Tyndall°Centre
for Climate Change Research

Foundations for climate resilient and sustainable growing settlements (U-RES)

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Introduction

Urban populations are particularly vulnerable to extreme weather events related to climate change, especially heat waves and floods. This vulnerability is derived from a combination of factors including existing inequalities, high population density with poor service provision, and a natural environment that has been transformed, often completely replaced by concrete surfaces and buildings, exacerbating risk and increasing exposure to certain types of environmental hazards. Existing inequalities are expressed through education, wealth as well as gender, age, class and other social differences, leading to marginalised groups that are particularly vulnerable to climatic extremes. As cities emerge from smaller settlements and nearby adjacent cities, little design goes into ensuring that they are established in appropriate locations, that new infrastructure is adequately resilient to current and future weather extremes, and that governance and growth take into account the specific needs of marginalised groups. Instead, urban development often appears chaotic and unplanned, locking citizens, particularly those who are most marginalised, into high states of vulnerability.

The Global Change Research Fund (GCRF) Resilience Foundation Awards has provided seed funding for the U-Res project which has the primary aim of establishing a community of trans-disciplinary researchers working together to support the transition from rapidly urbanising, unsustainable settlements to resilient and sustainable cities in the face of climate change. The U-RES project explored the foundations of how and where new cities emerge, and what are the opportunities for influencing their design while they expand to be resilient to extreme weather in a changing climate. The research team comprised of both academics and practitioners. Part of the work was done in collaboration with communities in Isiolo County and Isiolo town in Kenya and Quarry Road West informal settlement in Durban, South Africa to explore resilience and sustainability at the settlement scale using data and knowledge produced at a global, regional and local scale.

This working paper summarises the strands explored in this interdisciplinary project. It includes: I) Lessons from the archaeological past, II) Key principles of low carbon and climate resilient urbanization, III) III. Resilience, governance, and data integration at the settlement scale, with an appendix on the climate change risks for the study sites.

I. Lessons from the Archaeological Past

What constitutes a city, as perceived by the Global North, is rooted in long-held European and New World ideas around the ways in which the world's first civilisations arose in Egypt, Mesopotamia, Mexico (the Aztec civilisation) and Peru (the Inca civilisation). During the 19th and early-20th centuries some of the greatest archaeological discoveries were made under the backdrop of western colonial expansion. Neo-evolutionary notions of complexity infused the interpretations of the great archaeological excavations and cities like Troy in Turkey, Mycenae in Greece, and Nimrud, Nineveh in northern Iraq. Excavators of these sites were usually part of British, French and American diplomatic services or the military. The discoveries they made were contextualized within the cultural *milieu* of the time largely underpinned by European concepts of 'civilisation' and 'progress'. In a 1950's paper in the journal *Town Planning Review* (1950) the archaeologist V. Gordon Childe, who was already renowned as an archaeologist and cultural theorist, devised a list of ten characteristics essential to the development of urban life (including sedentism, large-scale public works, unequal distribution of wealth and writing) but many of these ten essential characteristics were later found to be absent in early indigenous African cities. The picture that is emerging now does not fit with the model proposed by Childe. Instead what we observe is significant variability in urban forms across the continent, examples of urban 'invisibility' where what is essentially an urban system lacks many of the criteria thought to characterise urban development, and an inability to classify or group different urbanisation processes.

It is now recognised among Africanist archaeologists that many of the ten characteristics identified by Child as necessary for identification as an 'urban centre' were absent in early African cities.

African cities did not necessarily have a ruling / governing class

Cities were not a priori sedentary in nature

Instead, other characteristics are representative of early African cities, such as;

1) Episodic mobility and / or transient populations. For example, Addis Ababa, the Tswana towns, Lithako I and II and Great Zimabbwe are all thought to have had large transient populations, or as in the case of Addis Ababa, were fully mobile (Fletcher 1998). Other models of mobility include Buganda in the 1800s where the capital city shifted from Ganda, then to Mulago then to Nabulagala near Kasubi in present-day Kampala" (Reid & Medard 2000).

