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### Authors

Dovie, Delali BK  
Dzodzomenyo, Mawuli  
Ogunseitan, Oladele A

### Publication Date

2017

### DOI

10.1016/j.scitotenv.2016.09.066

Peer reviewed



# Sensitivity of health sector indicators' response to climate change in Ghana

Delali B.K. Dovie<sup>a,b,\*</sup>, Mawuli Dzodzomenyo<sup>c</sup>, Oladele A. Ogunseitan<sup>d</sup>

<sup>a</sup> Regional Institute for Population Studies, and Department of Geography and Resource Development, University of Ghana, Legon, Ghana

<sup>b</sup> School of Animal, Plant and Environmental Sciences, University of the Witwatersrand, South Africa

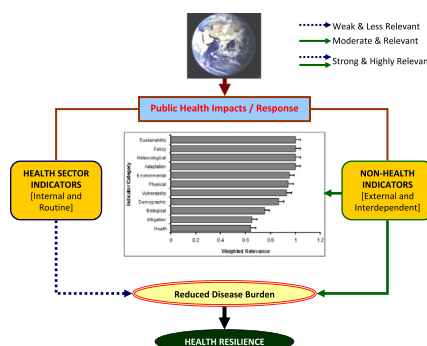
<sup>c</sup> Department of Biological, Environmental and Occupational Health Sciences, School of Public Health, University of Ghana, Legon, Ghana

<sup>d</sup> Department of Population Health and Disease Prevention, Program in Public Health, and School of Social Ecology, University of California at Irvine, USA

## HIGHLIGHTS

- Existing health indicators are limited in scope to build resilience to climate change.
- Indicators of socio-ecological origins of the coupled human – environment system established.
- Multivariate statistics with systematic reviews and expert consultations generated new insights.
- Resilience of climate-sensitive diseases is multidimensional, and driven by external factors.
- Non-health indicators have synergistic effect on health resilience to climate change.

## GRAPHICAL ABSTRACT



## ARTICLE INFO

### Article history:

Received 22 June 2016

Received in revised form 8 September 2016

Accepted 9 September 2016

Available online xxx

Editor: D. Barcelo

### Keywords:

Adaptation  
Disease burden  
Ecohealth  
Epidemiology  
Health surveillance  
Vulnerability

## ABSTRACT

There is accumulating evidence that the emerging burden of global climate change threatens the fidelity of routine indicators for disease detection and management of risks to public health. The threat partially reflects the conservative character of the health sector and the reluctance to adopt new indicators, despite the growing awareness that existing environmental health indicators were developed to respond to risks that may no longer be relevant, and are too simplistic to also act as indicators for newer global-scale risk factors. This study sought to understand the scope of existing health indicators, while aiming to discover new indicators for building resilience against three climate sensitive diseases (cerebro spinal meningitis, malaria and diarrhea). Therefore, new potential indicators derived from human and biophysical origins were developed to complement existing health indicators, thereby creating climate-sensitive battery of robust composite indices of resilience in health planning. Using Ghana's health sector as a case study systematic international literature review, national expert consultation, and focus group outcomes yielded insights into the relevance, sensitivity and impacts of 45 indicators in 11 categories in responding to climate change. In total, 65% of the indicators were sensitive to health impacts of climate change; 24% acted directly; 31% synergistically; and 45% indirectly, with indicator relevance strongly associated with type of health response. Epidemiological indicators (e.g. morbidity) and health demographic indicators (e.g. population structure) require adjustments with external indicators (e.g. biophysical, policy) to be resilient to climate change. Therefore, selective integration of social and ecological indicators with existing public health indicators improves the fidelity of the health sector to adopt more robust planning of

\* Corresponding author at: Regional Institute for Population Studies, University of Ghana, LG96 Legon, Ghana.  
E-mail address: [dbdovie@ug.edu.gh](mailto:dbdovie@ug.edu.gh) (D.B.K. Dovie).

interdependent systems to build resilience. The study highlights growing uncertainties in translating research into protective policies when new indicators associated with non-health sources are needed to complement existing health indicators that are expected to respond to climate change.

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## 1. Introduction

The fifth assessment report (AR5) of the Inter-governmental Panel on Climate Change (IPCC) has affirmed high confidence in the link between climate change and human health (Smith et al., 2014). The report emphasized that, despite the advances in understanding the influence of climate change on health, uncertainties and knowledge gaps must be addressed to improve decision support systems. There have been difficulties in introducing new climate-sensitive indicators to the health sector beyond the traditional environmental public health indicators (EPHI). Health indicators are measurable quantitative and qualitative parameters that represent phenomena such as disease outbreaks, complex risk factors, hazards, exposures, health effects, health resources interventions, disease-preventive activities, and communication elements to support decision making (English et al., 2009). Subsequently, there is a need to expand and prioritize indicators of social and biophysical origins that are relevant for integrating climate response into public health planning and resilience building (Ebi and Burton, 2008; Haines et al., 2006). Adverse health outcomes such as changing global patterns of disease incidence and mortality, shortage of food, water, and shelter, and inadequate sanitation, have emerged to challenge routine public health practices that focus exclusively on local stressors. The well-recognized local stressors exacerbate human exposure to additional harm from climate change, thereby providing new challenges for health planning (Costello et al., 2009; Houghton and English, 2014; McMichael et al., 2006). However, there is a severe shortage of experiences within the National Adaptation Programs of Action (NAPAs) of the United Nations Framework Convention on Climate Change (UNFCCC), which are relevant to moving the health sector beyond traditional coping mechanisms at national levels (IPCC, 2001; UNFCCC, 2007).

Ghana was selected as a case study for the current analysis, because the country relies on internationally mandated action plans such as the National Climate Change Adaptation Strategies (NCCAS). Further, the health sector received little attention in Ghana's National Communications to respond to the impacts of climate change (Government of Ghana, 2015; Government of Ghana, 2010). Similarly, the adaptation plans of some developed countries fail to recognize the vulnerability of the health sector to climate change with only 15% having an explicit human health component of their adaptation plans (e.g. Annex I parties) (Lesnikowski et al., 2011). The Annex I parties were the industrialized countries that were members of the OECD (Organization for Economic Co-operation and Development) in 1992, and countries with economies in transition as one of the three major groups of parties to the UNFCCC (UN, 1992). Major gaps remain in understanding the sensitivities of predictors of climate change and related risks to match existing public health indicators (Houghton and English, 2014; Mishra et al., 2015). Globally, the health-climate change nexus is still evolving in health policy and planning. The nexus is characterized mostly by perception and conjectures rather than empirical evidence (Clarke and Berry, 2012; Linnenluecke and Griffiths, 2012; Uittenbroek et al., 2013). The impacts of climate change on public health are expected to manifest through three pathways: (i) the direct emergency impacts relating primarily to extreme weather conditions, including heat, drought, and storms, (ii) the sub-acute effects mediated through natural systems, and

(iii) effects heavily mediated by human systems such as malnutrition (Costello et al., 2009; IPCC, 2014; Jankowska et al., 2012). Therefore, it is prudent that health sector indicators are expanded and adjusted to reflect these pathways.

