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Review article

Priority focus areas for a sub-national response to climate change and health: A South African provincial case study

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ABSTRACT

Introduction: The intersection of health and climate change is often absent or under-represented in sub-national government strategies. This analysis of the literature, using a new methodological framework, highlights priority focus areas for a sub-national government response to health and climate change, using the Western Cape (WC) province of South Africa as a case study.

Methods: A methodological framework was created to conduct a review of priority focus areas relevant for sub-national governments. The framework encompassed the establishment of a Project Steering Group consisting of relevant, sub-national stakeholders (e.g. provincial officials, public and environmental health specialists and academics); an analysis of local climatic projections as well as an analysis of global, national and sub-national health risk factors and impacts.

Results: Globally, the discussion of health and climate change adaptation strategies in sub-national, or provincial government is often limited. For the case study presented, multiple health risk factors were identified. WC climatic projections include a warmer and potentially drier future with an increased frequency and intensity of extreme weather events. WC government priority focus areas requiring further research on health risk factors include: population migration and environmental refugees, land use change, violence and human conflict and vulnerable groups. WC government priority focus areas for further research on health impacts include: mental ill-health, non-communicable diseases, injuries, poisonings (e.g. pesticides), food and nutrition insecurity-related diseases, water- and food-borne diseases and reproductive health. These areas are currently under-addressed, or not addressed at all, in the current provincial climate change strategy.

Conclusions: Sub-national government adaptation strategies often display limited discussion on the health and climate change intersect. The methodological framework presented in this case study can be globally utilized by other sub-national governments for decision-making and development of climate change and health adaptation strategies. Additionally, due to the broad range of sectoral issues identified, a primary recommendation from this study is that sub-national governments internationally should consider a "health and climate change in all policies" approach when developing adaptation and mitigation strategies to address climate change.

1. Introduction

Although climate change is a large threat to global health, more recently climate change has been deemed the "greatest global health opportunity of the 21st century" by the Lancet Commission on Health and Climate Change, whereby adapting to a changing climate might result in positive human health impacts and as such responding to climate change presents an opportunity to improve health (Watts et al., 2015). The impacts of climate change on human health are featuring more prominently in global research (IPCC, 2014). At a national level, governments in some low- and middle-income countries (LMICs), such as South Africa, Fiji and Jordan, have developed climate change and health adaptation plans (South Africa (National Climate Change and Health Adaptation Plan 2014–2019), Fiji (Climate Change and Health

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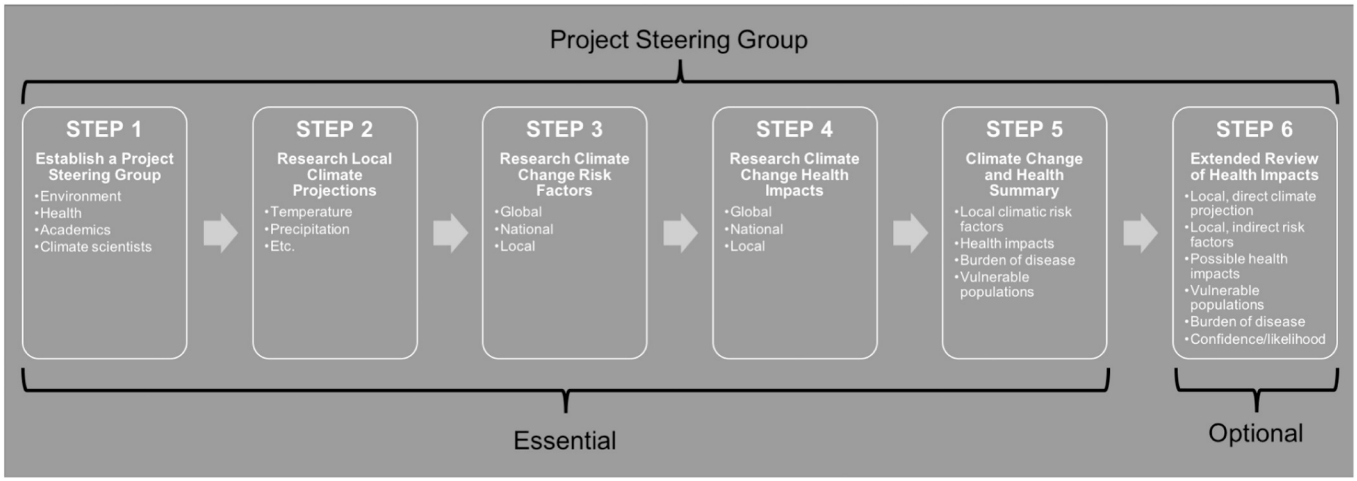

Fig. 1. A methodological framework that can be used by sub-national governments to assess climate change health risks and impacts.

Strategic Action Plan 2016–2020), Jordan (National Climate Change and Health Adaptation Strategy and Action Plan of Jordan, 2012)). At the sub-national level however, again using South Africa as an example, health sections within climate change adaptation plans are often limited (i.e. provincial (Western Cape Climate Change Response Strategy, 2014), local (Framework for Adaptation to Climate Change in the City of Cape Town, 2006)).

Huang et al. (2011) identified a number of barriers for public health adaptation, at the national and sub-national level, to climate change globally, including uncertainty of the extent of climatic changes and identification of vulnerable populations, financial and technological constraints, institutional limitations, a low level of social capital and individual cognition of climate change risks, vulnerabilities and adaptive capacity. Limited health-specific climate change adaptation strategies sub-nationally could also be due to the lower perceived threat of climate change to health by sub-national health departments compared to other health risks (Roser-Renouf et al., 2016).

Although not specific to health, Pasquini et al. (2013) argue, from their research in the Western Cape (WC) province of South Africa, that individual (e.g. lack of understanding), institutional (e.g. local politics) and socio-cultural (e.g. lack of interest) challenges exist to implementing sub-national climate change adaptation strategies. The problem of poor sub-national implementation is not unique to LMICs, as even in some high-income countries, such as Japan, municipalities report a lack of information and tools for adaptation to climate change as well as an inefficient "silo" approach between government departments (Baba et al., 2017). Roberts (2008) highlights the importance of making issues of climate change applicable to the local situation for meaningful institutionalization at the sub-national governmental level as she reflects on the case of Durban, a city municipality in South Africa. Others have researched barriers to climate change adaptation through a systematic review (Biesbroek et al., 2013), development of a framework (Moser and Ekstrom, 2010) and sub-national surveys (Amundsen et al., 2010). Thus, there has been substantial research on identifying the challenges and barriers to implementing climate change adaptation strategies, but less research has been conducted on the development of health and climate change adaptation strategies.

When it comes to the issue of health and climate change, often adaptation strategies at the sub-national level are not thorough enough to guide implementation due to the scarcity of health-specific information within the strategy such as the WC Climate Change Response Strategy (WCCCRS) of 2014 (DEA&DP, 2014). A sub-national survey conducted in the USA with 34 of California's 61 public health officers found that the officers reported feeling under-resourced with a lack of access to information about how to cope with the threat that climate change poses to public health (Bedsworth, 2009). Frumkin et al. (2008) advocate for science-based decision-making in developing a public health response to climate change and state that:

> "…planning for and managing the health impacts of climate change will need to draw on local data and will involve local and regional authorities and health care providers."

However, as is often the case for resource-deficient and capacity-stretched sub-national departments, developing such regionally appropriate health and climate change strategies is challenging. Particularly as there is a plethora of information available from a global perspective, which may not be accessible, applicable to, or translatable for local conditions. Thus, a mechanism needs to be created to assist sub-national departments in developing health and climate change policies and for setting sub-national priority focus areas. We present such a mechanism within this review using the WC province of South Africa as a case study.

2. Methods

A methodological framework for the literature review and gap analysis was developed by two of the authors (CNG and H-AR) to identify priority research areas (Fig. 1). Such a framework has not previously existed and began with the establishment of a multi-disciplinary Project Steering Group (PSG) which guided the research (discussed in detail below). The methodological framework aimed to comprehensively compare global research findings with national and sub-national research, and to identify and highlight priority focus areas for sub-national government health-related strategies and interventions. The framework employs five essential and one optional (resource permitting) investigative research steps and considers local climate projections with associated health impacts, provides reference to vulnerable populations whilst also addressing burden of diseases, and draws knowledge from the global and national setting.

This framework incorporates local climate change projections with anticipated health risk factors and impacts to provide both a detailed and generalized summary of how sub-national governments need to adapt and respond to climate change impacts on health. This method facilitated the co-production of knowledge through the engagement and input of relevant transdisciplinary actors by establishing a multi-stakeholder PSG (Ziervogel et al., 2016; Filipe et al., 2017; Djenontin and Meadow, 2018). The methodological framework was developed to guide this literature review and gap analysis specifically. However, what became evident during the use of this framework for this work, was that it could provide a structured approach for under-resourced (financial and human expertise) sub-national governments, who may lack capacity to undertake locally-applicable primary research of

climate change impacts on health specifically, with the intention of developing their sub-national adaptation strategies and priorities.

