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Climate change and communicable diseases in the Gulf Cooperation Council (GCC) countries

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ABSTRACT

A review of the extant literature reveals the extent to which the spread of communicable diseases will be significantly impacted by climate change. Specific research into how this will likely be observed in the countries of the Gulf Cooperation Council (GCC) is, however, greatly lacking. This report summarises the unique public health challenges faced by the GCC countries in the coming century, and outlines the need for greater investment in public health research and disease surveillance to better forecast the imminent epidemiological landscape. Significant data gaps currently exist regarding vector occurrence, spatial climate measures, and communicable disease case counts in the GCC — presenting an immediate research priority for the region. We outline policy work necessary to strengthen public health interventions, and to facilitate evidence-driven mitigation strategies. Such research will require a transdisciplinary approach, utilising existing cross-border public health initiatives, to ensure that such investigations are well-targeted and effectively communicated.

1. Introduction

The international response to the COVID-19 pandemic has demanded the development of multiple mathematical tools and models requiring close consideration of key factors such as population density, seasonal variation, international travel, and socioecological systems (such as the use of non-pharmaceutical interventions). All of these factors are intrinsically linked to the ongoing climate crisis, and will be considerably altered in the coming years (Hess et al., 2020), necessitating substantial further research into the expected changes to these elements, and how this will require adaptation to communicable disease responses, and the targeted policy advice given.

In this report, we initially summarise the extant scientific evidence on the association between climate change and communicable disease. We describe the mechanistic impact of mediating factors such as droughts, flooding, and increased temperature, as well as the more complex vulnerabilities introduced by interactions between environmental and social factors such as habitat loss and further urbanisation. We then critically assess current disease forecasts, with a particular focus on how they apply to the countries of the Gulf Cooperation Council (GCC) — the intergovernmental union consisting of Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates. We separately consider the risk posed by vector-borne and non-vector-borne diseases, and highlight areas where there is currently insufficient evidence regarding the future risk posed by such diseases. We conclude by reiterating the policy advice issued by the wider community in preparing for the challenges ahead.

2. Climate change and communicable disease

The majority of the relevant literature to date is primarily focused on the climate-induced changes likely to be seen in the spread of vector-borne diseases. This is partly due to the vast existing knowledge base on vector responses to changes in their environment, and an urgency driven by an increasing number of vector-borne disease outbreaks in areas previously unchallenged by such diseases, primarily in Europe (Hotez, 2016; Ligon, 2006). The most prolific disease vectors are the many species of mosquitoes that transfer disease from host to host via their bite. Like many other insects, mosquitoes are unable to self-regulate their body temperature, meaning that most features of their life-histories are temperature dependent (Carrington et al., 2013), leaving them particularly susceptible to thermal stress. Key mosquito life traits such as development rate, biting rate, and adult lifespan vary across a thermal performance curve of approximately 10–40 °C (Mordecai et al., 2019) in tropical species (though it is noted that eggs can tolerate much lower temperatures for short periods (Kramer et al., 2020; Rinehart et al., 2006)). Starting from a

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minimum temperature of approximately 0 °C–10 °C depending on the species, these key demographic parameters will gradually increase as the surrounding temperature does, improving overall species fecundity and subsequent human infection rates, before sharply dropping off at around 30–40 °C (species dependent) at which point the temperature becomes too great for the mosquito to perform optimally. Crucially, these warmer temperatures are also favourable for the transmission of the viruses and parasites carried by mosquitoes (Mordecai et al., 2019). Falciparum malarial protozoa for example are observed to develop in just 13 days at 25 °C, but require 26 days at a milder 20 °C (Epstein, 2001). Dengue similarly is observed to propagate faster within host mosquitoes in climates of greater temperature and humidity, with a proposed optimum temperature of 24–31 °C (Thu et al., 1998).