2) Absence of stratified society. Instead archaeologists and historians have identified what they term heterarchies, that is, cities based on clusters of settlements that worked 'horizontally'. McIntosh and McIntosh, excavating the ancient city of Jenne-Jeno in Mali record that it had sophisticated trade, large specialist populations but with no visible hierarchy, no unequal distribution of wealth and no monumental public buildings (McIntosh & McIntosh 1980, 1984; McIntosh & McIntosh 2003).

3) Organic city planning and an absence of monumental public works. Although many early African cities had city walls, the enclosed space within the walls included extensive open areas used for grazing or cultivation, a pattern of settlement based upon tradition that became a continual problem during the colonial period when European overlords tried to wrest land for development from traditional indigenous land owners (Connah 2000, 39). The blurring of the economic function of the city is a traditional behaviour that has its roots in the emergence of African cities in the past.

The purpose of this part of the U-RES work was to investigate the relevance of the past for informing future planning of resilient and sustainable cities. The most useful way to do this was to contextualise what we know about resilient or vulnerable ancient African cities in Dhakal's, *Ten Key Principles for Sustainable Urban Development,* as outlined in the (IPCC, WG3, AR5, Chapter 12). This study chose three ancient African cities for detailed analyses on the basis of them being pristine, located in challenging environments and belonging to the period when indigenous African cities first emerged in the 1st millennium BC.

<u>Garama</u>

Part of the Garamantian civilisation in southern Libya that urbanised and prospered during and immediately after the drying of the Green Sahara (Mattingly 2013; Mattingly & Sterry 2013). The city was at its height ~2nd C. AD and was the principal city of the Garamantian civilisation. It is thought that people aggregated in this region because of the availability of water. As the Sahara dried instead of abandoning the area they developed innovative technologies for extracting ground water for irrigation from the numerous springs that dotted the escarpments above the wadi. *Foggara* were underground irrigation tunnels that channelled water on a slowly declining gradient to fields thousands of metres away (Wilson & Mattingly 2013, 504). Yet it was not the innovation of foggara that enabled the Garamantes to survive the desiccation of the Sahara, it was that it acted as a gateway community between the mercantile trading emporia of the Roman world to the north and the sub-Saharan continent to the south. It controlled the Saharan trade routes to such an extent that other nearby communities with equal access to the knowledge to construct foggara were not able to urbanise and remained largely semi-nomadic pastoral communities.

<u>Thonis-Heracleion</u>

An Egyptian/Greek city now submerged off the coast of the Nile Delta (Goddio 2011; Goddio & Clauss 2006) Thonis flourished between the 2nd C. BC and the 2nd C. AD (Fabre and Goddio 2013). The city was one of a number of initial 'gateway' cities that controlled and regulated international trade and commerce between Egypt and the Mediterranean world. There is some ambiguity about who controlled the trade in and out of these cities but taxation texts written on stone statuary indicate that shipping taxes, effectively bills of lading, were imposed on trading ships by the Egyptians at both Thonis-Heracleion and further south at the delta site of Naukratis (Goddio 2011). Thonis-Heracleion was a-typical of ancient African cities in that it was built for the singular purpose of a trading emporium and gateway into Egypt.

Jenne-Jeno

The Inland Niger Delta clustered city, Jenne-Jeno, located between the Niger and Bani rivers (McIntosh, S.K. and McIntosh, R.J. 1980). The city flourished from ~ 2nd C. BC. Like Garama and Thonis-Heracleion, Jenne-Jeno was a prosperous commercial centre for regional trade based on a highly productive, diversified hinterland (McIntosh & McIntosh 1980). Jenne-Jeno's prosperity depended on its dual role as a critical trans-shipment point for long-distance trade and as a major production and exchange centre for regional commerce in staples and raw materials (McIntosh & McIntosh 1981, 7). Two factors were critical to Jenne's development as a city, its situation at the most south-westerly point of the navigable Inland Niger Delta and its extraordinarily productive agricultural hinterland. Jenne-Jeno is distinct for comprising a series of settlements all within a short distance of each other with a total population upwards of 50,000 people, described by the excavators as 'site clustering', effectively a city constellation (McIntosh & McIntosh 1979).