Climate change acts to exacerbate existing patterns of ill health by acting on the underlying environmental and socio-demographic vulnerabilities (McMichael et al., 2006; Nguendo-Yongsi and Dovie, 2007; Sheridan and Allen, 2015; Smith et al., 2014; Xu et al., 2013). The highly regulated health sector depends mostly on the EPHI to integrate environment-based issues, but the sector is confronted with organizational difficulties to integrate additional climatic risk indicators which are external to EPHI. This is because climatic risk indicators represent a mix of drivers mostly dictated strongly from effects of non-health sector interactions as EPHIs were not designed to respond to climatic risks. Climate change related large-scale ecological changes and losses impinge on human well-being concurrently (Haines, 2012; Houghton and English, 2014). Whilst the convergent effect of social and ecological change have been felt in recent times in conventional public health practice (Costello et al., 2009), loss of momentum to sustain such practices could undermine the potential co-benefits of effectively managing the climate change – human health interactions defined as planetary health or Ecohealth. Ecohealth practices generally leverage and engage human health issues concurrently with the coupled human – environment system defined by ecosystem services to regulate disease origins (Butler and Friel, 2006). This approach considers the dynamic interplay among ecosystem determinants, and between them and health outcomes. Examples are managing waste to generate electricity and diesel fuel, whilst reducing health hazards, and also using recycled wastewater from hospitals to manage landscapes and reducing costs associated with disposal, creating green jobs and minimizing greenhouse gases from health facilities. Therefore this study aimed to assess the scope of sensitivities of existing health indicators, with the potential to broaden the scope to include indicators external to the health sector that may improve response to the burden of climate change and contribute to resilience of public health infrastructure.

## 2. Cross-scale interactions of health indicators

The readiness of public health systems to adapt to the impacts of climate change has been described as facing delays because of limitations on the inclusion of social-ecological concepts in the planning process (Deppisch and Hasibovic, 2013; Downes et al., 2013; Few, 2007; Folke, 2006; Gallopin, 2006). For example, large-scale environmental changes such as biochemical pollution, extreme temperature events, loss of biodiversity and ecosystem services occur simultaneously, and will have cumulative and interactive adverse impacts on population health (Houghton and English, 2014; Sheridan and Allen, 2015; Zell, 2004). However, it is important to acknowledge that there is no guarantee that the inclusion of indicators outside the traditional health sector would result in improvements to public health to respond to climate change. Thus there are vaguely understood linkages between environmental quality, health planning and equity in the distribution of disease burden and inadequate translation of evidence from health, ecological and social systems into policies towards improved health status. The national climate change impact study of Ghana's health sector serves as the context within which we explore these gaps to produce a refined process of developing climate-sensitive indicators of resilience. This study therefore was not intended to showcase Ghana's milestones on

climate change but to scale up understanding of key findings in health based on new analytical framework in a global context. Differences in available economic assets to support social networks, physical infrastructure, and planning or maintenance of diagnostic and early warning protocols in public health may not be fully understood due to the complex interactions and widened disparities in vulnerability (Berkes, 2007; Few, 2007).

There is the need to reduce uncertainty by expanding indicators of predictive models of climate change vulnerability assessments (Bell, 2011; Deppisch and Hasibovic, 2013; Houghton and English, 2014). This is because the expansion will allow indicators from non-health sectors to be incorporated into public health management strategies towards resilience building (Linnenluecke and Griffiths, 2012; Pascal et al., 2012). Resilience defines the capacity for self-organization and adaptation to stress and change (Folke, 2006; Leichenko and O'Brien, 2008; Walker et al., 2006). Therefore, resilience has the potential to reduce the damages or increase benefits attributed to climate change (Alberini et al., 2006; Walker et al., 2006). Resilience of a public health system is concerned with its capacity to maintain health services among vulnerable populations in the process of and aftermath of external perturbations. Resilience is different from, but integrates the standard public health system properties such as disease prevention (e.g. vaccination coverage), wellness check-ups, and epidemiologic

assessment of disease burden (Luthar and Cicchetti, 2000; Walker et al., 2002).

### 3. Methodology

#### 3.1. Study site description

The study was conducted in Ghana, focusing on three specific administrative districts namely Bongo (10° 54' 28" N, 0° 48' 29" W) in the Upper East Region, Keta (5° 59' 0" N, 0° 56' 0" E) in the Volta region and Gomoa West (5° 17' 0" N, 0° 44' 0" W) in the Central region (Fig. 1). Gomoa-West and Keta both exhibit wetland conditions with the potential to flood and water remaining in pockets on the land surfaces with significantly low lying areas in Keta, whilst Bongo is characterized by drier conditions. The regions were selected to represent regional differences in the effects of savannah ecosystems and three climate-sensitive diseases of epidemiologic interests in the districts: Cerebrospinal Meningitis, Diarrheal Diseases and Malaria, respectively (Agyemang-Bonsu et al., 2009). Composite data related to these climate sensitive diseases formed the basis of all interpretations rather than for individual diseases and also by district (Supplementary Table S1), in order to reduce the complexity. The annual mean temperature typically ranges between 24 °C and 30 °C in Ghana. Mean annual temperatures from 1960 to