Mosquitoes lay their eggs on the surface of standing water pools, meaning that increased vector populations are often correlated with periods of heavy rainfall (Galardo et al., 2009). The exact mechanistic impact however is often dependent on the life-stage of the affected mosquito, as unexpected sudden rains may dislodge larval mosquitoes from spawning pools (Paaijmans et al., 2007), whereas periods of drought may also cause increases in mosquito populations in certain regions, due to dry spells limiting the number of natural predators (Chase and Knight, 2003) of predominantly rural species such as *Anopheles* spp., though this will not impact species that thrive within human dwellings such as *Aedes aegypti*. As such, mosquito populations are sensitive to both gradual increases in mean temperature (Iwamura et al. (2020) predict the global suitability for the development of *Ae. aegypti* to increase 3.2–4.4% per decade up to 2050), and to increased numbers of extreme weather events inducing unpredictable changes to mosquito population dynamics. Concerningly, early studies into the demographics of *Aedes albopictus* have shown considerable differences in the thermal performance curve of mosquitoes of the same species in temperate and subtropical climates (Marini et al., 2020), suggesting that some species may be adapting to perform better in newly emergent territories.

Similar relationships and behaviours are observed within other disease vectors. *Phlebotomus* sandflies have been observed to hatch and metabolise at a faster rate at 28 °C compared to 23 °C (Benkova and Volf, 2007), however only some species of the *Leishmania* parasites that they carry (responsible for leishmaniasis) are shown to multiply faster at such higher temperatures, with some species instead multiplying faster at lower temperatures (Hlavacova et al., 2013). Ticks are also found to have increased egg production and population density at greater temperatures (Süss et al., 2008). Significant heterogeneous patterns in European tick-borne encephalitis (TBE) cases drive hypotheses that other climate change factors beyond temperature, such as flooding and habitat-loss, may be triggering an increase in host-animal population density (Semenza and Menne, 2009), eliciting an increased risk of tick-borne diseases such as encephalitis, Crimean-Congo haemorrhagic fever, and Lyme disease.

Increased temperatures will directly increase the rate of food spoilage, and increase the growth rate of common gastroenteritis culprits such as *Salmonella* and *Campylobacter* (Kovats et al., 2005), while flooding has been attributed with increased gastroenteritis outbreaks by causing run-off from colonised sources to contaminate drinking water supplies, and livestock at the very start of the food chain (Nichols et al., 2009).

While mechanistic connections between climate change and droplet /airborne diseases have yet to be ascertained, seasonal trends in disease incidence are frequently observed. These trends differ between regions, with some pathogens displaying contradictory patterns. Respiratory syncytial virus (RSV) for example, a common virus transmitted by droplets, will display peaks in the summer at locations with persistently warm weather, but conversely will experience winter peaks in more moderate climates (Yusuf et al., 2007). Influenza transmission famously increases during the colder months for each particular hemisphere, spawning multiple hypotheses as for this climate-driven surge. Host susceptibility may be affected by melatonin levels responding to the day/night cycle (Dowell, 2001). Seasonal changes in human movements such as the opening and closing of schools have been shown to influence the rate of influenza transmission (Cauchemez et al., 2008). Alternatively, the survival rate of influenza virus has been shown to be higher in conditions of low vapour pressure (a measure of absolute quantity of moisture in the air) (Shaman and Kohn, 2009), synonymous with the winter months. Unfortunately, the conflation of so many potential mechanisms together means that definitive explanations have been difficult to present (Lipsitch and Viboud, 2009). Regardless of these seasonal patterns, factors such as an increasing global population, environmental degradation/desertification, rising sea levels, and increased urbanisation point towards a future of increased agglomeration and population densities (Liang et al., 2020). Perhaps unsurprisingly, population density has been definitively attributed as having greatly increased location-specific transmission rates throughout the COVID-19 pandemic (Wong and Li, 2020).

