a positive correlation with infections is often detected (Hashizume et al., 2008; Kovats et al., 2004). In fact, the exposure–response relationship shown in Fig 3 exhibits a decrease in number of illnesses with increasing temperature until reaching a threshold, in this case 19.2 °C, beyond which the number of morbidity cases increases with temperature. The non-linearity in relationship between ambient temperatures and morbidity cases complicates the interpretation of how changes in temperature affect the rate of food- and water-borne morbidity occurrences. Since the relationship between $\log(\lambda_i)$ and temperature proved to be quadratic in nature (Eq. (4)), the effective slope on temperature will vary depending on the recorded temperature. This is clearly shown in Fig. 5 that tracks how an increase of 1 °C results in a different percent change in the morbidity rates along a temperature gradient. Evidently, an increase of 1 °C reduces the morbidity rate for temperatures below the threshold, while the same 1 °C change increases the morbidity rate past the threshold point. The observed slopes for Beirut are within the ranges reported by Singh et al. (2001) for the Pacific Islands (slope = +3% per 1 °C temperature increase), Hashizume et al. (2007) for Bangladesh (slope = +5.6% per

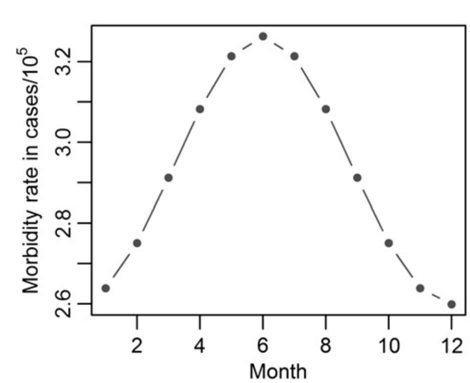

Fig. 4. Modeled seasonal changes in the morbidity rate as a function of months. The rates are for a mean temperature of 20 °C.

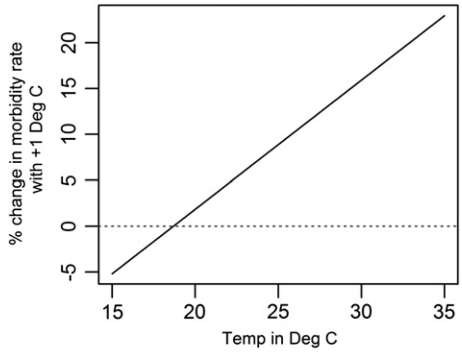

Fig. 5. Modeled nonlinear response in the percent change in the morbidity rates (as a result of 1 °C increase) is plotted along a temperature gradient. Negative rates indicate a decrease in the morbidity rates with the increase in temperature. Positive values correspond to amplified morbidity rates.

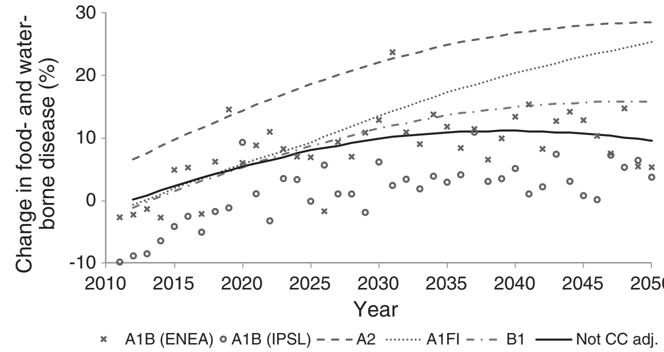

Fig. 7. Projected change (%) in food- and water-borne morbidity for the period 2012–2050, with respect to the base period 2001–2009. "Not CC adj." stands for "not climate change adjusted".

1 °C temperature increase) and Checkley et al. (2000) for Peru (slope = +8% per 1 °C temperature increase).

Because of the lack of studies addressing the relationship between temperature and total food- and water-borne diseases, diarrhea and pathogen-specific correlations with temperature (Table 2) were used for comparison purposes. The threshold established in this study is higher than those reported by Kovats et al. (2004) (−2 to +15 °C) for climates colder than Beirut, and lower than that reported by Hashizume et al. (2008) (29 °C) for the warmer weather of Bangladesh (Table 2). The exposure–response relationship developed in this study was compared with linear temperature–diarrhea relationships observed in other countries, beyond 19 °C, including Bangladesh (Hashizume et al., 2007), Pacific Islands (Singh et al., 2001), Peru (Checkley et al., 2000) and Denmark (Kovats et al., 2004). The resulting graphs fall between the minimum (1.1%, Kovats et al., 2004) and maximum (8%, Checkley et al., 2000) reported slopes. Given that the established association is year- and month-dependent, only the graphs for year 2010 were plotted in Fig. 6 for illustrative purposes.