2.1. Case study context

Nine provinces make up the Republic of South Africa and, while the overarching co-ordinating responsibility and focal point for climate change is the National Department of Environmental Affairs, each province is mandated with preparing a climate change response strategy (DEA, 2011). At a national level, the Department of Health developed the National Climate Change and Health Adaptation Plan 2014–2019 (Department of Health, 2014) that provides a broad adaptation framework for the health department and informs the overall provincial strategy, but it is not specific to each province. The WC province will be used as a case study in this review, particularly as the WC Department of Environmental Affairs and Development Planning (DEA&DP) commissioned a review of the health impacts of climate change for the region. The current provincial climate change strategy of the WC government (WCG) (i.e. WCCCRS (DEA&DP, 2014)) has a brief section on health. The strategy, however, is not comprehensive most likely due to the paucity of available WC-specific research as well as government's limited access to published journal articles.

The steps of the methodological framework, as outlined in Fig. 1, were applied to a case study of the WC and are described below.

2.2. Establishing a project steering group (step 1)

At the onset of the project, a PSG was established. Stakeholders were selected and invited by two of the authors (CNG and H-AR). Selection was based primarily on the stakeholder's affiliation, expertise, level of influence and ability to commit time to attend meetings and engage with the research as well as members who were also involved in writing the proposal for the project funding. It is recommended that at least one stakeholder from the following is invited to the PSG: sub-national environment department or the relevant sub-national department responsible for climate change; sub-national health department, climate scientist focused on the region of interest; public and environmental health specialists such as academics and researchers. The PSG was established to provide input into the methodology, comment on the findings, and provide grey literature resources and relevant contacts.

2.3. Research local climate projections (step 2)

Local climate projections were obtained by climate scientist experts from the African Climate and Development Initiative (ACDI; www.acdi.uct.ac.za) and from grey literature sources such as the Climate Systems Analysis Group (CSAG) (Blamey et al., 2014), DEA&DP (2016) and DEA &DP (2016). Local climate projections from these sources were discussed with the PSG who provided expert opinion as to the most appropriate climate projections for the province.

2.4. Research climate change health risk factors and impacts (steps 3 and 4)

Indicators and keywords of climate change-related risk factors and health impacts were identified from reference documents to determine climate change risks and health impacts, as well as to conduct a gap analysis. These reference documents were selected because they were peer-reviewed, published by a reputable source and were largely considered the benchmark report for the relevant scale of inquiry (Table 1). Guidance on the selection of the documents was also provided by the PSG.

2.5. Climate change and health summary (step 5)

Creating a summary of climate change-related health impacts for the WCG was the final essential step in our framework; this enabled presentation of the broader distribution of information in a concise and accessible format. Direct and indirect risk factors are represented alongside projected health impacts. It was also important to highlight vulnerable populations and the province's burden of disease to indicate which diseases on the burden of disease list were likely to be affected by climate change. For provision of the anticipated health impacts attributed to direct risk factors, additional literature was researched. The IPCC's (2014) Chapter 11 on health provided the summary of direct climate and weather impacts on health, which is useful for obtaining summary data on heat- and cold-related impacts as well as on floods and storms. The WHO Atlas of Health and Climate (2012) was used for obtaining summary data on floods, cyclones, drought and heat stress. For other climatic risks, such as sea-level rise, it was necessary to search for a dedicated review using the search terms “health” and “sea level” in PubMed and Scopus and filtering by Review.

2.6. Extended review of health impacts (step 6)

Resource permitting, an optional step of the methodological framework can be undertaken to provide an indication of the attribution pathways and mechanisms for exposures to result in health impacts. This stage is useful for intervention and adaptation planning but is not essential to identify potential health impacts. A search strategy was employed using the indicators and keywords identified in Steps 3 and 4. As this stage was labour intensive and beyond the scope of the project objectives, only temperature and health impacts were searched (i.e. hot temperature OR heat OR ambient temperature OR heat wave AND depression). This provided an example of what type of research could be conducted in the future as well as the type of results that could be expected. Therefore, completing the extended search for all climatic variables and risk factors, not only increased temperature, is recommended for governments with adequate resources to identify attribution pathways for adaptation planning.

Occasionally, upon searching for research articles, additional health impacts would become apparent, such as “hand foot and mouth disease” or “urinary tract infections”, that were not mentioned in any of the reference documents. These health impacts were included in the review but were highlighted as being identified through the PSG's search. In reviewing the relevant articles, particular notice should be taken of vulnerable populations mentioned for effective adaptation planning. Articles were excluded from review if they were not peer-reviewed nor published in English. The following search domains were used: PubMed, Scopus and Google Scholar (first 10 pages). To avoid presenting the results of this stage in an unordered list that might lead to fatalism among policy-makers (Clayton et al., 2017), health impacts were categorized in the first column in relation to the province's burden of disease (top 10 diseases that burden the sub-national region for ease of reference, obtained from the sub-national Department of Health) to provide an indication of urgency (i.e. diseases that are already resulting in morbidity, mortality and incurring financial costs are likely to be exacerbated by climate change thus becoming increasingly burdensome). Next, as the results of this search were likely to be extensive, it was necessary to create an additional column which provided a comment on the degree of certainty of various health impacts from occurring to give an indication of prioritization. The IPCC confidence ratings (IPCC, 2014) were useful for this purpose, although it did not provide confidence ratings for all health impacts. Therefore, a final column was created which contained all the possible health impacts that were either not linked to the top 10 burden of disease, nor given a confidence rating by the IPCC, but were identified by Steps 3 and 4. The benefit of Step 6, apart from attempting to categorize health impacts for improved clarity of review by decision-makers, would also come from the attribution pathway (how an exposure likely leads to a health impact) knowledge generated by reviewing relevant articles. This knowledge would be important to use during intervention and adaptation planning.

Table 1
Reference documents chosen, with justifications of choice, for researching climate change health risk factors and impacts.

Region	Reference document	Justification for choice
Global	Lancet commission on health and climate change (Watts et al., 2015).	The Lancet has a long-standing reputation as a leader in health research, and the Commission was specifically created to identify the possible impacts of climate change on health to ensure necessary policy responses based on the highest attainable standard of healthcare.
Africa	Africa Chapter (Niang et al., 2014) from the Intergovernmental Panel on Climate Change's (IPCC) latest report (IPCC, 2014).	The IPCC is the benchmark report for the region on climate change.
Southern Africa	Journal article published in the South African Medical Journal (Myers et al., 2011).	The article provides a thorough overview of how climate change is likely to impact on public health, it is peer-reviewed, and it has been widely cited.
South Africa	Long-term Adaptation Scenarios (LTAS) technical report on Human Health (DEA, 2013).	The LTAS is a flagship research programme facilitated by the National Department of Environmental Affairs and was developed in response to the South African National Climate Change Response White Paper (DEA, 2011).
Western Cape	Western Cape Climate Change Response Strategy (DEA&DP, 2014).	The WCCCRS is the current climate change response strategy for the province.

3. Results and discussion

The results and discussion section below are combined and follow the order of the methodological framework presented (Fig. 1), that being, a discussion on the efficacy and involvement of the PSG, presentation of the local climatic projections, risk factors and health impacts. The gap analysis is presented in the form of two tables with gaps of the 2014 WCCCRS (DEA&DP, 2014) noted and discussed in detail. Finally, a summary of how climate change impacts health, noting vulnerable populations and the burden of disease, is presented.

3.1. Project steering group

Since there were several key government officials and academics working on climate change and health-related issues in the WC, it was important to involve these stakeholders in the co-production of the literature review for this project. Thus, the PSG was established at the onset of the project, building on members who were also involved in writing the proposal for the project funding. This provided a co-production platform for exchanges of ideas and information, drawing on the expertise of members and the joint construction of the knowledge represented by the methodological approach and the analysis of the research findings. As a key element to the co-production of knowledge requires researchers and practitioners to collaborate through direct connection, the group met seven times during the project, from April 2017 to April 2018 (Djenontin and Meadow, 2018) with meetings, on average, lasting 2.5 h whereby PSG members discussed relevant research findings and implications at various stages of the research. The initial meeting outlined the aim of the project and discussed the role of the PSG, along with expectations and was largely an information sharing meeting. The following five meetings took place at the different steps of the methodological framework and included a discussion on progress, challenges and results of the previous step as well as actions and approval for the next step with the final meeting discussing the procedure for dissemination of the results.

Although lack of time is often identified as a barrier to co-production of knowledge, a core group of PSG members regularly attended meetings ensuring continuity and building a meaningful relationship and interaction (Polk, 2015). The authors believe that the PSG greatly contributed to the overall success of the project, with public and environmental health specialists, climate scientists and government officials providing technical input, advice, access to information and grey literature reports as well as relevant contacts when necessary. Most importantly, the PSG provided feedback at each step of the project and ensured that any recommendations would be realistic and achievable within the sub-national setting which promoted “value production” (Filipe et al., 2017). Another benefit of this transdisciplinary co-production was what Polk (2015) refers to as the “usability” of the research and findings (i.e. relevance and accessibility). PSG members were integral in assisting with research translation and dissemination (e.g. development and distribution of a policy brief) of the findings to the academic and sub-national government community (i.e. to all WCG departments via a transversal, cross-departmental, provincial work group focussed on the provincial government's climate change response).