3. Climate change in the GCC countries

Future communicable disease threats are closely linked to environmental impacts caused by climate change, and the Arabian Gulf is one of the most vulnerable regions in the world to these impacts (Waha et al., 2017). The GCC countries are forecast to be particularly struck by water stress (Menzel and Matovelle, 2010), and severely dangerous heat waves (Salimi and Al-Ghamdi, 2020), such that limits for human adaptation are brought into question (Pal and Eltahir, 2016). Many of the most populous regions in the GCC are along the coast of the Gulf, placing them at particular danger of rising sea levels. Under the current worst-case (RCP8.5) estimations of the Intergovernmental Panel on Climate Change (IPCC) of an approximately 1 m rise in sea levels by 2100 (Oppenheimer et al., 2019), 1,215 km^2 of GCC land is projected to be inundated by sea level rise (Hereher, 2020). Already an average 4 °C rise in ambient temperature from the 1960s has been recorded, reaching average summer temperatures of approximately 40 °C, but with record highs reaching > 50 °C (Al-Maamary et al., 2017).

In the face of global temperature increases, Gasparrini et al. (2017) constructed a model to forecast the likely increases in excess mortality to be observed globally by the end of the century, including the associated impacts of increases in communicable diseases. Indeed, an increase in MERS-CoV incidence in Riyadh has previously been associated with increased temperature and UV radiation (Altamimi and Ahmed, 2020), (1.054 and 1.401 incidence rate ratios respectively), aligning with general findings of higher case reports in the summer months (Aly et al., 2017). While waves of MERS prevalence generally see a two-phase annual cycle due to the dry and cold conditions of winter weakening host immune systems (Audi et al., 2020) (2019 in particular noted more cases in January and February (WHO, 2022a)), incidence in the summer poses a particular challenge due to the underlying increased risk of adult respiratory distress syndrome (ARDS) due to heat stress (Varghese et al., 2005), as has been reported during summer Hajj dates (El-Kassimi et al., 1986) (the annual pilgrimage to Mecca).

Under the most extreme heating assumptions, Gasparrini et al. (2017) predict rises in excess mortality ranging from 3% in Northern Europe to upwards of 15% in South East Asia. Notable however, is that no projections are able to be computed for the entirety of the Middle East due to a lack of any informing data capturing temperature and mortality linkage. As we display below, this omission of the Arabian Peninsula is a frequent occurrence in the scientific literature. As the GCC population continues to rapidly grow, having doubled from approximately 30 to 60 million in the last twenty years (Chaabna et al., 2017), we find ourselves with a considerable, and growing, subset of the global population for whom we know dangerously little of their projected health challenges.

As the population increases, so too does water demand, which is predicted to only become harder to satisfy under projected longer periods of drought (Kim and Byun, 2009), and increasing ocean salinity (Bashitialshaaer et al., 2011). Under the current forecasts, the UAE, Saudi Arabia, and Oman are all predicted to, at worst, face greater demand for water than it can feasibly meet by 2050, with a combined loss of agricultural exports totalling $10 billion (Borgomeo et al., 2018).

4. Vector-borne disease forecasts

In a review investigating all reported mosquito species native to Saudi Arabia, Alahmed et al. (2019) list a total of 49 mosquito species that have been reported within the country, 44 of which are made up of the *Aedes, Anopheles,* and *Culex* genera. These three genera are those most implicated with the spread of disease. *Aedes Aegypti* is a particularly hardy and widespread vector of numerous viral infections including Zika, dengue, yellow fever, and chikungunya. The species is well reported in Saudi Arabia and is present all-year round (El-Badry and Al-Ali, 2010), as the native temperatures fall within the species' optimal thermal performance curve (Reinhold et al., 2018). Importantly, the vector is notoriously found in urban hubs, frequently sheltering indoors for protection from external climate factors (Jansen and Beebe, 2010), which is likely to protect the species from the extreme temperatures forecast in the region. *Anopheles* mosquitoes meanwhile are the foremost carriers of the *Plasmodium* parasite responsible for malaria. They are similarly found year-round in Saudi Arabia (Al-Sheik, 2011), with a similar thermal performance range to *Aedes* mosquitoes (Villena et al., 2022), however they predominantly breed in rain pools as opposed to man-made pools or water containers. It is due to this that rural communities are those most threatened by malaria prevalence, with approximately 5% of the Saudi population currently living in such areas (Al-Sheik, 2011). *Culex* mosquitoes are vectors of multiple arboviruses and are frequently identified year-round along the western coast of Saudi Arabia (Hassan et al., 2017), although populations are less frequently observed in the summer months, in-line with experiments on different *Culex* species positing a lower optimal temperature compared to *Aedes* and *Anopheles* (Loetti et al., 2011).