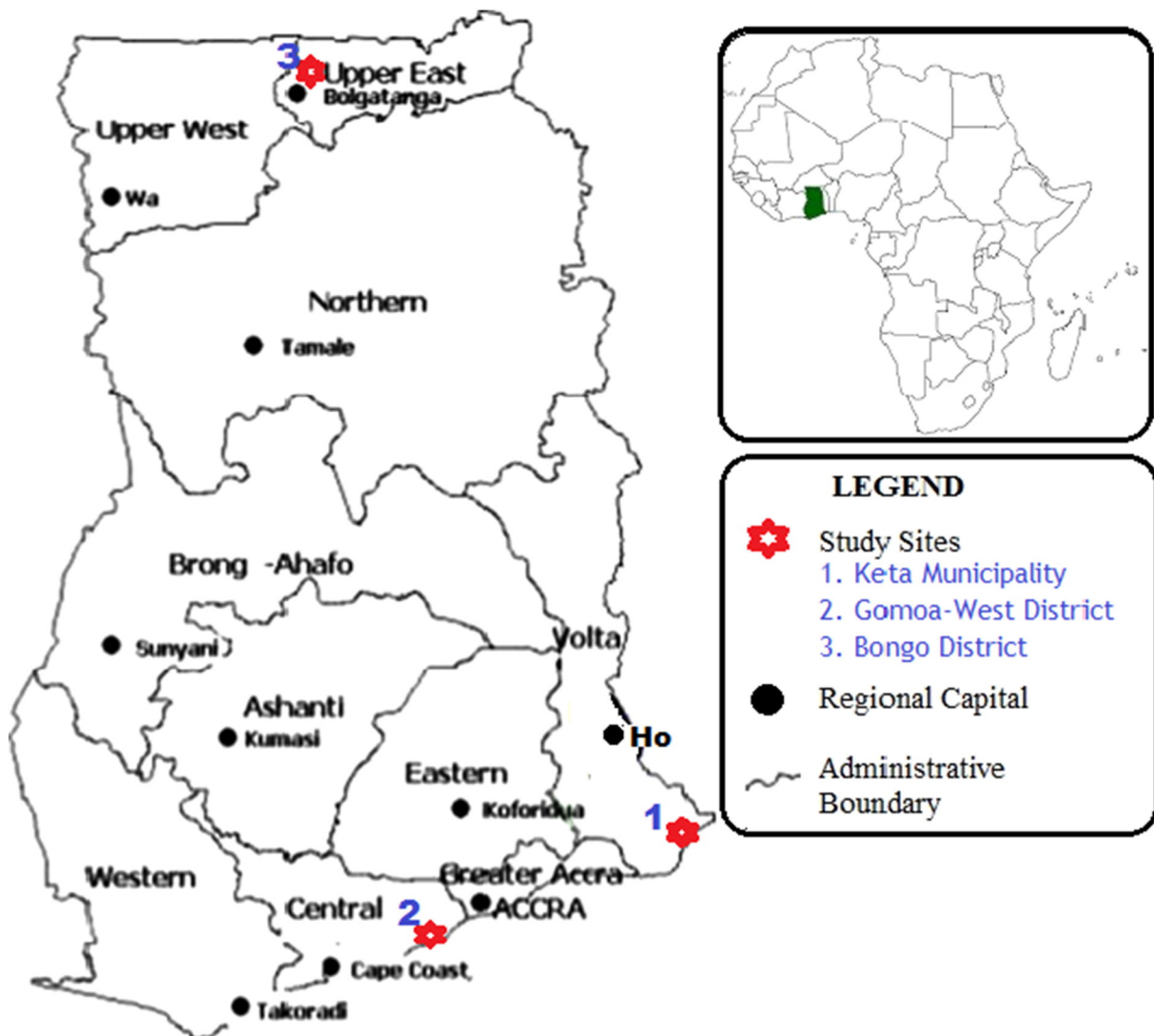


Fig. 1. Map of Ghana showing the Districts of the health care facilities which participated in the study and their respective regions.

2000 for six major ecological zones reveal evidence of increasing air temperature, predicted to rise in all agro-ecological zones. Average annual temperatures are estimated to increase by between 0.8 °C and 2.4 °C for the years 2020 and 2050, respectively. Within the same period average annual rainfall total is estimated to decline by between 1.1%, and 20.5% (World Bank, 2009). Ghana is a signatory to the UNFCCC, and ratified the Kyoto Protocol to the UNFCCC in 2003. The recommendations of a Ghana National Capacity Self-Assessment Project (NCSA) from June 2003 to October 2005 on the capacity needs of Ghana in meeting the country's commitments under the three Rio Conventions formed the basis of some climate adaptation initiatives. The initiatives included a project funded by the Global Environment Facility (GEF) and conducted by the Ghana Ministry of Health (MOH) and the United Nations Development Program (UNDP) to pilot climate change adaptation for health in Ghana. At present, infections that are known to be influenced significantly by climate related events already are among the top five leading causes of morbidity in Ghana including diarrheal diseases, and malaria, in addition to malnutrition aggravating the impacts of the infections.

### 3.2. The resilience analysis framework

The resilience of a health system can be analyzed using a step-wise process (Fig. 2). In Step 1, the main components and processes of the health system under investigation are defined in order to provide information on the amount of change that the health system can undergo as a result of episodic events such as abrupt climate change. The information may include communication strategy, information management, surveillance and early warning systems, human resources, physical infrastructure, public health policy, collaborative and integrative partnerships. Step 2 involves examining the role of policy drivers and stakeholder actions to develop a set of possible future scenarios to establish a range of possible responses to climate change for the purpose of identifying potentially resilient responses. Step 3 consists of exploring the neutral, counteracting, or synergistic interactions of the first two steps. Step 4 represents stakeholder evaluation of the whole process and analyzing the implications for policy development and management options (Fig. 2).

### 3.3. Data collection and analysis

Global and national level analyses were undertaken, the former based on secondary data, archival and literature review, to contextually support primary data at the national level. The primary data collection focused on identifying the existing determinants of public health conditions and the extent to which these determinants are sensitive to climate change, and are deliberately modifiable for adaptation and resilience. The keywords search was carried out using the terms “indicator”, “determinant” and “driver” for different uses in the health literature, and in combination with “climate”, “climate change”, “climate variability”, “adaptation” and “mitigation” to discover their usage as opposed to frequencies from the following databases: SCOPUS, ScienceDirect, Google Scholar, JSTOR, PubMed, EBSCO Host, SAGE Premier Online, SpringerLINK, Web of Science, Taylor & Francis, for a 10-year period from 2006 to 2015. Gray literature was also captured, to reflect the active period of climate change science, global burden of disease assessments, and global climate actions. Thus, the secondary data resulting from the review provided the baseline understanding of health vulnerability and disease burden from global to the local level perspectives. The keywords represented different schools of thought supported by IPCC and UNFCCC Technical Reports including Ghana's National Communications. The local reviews which were equivalent to the Ghana country status involved the examination of health reports from national to district levels on (i) the totality of the health sector and (b) the three specific base diseases identified for the study. Expert knowledge solicitation, an important tool for understanding the dynamism of climate change and social change (Walker et al., 2006), was adopted for evaluating the link between ecosystems degradation, health management, and policy decision-support. It comprised of large mix of personnel from different specialized divisions within the health sector operating mostly at the regional level who facilitated own discussion after the initial introduction of theme. It included the views of public health administrators, medical doctors, disease control officers, health information analysts, environmental health officers, community health facilitators and volunteers, health economists and planners at the local and regional levels. Characteristics of the indicators for assessment cut across social, environment, edaphic, geologic and management factors and values determined from the qualitative scoring of relevance to

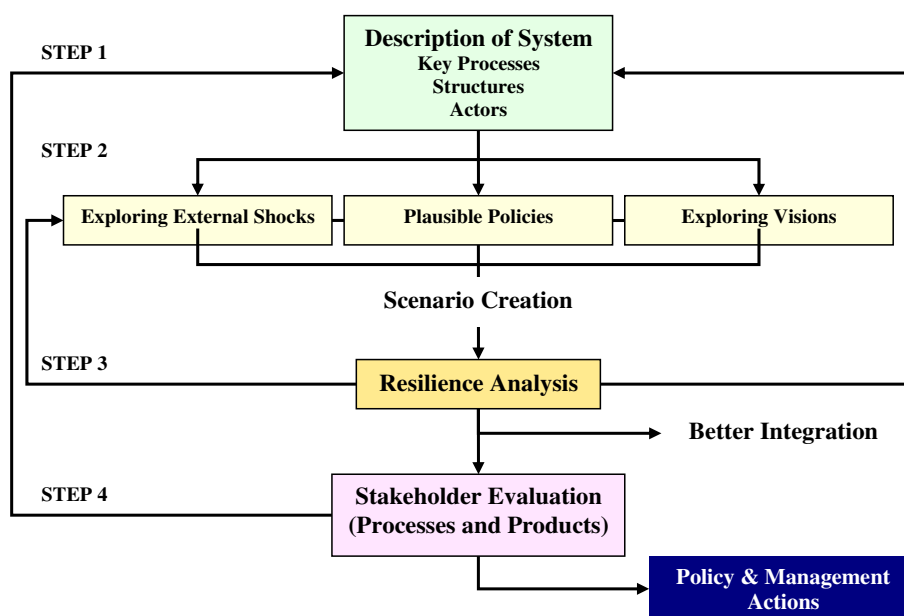


Fig. 2. Resilience analysis framework adapted from Walker et al. (2002).



health by the experts. These were complemented with the outcomes of key informant interviews of non-health personnel such as from the Environmental Protection Agency, Ghana Meteorological Agency, and National Disaster Management Organization. These were one on one open ended conversations around the following questions: (i) What precisely is the current health system? (ii) What is it attempting to accomplish? (iii) What are its component parts? (iv) How do these systems interact with society? (v) How universally accessible are they? (vi) What is the role of the health system in ensuring early adaptation? (vii) What are the factors which threaten their collapse in the face of external shocks such as climate change, their adaptability and their capacity to transform to more desirable system(s)? Responses were enriched with unpublished background information on baseline vulnerability and responses already established by the Ministry of Health, and also with information from a national vulnerability assessment (Agyemang-Bonsu et al., 2009). For example, the selected districts were categorized as prone to the tracer diseases, endemic and at risk of epidemics.