3.2. Local climate projections

Local climate projections were challenging to obtain, particularly for the WC due to the geographic characteristics of the province, long coastline with ocean currents of differing temperatures, varied landscape (mountain ranges, oceans, inland plateau areas) and variable weather patterns arising from the Southern Ocean (Blamey et al., 2014; DEA&DP, 2014). The final WC climate projections were the result of analysing the numerous grey literature reports (Blamey et al., 2014; DEA&DP, 2014, 2016, 2016) and of discussions with the PSG climate scientists who collated information from the reports and provided expert opinion based on the different modelling methods used in the reports. Generally, models agree on a warming trend with possible shifts in seasonality (Blamey et al., 2014; DEA&DP, 2014, 2016).

3.2.1. Temperature

Local temperature projections suggest a continued warming trend of uncertain magnitude with the greatest impact during summer months (Blamey et al., 2014; DEA&DP, 2014). There are likely to be more frequent extreme heat days, with fewer cold days annually (DEA&DP, 2014). Although not mentioned in the provincial strategy (DEA&DP, 2014), summer maximum temperatures are projected to increase by 1.5 °C to 2.3 °C throughout the region with some models projecting an increase as high as 3.0 °C by 2060 (Blamey et al., 2014). There is also a projected increase of between 1 °C and 2 °C in summer minimum temperatures (Blamey et al., 2014). Increased temperatures and frequency and duration of heat waves, as projected for the WC (Blamey et al., 2014), directly impact on human health, leading to increased mortality and morbidity (Amegah et al., 2016). Higher temperatures can also result in decreased labour productivity, especially for outdoor workers (Varghese et al., 2018), which is a particular concern for the WCG due to its large agricultural sector (WCG, 2017).

3.2.2. Rainfall

Rainfall patterns are difficult to predict due to greater spatial and temporal variations as compared to temperature projections, as well as the influence of the local topography (Blamey et al., 2014). Although projections are equivocal, it is likely that there will be a drying trend long-term (DEA&DP, 2016). There is also the possibility of more droughts due, in part, to increased evapotranspiration resulting from higher temperatures (DEA&DP, 2016). These trends are concerning for the WCG, as it is already a water-scarce region. There are also

projections that the number of rainfall days might decrease, but that the intensity of rainfall (classified as ≥10 mm per day) might increase, with longer time periods between intense rainfall events resulting in droughts (Blamey et al., 2014; DEA&DP, 2014, 2016) and floods (DEA, 2013; DEA&DP, 2016). As the WC is a coastal province, it is likely that the intense rainfall events, combined with possible storm surges, will also increase the hazard of excessive coastal flooding. An increased frequency of extreme weather events, such as droughts, floods and storm surges, impacts on health directly (e.g. injuries) and indirectly (e.g. malnutrition), particularly in informal settlements, where the absence of adequate storm water systems, combined with often flood-prone locations on unsuitable land, results in high flood risk (WCG, 2016).

3.2.3. Sea-level and ocean temperatures

Sea-level is projected to continue rising, increasing the risk of coastal erosion and possible salinization of groundwater and coastal soils (DEA&DP, 2014, 2016, 2016). Salinization of groundwater would have a negative impact on health, particularly as the water-scarce province currently uses groundwater reserves as a drought adaptation strategy. Salinized groundwater severely disrupts the hydrological cycle, with devastating consequences for human and ecological health. Limited supplies of usable water for drinking, personal hygiene and food production could increase the incidence of dehydration and water stress, infectious disease, food insecurity and civil conflict over water resources (Ford, 2016). Globally, melting glaciers and ice sheets and the warming of oceans could result in a sea-level rise by 45 cm to 82 cm by 2100 under an RCP8.5 scenario (IPCC, 2014). It is likely that there will be increased frequency of storm surges resulting in an increased susceptibility to coastal flooding (DEA&DP, 2014, 2016, 2016). Average ocean temperatures are projected to continue increasing (IPCC, 2014) and although the IPCC has low confidence in projecting future storm surges (IPCC, 2014), these have been correlated with increased ocean temperatures and intensified cyclone activity. These impact directly (e.g. injury) and indirectly (e.g. cholera outbreaks) on human health and should be of particular concern to the coastal areas of the WC province (Emmanuel, 2005; Dasgupta et al., 2009).

3.2.4. Wind, smog, fire

Wind velocity is likely to increase in the WC (DEA&DP, 2016; 2016) and there are projections of increased smog (South Africa's Draft 3rd National Communication to the UNFCCC, 2017). Many diseases are affected by changes in wind (e.g. meningitis (Perez Garcia-Pando et al., 2014)) and levels of smog (e.g. asthma (Abramson et al., 1995)) and thus are a concern for the province. There is a greater risk of fire incidents that may increase in extent and severity due to hotter and drier conditions, increased evapotranspiration, longer dry spells, and increased wind speeds (DEA&DP, 2014, 2016, 2016). Fires, which require fresh water for control and hence places excess strain on water resources, can lead to loss of life, have devastating impacts on social activities (e.g. recreation in green spaces) and livelihoods, adverse effects on mental health (e.g. major depression (Marshall et al., 2007)), and increased morbidity (e.g. respiratory disease (Mirabelli et al., 2009)). Finlay et al. (2012) provide a review of the health impacts of wildfires.

3.3. Local climate change risk factors

Climate change-related risk factors for human health can be directly the result of climate or extreme weather events but can also be indirect. Indirect risk factors for health include issues that we have inductively grouped within two broad areas: environmental and social (Table 2). Often an indirect risk factor might span both areas for example indoor air pollution. The global, national and sub-national risk factors (indicators and key words identified from the reference documents) for health are listed in Table 2. It is also clear from Table 2 the gaps concerning provincial climate change risk factors for health (all grey shaded cells). These gaps were further researched to provide an indication as to whether the issues were relevant to the WC region specifically (see review from Sections 3.3.1 to 3.3.4). In addition, consultation was sought from the PSG for relevance to the specific sub-national situation before being noted as a priority focus area for the sub-national government. Therefore, based on this, in the case study of the WC, the sub-national government should focus further research efforts on the following priority focus areas: population migration and environmental refugees, land use change, violence and human conflict, and vulnerable groups such as those whose occupational health is likely to be affected by climate change (discussed in detail below).

It should be noted that due to the silo nature of most sub-national governments, where environmental management, health and disaster risk management may often be located in different departments, addressing climate-related risks requires cross-departmental collaboration. This can, however, be very difficult in practice, especially in addressing a risk where non-experts could be confused by conflicting messages from various interest groups and the media. In the WCG specifically, this is addressed through the use of a transversal management system, where cross-departmental work groups (in this case the Climate Change Response Work Group, led by the Climate Change Directorate within the DEA&DP) are responsible for coordinating WCG-wide response to an area of work. This approach could be adopted by other sub-national governments.

3.3.1. Population migration and environmental refugees

The impacts of climate change and the increased frequency of extreme weather events on human health are not only direct hazard-specific mortality and morbidity, but there are also social consequences, such as displacement of communities and the creation of environmental refugees (Myers, 2012). As a result of these changes to existing social structures, interpersonal violence or conflict over limited resources may increase (McMichael et al., 2012). Women and children are among those particularly vulnerable to increased violence, such as domestic abuse, trafficking and sexual violence after extreme weather events (WHO, 2014). Following a disaster, a lack of privacy in makeshift shelters and sexual abuse affect adolescent girls particularly (Bartlett, 2008). Sub-national governments should, therefore, make provision for gender-sensitive preparedness to care particularly for the protection of women and children post-extreme weather events. Mental health issues, substance abuse and the increased spread of infectious diseases can also arise from severe social disruptions (McMichael et al., 2012). These issues would further add to the disease burden requiring additional resources and capacity for an adequate health response from the WCG.

3.3.2. Land use change

Animal agriculture contributes directly to the production of greenhouse gases and thereby indirectly affects health through climate change (Gerber et al., 2013). The health of farmers and farm workers are also vulnerable to changing weather patterns with examples of increased temperatures resulting in heat-related illness (Xiang et al., 2014) and droughts being associated with increased farmer suicide (Page and Fragar, 2002). Often a result of a changing climate, particularly in sub-Saharan Africa, in conjunction with other driving forces unrelated to climate change, there is increased rural-urban migration as rural farmers look for more profitable opportunities in urban areas (Barrios et al., 2006; Satterthwaite et al., 2010). Due to urbanisation, environmental refugee migration and industrialization, regions often undergo rapid land use change particularly towards urban land cover. This change involves a greater surface of the ground covered with largely impermeable materials, such as concrete, that restrict the amount of water that seeps into groundwater and creates flood channels so that when it rains heavily, much of the storm water is channelled through densely populated areas and increases vulnerability to flood-related disasters (Zhang et al., 2008). Storm water runoff from

Table 2
Indicators and keywords of global, national and sub-national climate change risk factors for health drawn from reference documents detailed in Table 1. Gaps for the Western Cape, as indicated by the grey cells, are highlighted as areas requiring further research and discussion from the Project Steering Group for recommendation as priority focus areas for the Western Cape.