Urban resilience and vulnerability

The success or failure of many ancient cities was partly contingent upon diversity, that is, cities that had rich resource bases, were involved in regional and international trade and had a population with a diverse range of skills, which made them less likely to be vulnerable to environmental shocks than cities founded for specific purposes. When too few elements (reasons for a city to exist) underpinned the urban process, cities became vulnerable to risk. Looking at each case study in turn, Garama survived throughout the desiccation of the Sahara because it had a diversified infrastructure. It had developed organically from indigenous roots in an area already populated by early pastoralist communities. It developed an ingenious technology (foggara) for water extraction that enabled it to thrive on a strong agricultural base, which supplied the surrounding regions with staple food crops. In addition, from an early point in its development it controlled trade between the Mediterranean world and the Saharan interior. Jenne-Jeno mitigated the unpredictability of the annual inundation of the Inland Niger Delta region because of the dispersed nature of the city, being located across a series of 'turtlebacks' within less than a kilometre of each other, enabled the community to literally 'spread the risk'. Jenne-jeno, like Garama, emerged indigenously from a population of people that had aggregated in the region for some time prior to the genesis of the city. It had rich and varied food staples, which were traded for salt at a local scale with Timbuktu and its strategic location at the most southerly point of the navigable part of the Inland Niger Delta, gave it access to, and control over, trade with the gold sources further south and, via the Niger, the Saharan trade routes to the north. Thonis-Heracleion is very different from both Garama and Jenne-Jeno; the city was purposefully constructed to facilitate international trade between the Mediterranean world and Egypt (Fabre and Goddio 2013). It did not posses a diverse resource base due to its position at the entrance to the Nile Delta and all food staples had to be imported. It was built on the sediment substrate that characterised the Nile Delta and no contingency planning in the event of subsidence appears to have been factored into construction. The vulnerability of Thonis-Heracleion to subsidence appears to be based on political decisions to place lucrative, short-term financial gain before long-term sustainability.

From the analysis of archaeological data presented in this section, four key principles for sustainable cities stand out as crucial for the success and resilience of ancient cities; 1) access to trade and resources beyond the borders of the emerging city, 2) access to technologies that enable and enhance urban existence, 3) resources close to the settlement areas or easily moved, and 4) satellite towns providing goods and services from the surrounding region.

II. Key principles of low carbon and climate resilient urbanization

The contexts of key principles is expanded further in this section for the following reasons:

- There is a need to re-orient the expected urbanization in emerging cities for low carbon and climate resilient urban development. IPCC and other recent papers have said that a large opportunity exists there, and next two-three decades are crucial. Africa and Asia are on the forefront of this new urbanization.
- There is a need to make "existing cities" low carbon and climate resilient since a large fraction of population already live in cities. This requires adapting existing cities and making them efficient.
- The climate agenda is new and adds to other sustainability challenges that cities are facing. Therefore, the climate agenda must also address other sustainability concerns including equity, inclusion, justice, recognition, power-relations, informality and the most vulnerable groups.
- City decision makers undertake collectively urban-wide and sectoral planning, and address multiple concerns at once; therefore, synergies and trade-offs between issues related to the climate agenda and broader issues linked to urban development must be given due care and there are large potentials to harmonize them.
- Urbanization in Africa are distinct on few fronts, mainly, the prevalence of poverty, informality, multiple forms of governance, stronger links to rural livelihoods, and the peri-urban dominance.
- These principles are city-wide principles