Focus group interviews were used to interrogate major stakeholders consisting of the Health Management Teams at the District and Regional levels and personnel from non-health sectors (e.g. Planning and Community Development, Disaster Management). Three focus groups were carried out at the district level, one in each of the working districts with participants ranging from seven to twelve per group, held at the District Health Service premises. Discussions focused on the processes of developing and operationalizing indicators in the health sector using questions, including: (a) what measures are in place now to reduce the burden of disease? (b) If these are policies, structures or structures, how effective have they been? (c) What measures can be taken to reduce vulnerability to disease burden? (d) Are there main barriers to implementation of measures (e.g., technology gap or political support)? All the consultations culminated in three different options by which the health sector will be able to become resilient to impacts of climate change based on the ranking of the relevance of individual indicators. The first option represents a situation whereby traditional determinants of public health will be able to respond to the impacts of climate change without modification, the second comprising of modifiable determinants in response to impacts of climate change, and thirdly, examining interactions between indicators that are not typical public health determinants with traditional determinants in response to impacts of climate change. The indicators were further refined based on orientation to health either directly, indirectly, or in concert.

A qualitative management analysis of Strengths, Weaknesses, Opportunities and Threats (SWOT) was used to assess the importance of the routine health sector indicators to respond to cases based on the three climate sensitive diseases. The SWOT framework was used to assess the internal capacity of the health sector to implement health management strategies before and after the projected impacts of climate change. A multivariate statistical analysis defining the current associations and correlations between disease outcomes and climate variability and change using the weighted scores of all indicators as variables was used to prioritize indicators for resilience building. Health effects were traced to the source of the predisposing factors to understand whether or not the indicators were responding directly or indirectly. At various levels of data collection, expert panelists classified the relevance of the indicators on a scale in the range “very high”, “high”, “moderate”, and “low” in relation to resilience building in the health sector. The percent contribution of each specific indicator to a category was derived, and the composite average weight calculated for the broad indicator category  $W_{ind}$  using Eq. (1) (Jongman et al., 1987),

$$W_{ind} = \frac{1}{100}(x_{i1}w_{i1} + x_{i2}w_{i2} + \dots + x_{is}w_{is}) \quad (1)$$

where  $x_1$  is the relative percentage value for each specific indicator within a category of indicators and  $w_i$  is the weighting value (1 to 4), and weighted averages plotted (Fig. 3). The derived nominal values

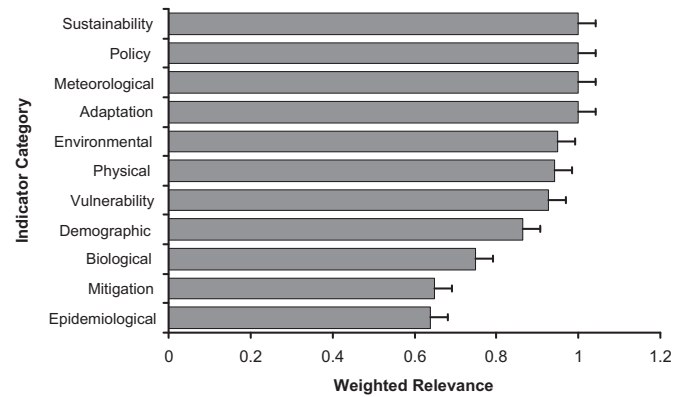


Fig. 3. The types and relevance of indicators for building resilience in the health sector, in response to climate change based on weighted averages of the relative weights of the individual indicator variables. Indicator categories of social–ecological origins weighted more than the existing conventional health sector categories.

were analyzed using a Principal Component Analysis (PCA) (Jongman et al., 1987), a type of multivariate statistics to estimate the relative expression of the attributes of the indicators (Fig. 4). PCA was chosen to understand the links between the multiple indicator variables across social and ecological domains and, to emphasize the variation in the selected indicators based on weights to reveal distinctive patterns in the data. In order to determine whether or not there was an independence of relevance of the indicators and the types of health response to impacts of climate change for resilience building (direct, indirect, both), a Chi Square Test of Independence was performed using Eq. (2).

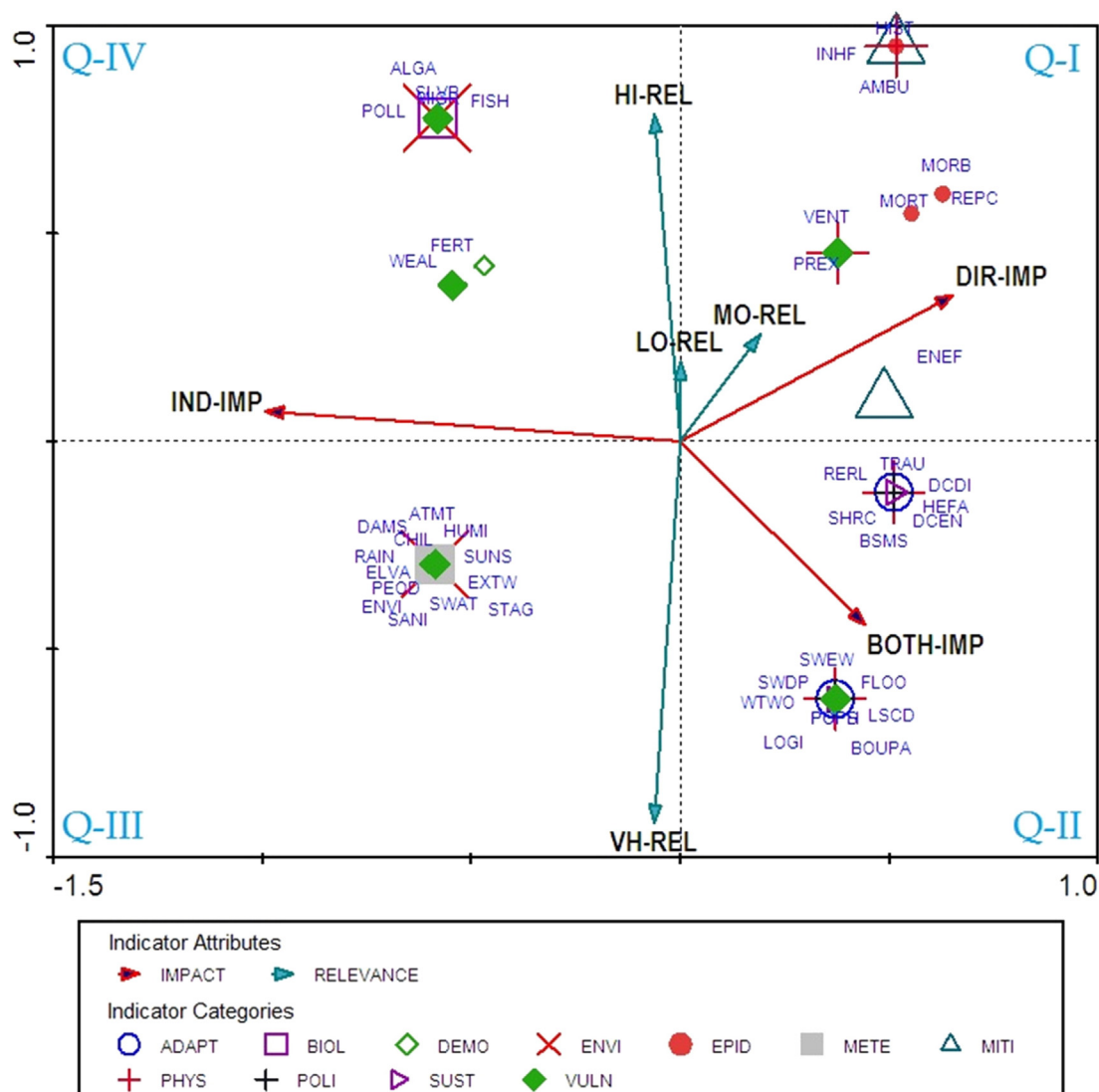
$$\sum_{i=1}^R \sum_{j=1}^C \frac{(O_{ij} - E_{ij})^2}{E_{ij}} \quad (2)$$