Global Watts et al. (2015)	Africa Niang et al. (2014)	Southern Africa Myers et al. (2011)	South Africa DEA (2013)	Western Cape WCCCRS (DEA&DP, 2014)
		Environmental		
Air pollution	**Air pollution**	**Air pollution**	**Air pollution**	**Atmosphere pollution**
> Pollen allergenicity		> Air-borne pollens & spores	> Pollens & spores	
> Particulate pollution	> Particulate matter		> Particulate matter	
> Indoor air pollution	> Smoke cooking fires			
> Ground-level ozone	> Ozone	> Ground-level ozone	> Ozone	
> Nitrogen oxides			> Nitrogen dioxide	
> Sulphur dioxides			> Sulphur dioxides	
> Carbon (black & organic)				> Carbon emissions/footprint
> Aerosols	> Aerosols			
> Carbon monoxide	> Carbon monoxide		> Carbon monoxide	
> Air stagnation				
		> Carbon dioxide		> Carbon dioxide
		> Methane		> Methane
		> Aeroallergens	> Allergens	
				> GHGs
	> Dust			
	> Air quality		> Air quality	
			> Benzene	
			> Lead	
> Mould			> Mould	
> Ocean acidification				
> Fishing & aquaculture productivity				
Water quality & quantity		**Water quality & quantity**	**Water quality**	**Water quality & quantity**
> Water availability		> Water security	> Water insecurity	> Water availability/security
> Bacterial growth		> Bacterial growth		
		> Loss productive farmland		> Agriculture
		> Contamination by runoff & sewage	> Contamination of drinking water	> Contamination by waste
		> Salt & chemical contaminants		
		> Increased water temperature		
		> Increased water acidification		
		> Decreased consistency of river flows		> Decreased water balance
Food security/undernutrition	**Food insecurity**	**Food security/undernutrition**	**Food security**	**Food security/undernutrition**
> Food availability	> Food accessibility		> Food availability	
> Food affordability			> Food prices	

(*continued on next page*)

Table 2 (*continued*)

Global Watts et al. (2015)	Africa Niang et al. (2014)	Southern Africa Myers et al. (2011)	South Africa DEA (2013)	Western Cape WCCCRS (DEA&DP, 2014)
> Crop yield		> Food yield	> Crop yield	> Crop yield
> Agricultural productivity		> Agricultural yields	> Agricultural yields/productivity	> Agricultural productivity
> Livestock physiological limit				> Livestock physiological limit
		> Loss of rural livelihood		
				> Soil biodiversity/fertility
				> Fisheries sector abundance & seasonal variability
	> Animal diseases			
	> Nutrition		> Food quality	
			> Food storage & transportation	
Ecological change		**Ecological change**	**Ecosystem**	**Ecological change**
> Biodiversity loss			> Biodiversity	
> Ecosystem collapse			> Ecosystem	> Ecosystem collapse/degradation
> Desertification				> Desertification
> Harmful algal blooms				> Invasive species
> Pests	> Rodents & ticks		> Mosquitoes & ticks	> Extended range & activity of pests
	> Snails			
	> Shrews & moles			
	> Tsetse fly			
				> Coastal barrier dunes/infrastructure
				> Wetlands
				> Flood plains
			> Landslide	> Soil/river bank erosion
				> Urban-induced soil erosion
		> Fish populations		> Fish & marine species
		> Coral reef damage		
				> Heat stress in wildlife
				> Drying river ecosystem
				> Coastal erosion
				> Estuaries
			> Vector ecology/abundance	
			> Environmental resources	
Incidence & geographical range infectious diseases	**Incidence & geographical range infectious diseases**	**Incidence & geographical range infectious diseases**		**Incidence & geographical range infectious diseases**
> Distribution of disease vectors	> Distribution of disease vectors	> Density & movement of disease vectors	> Distribution of disease vectors	> Distribution & activity of disease vectors
> Reproductive rates & lifecycles	> Production of immature mosquitoes	> Vector populations & habits	> Vector abundance	
	> Parasite prevalence	> Infectious agents (dengue,		

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Table 2 (*continued*)

Global Watts et al. (2015)	Africa Niang et al. (2014)	Southern Africa Myers et al. (2011)	South Africa DEA (2013)	Western Cape WCCCRS (DEA&DP, 2014)
		bacteria, protozoans)		
	> Species composition			
Land use change			**Land use**	
> Urban land cover				
Urbanisation			**Urbanisation**	**Urbanisation**
> Heat island effect				> Urban heat island
				> Storm water systems
				> Urban management
Social				
Mass migration/population density/growth	**Migration**	**Population migration**	**Forced migration/population density/growth**	
> Cultural identity				
> Impaired air quality				
> Security		> Interpersonal violence		
		> Refugee pressures	> Environmental refugees	
		> Social tension		
			> Overcrowding	
Violent conflict & human security		**Violent conflict & human security**	**Violence & conflict**	
> Perception of insecurity/safety				
		> Behaviour (accidents/aggression/ risk taking)		
		> Access to crops, land & water		
		> Civil & military violence		
		> Gender violence		
			> Conflict over limited resources	
Biological factors		**Vulnerable populations**	**Vulnerable groups**	**Biological factors**
> Age (elderly & young)	> Age (children)	> Age (elderly & children)	> Age (children & elderly)	> Age (elderly)
> Gender	> Gender (women)	> Gender (women)	> Gender (women)	
		> Pregnant women		
			> Rural communities	
			> Socially isolated	
Poverty/socio-economic status/social capital	**Poor populations/poverty**	**Poverty/socio-economic status/social capital**	**Poverty/socio-economic status**	**Poverty/socio-economic status/social capital**
> Education levels			> Education	
> Resource availability	> Resource availability		> Access to water	> Increase cost of water
	> Livelihoods	> Lost livelihood	> Livelihoods/unemployment	> Unemployment
		> Food insecure		
		> Economically disadvantaged		
		> Transactional sex, commercial sex work &		

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Table 2 (*continued*)

Global Watts et al. (2015)	Africa Niang et al. (2014)	Southern Africa Myers et al. (2011)	South Africa DEA (2013)	Western Cape WCCCRS (DEA&DP, 2014)
		partner numbers		
		> Risk taking behaviour		
			> Informal settlements	> Informal settlements/apartheid planning
	> Sanitation	> Sanitation	> Sanitation	
	> Access to safe water			
			> Access to air conditioners	
Occupational health		**Occupational health**	**Occupational health**	
		> Ventilation & hot conditions		
		> Physical hazards	> Outdoor occupations	
		> Manual labour		
		> Chemical hazards from fires		
		> Emergency & health personnel		
Labour productivity	**Labour productivity**	**Labour productivity**		**Labour productivity**
				> Fisheries-based livelihoods
	> Agricultural employment			> Agricultural employment
Health status	**Population susceptibility**	**Health status**		**Health status**
> Existing health status/disability	> Existing health status	> Existing health status/disability	> Existing health problems	> Existing health status/disability
> Burden of disease				> Burden of disease
> Reduced work capacity	> Work capacity loss	> Workplace productivity		
		> Taking medication		
	> Co-infection			
		Substance misuse	**Substance abuse**	
		> Alcohol	> Alcohol	
		> Narcotics		
Technology				
Governance structure	**Poor governance**			
Public health infrastructure		**Public health infrastructure**		
	> Access to healthcare facilities	> Quality, availability & readiness		
		> Disease surveillance		
		> Health promotion		
		> Community mobilization		
	> Early warning systems	> Disaster preparedness	> Disaster preparedness	> Pressure on disaster relief systems
		> Emergency service response		
		> Training of emergency & health personnel		
	> Healthcare systems	> Programme evaluation	> Condition of healthcare systems	
	> Adaptation & mitigation	> Adaptation & mitigation research & innovation		

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Table 2 (*continued*)

Global Watts et al. (2015)	Africa Niang et al. (2014)	Southern Africa Myers et al. (2011)	South Africa DEA (2013)	Western Cape WCCCRS (DEA&DP, 2014)
	> Inadequate housing facilities			
	Infrastructure	**Infrastructure**	**Infrastructure**	**Infrastructure**
				> Electric cooling demand
		> Damage to essential infrastructure	> Damages	> Damages
		> Coastal, urban, low-lying, islands, vector border regions	> Coastal flooding	> Coastal properties
		> Quality of water & sanitation	> Sewerage	
		> Quality of roads & transport	> Access to services	> Access to roads
		> Fuel availability		
				> Critical infrastructure
				> Drainage networks
	> Rural areas		> Rural & urban settlements	> Rural human settlements
				> Flood-prone areas & sand dunes
			> Built environment	> Inferior building materials
				> Energy security
	> Water resource development			
				Tourism
			> Ultra-violet radiation	
				Risk to economy/financial burden
			> Emergency response capacity/service delivery	> Service delivery
				> Land management

*Note that the original language used in the reference document was maintained in the table.

intensively farmed or populated areas may also be heavily polluted by chemical and biological contaminants from industry, agriculture, municipal waste and sewage, particularly in areas with poor sanitation infrastructure. Exposure to chemical and water-borne pathogens can occur through ingestion of contaminated water or via recreational use (Ford, 2016). As the agricultural sector of the province fuels economic growth and provides employment for the region (WCG, 2018), these issues should be noted by the WCG.