In the last few years several high-profile maps have been published demonstrating the risk posed by, specifically, *Aedes*-borne disease in the coming century, informed by projected climate and population data (Kraemer et al., 2019; Ryan et al., 2019). The general consensus of these maps portrays a minor shift in risk for the GCC countries; however, projections are only as good as the data informing them, and the GCC is woefully under-represented in the relevant data informing these maps. Indeed, less than 1% of the sourced data by Kraemer et al. (2015) represents the entire Eastern Mediterranean Region (EMR) (Ducheyne et al., 2018). In attempting to quantify the uncertainty surrounding the predictions for this region, Ducheyne et al. (2018) produced suitability maps identifying areas of high risk for vector-establishment throughout all GCC countries that were previously overlooked by the broader global maps. Such models have considerable room for further refinement, as existing mosquito population dynamics are poorly captured in the region (Camp et al., 2019). Indeed, the severe temperature increase and decline in precipitation predicted for most of the Middle East (Bayram and Öztürk, 2021) will require further research into the assumed impact on all manner of disease vectors. While summer temperatures of greater than 40 °C and longer drought periods may suppress rural *Anopheles* and *Culex* populations, current human population increases will require greater urban expansion and water provision — increasing the risk of vector establishment. Substantial water loss may eliminate many sources of infection, or conversely induce greater migration into dense population hubs (Habib et al., 2010).

Given the extent of the predicted temperature increases in the GCC countries, climate change will likely introduce a competing selection of factors that both increase and decrease risk. Certain geographic areas will likely become inhospitable for certain vectors, while others will become a more favourable source of pathogen transmission. To investigate the similar scenario of ecological trade-offs predicted in Ecuador, Escobar et al. (2016) designed a model forecasting the geographic shift in risk posed by 14 different disease vectors across Ecuador up to 2100, revealing a substantial change over time in both the regions of the country most challenged, and the vectors likely to be present there. A similar study could, potentially, be conducted immediately specifically for the GCC using global land surface temperature estimates sourced from the WorldGrids repository (Reuter and Hengl, 2012). However, model inference will be weakened due to substantially less vector occurrence data available for the GCC (especially outside of Saudi Arabia) compared with Ecuador, and due to a lack of updated air temperature and precipitation data due to no routine collection from field stations — an immediate research priority for the GCC.

5. Further communicable disease forecasts

Beyond solely vector-borne communicable diseases, forecasting the spread of diseases via human-to-human interactions in relation to climate change is significantly more challenging. While climate-related factors greatly influence the spread of such diseases, the clear climatic signal is particularly difficult to extract from case data. Since many infections impart acquired immunity for some period of time, each infection will both incite further transmission, but also lessen the available pool of susceptible individuals. These "feedbacks" in transmission will, in some instances, mask the associations with periodic climate patterns, as demonstrated by Metcalf et al. (2017). This is then further exacerbated once one considers the variation in disease incidence induced by a wide variety of other time-varying factors seen in the last century, such as health-inequality, urbanisation, and the increase in international trade and tourism (driving increases in disease importation) (Murray et al., 2020). As the number of confounding factors grows, even greater amounts of data are required to be able to unpick the correlating patterns. The COVID-19 pandemic will enable a far greater understanding of these dynamic patterns, providing an immense dataset of incidence and mortality under a wide-reaching system of global covariates. However, the extent to which such conclusions generalise to a wider array of pathogens remains to be seen.