where  $O_{ij}$  and  $E_{ij}$  are the frequencies of the observed and expected data respectively for datasets  $i$  to  $j$ ,  $R$  = number of rows,  $C$  = number of columns. The null and alternative hypotheses are:  $H_0$ : The relevance of the indicators and the type of health response to climate change impacts are independent.  $H_A$ : The relevance of the indicators and the type of health response to climate change impacts are related.

## 4. Results

### 4.1. Links between existing public health indicators and climate change

Public health responses were characterized frequently by demand-driven interventions due to limitations of resources. This meant that resources were mostly mobilized to match needs during and after occurrence of events as the standard health practice and having no clearly stated innovative procedures that used climate-sensitive indicators. Although some programs and protocols relate to climate sensitive health issues such as infectious disease prevention and control, they were not designed to monitor climate change impacts. Standard practices included (i) global prescriptions and frameworks of indicators by international agencies (e.g. World Health Organization), (ii) national standards set by national health authorities (e.g. Ghana Ministry of Health), (iii) periodic analysis of health surveillance data as part of health information management for indicators, with better responses in the sector, (iv) trends in disease management conditions over longer time periods representing disease burden and interventions e.g., disease hotspots and endemism for early warnings, (v) decentralized health operations to community facility levels comprising two-way information flow from volunteers to professional health personnel for setting operational guidelines as proxy



**Fig. 4.** Principal Component Analysis (PCA) expression profiles of (i) categories of indicators and (ii) individual specific indicators, in relation to their relevance to the health sector in responding to impacts of climate change (i.e. LO-REL, Low relevance; MO-REL, Moderate relevance; HI-REL, High relevance; VH-REL, Very high relevance), and type of impact on the health sector (e.g. DIR-IMP meaning Direct Impact; IND-IMP, Indirect Impact; and BOTH-IMP for combined Direct and Indirect Impacts). The 11 indicator categories are ADAPT - Adaptation, BIOL - Biological, DEMO - Demographic, ENVI - Environmental, EPID - Epidemiological, METE - Meteorological, MITI - Mitigation, PHYS - Physical, POLI - Policy, SUST - Sustainability, VULN - Vulnerability, whilst specific indicators are in blue text and qualified further by specific indicator variables in Table 2 and explained in Supplementary data (Glossary of indicator categories). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

for health outcome indicators. The standards omitted specifics on social-ecological systems, such as economic disparities and differences in access to health care facilities across the general population.

There was no clear evidence of the Ghanaian Ministry of Health currently monitoring indicators beyond the traditional disease incidence, health monitoring and interventions and the emphasis was on five

**Table 1**  
Outcome of the SWOT analysis of five conventional health indicators in their traditional roles as health indicators, thus, business as usual (BAU) and as climate change indicators (CCI), towards building resilience in the health sector. Indicators with both BAU and CCI (i.e. BAU/CCI) exhibit both attributes with respect to the surveillance indicators.

Swot measure		Conventional health surveillance indicators				
		Morbidity	Mortality	Outbreak proxy	Confirmed cases	Disease classification
Strength	Very strong		BAU	CCI	CCI	BAU/CCI
	Strong	CCI		BAU	BAU	
Weakness	Less strong	BAU	CCI			
	Very weak	BAU	CCI			
Opportunities	Weak	CCI			BAU	
	Less weak		BAU	BAU/CCI	CCI	BAU/CCI
	Very high	CCI	BAU	BAU/CCI	CCI	BAU/CCI
	High				BAU	
Threats	Less high	BAU	CCI			
	Very high	BAU/CCI	BAU/CCI			
	High				BAU/CCI	
	Less high			BAU/CCI		BAU/CCI

conventional indicators (Table 1): (i) Morbidity, using both in and out-patients and thus hospital admissions and visits to health care centers, (ii) Mortality, (iii) Behavioral proxies for disease outbreaks, (iv) Reported and confirmed cases, and (v) Disease classification. Of these, confirmed cases and disease outbreak proxies exhibited very strong attributes towards resilience to climate change impacts as opposed to it being strong as a conventional health indicator (business as usual scenario) (Table 1). Similarly, disease classification was very strong in responding to climate change impacts and as conventional health indicator for building resilience but was weak in its surveillance role (Table 1). Outbreak proxies and disease classification further exhibited very high opportunities concurrently for routine health practice (business as usual) and in responding to climate change impacts (Table 1).

#### 4.2. Relevance of indicators and response to climate change impacts

A total forty-five individual indicator variables were generated from both health and non-health sectors based on observed similarities. The indicators include, for example, algal blooms which are associated with nutrient pollution of coastal water systems; shorter response/confirmation time is in reference to time taken for health personnel to confirm the presence of disease in an area towards taking appropriate measures; ventilation has to do with the extent of air circulation especially within the hospital environment whilst buffer stock is the management of logistics such that there is sufficient material resources to contain an outbreak of a disease and may include vaccines, prophylaxis and nutritional supplements are crucial; resident reference laboratories analyze and confirm the detection of diseases. Boundary partnership is used to describe institutions at the fringes of health whose activities can affect the health sector yet are not included in health sector decision-making; sector-wide DHMT planning describes the opening up of the health sector to other sectors that demonstrate similarity in goals as health sector, whilst previous exposures describe the past size and characteristics of the at-risk population (Table 2). Between 71% and 73% of the specific indicator variables were identified with malaria in all three study districts. For diarrhea 94% of indicators were identified in the Gomoa-West, 91% in Keta and 84% in Bongo District. Eighty percent of the specific indicator variables were identified with cerebrospinal meningitis (CSM) in the Bongo district only and that there was no history of CSM in the other two districts.

The specific indicator variables were grouped into eleven predetermined indicator categories based on predefined denominators and level of relevance identified from systematic reviews and expert opinions. The categories were: adaptation (involves adjustments in response), biological (life animal and plant based), demographic (population driven), environmental (physico-chemical surroundings), epidemiological (disease related), meteorological (weather), mitigation (greenhouse gas emission related), physical (health infrastructure and logistics), policy (rules and plans), sustainability (considering the future) and vulnerability (hazards, risks, loss and damage). The distribution of all 45 indicators among these 11 categories is presented in Table 2. The indicators were examined for their potential to respond to health impacts of climate change, directly or indirectly, and “relevance” to health and the environment (Table 2). The existing or traditional health indicators exhibited moderate to high relevance, yet not responding very highly to climate change impacts, whilst policy indicator appeared to be very highly relevant. The social-ecological indicators also showed high to very high relevance although they were mostly indirectly related to health (Table 2). Chi square test statistics showed an association between the relevance of an indicator and type of response (direct, indirect, or both) on health ( $\chi^2 = 2.49$ ;  $p = 0.869$ ).