Increased urbanisation and associated land use change also leads to the development of urban heat islands whereby densely built urban areas, such as cities and informal settlements, are hotter than surrounding, less dense, rural areas. This is due to less vegetation in these urban areas as well as the abundance of urban construction materials that absorb heat and have a high thermal mass, such as concrete and tar (Kjellstrom et al., 2009). Due to the increased ambient temperature, individuals living in urban heat islands possess a higher risk of heat-related illnesses (Tan et al., 2010). It should be noted that urban heat islands can provide an optimal environment for the breeding of vectors that thrive in warmer conditions; for example, a study conducted in Brazil found that the incidence of dengue fever was increased in urban heat islands compared to other urban areas (Araujo et al., 2015).

Related to urbanisation changes in LMIC is the growth in informal settlements, which put public health at risk from multiple environmental hazards. Examples of these hazards include overcrowding, poor indoor and outdoor air quality, household toxins and moulds, unhygienic water and sanitation systems, lack of municipal waste collection, poor street lighting and unsafe pedestrian routes (Frumkin, 2016). The building materials and the constructions are often unsafe, especially those in marginal areas that may be particularly exposed to severe weather conditions and flooding (Douglas et al., 2008). Furthermore, a study conducted in informal settlements in Nairobi, Kenya found that an increase in child mortality due to non-communicable diseases (NCDs) coincided with an increase in temperature (Egondi et al., 2012). Scovronick and Armstrong (2012) explored housing type as a risk factor in heat-related deaths and found that those living in informal houses were more vulnerable to heat-related mortality than those living in formal housing. In a report by the Housing Development Agency (HDA), which is an agency of the Department of Human

Settlements, 13% of all WC households lived in informal settlements or shacks in 2011 (HDA, 2013), thus the impacts of climate change on the health of these individuals should be of concern in adaptation planning.

3.3.3. Violence and human conflict

Quantitative analysis of the influence of climate on the risk of human conflict, including inter alia interpersonal violence, intergroup violence and crime, has recently become a research area of interest within the climate change and health literature. Hsiang et al. (2013) found that the risk of human conflict increases as precipitation and temperatures deviate from normal ranges. Intergroup riots in India seem to increase with rainfall loss (Bohlken & Sergenti, 2010) and political and intergroup violence in East Africa and Kenya increased as temperatures rose, although the political landscape often has greater influence on collective violent conflict than climate change (O'Laughlin et al., 2012; Theisen, 2012). Mares and Moffett (2016) have estimated that globally, a 1 °C rise in temperature could account for a 5.92% increase in homicide rates, whereas in Africa a similar rise is equated with a 17.94% increase. The authors suggested that, in Africa, street violence and economic inequality were contributing factors to the high homicide rates.

Associations have been established globally between temperature and aggression (Anderson, 1989), domestic violence (Auliciems and DiBartolo, 1995), homicides (Mares and Moffett, 2016), assault and rape (Ranson, 2014). Breetzke's extensive work on temporal analysis of crime in South Africa has revealed that property crime and violent assault rates are highest during summer, particularly in the month of December (Breetzke and Cohn, 2012; Breetzke, 2015). It is important to note that although the temperature/aggression theory was acknowledged, a link between temperature and criminal activity was also explored through routine activity theory, whereby many people are outdoors or away from their homes in December due to the pleasant weather and are therefore more vulnerable to being victims of criminal acts. Breetzke and Cohn (2012) state that whilst both the temperature/aggression and routine activity theories predict seasonal changes to crime levels, other confounding variable such as alcohol use and public holidays should also be considered. A theoretical study by Rabie (2008) suggests that there is a link between xenophobia, climate change, and migration in South Africa, hypothesizing that scarcity of resources exacerbated by climate change has the potential to increase the likelihood of violence against migrant groups.

This is particularly relevant to the WCG because of existing high levels of interpersonal violence in many WC communities, often targeted at vulnerable groups (WCG, 2013). Additionally, domestic abuse of women and children, xenophobic violence towards foreign nationals and criminal violence in poor communities with inadequate policing and security services are prevalent throughout WC communities (WCG, 2013).

3.3.4. Vulnerable groups

3.3.4.1. Poor. It is often the poorest in societies who are more likely to be impacted by climate change and yet the poorest have a reduced capacity to adapt. The poor are unable to invest in education, have limited resources to improve adaptive capacity and often work in climate-sensitive sectors such as farming, construction and fishing. They also often do not have access to service facilities such as basic sanitation and safe drinking water and have less access to air conditioning (Hallegatte & Rozenberg, 2017), which are all risk factors to health. These issues are particularly important to the WCG because of the high prevalence of poor communities with inadequate housing, low levels of employment, and poor health status (Govender et al., 2010).

3.3.4.2. Occupational health. Outdoor labourers, particularly those who have to wear personal protective equipment, and those who are physically active in their occupation, such as fire fighters, construction workers and emergency health workers, are at increased risk of suffering heat-related deaths and illnesses and hazard-specific injuries such as burns and concussions (Schulte & Chun, 2009; Mathee et al., 2010) due to the climate change-related further increase in temperature and intensity of extreme weather events (IPCC, 2014). Therefore, these injuries, morbidities and mortalities will likely be exacerbated by a changing climate, particularly that which is projected for the WC region. There is also the potential loss or disruption of livelihoods and occupations in climate-sensitive industries such as aquaculture, fisheries, and agriculture. For example, ocean acidification often results in a decrease in fish stocks for a certain region thereby impacting on a fisherman's livelihood (Allison et al., 2009). Another example is that of the thermal tolerance of certain crops which can significantly impact a farmer's yield (Lobell et al., 2011). The impact of a changing climate on occupational health is a global challenge and the WC population who work outdoors or depend on agricultural outputs to sustain themselves and their families will be impacted.

3.3.4.3. Chronically and mentally ill. Individuals with a compromised immune system, such as those with HIV/AIDS (Drimie and Gillespie, 2010), and the chronically ill, such as those with diabetes (Semenza et al., 1996) and depression (Clayton et al., 2017), possess less adaptive capacity to climate change-related impacts and are therefore vulnerable. Furthermore, individuals that have a poor health status may be more susceptible to acquiring new climate-related diseases or co-infections (Woodward, 1998; Cegielski & McMurray, 2004), exacerbations of existing diseases (Myers et al., 2011), may have a reduced physical capacity to be productive in their occupation, particularly under conditions of heat stress (Mathee et al., 2010) or may be taking medications that place them at increased risk of developing heat illness (Luber & McGeehin, 2008). Mental illness in the context of a changing climate is discussed in detail below however, often the socially isolated and mentally ill, such as those suffering with depression, are particularly vulnerable to a changing climate and extreme weather events because they possess less adaptive capacity to cope with the adverse impacts (Clayton et al., 2017).

The concern for chronic disease in the context of a changing climate is important for the WCG to consider given the high burden of NCDs, mental ill-health and other chronic conditions such as HIV (Kleintjes et al., 2006; Mayosi et al., 2009; Morden et al., 2016). Thus, in conclusion any adaptation strategy for addressing health impacts of climate change in the WC will need to address the above risk factors so as not to undermine the efforts of those strategies.

3.4. Local climate change health impacts

There are several climate change-specific health impacts that may be directly or indirectly climate-related that sub-national governments should consider in climate change and health adaptation strategies. The global, national and sub-national health impacts are listed in Table 3. From Table 3 it is clear where the priority focus areas for sub-national climate change health impacts should be for the sub-national government (i.e. the grey cells). As with the risk factors, again these gaps were further researched to provide an indication as to whether the issues were relevant to the WCG specifically (see review from Sections 3.4.1 to 3.4.7). Again, consultation was sought from the PSG for relevance to the specific sub-national situation before being noted as a priority focus area for the sub-national government. Therefore, based on this, in the case study of the WC, the sub-national government should focus further research efforts on the following priority focus areas: mental health, NCDs, injuries, poisonings from chemical use, malnutrition, water- and food-borne diseases and reproductive health. These priority focus areas are discussed in detail below.

Table 3
Indicators and keywords of global, national and sub-national climate change health impacts drawn from reference documents detailed in Table 1. Gaps for the Western Cape, as indicated by grey cells, are highlighted as areas requiring further research and discussion from the Project Steering Group for recommendation as priority focus areas for the Western Cape. Health impacts identified by the Project Steering Group are marked as PSG.