While improved data gathering in the region will improve the quality of future projections for the challenges facing the GCC countries, modelling unique to the region will be crucial due to the particular demographic dynamics of the area. The countries of the GCC have uniquely large expatriate populations — an average of 53.43% expatriates across the GCC in 2010, compared to the 9.5% expatriate average in the broader Middle East and North Africa (MENA) region (Abyad, 2018). This demographic composition means that while many diseases may not be indigenous to the country, a far higher number of imported cases are observed than may be seen elsewhere globally. For example, in 2010–2019, 98.5% of the 7,327 reported cases of malaria in the GCC were imported cases (Al-Awadhi et al., 2021). The majority of this expatriate population is made up of immigration from India, Pakistan, the Philippines, and Bangladesh (International Labour Office, 2022), countries which all face similarly substantial climate and disease challenges (Hasnat et al., 2018; Lobo et al., 2011). Such distinctive transmission dynamics mean that the conclusions of international disease modelling efforts may not necessarily directly apply to outbreaks in the GCC population.

Habib et al. (2010) conducted a focused literature review into the existing climate change and health research unique to the EMR region. Of the mere 64 publications that qualified for review at the time, less than 10 could arguably be said to provide meaningful results applicable to the Arabian gulf. They concluded that such information gaps would severely limit the region's ability to prepare for public health challenges and support the adaptability that would be required. Indeed, attempts to quantify the global warming-induced human health risk by Husain and Chaudhary (2008) were hindered by inconsistent forecasts for the Gulf countries due to low data availability.

6. Policy advice

The advice to policy makers from across the field consistently stresses the need for increased investment in cross-border research and data gathering. Beyond simply increasing the reach of the research output, cross-border initiatives allow deeper conclusions to be drawn from greater data variability. Linking such data to specific local priorities and healthcare capacities will require careful consideration to capture the most appropriate spatial resolution of disease incidence (Parham et al., 2015). For example, careful marrying of detailed environmental data pertaining to the Amazon rainforest has been shown to be deeply informative of disease outbreaks in Brazil (Castro et al., 2019), where deforestation creates ideal conditions for some disease vectors, requiring the targeted use of treatment, intervention, and surveillance. Such systems have succeeded in greatly reducing cases of malaria in Brazil to 130,000 in 2016 — the lowest recorded in 38 years prior. Likewise, the recently established European Climate and Health Observatory sources a wide array of climate and health data to prepare for the impacts of climate change by developing indicators, early warning systems, and information systems (Semenza and Paz, 2021; ECHO, 2022). More specific to the Middle East, the Middle East Consortium for Infectious Disease Surveillance (MECIDS) has recently had great success in monitoring and suppressing outbreaks of both avian influenza and H1N1 influenza in a cross-border collaboration between Jordan, Israel, and the Palestinian Authority (Leventhal et al., 2013). Rapid introduction of cross-border screening, laboratory testing, outbreak communication, and targeted agricultural culling was practised alongside the shared knowledge of experts within both public health and government, as well as representatives from the transportation, education, laboratory, and media sectors.

On this point, it is advised that such research investment must facilitate a “transdisciplinary approach” (Hess et al., 2020), requiring the collaboration of specialists covering ecology, climatology, social sciences and biology, beyond just the expertise of mathematical modellers and epidemiologists. Specialists will be required to evaluate and identify weak points in the health systems and surveillance of specific countries, and highlight the specific climate challenges posed to particular regions, to ensure that the most pertinent research outputs are prioritised. An example of such cross-specialisation knowledge sharing is seen within MECIDS, where summer schools and virtual events have been hosted to provide training and networking opportunities for epidemiologists and laboratory technicians, within both academia and their respective health ministries (Torjesen, 2020). Support for policy enactment is available from the World Health Organisation Regional Office for the Eastern Mediterranean. In their most recent strategic framework output, they outline clear priority objectives for member states and an actionable task force implementation checklist (WHO, 2022b). The same document notes the primary barriers to establishment of such health efforts: a lack of transferable evidence for regional decision making; no certified training courses available; immense human resource deficiencies; and a lack of regional success stories to emulate.