Most indicators (65%) were very highly relevant in types of response (i.e., direct, indirect, both) to the impacts of climate change in the health sector followed by indicators with high relevance (22%), moderate (9%) with 4% showing low relevance. Moreover, 45% of the indicators that exhibited very high relevance were indirectly related to health in

**Table 2**

Indicator types, types of impacts (i.e. D – direct; IND – indirect) and character of relevance of the impact on the health sector (low to very high) in relation to climate change.

Category/typology	Specific indicator (acronym in PCA)	Health impact	Relevance
Adaptation	Well trained workforce (WTWO)	D, IND	Very high
	Health facility accessibility (HEFA)	D	Very high
	Linked surveillance and climate data (LSCD)	D, IND	Very high
Biological	Shell fish bumper harvest (FISH)	IND	High
	Algal blooms (ALGA)	IND	High
Demographic	Population structure (POPS)	D, IND	Very high
	Population health (POPH)	D, IND	Very high
	Fertility (FERT)	IND	Moderate
	Migration/displacement (MIGR)	IND	High
Environmental	Pollution (POLL)	IND	High
	Sanitation (SANI)	IND	Very high
	Stagnated water (STAG)	IND	Very high
	Environmental temperature (ENVI)	IND	Very high
Epidemiological	Mortality (MORT)	D	Low
	Morbidity (MORB)	D	Moderate
	History of occurrence (HIST)	D	High
	Reported/confirmed cases (REPC)	D	Moderate
Meteorological	Rainfall (RAIN)	IND	Very high
	Atmospheric temperature (ATMT)	IND	Very high
	Humidity (HUMI)	IND	Very high
	Sunshine/heat (SUNS)	IND	Very high
	Extreme weather (EXTW)	IND	Very high
Mitigation	Energy efficiencies (e.g. solar usage) (ENEF)	D, IND	Moderate
Physical	Increased health facilities (INHF)	D	High
	Shorter response/confirmation time (SHRC)	D	Very high
	Ventilation (VENT)	D, IND	High
	Buffer stock (BSMS)	D	Very high
	Resident reference laboratories (RERL)	D	Very high
	Trauma facilities (TRAU)	D	Very high
	Logistics/human resource (LOGI)	D, IND	Very high
	Increased ambulance service (AMBU)	D	High
	Decentralization (DCEN)	D	Very high
Policy	Boundary partnership (BOUP)	D, IND	Very high
	Sector-wide DHMT Planning (SWDP)	D, IND	Very high
	Diminished cases of diseases (DCDI)	D	Very high
Sustainability	System wide early warning (SWEW)	D, IND	Very high
	Sea level rise (SLVR)	IND	High
Vulnerability	Flooding (FLOO)	D, IND	Very high
	Stagnated water (pockets)/pools (SWAT)	IND	Very high
	Dams and ponds (DAMS)	IND	Very high
	Wealth status (WEAL)	IND	Low
	Elderly living alone (ELVA)	IND	Very high
	Children (CHIL)	IND	Very high
	People with disabilities (PEOD)	IND	Very high
	Previous exposures (PREX)	D, IND	High

responding to impacts of climate change. The combined response of the indicators (direct and indirect) contributed 31% of the very highly relevant indicators, 25% moderately relevant to the sector's response to impacts of climate change and 20% high relevance to health response to impacts of climate change. The weighted relevance of the indicator categories (Fig. 3) shows that policy, meteorological, adaptation and sustainability were highly weighted (1.0), and existing health surveillance indicators were the least weighted (0.64).

Generally, the weighted relevance of all indicators was sensitive as climate change resilience indicators ( $>0.5$ ). The 1st axis of the Principal Component Analysis (PCA) (Fig. 4) explains the attributes of the impacts and relevance of the specific indicator variables and by the indicator categories are interconnected in the health sector and explaining  $<40\%$  of the variation in the indicators. Thus the indicators are robust and when they simultaneously exhibit both direct and indirect impacts,



as observed by the cluster of indicators along the vector defining the direct and indirect impacts in quadrant II (Fig. 4). Within the clustering in the same quadrant adaptation, vulnerability and physical indicators were highly expected to respond to climate change. Indicators that showed very high relevance emerged mostly from sources where both direct and indirect indicators were acting together (Fig. 4). Where there is clustering of the indicators for both specific variables and associated categories, the indicators expressed similar profiles in responding to climate change impacts. Similarly, the cluster of some indicators along the axis 2 (which explains over 60% variance in data) appear not to have strong influence in quadrants IV and I and may not be expressively strong when acting together.

## 5. Discussion

### 5.1. Baseline characteristics of health sector indicators and climate change

The results suggest that existing health sector indicators acting alone are not sufficiently adequate to establish resilience to climate change. Therefore, it is instructive that health managers are trained to take charge of resilience in consultation with relevant sectors to identify indicators that are sensitive to climate change and driving resilience (Fig. 2). This is because the role that social–ecological systems play in building resilience of the health sector has eluded the debate on climate change and health due to limited knowledge on the fundamental determinants of resilience, how to manage it, by whom, and which indicators to use for monitoring. Thus, social or ecological systems need to absorb disturbances whilst retaining the same basic structure and ways of functioning after a shock or stress (Folke, 2006; Leichenko and O'Brien, 2008; Luthar and Cicchetti, 2000). Table 2 suggests that the relevance of the indicators was significant in relation to whether or not the influence of indicators on health response was direct, indirect or concurrent. From a developing country perspective where competition for limited resources for development is often intense, such information would be useful in minimizing waste, enhancing efficiency and improving opportunities for building resilience. The overlap of some indicators not considered as high or very high if they were acting alone influenced their relevance to the health sector's capacity to respond to climate change impacts (Fig. 4). Some physical indicators in the 1st quadrant of the PCA interacted with epidemiological indicators, the combination of which led to moderate responses to climate change impacts and also confirming that clusters of indicators were most likely to have direct impacts on public health. The study affirmed the emerging relevance which is attached to climate change and diarrheal diseases (Alexander et al., 2013; Carlton et al., 2014) by eliciting highest indicators in all three districts as compared to malaria and CSM, the latter only studied in a single district.

### 5.2. Conventional health surveillance systems and climate change impacts

Geographical scope of climate change impacts would require local knowledge and action to promote health co-benefits of climate change mitigation policies (Haines, 2012). Weather is known to be a major determinant or driver of disease transmission and can be said to be highly sensitive to extreme weather events such as heat from the health perspective and important as health surveillance indicator but the analysis shows that the existing health determinants are less sensitive to the impacts of extreme weather unless acting in combination with other indicators. Therefore, indicators that inform early warning, for which proxies and geographical classification of disease is a part, are highly relevant (Table 2). Morbidity data are reliable indicators of the state of disease burden and therefore provide some opportunity for disease reporting as may apply to climate change. However, mortality, although confirmatory for disease impact, cannot be a response option for resilience to climate change impact because saving lives and preventing death is paramount to resilience. Whilst proxies of disease incidence

such as reporting suspected cases and intermittent screening are good triggers for early warning as confirmed cases, proxies require increased and sustained monitoring which may not be financially affordable to the central government. Because proxies are intermediaries of disease detection instead of the use of direct diagnostic evidence, they are preferred in managing the health sector's resilience to climate change scenarios which are characterized by uncertainties such as the probabilities of occurrences of extreme events.