Global Watts et al. (2015)	Africa Niang et al. (2014)	Southern Africa Myers et al. (2011)	South Africa DEA (2013)	Western Cape WCCCRS (DEA&DP, 2014)
Mental health		**Mental health**	**Mental health**	
> Depression		> Depression	> Depression	
> Anxiety		> Anxiety	> Anxiety	
> Solastalgia				
> Chronic distress			> Chronic distress	
> Suicide		> Suicide		
> PTSD		> PTSD	> PTSD	
		> Trauma due to loss & displacement	> Trauma	
		> Mood	> Behavioural problems/mood disorders	
			> Cognition	
			> Somatoform	
			> Apathy	
			> Helplessness	
			> Grief	
Death		**Death**	**Mortality/loss of Life**	**Loss of life**
Heat stress	**Heat-related health effects**	**Heat-related Illness**	**Heat stress**	**Heat stress**
> Dehydration		> Dehydration	> Dehydration	
> Morbidity & mortality	> Mortality & morbidity	> Morbidity & mortality	> Morbidity & mortality	> Morbidity & mortality
		> Heat cramps		
		> Heat exhaustion	> Heat fatigue	> Heat-related illness
		> Heat syncope		
		> Heat stroke		
Cardiovascular disease		**Cardiovascular disease**	**Cardiovascular disease**	
> Obesity				
> Diabetes			> Diabetes	
> Coronary heart disease				
> Stroke		> Stroke	> Cerebrovascular disease	
		> Cardiac failure		
Respiratory disease		**Respiratory disease**	**Respiratory disease**	
		> Asthma	> Asthma/wheeze	

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Table 3 (*continued*)

Global Watts et al. (2015)	Africa Niang et al. (2014)	Southern Africa Myers et al. (2011)	South Africa DEA (2013)	Western Cape WCCCRS (DEA&DP, 2014)
		> Chronic lung disease		
		> COPD		
			> Bronchitis	
			> Acute respiratory infection	
			> Lung damage	
			> Cough	
		Other chronic disease		
		> Renal disease	> Renal impacts	
		> Kidney stone disease		
Injury		**Injury**	**Injury**	
		> Motor vehicle accidents		
Allergies			**Allergies**	
Poisoning			**Chemicals e.g. pesticides**	
Undernutrition & food security	**Malnutrition**	**Malnutrition**	**Malnutrition/hunger**	
	> Stunting	> Stunting	> Stunting	
	> Anaemia		> Anaemia	
			> Goitre	
			> Vitamin deficiency	
			> Hypokalaemia & hyponatremia	
Infectious disease		**Infectious disease**	**Communicable/infectious disease**	**Communicable disease**
> Ebola				
> Avian influenza				
		> Hepatitis E		
		> Hepatitis general		
			> TB	> TB
	> Meningococcal meningitis			
			> Colds & flu	
			> Measles	
				> Pneumonia (PSG)
				> Hand, foot and mouth disease (PSG)
Water-borne disease	**Water-borne disease**	**Water-borne disease**	**Water-borne disease**	
> Cholera	> Cholera	> Cholera	> Cholera	
			> Typhoid	
> Bacterial diarrhoea	> Diarrhoeal diseases	> Diarrhoeal diseases	> Diarrhoeal diseases	
				> Legionnaires' disease (PSG)
		> Hepatitis A		
	Food-borne disease	**Food-borne disease**	**Food-borne disease**	

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Table 3 (*continued*)

Global Watts et al. (2015)	Africa Niang et al. (2014)	Southern Africa Myers et al. (2011)	South Africa DEA (2013)	Western Cape WCCCRS (DEA&DP, 2014)
		> Salmonella	> Salmonellosis	
Vector-borne disease	**Vector-borne disease**	**Vector-borne disease**	**Vector-borne disease**	**Vector-borne disease**
> Dengue		> Dengue fever	> Dengue fever	
> Malaria	> Malaria	> Malaria	> Malaria	
				> Chikungunya fever (PSG)
> African trypanosomiasis	> African trypanosomiasis			
> Lyme disease	> Tick-borne diseases	> Tick-borne encephalitis	> Tick bite fever/Lyme disease	
> Schistosomiasis	> Schistosomiasis		> Schistosomiasis	
> Hantavirus	> Hantavirus			
> West Nile Virus				
		> Plague		
	> Leishmaniasis			
	> Rift valley fever			
			> Yellow fever	
				> Leptospirosis (PSG)
				> Crimean-Congo haemorrhagic fever (PSG)
		Other water illnesses		
		> Ear, nose & throat		
		> Skin	> Skin irritations & dermatitis	
		> Gastro-intestinal	> Gastro-intestinal	
		> Giardiasis		
		> Cryptosporidiosis		
			> Eye irritation	
			Reproductive and developmental effects	
				> Urinary tract infections (PSG)
			Cancer risk	
			> Skin cancer	
			> Lung cancer	
		Amplification of existing burden of disease		**Existing burden of disease vulnerability**
		Sexually transmitted infections	**Sexually transmitted infections**	
	> HIV/AIDS	> HIV	> HIV/AIDS	> HIV/AIDS
			Immune dysfunction	
			> Autoimmune disease	
			Musculoskeletal disorders	
			Tight Building syndrome	
		Health benefits	**Health benefits**	**Health benefits**
		> Warmer winters		> Reduce risk cold-related deaths

*Note that the original language used in the reference document was maintained in the table.

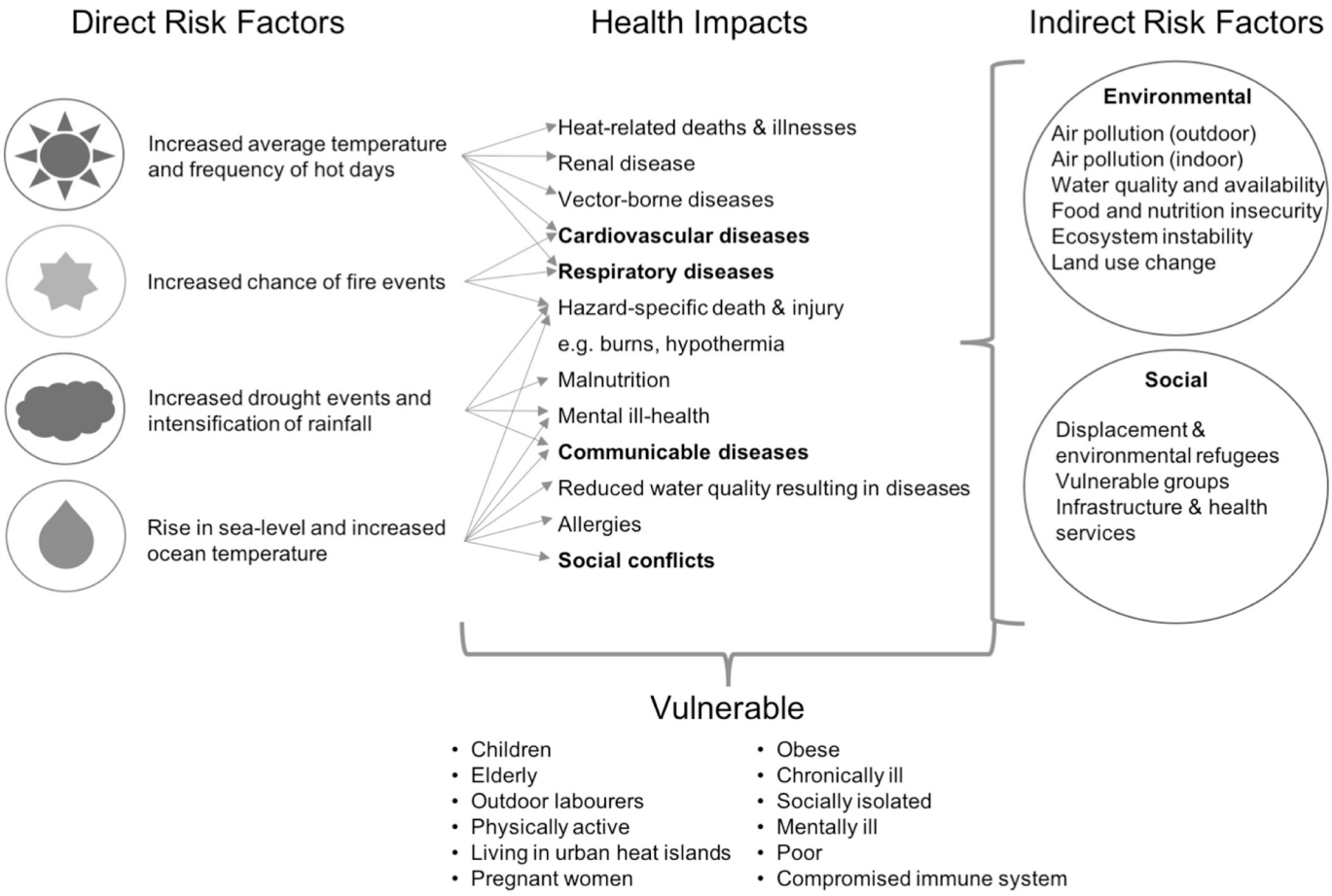

Fig. 2. Summary of the main climate change-related health impacts, direct and indirect risk factors and vulnerable populations of concern. Health impacts that are bolded are already within the province's top ten burden of disease.

3.4.1. Mental health

Trauma, post-traumatic stress disorder, anxiety and depression after a catastrophic or life-threatening event will become more prevalent as climate change increases the frequency and severity of extreme weather events such as flooding and drought (Ahern et al., 2005; Berry et al., 2010). Severe and prolonged drought, floods and high temperatures can drive individuals, particularly farmers, into depression and even suicide (Maes et al., 1994; Page and Fragar, 2002; Ahern et al., 2005). Climate change might also result in chronic distress (Brugha & Cragg, 1990; Coelho et al., 2004) and increased solastalgia, a distressing sense of loss due to environmental change (Higginbotham et al., 2006). Children are extremely vulnerable to early-life trauma that can affect subsequent emotional development (Perry et al., 1995). Often in poverty situations brought about by extreme weather events and climate change, children are left either unsupervised or in the care of non-primary caregivers, leading to physiological and psychological strain and possible collapse of social networks (UNICEF, 2011). Furthermore, absenteeism from school increases due to extreme weather events, climate change-induced poverty or other situational issues such as having to walk longer distances to collect water (UNICEF, 2011). Children and women are often victims of interpersonal violence in times of disasters, which is not only traumatic, but might also increase the spread of sexually transmitted diseases (Myers et al., 2011). Consideration of mental health in climate change adaptation planning is particularly relevant to the WCG given the many vulnerable groups affected such as women, children and farmers as well as the high prevalence of mental disorders in the WC region (Kleintjes et al., 2006). Thus, mental ill-health resulting from climate change should be strongly considered during sub-national strategic adaptation planning, specifically for vulnerable groups.