3.2. Future climate-related morbidity

Eq. (5) was used with temperature projections under the A1B, A2, B1 and A1FI scenarios in order to calculate the expected increase in food- and water-borne diseases under future climate change scenarios. Only minor changes were predicted under the A1B scenario due to the cold bias in the CIRCE (IPSL and ENEA) models. However, a significant increase in morbidity of 16, 25, and 28% under the B1, A1FI and A2 scenarios, respectively, is predicted during the first half of this century (Fig. 5). For comparison purposes, the expected increase in morbidity due to population growth alone, i.e. without considerations for climate change, was calculated by setting the temperature variable in Eq. (5) equal to the baseline average (Fig. 7). Accordingly, the number of water- and food-borne diseases is expected to increase by ~10% by year 2050 if the climate does not change.

Beyond 2050, the number of water- and food-borne cases continues to increase under the A2 and A1FI scenarios. In early 2070s, morbidity peaks (Fig. 8) under the A1FI scenario, presumably because of large increases in temperature due to the cumulative effect of intensive fuel combustion. Under the B1 scenario, the change in morbidity is expected to drop to ~0% by the year 2095 (Fig. 8), implying the possibility to mitigate climate impact on the total number of water- and food-related diseases in response to long-term environmental protection characterized by clean and resource-efficient technologies. To note that, in the absence of climatic changes, the total number of disease would be reduced by 14% as a result of population decrease by 2095 (Fig. 8). Accordingly, by the end of the century, the number of water- and food-disease cases is expected to (1) increase by 35% to 42%, under the A2 and A1FI scenarios, respectively, or (2) decrease to values similar to the 2001–2010 baseline under the B1 scenario (lowest emissions trajectory). Thus, depending on global efforts to reduce fossil fuel dependence and mitigate GHG emissions and the prevailing socio-economic settings, the number of illness cases can be limited or exacerbated.

4. Adaptation perspectives

While the above analysis is associated with various uncertainties, climate change is expected to impose serious health impacts in the

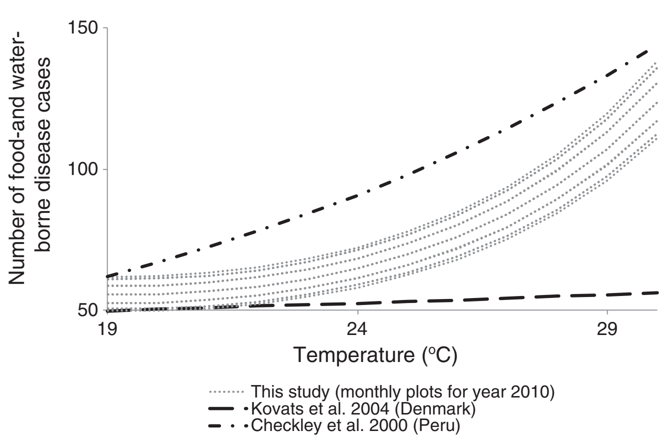

Fig. 6. Comparison of modeled number of food- and water-borne disease cases as a function of temperature with predictions based on other models. The plotted curves correspond to monthly trends in year 2010, with upper curves corresponding to warmer months.

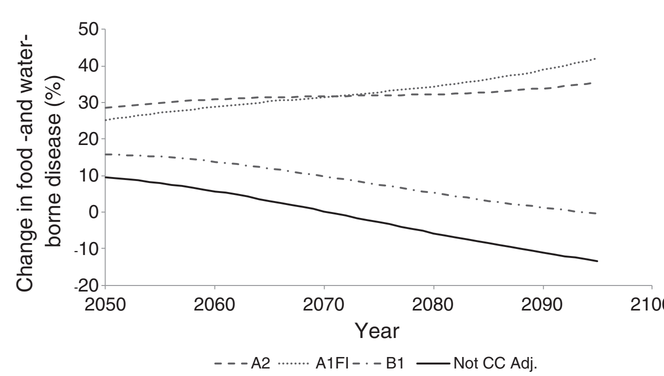

Fig. 8. Projected increase (%) in food- and water-borne morbidity in Beirut for the period 2050–2095 as compared to the period 2001–2009. "Not CC adj." stands for "not climate change adjusted".

Table 4
Water use in Middle Eastern countries.
Data source: FAO (UN Food and Agriculture Organization) (2008).