<u>Concept of low carbon and climate resilient urbanization</u>

Following the Paris Agreement, different countries have pledged to specific targets to limit greenhouse gas emissions and devised climate adaptation strategies. As the concept of low carbon and climate resilience permeated to the local scale, with realization of collective significance of cities in the global climate, a number of cities around the world have shown farsighted leadership in setting targets, devising and implementing plans to reduce these greenhouse gas emissions, developing risk assessment and the adaptation plans. Despite less than 2% coverage of the earth's surface, cities consume over two thirds of the world's energy; produce over 71-76% of global energy related CO_2 emissions and more than 60% of total greenhouse gas emissions combining energy generation, vehicles, industry, and biomass use (Seto et al. 2014). Cities are the major contributor to climate change and also the most affected one from the implications of climate change, impacting its bio-physical and socio-economic functions. With the world's urban population expected to double up to 6.3 billion from 3.48 billion (in 2014) by 2050, roles of cities in global climate will only become more crucial. Concepts of new development pathways such as, climate compatible development have become widely acknowledged. Climate compatible development as defined by Mitchell and Maxwell (2010), is the triple-win strategy aiming to achieve low carbon emissions, build resilience and promote development simultaneously. It integrates climate threats and opportunities focusing on both climate mitigations directly and indirectly and building climate resilient environment simultaneously. Climate change brings both threats and opportunities in the cities, as cities can reduce their greenhouse gas emissions while simultaneously addressing other pressing local environmental problems such as air pollution, waste, and transport, not to mention other challenges such as local economic development. Under the concept of low carbon and climate resilient urbanization, with simultaneous mitigation and adaptation strategies, cities also have opportunities for substantial co-benefits including public health improvements, cost savings through increased efficiency, and the energy security amongst others.

<u>Objectives and audiences of principles</u>

- o The objectives are to provide guidance to decision-makers who are responsible for addressing low carbon and climate resilient development in cities. This guidance must be well vetted in evidence-based science. However, a broader practice-community can be benefitted from these principles.

The framework

The key principles reflect a diagnostic and solution-oriented approach. Considering cities' state of emissions, social environment and climate vulnerabilities; as well as identifying drivers for climate vulnerability and resilience, the key principles provide solution-oriented options and strategies.

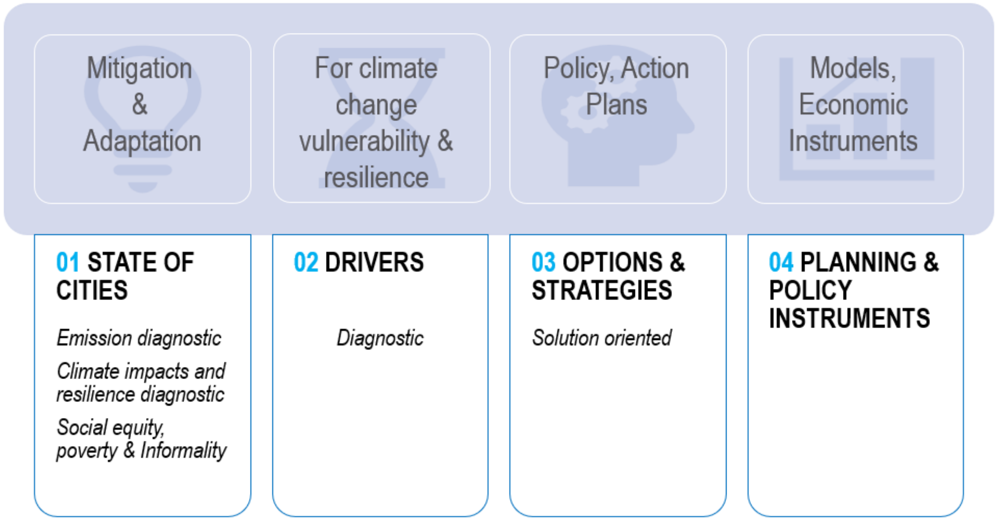

Figure 1. Framework for identifying key principles

Urban key underlying components

It is essential to understand the multiple layering of bio-physical, socioeconomic and political components of a city that influence the urban systems' forms and growth, in order to conceptualize the framework of key principles which can capture climate resilience and vulnerability at the local level.