### 5.3. Interplay between indicators and typologies of health resilience

No obviously defined framework for joint assessments and planning between health and relevant non-health sectors was identified. Yet it is possible that such joint planning can be conducted but the legitimacy will lie more with the health sector to initiate the process by inviting other sectors with activities that engage indicators not routinely administered in the health sector. Lessons elsewhere show cross-sector integration in health database management and physical planning (English et al., 2009; Ghebreyesus et al., 2012; Lesnikowski et al., 2013). Relevance of indicators for the health sector (Fig. 3), suggests that prominent existing routine health sector indicators (e.g. mortality and morbidity) and EPHI alone fall short of vulnerability information without accompanying ecosystem and socio-economic data.

The strong expression of indicators of meteorological and policy sources suggests two typologies of health sector resilience, “internal” (state of resilience of the health sector based on the existing indicators) and “external” (resilience of the sector brought about as a result of the incorporation of not routinely captured indicators related to health). The external resilience is driven by other sectors and linked mostly to ecosystems and the climatic system (e.g. agriculture and food security, water resources and water supply, air quality). Therefore, there is need for a health sector environment accommodating policies that leverage the dynamic interplay among ecosystem determinants driven mostly by ecosystem services, and between them and health outcomes (Butler and Friel, 2006; Parkes et al., 2010). Ecohealth concept and practice present opportunities to minimize the outcomes of ecosystems shock or stress with potentially increasing impacts of climate change acting adversely against resilience in the public health sector (e.g., see Fig. 5). Using Ecohealth approach will require that public health managers take active steps to reorganize health practice that reduces the damages from, and increase the benefits attributed to climate change (Alberini et al., 2006) through critical policy thinking in eco-epidemiology. This is because the role of ecosystem services in regulating disease origin and occurrence would very much prepare public health against loss and damage from climate change.

### 5.4. Non-health indicators and health policy mainstreaming

The failure to address climate change impacts on health will be costly and likely to erode successes of development especially for low income countries. Lessons from this study suggest that (i) the health sector's readiness to adapt to the impacts of climate change is uncertain in spite of the available capacity and stringent health based policies, (ii) the health system is under-developed to promote adaptive management orientation of health sector policies to incorporate aspects of non-health indicators from other sectors, and (iii) the need to integrate outcomes of health response and surveillance learnt over time to facilitate, review and appraise management capability and practice within the health sector towards resilience building. Additionally, strong leadership would be required to translate science into policy to make adaptation in the health sector more pragmatic than known currently and taking advantage of the benefits that climate change present as observed elsewhere (e.g., Lesnikowski et al., 2011, McMichael et al., 2009). The implementation of social–ecological indicators in the decision making process of public health surveillance will be influential due to a highly regulated sector planning framework in Ghana. This is



**Fig. 5.** Sea water intrusion, coastline attrition and dilapidated infrastructure are major risks informed by sea level rise in the community of Totope in Ada East of Ghana, requiring indicators beyond conventional health indicators to manage the health risks. Inset (Fishmonger scooped sand, debris and pollutants before accessing her room with health challenges).

because the relationship between human health and climate change is portentous for public health, warranting increased awareness of policymakers to work with ecosystem based indicators (Haines, 2012).

## 6. Conclusions

The baseline study of the three diseases (malaria, diarrhea and CSM) shows that the impacts of climate change on human well-being are becoming relevant hotspots for public health planning and health impact assessments. However, there is slow pace at establishing, integrating and expanding broader climate-sensitive indicators in health. The traditional indicators such as mortality, history of disease occurrence, reported and confirmed disease cases and morbidity, alone cannot adequately adapt to the added burden of climate change unless complemented with new indicators that are external to the sector. Demographic indicators such as population structure and fertility, as well as environmental health indicators which include pollution and environmental temperature are unable to support resilience of the sector unless they were a function of meteorological, mitigation, biophysical, policy, vulnerability and biological indicators, explained by the PCA outcomes. Therefore, resilience of the health sector resides both within the health sector itself and outside, the latter predetermined by non-health related biophysical and social change, and associated policy decisions. Therefore, different social-ecological settings that are external to the health sector were likely to present differences in challenges of climate change including degree of exposures, incidences and burden of health outcomes. Hence, building resilience within the health sector to respond to climate change is multidimensional. However, capturing relevant climate sensitive indicators of the total environment in health sector management would require flexible planning horizons and prioritization to refine public health management tasks. Certain degrees of hybridization that match health interventions with climate change adaptation at the boundary of health and non-health sources will be required. The overlapping of most health and non-health indicators underscore the relevance of indicator behavior in public health sector's planning to generate high value response measures to reduce vulnerability to climate change. Subsequently, public health related climate change policies and strategies should reflect (i) indicators of interventions that match the scale of impacts, (ii) sufficient action to engage external resilience sources, and non-health indicators, and (iii) actions sufficiently addressing social-ecological linkages including ecosystem services. The health - climate change nexus provides opportunities for interrogating how to manage modifications of components of the total environment, and links with the origin, incidence and management of climate - sensitive diseases such as malaria, and diarrhea. It is expected that seamless cross-sector and cross-scale harmonization of relevant and climate - sensitive indicators will make health planning more successful in responding to climate change.

## Funding information

This article emerged from the UNDP-GEF funded Project #3218 on “Integrating Climate Change into the Management of Priority Health Risks” awarded to the Ministry of Health, Ghana.

## Acknowledgements

The authors are grateful to the comments of several experts within the health and non-health sectors and also the various consultants that worked on the UNDP-GEF funded Project on “Integrating Climate Change into the Management of Priority Health Risks” executed by Ministry of Health, and Environmental Protection Agency, Ghana for their invaluable inputs and some data that were shared.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at <http://dx.doi.org/10.1016/j.scitotenv.2016.09.066>.

## References

- Agyemang-Bonsu, W.K., et al., 2009. Ghana Climate Change Impacts, Vulnerability and Adaptation Assessments. Environmental Protection Agency, Accra.
- Alberini, A., Chiabai, A., Muehlenbachs, L., 2006. Using expert judgment to assess adaptive capacity to climate change: evidence from a conjoint choice survey. *Glob. Environ. Chang.* 16, 123–144.
- Alexander, K.A., Carzolio, M., Goodin, D., Vance, E., 2013. Climate change is likely to worsen the public health threat of diarrheal disease in Botswana. *Int. J. Environ. Res. Public Health* 10, 1202–1230.
- Bell, E., 2011. Ready health services for climate change: a policy framework for regional development. *Am. J. Public Health* 101, 804–813.
- Berkes, F., 2007. Understanding uncertainty and reducing vulnerability: lessons from resilience thinking. *Nat. Hazards* 41, 283–295.
- Butler, C.D., Friel, S., 2006. Time to regenerate: ecosystems and health promotion. *PLoS Med.* 10, 1692–1695.
- Carlton, J., Elizabeth, J., Eisenberg, N.S., Goldstick, J., Cevallos, W., Trostle, J., Levy, K., 2014. Heavy rainfall events and diarrhea incidence: the role of social and environmental factors. *Am. J. Epidemiol.* 179, 344–352.
- Clarke, K.-L., Berry, P., 2012. From theory to practice: a Canadian case study of the utility of climate change adaptation frameworks to address health impacts. *Am. J. Public Health* 57, 167–174.
- Costello, A., et al., 2009. Managing the health effects of climate change. *Lancet* 373, 1693–1733.
- Deppisch, S., Hasibovic, S., 2013. Social-ecological resilience thinking as a bridging concept in transdisciplinary research on climate-change adaptation. *Nat. Hazards* 67, 117–127.
- Downes, B.J., Miller, F., Barnett, J., Glaister, A., Ellemor, H., 2013. How do we know about resilience? An analysis of empirical research on resilience, and implications for interdisciplinary praxis. *Environ. Res. Lett.* 8, 014041.
- Ebi, K.L., Burton, I., 2008. Identifying practical adaptation options: an approach to address climate change-related health risks. *Environ. Sci. Pol.* 11, 359–369.
- English, P.B., et al., 2009. Environmental health indicators of climate change for the United States: findings from the state environmental health indicator collaborative. *Environ. Health Perspect.* 117, 1673–1681.