3.4.2. Non-communicable diseases

Although NCDs have been identified as a key issue for the 21st century, there has been limited focus on the link between NCDs and climate change globally, and particularly for the WC region (Friel et al., 2011). This is despite several common NCDs being climate sensitive, such as asthma, allergies, bronchitis, respiratory diseases, renal disease, chronic obstructive pulmonary disease (COPD), type 2 diabetes, obesity, cancer (skin and lung), cerebrovascular disease and cardiovascular disease (Friel et al., 2011; Colagiuri, 2013). The severity of cardiovascular symptoms, for example, is linked to increased temperatures (Giang et al., 2014).

Increased average temperatures and number of hot days with an increased frequency of heat waves can also lead to mortality from cardiorespiratory diseases and exacerbation of renal diseases and kidney stones (Tasian et al., 2014; Glaser et al., 2016; Watts et al., 2017). Scovronick et al. (2018) investigated the relationship between temperature and mortality (8.8 million recorded deaths) in South Africa over a 17-year period. Significantly more people died on very hot days (99th percentile) with a relative risk of all-cause, all-age mortality of 1.06 (1.03,1.09)). The elderly (> 65 years old) and young (< 5 years old) were found to be particularly vulnerable. Major causes of death were cardiovascular and respiratory diseases. Thus, within the context of climate change, sub-national governments should be prepared for an increased burden of disease resulting from cardiorespiratory diseases as well as other NCDs that are climate sensitive.

This is particularly important to the WCG because of the high existing burden of diseases associated with poverty and poor access to health care that will be exacerbated by the additional climate stressors of more prolonged droughts and higher temperatures in the WC in

Table 4
An extended review of climate change-related health impacts (temperature only) categorized into three columns for evidence-based decision-making and prioritization by sub-national policy-makers.

Temperature increases			
Western Cape burden of disease	IPCC confidence levels (global health and Africa health chapter)	Other based on research (framework for search from indicators and keywords)	
• Increased hospital visits for respiratory disease (Astrom et al., 2013)	• Likely, robust evidence, very high confidence Heat-related illnesses, including heat stroke, heat exhaustion, heat cramps, heat syncope and heat-related mortality (Honda et al., 2014; Kilbourne, 1997; Semenza et al., 1996)	• Increased hospital admissions for asthma (Kim et al., 2014)	• Increased diagnoses of Grave's Disease (Westphai, 1994)
• Increased risk of pneumonia (Xu et al., 2014)	• Robust evidence in countries with endemic cholera Increased incidence of cholera (Reyburn et al., 2011)	• Increased allergic rhinitis (Breton et al., 2006)	• Increased incidence of meningitis (Dukić et al., 2012)
• Increased COPD morbidity (Monteiro et al., 2013)	• Very high confidence Increase in injuries (Im Kampe et al., 2016)	• Increased hospital visits for electrolyte imbalances (Knowlton et al., 2009)	• Increased number of hospital visits for diarrhoea (Hashizume et al., 2008)
• Increased hospital visits for cardiovascular diseases (Knowlton et al., 2009)	• High confidence with high humidity Increased undernutrition (Battisti and Naylor, 2009)	• Increased risk of mortality from suicide (Likhvar et al., 2011)	• Increased incidence of measles (Omonijo et al., 2012)
• Increased incidence of cerebrovascular disease (Yoon et al., 2014)	• High confidence in global effect Increased incidence of dengue (Araujo et al., 2015)	• Increased hospital admissions for dementia (Hansen et al., 2008b)	• Increased incidence of chikungunya (Chadsuthi et al., 2016)
• Increased hospital visits for diabetes (Hajat et al., 2017)	• High confidence in local effect Increased malaria transmission (Ebi et al., 2005)	• Increased hospital admissions for mood disorders [12]	• Increased incidence of yellow fever (Vasconcelos et al., 2001)
• Increased risk of violence (Burke et al., 2009)	• Low confidence in effect Increased incidence of tick-borne encephalitis (Tokarevich et al., 2011)	• Increased emergency department visits for mental and psychosocial problems (Vida et al., 2012)	• Increased incidence of African trypanosomiasis (Moore et al., 2012)
• Increased incidence of tuberculosis (Onozuka and Hagihara, 2015)	• Low confidence in effect Increased incidence of Lyme borreliosis (Bennet et al., 2006)	• Increased psychological distress (Tawatsupa et al., 2010)	• Increased incidence of leptospirosis (Sumi et al., 2017)
• Increase in severe influenza epidemics with early onset (Towers et al., 2013)	• High confidence in local effect Increased incidence of Hemorrhagic fever with renal syndrome (Fang et al., 2010)	• Increased major depressive episodes (Shapira et al., 2004)	• Increased risk of schistosomiasis infection (McCreesh and Booth, 2014)
• Increased risk of motor vehicle crashes (Basagana et al., 2015)	• Low confidence in effect Increased incidence of human plague (Stenseth et al., n.d)	• Increased hospital admissions for somatoform disorders [12]	• Increased transmission of West Nile Virus (Reisen et al., 2006)
		• Increased mortality from mental and behavioural disorders [12]	• Increased cryptosporidiosis notifications (Kent et al., 2015)
		• Impairment of cognition, reaction time and attention (Mazloumi et al., 2014)	• Increased incidence of giardiasis (Britton et al., 2010)
		• Increased risk of renal dysfunction (Hansen et al., 2008a)	• Increased incidence of hand, foot & mouth disease (Phung et al., 2018)
		• Increased risk of kidney stones (Theisen, 2012)	• Increased incidence of Legionnaires' Disease (Karagiannis et al., 2009)
		• Increased incidence of salmonella food poisoning (Zhang et al., 2010)	• Increased incidence of typhoid (Wang et al., 2012)
		• Increased harmful cyanobacterial algal blooms (Paerl et al., 2011; Marques et al., 2010) resulting in poisonings from fish and shellfish (Chateau-Degat et al., 2005)	• Increased incidence of dermatitis (Olumide et al., 1983)
		• Increased poisoning due to increased exposure to pathogens and chemicals from agriculture (Boxall et al., 2009)	• Increased reproductive dysfunction (Rachootin and Olsen, 1983)
		• Lowered birth weight (Wells and Cole, 2002)	• Increased incidence of skin cancer (Van der Leun and de Gruijl, 2002)
		• Increased preterm births (Basu et al., 2010)	• Increased occupational pain (Sahu et al., 2013)
		• Increased urinary tract infections (Liu et al., 2017)	• Decrease in cold-related deaths (Kalkstein and Greene, 1997)

future (Mayosi et al., 2009; Myers, 2012).

3.4.3. Injuries resulting from extreme weather events

Climate change is already increasing the risk and frequency of climate-related disasters worldwide (IPCC, 2014). As these extreme events become more common, the health impacts, including injuries, will also increase. There are many hazard-specific injuries, such as concussions and drownings, that may occur due to extreme weather events. As an example, with a greater frequency and intensity of fires, there is an increase in the demand for water when controlling fire outbreaks as well as increased health risks such as hazard-specific injuries (burns and trauma) and cardiorespiratory diseases among firefighters and local residents (Stefanidou et al., 2008). Communication with the WCG department responsible for providing a situational analysis of the 2017

Knysna fires stated that many people were treated for dehydration and smoke inhalation and one firefighter was treated for serious burns. This analysis also highlights the particular vulnerability of emergency response personnel in a changing climate as has been highlighted by others (Benedek et al., 2007; Applebaum et al., 2016).

3.4.4. Poisonings

There is likely to be an exacerbation of pest infestations, particularly in cities in low socio-economic communities with a changing climate and other risk factors such as population migration, overcrowding, poor infrastructure, and poor service delivery (Barata et al., 2011; Freitas et al., 2014). Higher temperatures result in higher reproduction of pests, with pests moving into areas previously not inhabited and turning non-pests into new pests (Barata et al., 2011; Zinyemba et al., 2018). Additionally, within the agricultural sector, there is likely to be a proliferation of pests on crops as a result of climatic risk factors (Rosenzweig et al., 2001). Ultimately an increase in pests will result in an increased need for effective pest control with individuals often resorting to chemical methods. It should also be noted that the acting effects of certain pesticides might also change in response to a changing climate such that chemical compounds could become more hazardous, or a higher quantity of chemicals might be required (Patterson et al., 1999; Boxall et al., 2009). Therefore, there is likely to be increased exposure to hazardous chemicals and pesticides with subsequent poison-related incidences with a changing climate (Zinyemba et al., 2018). Often in the WC, the chemicals used in poor urban areas for pest control are illegal “street pesticides” that are too toxic for domestic use and as such, the likelihood of poisoning or death increases in these areas (Rother, 2010; Rother, 2016). Additionally, in times of flooding there is increased runoff, and with an increased use of chemical pest control, there may be a subsequent elevation in chemical pollutants in flood waters (Patz et al., 2008).