Figure 2. Key urban underlying components

Built environments are critical for supplying food, water, energy, sanitation, shelter, transportation, and communication, and their development is therefore essential for alleviating poverty and promoting economic growth. However, trend of city expansion shows that the built environments gradually replace the existing natural landscapes giving rise to the phenomena of urban heat islands (Golden, 2017; Levermore et al., 2017; Soo et al., 2017) and affecting the natural water cycle causing urban floods and serious implications for human health and economy (Chen et al., 2015; Idris and Dharmasiri, 2016; Israel, 2017). Urban climate change hazards are not only increasing in severity and frequency, but also are likely to have a profound impact in a wide range of urban infrastructures, services, the built environment, and supporting ecosystems (Revi et al., 2014a). Carbon emissions from built environment has been immensely growing; building sector alone was responsible for 32% of global final energy consumption and 19% of energy-related CO_2 emissions; and 51% of global electricity consumption in 2010 (Lucon et al., 2014).

Understanding urban resource consumption patterns, social, cultural and psychological drivers of human behaviour, provides opportunities for socio-technological innovation. Establishing low carbon urbanization require proper integration of human development and climate action, which requires an adequate understanding of how infrastructures contribute to well-being and greenhouse gas emissions (Müller et al., 2013).

Successful urban governance for implementing climate actions requires identifying responsibilities of actors and decision makers, such as who delivers climate change action, what are the motivations and capacities of the actors in delivering climate action (Broto, 2017). Capacities and resources of the local government is one of the underlying element which helps in fostering climate action and resilience strategies. Local government can provide significant role in formulating a framework to encourage a behavioural shift that contributes to GHG emissions reduction, along with removing bureaucratic and regulatory barriers and providing support for local initiatives. Effective urban adaptation strategies require local governments to work in partnership with low-income groups and vulnerable communities (Revi et al., 2014b).

The principles

Our principles are solution-oriented, useful to decision makers, and evidence-based. These map over key underlying urban components with sets of options and solutions which give due consideration to what goes into the process.

Based on this framework, we propose 12 key principles for sustainable urban development, organised under (A) options and solutions, and (B) the process needed to reach or implement solutions, as detailed below.

A. Options and solutions

1. Ensuring right urban form (density, layout, accessibility) and design through spatial planning
2. Urban infrastructure to ensure better connectivity, built-environment efficiency and affordability supporting social-economic needs in cities
3. Tap the power of technology- necessary but not sufficient for scale-of-change that are needed
4. Re-orienting behaviour and choices of urban dwellers
5. Improving preparedness to address low carbon and climate resilient development (DRR, ability to explore options and solution)
6. Supporting to generate evidence-based knowledge and vetting them into solutions
7. There are silver bullets- solutions must be tailored to local context and must be built on local reality

B. The process to reach/implement solution are key

8. Ensuring participation in identification and implementing solutions
9. Inclusion, equity, justice, recognition need careful link; ensure solutions do not deprive (and support) vulnerable groups and informality in cities
10. Reflecting on right mix of multiple modes of governance – including formal administrative systems and the traditional governance systems – innovative ways
11. Taking a good view of synergies and trade-offs of solutions with other aspects of urban sustainability
12. Long-term and high impact options- see the big picture

III. Resilience, governance, and data integration at the settlement scale

This section focuses on three critical elements of building resilience at the settlement scale given the focus of the U-Res project:

1. To understand how different forms of governance interface with each other and whether these intersections can be conceived as critical intervention points which can be leveraged to deliver better adaptation to risks associated with a changing climate?
2. To explore how different scales (temporal and spatial) of data can be brought together and utilised productively (potentially explored through mapping) to build resilience at different scales
3. To facilitate engagement between the urban principles and a grounded reality using the two case studies of Isiolo and Durban as experimental sites for ground truthing the principles.

Two case study sites were selected for the empirical research being conducted for WP3. Researchers from the University of East Anglia have been working in Isiolo County and Isiolo town exploring the relationship between governance systems and climate-related risks. Quarry Road West informal settlement in Durban was selected as a case study as the South African based U-Res researchers were already working in the settlement as part of the Palmiet Rehabilitation Project (PRP), which is focused on water and climate governance in the Palmiet Catchment, and so had good relationships with the community and with the municipality. The U-Res research, which includes a community based mapping project, has therefore added value to the baseline and governance research that has already been undertaken in the settlement.