- Few, R., 2007. Health and climatic hazards: framing social research on vulnerability, response and adaptation. *Glob. Environ. Chang.* 17, 281–295.
- Folke, C., 2006. Resilience: the emergence of a perspective for social–ecological systems analyses. *Glob. Environ. Chang.* 16, 253–267.
- Gallopin, G.C., 2006. Linkages between vulnerability, resilience, and adaptive capacity. *Glob. Environ. Chang.* 16, 293–303.
- Ghebreyesus, T.A., Tadese, Z., Jima, D., Bekele, E., Mihretie, A., Yihdego Y. Y., Dinku, T., Connor, S.J., Rogers, D.P., 2012. Public health services and public weather services: increasing the usefulness of climate information in the health sector. *WMO Bull.* 57, 256–261.
- GoG (Government of Ghana), 2010. Ghana's Second National Communication Report to the UNFCCC. Government of Ghana, Accra.
- GoG (Government of Ghana), 2015. Ghana's Third National Communication Report to the UNFCCC. Government of Ghana, Accra.
- Haines, A., 2012. Sustainable policies to improve health and prevent climate change. *Soc. Sci. Med.* 74, 680–683.
- Haines, A., Kovats, R.S., Campbell-Lendrum, D., Corvalan, C., 2006. Climate change and human health: impacts, vulnerability and public health. *Public Health* 120, 585–596.
- Houghton, A., English, P., 2014. An approach to developing local climate change environmental public health indicators, vulnerability assessments, and projections of future impacts. *J. Environ. Public Health* <http://dx.doi.org/10.1155/2014/132057>.
- IPCC (Intergovernmental Panel on Climate Change), 2001. *Climate Change 2001: The Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge.
- IPCC Climate Change, 2014. Summary for Policymakers. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge and New York.
- Jankowska, M.M., Lopez-Carr, D., Funk, C., Husak, G.J., Chafe, Z.A., 2012. Climate change and human health: spatial modelling of water availability, malnutrition, and livelihoods in Mali, Africa. *Appl. Geogr.* 33, 4–15.
- Jongman, R.G.H., ter Braak, C.J.F., van Tongeren, O.F.R. (Eds.), 1987. *Data Analysis in Community and Landscape Ecology*. Pudoc, Wageningen.
- Leichenko, R., O'Brien, K., 2008. *Environmental Change and Globalization: Double Exposures*. Oxford University Press, Oxford.
- Lesnikowski, A.C., Ford, J.D., Berrang-Ford, L., Paterson, J.A., Barrera, M., Heymann, S.J., 2011. Adapting to health impacts of climate change: a study of UNFCCC annex I parties. *Environ. Res. Lett.* 6, 044009.
- Lesnikowski, A.C., et al., 2013. National-level factors affecting planned, public adaptation to health impacts of climate change. *Glob. Environ. Chang.* 23, 1153–1163.
- Linnenluecke, M.K., Griffiths, A., 2012. Assessing organizational resilience to climate and weather extremes: complexities and methodological pathways. *Clim. Chang.* 113, 933–947.
- Luthar, S.S., Cicchetti, D., 2000. The construct of resilience: implications for interventions and social policies. *Dev. Psychopathol.* 12, 857–885.
- McMichael A. J., Woodruff R. E., Hales, S., 2006. Climate change and human health: present and future risks. *Lancet* 367, 859–869.
- McMichael A. J., Neira, M., Bertollini, R., Campbell-Lendrum, D., Hales, S., 2009. Climate change: a time of need and opportunity for the health sector. *Lancet* 374, 2123–2125.
- Mishra, S.J., Bhandari, P.M., Issa, R., Neupane, D., Gurung, S., Khanal, V., 2015. Climate change and adverse health events: community perceptions from the Tanahu district of Nepal. *Environ. Res. Lett.* 10, 034007.
- Nguendo-Yongsi, H.B., Dovie, D.B.K., 2007. Diarrhoeal diseases in the history of public health. *Arch. Med. Res.* 38, 159–163.
- Parkes, M.W., Morrison, K.E., Bunch, M.J., Hallström, L.K., Neudoerffer, R.C., Venema, H.D., Waltner-Toews, 2010. Towards integrated governance for water, health and social–ecological systems: the watershed governance prism. *Glob. Environ. Chang.* 20, 693–704.
- Pascal, M., Viso A. C., Medina, S., Delmas M. C., Beaudou, P., 2012. How can a climate change perspective be integrated into public health surveillance. *Public Health* 126, 660–667.
- Sheridan, S.C., Allen, M.J., 2015. Changes in the frequency and intensity of extreme temperature events and human health concerns. *Curr. Clim. Chang. Rep.* 1, 155–162.
- Smith, K.R., Woodward, A., Campbell-Lendrum, D., Chadee, D.D., Honda, Y., Liu, Q., Olwoch, J.M., Revich, B., Sauerborn, R., 2014. Human health: impacts, adaptation, and co-benefits. In: Field, C.B., et al. (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge and New York, pp. 709–754.
- Uittenbroek, C.J., Janssen-Jansen, L.B., Runhaar, H.A.C., 2013. Mainstreaming climate adaptation into urban planning: overcoming barriers, seizing opportunities and evaluating the results in two Dutch case studies. *Reg. Environ. Chang.* 13, 399–411.
- UN (United Nations), 1992. *United Nations Framework Convention on Climate Change*. United Nations, New York.
- UNFCCC, 2007. *Climate Change: Impacts, Vulnerabilities and Adaptation in Developing Countries*. United Nations Framework Convention on Climate Change, Bonn.
- Walker, B., Salt, D., Reid, W., 2006. *Resilience Thinking: Sustaining Ecosystems and People in a Changing World*. Island Press, Washington DC.
- Walker, B., et al., 2002. Resilience management in social–ecological systems: a working hypothesis for a participatory approach. *Conserv. Ecol.* 6, 14.
- World Bank, 2009. *Ghana Economics of Adaptation to Climate Change*. Washington DC, The World Bank.
- Xu, Z., Huang, C., Turner, L.R., Su, H., Qiao, Z., Tong, S., 2013. Is diurnal temperature range a risk factor for childhood Diarrhoea. *PLoS One* 8 (5), e64713.
- Zell, R., 2004. Global climate change and the emergence/re-emergence of infectious diseases. *Int. J. Med. Microbiol.* 293, 16–26.