	Lebanon	Jordan	Palestine	Syria	Yemen	Region average	Gulf countries
Ratio of reused wastewater to withdrawn fresh water (%)	0.2	9.9	2.5	4.0	0.2	1.7[a]	2.2
Ratio of desalinated water to withdrawn freshwater (%)	3.8	1.2	0.0	0.0	0.3	1.1	10.2
Ratio of (desalination + reused wastewater) to withdrawn freshwater (%)	3.9	11.0	2.5	4.0	0.5	4.4	12.4
Freshwater withdrawal as % of total renewable water resources (%)	28.0	90.5	48.8	82.7	161.1	82.2	924.8
Agricultural water withdrawal as % of total renewable water resources	17.3	65.2	22.6	87.3	145.7	67.6	1034.7
Percent of pressurized irrigation/total agricultural water managed area (%)	36.4	82.4	0.0	13.0	0.1	26.4	62.6

[a] Jordan was excluded from the calculation given its high percentage (outlier) with respect to remaining countries.

study area (up to 46% increase in morbidity by the end of the century), which translate into a significant economic burden necessitating timely adaptation strategies. In this context the access to clean potable water is reportedly the most effective adaptive measure to waterborne and foodborne diarrheal diseases (WHO 2003). Vulnerability assessment of sanitation infrastructure to extreme precipitation events (including droughts and floods) is necessary with the introduction of needed rehabilitation programs. Preventive health measures targeting children under five, such as breastfeeding promotion, rotavirus, cholera, and measles immunizations are also recommended (Ebi, 2008). Other adaptation measures include awareness campaigns to encourage food hygiene and the use of soap and water for hand washing, as well as temporary measures to reduce pathogen concentration in drinking water, such as chlorination, UV radiation, or boiling water at points of consumption.

Long term strategies for water resource planning and management are equally important in facing water scarcity/shortage, which remains a key underlying cause of water-related illness in arid and semi-arid urban coastal cities. At present, decision makers continue to explore conventional water solutions such as increasing storage capacity through small dams and lakes, diversion from other watersheds, and extraction of groundwater all emphasizing supply side management and officially approved by the government (Council of Ministers, 1999). However, with the anticipated decrease in precipitation, the observed reduction in surface and groundwater quantities, as well as severe salt water instruction along coastal shores (El-Fadel, 2010; Shaban, 2009), non-conventional options with less dependence on precipitation and groundwater will become inevitable including:

- *Desalination*: while largely concentrated in extremely water-scarce Gulf regions (Table 4), desalination can be an economically competitive option for coastal cities such as Beirut (Yamout and El-Fadel, 2005) because of the relatively lower distribution cost compared to dams and diversion from other watersheds.
- *Wastewater treatment and reuse*: Currently at its lowest with reuse estimated at 0.2% (Table 4), wastewater recycling offers a potential for the remaining agricultural practices around Beirut, with a viable cost benefit ratio (Massoud and El-Fadel, 2002).
- *Reduction in unaccounted for water*: exceeding 50% due to leaks in distribution networks, unaccounted for water can be minimized through monitoring and control coupled with regulatory reform on pricing policies, which reportedly resulted in a 65% reduction in water losses in semi-arid urban areas (Ragab and Prudhomme, 2002).

5. Concluding remarks

While specific assumptions and limitations were outlined, the main constraint is associated with the lack of accurate and long-term monitoring data on occurrences of food- and water-borne diseases, especially related to differentiation among various causes, patient age categories and social and economic classes. Equally significant, the approach adopted in this study is based on the assumption that current associations will remain unchanged in the future which might introduce uncertainties because biological acclimatization as well as technologic and socio-economic developments will likely influence population vulnerability and exposure–response relationships. In this study, the latter exhibits a decrease in number of illnesses with increasing temperature until reaching a threshold of 19.2 °C, beyond which the number of morbidity cases is expected to increase with temperature.

The corresponding results show that, by the end of this century, the increase in food- and water-borne related morbidity in Beirut can be negligible under the B1 (lowest emission trajectory) scenario and might reach 35% and 42% under the A2 (business as usual) and A1FI (highest emission trajectory) scenarios, respectively. Water scarcity is considered a major determinant of water quality, which in turn is the driving factor for water-borne morbidity. While adaptation alternatives require improved awareness and enhanced health systems, the most influential determinants are proper sanitation and clean water accessibility. The latter can be enhanced through an equal commitment for demand vs. supply side management strategies coupled with non-conventional water sources such as desalination, wastewater reuse and reduction in unaccounted for water losses, all economically viable under proper regulatory reforms and pricing strategies.

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