<u>III.1. The context of Isiolo and Quarry Road West informal settlement</u>

Isiolo is a mid-sized town located at the intersection of the drier, more arid, pastoralist parts of Northern Kenya and the wetter, more humid, and agricultural areas of central Kenya (Carrier and Kochore, 2014). The town and surrounding area is water scarce, exposed to urban flood risk and also heat stress. In 2009, Isiolo town had a population of 44,154. The area around Isiolo town has been earmarked by the Government of Kenya as a junction in a transport corridor - the Lamu Port South Sudan Ethiopia Transport Corridor (LAPSSET). These developments suggest that the town and its population will continue to grow and develop potentially at a faster rate than has been witnessed up to now potentially exacerbating the existing climate-related hydrometeorological risks. The situation presents an opportunity through which we can build understanding and generate new knowledge of the sorts of interventions required to increase resilience to current and future climate extremes whilst concurrently supporting and empowering the more marginalised who tend to be excluded from the development gains.

Quarry Road West informal settlement is located on the flood plain of the Palmiet River in the urban core of Durban. It is a well-established informal settlement that has been in existence for over 30 years. There are just over 1000 households in the settlement. Residents retain strong links to the rural areas from which they come, engaging in the process of circulatory migration. Living conditions in the settlement are extremely challenging with the main risks being acute flooding from the river, chronic flooding due to poor drainage, fire, the danger of illegal electrical connections, poverty, unemployment, crime, and low levels of services, with poor waste management impacting on both the residents and the river exacerbating risk.

<u>III.2. Developing a community of researchers</u>

One of the main aims of the U-Res project was to develop a community of researchers, by creating and supporting partnerships between academics, practitioners and community members, around the ideas of urban resilience and sustainability in the face of climate change. Within WP3, research partnerships have been developed both within the project team and with multiple actors in the case studies through action research on the ground and the partnerships established are continuing beyond the life of the project. The researchers collectively developed the WP3 research objectives through a series of skype meetings in the early phases of the project.[1]

Once the objectives for WP3 had been established and the case studies selected, the community of researchers, or network, began to expand to include a broader group of actors. In the case of Isiolo, the research process resulted in Mark Tebboth engaging with elders and community groups, leaders of CBOs, and county government officials, as part of the data collection process for WP3. The core U-Res researchers in Durban, which included two municipal officials and five university researchers, engaged with community members around the mapping of the settlement for the U-Res project. They also continued to remain part of and explore the governance arrangements in the PRP[2].

The second objective of WP3 drew another group of actors in to the research network developed through the U-Res project. A group of twenty mapmakers were selected by the Quarry Road West informal settlement committee to participate in a community based mapping project of the informal settlement as part of Goal 2 of WP3. The fieldwork visit of the UK U-Res researchers included a site visit to Quarry Road West informal settlement on 30 June 2017. Bahle Mazeka, a UKZN researcher was invited by the UK U-Res researchers to attend a week long study tour, led by Alistair Ford at the School of Engineering and Geosciences, University of Newcastle. His travel was funded by the SANCOOP CLIMWAYS project and he was hosted by the U-Res researchers at the University of Newcastle and hence co-funding was used to enhance research partnerships and to build the capacity of young researchers.

<u>III.3. Building resilience at the settlement scale</u>

The three goals or objectives of building resilience at the settlement scale, as identified in WP3, are:

Goal 1:

- To identify different forms of governance 'present' in the case study sites
- To understand where and how different forms of governance intersect.
- To explore if the overlaps between the different forms of governance provide potential intervention points that will ultimately contribute to more sustainable forms of urban development (within an African context)?
- To explore the potential for positive change if these different forms of governance can be harnessed and enhanced

Goal 2:

- To document and explore the value of existing mapping processes and to develop and conduct community-based mapping in Durban:
    - More participatory and locally grounded maps of settlements and climate risks
    - (Inter)National scale maps of climate indices
    - Regional maps of urbanisation trends
    - Historical archaeology and settlement change
- How can these different data be integrated (when working at such different spatial and temporal scales and across disciplines) in a way that is useful for decision-makers at a local level?
- How does spatial representation help us to understand the nature of the problems we face and in the solutions, we identify?
- How does the construction and use of spatial data enhance governance processes

Goal 3:

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[1] This included the two lead researchers of each case study in WP3, Mark Tebboth and Catherine Sutherland, a spatial knowledge researcher Alistair Ford, a practitioner from Oxfam, Daniel Morchain, as well as two municipal officials from eThekwini Municipality, Debra Roberts and Jo Douwes.