The GCC has successfully established multiple existing cross-border public health initiatives. The GCC Food Safety Committee has introduced GCC-wide protocol on food safety; the Gulf Cooperation Council Center for Infection Control (GCC-IC) has established a region-wide strategic plan for combatting antimicrobial resistance (AMR) (Balkhy et al., 2016); and in 2006 a region-wide malarial control scheme was agreed upon at a meeting of Health Ministers of GCC countries (Snow et al., 2013). This history of collaborative public health governance will be crucial in facing the future challenges posed by changing climate factors.

In terms of disease vector surveillance, a GCC-wide surveillance programme will need to identify areas of increased vector populations and set up pilot surveillance hubs at these sites. These research locations should then initiate studies into habitat associations of the various species identified, and track patterns in seasonal abundance, blood feeding patterns and pathogen transmission capability. Recently such data-gathering efforts have been successfully accelerated in Spain through the use of “citizen science” data gathering (Palmer et al., 2017), whereby citizens may report mosquito sightings through the use of an app — submitting taxonomic and geolocation surveys to be assessed remotely by an expert panel. This data will then allow for simulation through mathematical modelling methods of likely vector populations across the region based on environmental and human demographic data (Kading et al., 2018). This data collection and modelling work then forms the core basis needed for the eventual development of early outbreak response technologies. Badurdeen et al. (2013) summarise how other countries have utilised such data for their own early outbreak response protocols, and offer best-practise guidance in how to utilise such routine data gathering for the construction of an “outbreak alarm” system.

While establishing a strong interdisciplinary surveillance and modelling team is crucial, such expertise can be wasted if findings are not then smoothly translated into public health action. Rivers et al. (2019) reference multiple occasions where public health responses have been stymied due to poor linkage between model developers and model users. The addition of monitored climate change factors is likely to increase this divide further. As such they recommended the induction of “outbreak science” specialists, fielded to respond to three specific challenges; (i) establish and communicate model capabilities for decision makers, (ii) develop communication pathways between all required parties, (iii) promote cross-disciplinary training. Rivers et al. (2019) note that while many of these points may be rapidly addressed during specific epidemics, permanent capabilities are rarely supported long-term.

While much has been written previously on the need for public health capacity building in the GCC (Sheikh et al., 2019; Khoja et al., 2017) little attention has thus far been given to the need for increased disease surveillance and climate data gathering. The recent 2022 United Nations Climate Change Conference (COP27), hosted in Sharm El Sheikh, Egypt, provided a valuable platform showcasing the research agenda for the wider MENA region, helping inform the next steps in identifying communicable disease research priorities for the GCC. An initial step will be to begin economic analysis of the cost of conducting a climate risk assessment and further implementing climate data gathering that can be openly provided to the global climate research community. Such costing work and cost–benefit analyses have already been funded by the Gulf Health Council for Cooperation Council States for non-communicable disease (Elmusharaf et al., 2022), and should be expanded to the knowledge gaps discussed above. Only after this initial assessment work can research progress to a GCC early-warning system of climate and health impacts.

Responding to the various challenges throughout the COVID-19 pandemic has required the consideration of multiple “what-if” scenarios. Such projections depend wholly on robust, efficient, and information-rich data streams. The approaching climate change crisis and its effect on the spread of communicable diseases will require the consideration of substantially more “what-if” scenarios, and likewise will depend on equally vastly expanded data streams. It is vital therefore that such surveillance systems, international partnerships, response systems, and research capacity are developed sooner rather than later.

7. Conclusions

Immense data gaps exist in recorded climate dynamics, disease vector populations, and communicable disease monitoring across the GCC. As a result, the GCC is unrepresented in leading global health forecast research, leaving the region unable to adequately anticipate the scale of health challenges in the coming decades. International cooperation between GCC countries and initial scoping research is required to begin addressing this lack of understanding, alongside establishment of key public health task forces as advised by regional WHO offices. Only then can further discussion begin on mitigation strategies.

CRediT authorship contribution statement

Thomas Rawson: Investigation, Writing – original draft, Writing – review & editing. **Patrick Doohan:** Writing – review & editing. **Katharina Hauck:** Conceptualization, Writing – review & editing. **Kris A. Murray:** Writing – original draft, Writing – review & editing. **Neil Ferguson:** Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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