3.4.5. Food and nutrition insecurity-related diseases

The IPCC (2014) identifies food security as a key risk for urban populations due to climate change and states with high confidence that climatic drivers will exacerbate food insecurity. Food insecurity will be felt particularly by the urban poor from spikes in food prices and food-price shocks. Adverse health impacts of food insecurity include malnutrition (Grace et al., 2012), stunting (Jankowska et al., 2012) and anaemia (Denton, 2002). Health impacts of malnutrition include both stunting due to climate change-related food insecurity and nutrient deficiencies due to inadequate nutrition or diversity of diet (Dangour et al., 2015). In this way, climate change-induced food and nutrition insecurity is likely to affect not only the poor, particularly those living in townships, but many others through reduced availability of nutritious fresh foods. As the urban poor are a large social group residing within the WC (de Swardt et al., 2005), this vulnerable population should be a particular concern in climate change adaptation planning.

3.4.6. Water- and food-borne diseases

Water-borne diseases are highly susceptible to increases in temperature (El-Fadel et al., 2012) and also surge in times of drought due to poor sanitation and hygiene practices, as well as reduced water quality (Cann et al., 2013). Relationships have been established between increased temperature and/or extreme weather events such as flooding, heavy rainfall, drought, El Niño Southern Oscillation and hurricanes; and hepatitis, rotavirus, norovirus, enterovirus, cholera, giardia, typhoid and legionnaires disease (Karagiannis et al., 2009; Wang et al., 2012; Review by Cann et al., 2013). For coastal regions, an increase in harmful algal blooms and increased ocean temperatures have been correlated with outbreaks of cholera as the bacteria is transmitted to humans through the consumption of raw shellfish (Epstein et al., 1994; Colwell, 1996). Water-borne diseases and diarrhoea often result in severe dehydration of individuals, especially children, which not only is a severe health impact that can be fatal (Whitehead et al., 1996), but can also make individuals susceptible to heat-related deaths and illnesses. Dangour et al. (2013) provide a conceptual framework of how low water quantity and quality can directly and indirectly affect adequate sanitation, hygiene and food and nutrition insecurity. This is a useful framework to review for sub-national adaptation planning and is particularly relevant to the WCG given the large-scale drought and water shortages that occurred in the province in 2015–2018.

Most of the urban poor who live in townships and some of those living in rural areas cannot afford refrigeration in their homes and, with temperatures projected to increase along with increasing water scarcity, food-borne diseases such as salmonellosis, campylobacteriosis and listeriosis are becoming increasingly common. In the UK, Lake (2017) has identified campylobacteriosis incidence peaks in warmer temperatures. Since the disease is prevalent in Cape Town (Lastovica et al., 1986), it should also be considered within the context of climate change in the province. Recently in the WC, there have been reports of increased incidence of the food-borne disease listeriosis, with the most vulnerable populations being those whose immune systems are compromised, and the elderly, infants and pregnant women (Pava-Ripoll et al., 2012). Generally, changing climatic conditions such as increased temperature and altered rainfall can result in increased pathogen survival, proliferation and development as well as increased prevalence within the host (Greer et al., 2008). Pava-Ripoll (2012) conducted the first study, in the USA, which identified flies (*Lucilia sericata* and *Lucilia cuprina* from the family Calliphoridae) as vectors for L. *monocytogenes* (the bacteria causing listeriosis). *Lucilia sericata* and *Lucilia cuprina* are prevalent throughout the WC and their distribution patterns appear to be affected by rainfall, humidity and maximum temperature (Williams et al., 2014). The L. *monocytogenes* can withstand temperature ranges of 0 °C to 45 °C and there have been conflicting results in research studies of seasonal impacts on L. *monocytogenes*. Globally, more research is required on Listeria transmission in relation to climate change as the influence of seasonality is unclear (Semenza et al., 2012). Overall, sub-national adaptation planning should address food- and water-borne diseases that will be affected by climate change.

3.4.7. Reproductive health

Climate change, specifically increased temperature, will also impact on reproductive health, such as an increased risk of preterm births (Basu et al., 2010) and an increased incidence of urinary tract infections (Liu et al., 2017). Although not a climate-related disaster, the psychological trauma suffered by pregnant women and their foetuses during the attack on the World Trade Centre in 2001, which created a large-scale environmental disaster for New York City, was highly correlated with longer gestation and decrements to the infant's head circumference (Engel et al., 2005). This study provides evidence that psychological trauma can result in adverse birth outcomes and should be addressed in sub-national adaptation planning. With temperature and the intensity of extreme weather events projected to increase for the WC region, the climate-related disruptions to reproductive health should be further researched.

3.5. Climate change and health summary

By presenting stakeholders and decision-makers with such a review of adverse health impacts as mentioned above, there is a risk of inducing fatalism that can lead to inaction or disengagement (Clayton et al., 2017). Therefore, it was vital to present a summary of the risk factors and broad health impacts resulting from climate change based on a review of relevant literature as described in Section 2 (Methods). Fig. 2 provides a summary of the direct and indirect risk factors and associated health impacts. This includes mention of the burden of disease, with climate-sensitive health impacts bolded, as well as vulnerable populations. Many of the health impacts have been reviewed in detail above for the sub-national context and Fig. 2 provides a summary of the climate change and health priority focus areas for the sub-national

government.

Overall, it is vital that both direct and indirect (environmental and social) risk factors should be addressed in future policy decisions, by a range of relevant government departments, to reduce the prevalence of climate change-related health impacts. This study highlights that to address the risks and health impacts effectively, climate change and health needs to be more than an area of concern for the departments of health and environment alone, given the broad range of sectoral issues. Rather, there needs to be an alignment of health-related climate issues in existing government priorities and policies. Thus, we advocate for the World Health Organization's "Health in All Policies" approach to be an exemplary framework for countries to promote "health and climate change in all polices" for effective mitigation and adaptation strategies (Rudolph et al., 2013). Regarding the specific case study, the health chapter of the WCCCRS (DEA&DP, 2014) update needs to include the health-specific priority focus areas mentioned above. Sub-national governments' specific outreach activities, communication campaigns and health promotion strategies on climate change impacts on health should target vulnerable groups (e.g. outdoor workers, children and women). Ideally, vulnerable group-sensitive early warning systems, forecasting, surveillance and monitoring should be implemented by the sub-national government.

The methodological framework developed and applied in this review provided a structure for incorporating information from different sources to assess potential climate change-related risks and health impacts within a sub-national context. Through this novel and integrated approach, we were able to identify priority focus areas and determine gaps in the current sub-national strategy. Through actively engaging with government officials and academics throughout the process, we were able to rigorously identify trends in health risks globally whilst pinpointing those relevant at the sub-national level. Engagement from key stakeholders also allows for greater research translation. This framework provides an approach for sub-national government to work with local academics to sift through the multitude of information to recognize current needs but also to identify areas of focus in the future.

3.6. Temperature-specific health impacts

Table 4 categorizes the results of an extended review of the health impacts of increased temperature and frequency of heat waves. The literature reviewed in this step of the methodological framework are useful in intervention and adaptation planning as it provides an indication of the attribution pathway. However, this step of the framework is not essential in identifying anticipated sub-national health impacts. To assist with providing structure of health impacts from temperature for policy-makers, the health impacts were categorized. Firstly, impacts on the top 10 burdens of disease for the province were categorized in the first column to provide an indication of the extent that temperature will exacerbate the current disease burden of the province. Second, to aid in evidence-based decision-making, it was also necessary to comment on the degree of certainty that a health impact would occur. The IPCC confidence intervals were used to comment on the degree of certainty of the health impact occurring and to provide an indication of prioritization for policy-making. Finally, any projected health impacts that did not affect the top 10 burdens of disease nor were assessed for certainty by the IPCC, were placed in a third column for consideration by policy-makers. The table would then be presented to the policy-maker with the three columns allowing the policy-maker to determine which health impacts should be prioritized based on their sub-national situation.

An analysis of the results contained in Table 4 suggest that the sub-national government should be cognizant that most of the diseases presenting in the top 10 burden of disease for the province are likely to be impacted by an increased temperature, as is projected for the WC. Furthermore, it is important to include those diseases where there is a very high confidence in effect such as heat-related deaths and illnesses and cholera incidences. Although not presented in Table 4, when this extended review is conducted investigating the attribution pathway, it is important to note any vulnerable populations to a specific health impact which is useful in targeting specific groups in adaptation planning.

4. Conclusions

Through the use of our novel methodological framework, which included the active participation of sub-national stakeholders, this literature review highlighted climate change priority health focus areas for the sub-national government and has emphasised vulnerable populations of concern. Although the WC province of South Africa was used as a case study, this framework can be globally used as a template by other sub-national governments for decision-making and development of climate change and health adaptation strategies. It is recommended that all sub-national governments consider a "health and climate change in all policies" approach when developing and implementing adaptation and mitigation strategies.

Declaration of interest

The authors confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

Author contributions

CNG was the primary researcher, project manager and conducted the literature research, analysis and prepared the publication. H-AR was the grant holder and provided guidance on the research and analysis and commented on drafts of the publication. H-AR is an associate with ACDI. JI, FvdM and MN were members of the project steering group and provided guidance on the research and analysis and commented on drafts of the publication.

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