[2] The PRP is developing an innovative governance model, through partnerships between eThekwini Municipality, University of KwaZulu-Natal, community based organisations, local environmental forums, and community members to address water and climate governance in eThekwini Municipality, with a particular focus on rehabilitating Durban's rivers.

- The principles of resilient urban development (WP1) are portraying an idealised form of urban development that will come under pressure during process of implementation. One role for the case study sites is to reflect back on the principles and to highlight some of the challenges and issues with the principles when confronted with complex governance systems, constrained budgets, inefficient and politicised decision-making processes etc.
- To what extent are these principles travelling from a 'developed world' context and how applicable are they within the context of African urbanisation

III.3a. Governance for urban resilience in Isiolo and Quarry Road West informal settlement

The U-Res research identified critical issues that shape water and climate governance in Isiolo and Durban. These issues are now being analysed and synthesised into a framework of governance which will lead to the production of a paper on governance for urban resilience at the settlement scale in Kenya and South Africa. The context within which this governance emerges is also critical and hence an understanding of the history and character or African urbanism is now being explored and will also form the basis of a paper on African settlements 'then and now' and how this impacts on future governance for resilience.

The broader legislative and policy frameworks for water governance in both Kenya and South Africa are important as they form the frame within which locally established governance arrangements operate. Water is considered to be a basic human right both in Kenya and in South Africa. Kenya's Vision 2030 and a recent bill which was passed in 2016 at the national level enshrines water rights for every citizen in the country. However, even with this right, access to water is a critical issue in Isiolo. The South African Constitution Section 27 (1996) states that everyone has the right to water. In South Africa, Water Services Authorities (WSAs), which in most cases are municipalities, are mandated to provide water and sanitation services. This means that local government is responsible for the delivery of these services. In Quarry Road West informal settlement, residents have access to water through communal ablution blocks (CABs) and communal tap points. However sanitation and storm water management remain major challenges.

The governance arrangements in the two settlements differ considerably, mostly due to the way in which relations between the state and citizens are formally structured, and due to one settlement being located in a rural context, while the other is in the urban core of a large city. However, in both cases the relationship, or lack of relationship between the state and citizens has been the critical issue in building urban resilience. The two cases, although different do share some core elements of governance that could be used as leverage points.

Defining water and climate governance. Water governance encompasses a wide range of issues and elements. Both case studies revealed that water connects to all elements of life: social, political, environmental and economic and hence it is difficult to remain focused on water access and provision alone. Water governance is not only related to the provision of potable water: it is also directly connected to sanitation services. Water is produced as waste or grey water through human practices and storm water needs to be managed as this forms surface flow, which if not well managed is a major environmental risk when floods and droughts occur. These issues have emerged as being important in the two settlements.

Climate governance in both cases focused more on adapting to current variability in weather than on longer-term adaptation planning and mitigation. Mitigation in the case studies takes on a different meaning, due to the low use of resources that contribute to anthropogenic climate change in these settlements or the ability of local people to change the systems that do, and hence it cannot be the priority of climate governance. Leverage points in governance that will emerge from on-going work from the U-Res project will focus on adaptation.

Relationship between the state and citizens

In Isiolo the main actors involved in governing are the County government, locally elected leaders (local elders or 'chiefs'), and NGOs and CBOs. Communities do not access the national government themselves, but work through their elected representative, who in many sub-areas are elected to represent as few as ten households. In some cases, meetings are held between county officials and community members to discuss critical issues such as the drought and security and here too the community representative plays a critical role. Kenya-RAPID which is a development programme funded by US-AID has played a central role in ensuring that national water bill is taken up at the County level. Kenya-Rapid has consulted with other NGOs to support the implementation of drought and water projects in Isiolo by the County government.

The community-led governance system is responsive in some sub-areas to community concerns. If the community feels that the elder representing them is weak or not doing their job properly then this person can be deselected and replaced. The elected community leaders have a council and they meet regularly (most often monthly) to discuss community issues. It is the responsibility of community leaders to report to the County government and to ask for support. All of the respondents interviewed stated that community leaders did report the concerns of their communities to the County government, which more recently has focused on water issues, security and the need for food parcels and other poverty alleviation measures and that these concerns were heard. Almost all of the support for the population of Isiolo comes from County government, not from national government (due to decentralisation or devolution to the local scale). Respondents stated that the councils and engagement between the community leaders and those they represent were democratic and participatory. In the case when the council did not agree on matters voting takes place and the voices of the communities are taken in to account. However both a government official and clan leader were concerned that the election of leaders can be political and that some clans were excluded from decision making as they did not have elected representatives on Council, leading to increasing poverty and marginalization of some sub-areas. However, if the elders pass a judgement which a community strongly disagrees with, then the group that is dissatisfied with the decision can challenge the contested decision through the government courts.

The governance arrangements in Quarry Road West informal settlement reflect two forms of governance: the first is the way in which the relations between the state and citizens is shaped by the Ward Committee system which was developed in South Africa post 1994. This system is outlined in the Municipal Structures Act 117 of 1998. Municipalities are divided in to wards and each ward has an elected councillor (through local government elections) and a proportional representative councillor. The councillor represents his or her ward through the Council of the municipality, upon which he or she sits, and through engagement with municipal authorities. The Councillor elects a ward committee which includes representatives from the communities in his or her ward. Sub-ward committee members often sit on local community committees and they report to ward committee members who in turn report to the councillor. This means that there is a very structured approach to defining the relations between the citizen and the local state, with citizens reporting all issues in their communities through this system to the councillor. The municipality has established Sizakala Centres, which are a 'one stop shop' for residents to report issues to the municipality, with a particular focus on services. However, residents in informal settlements seldom access these centres as their informality means that they are located outside of the formal systems of the local state. However, they can use the local call centres to report services faults. They seldom use this approach as their relations with the state are carefully structured through the political control of the councillor.

In this way, governance in Quarry Road West informal settlement is very similar to Isiolo, where elders or councillors control the engagement of ordinary citizens with the state. In a similar way that meetings are called when issues cannot be resolved in Isiolo, meetings are held in Quarry Road West informal settlement, but these meetings usually only occur after protests which draws the councillor to the settlement. Protests are common in South Africa and particularly in informal settlements as residents mobilise regularly when they feel that their voices are not being heard. Party politics controls the ward committee system in South Africa where the state and the party has become conflated and this has meant that communities often do not engage in ward committee processes as they state that the discussions always centre around politics and not development. However, the Quarry Road West informal settlement community committee has shown itself to democratic, as is evident in the ease with which the mapping process took place in the settlement. The ward within which Quarry Road West is located changed from being an African National Congress (ANC) ward to a Democratic Alliance (DA) ward post the local government elections in October 2016, interestingly this major shift has not impacted on the governance arrangements in the settlement significantly. However the community has stated that it is now much more difficult for the DA councillor to get support for Quarry Road West informal settlement as the eThekwini Municipality is an ANC municipality. Just as in the case of Isiolo, politics and power really matters.

The second form of governance in Quarry Road West informal settlement is a new form of governance which is emerging through the partnerships and networks being established as part of the PRP. The most significant outcome of this work has been the relationship building that has taken place between the community and local government officials which has significantly changed the views of 'the other' (in relation to the state and citizens). Building direct state citizen relations has been a major focus of the work of the PRP.

Lack of resources and capacity. One of the main factors constraining the ability of the County and eThekwini Municipality to engage with citizens and address service and other development needs is that government offices are understaffed and underfunded. There are also officials working in government who do not have the technical skills to do the work that is required.

Dual governance systems. There is a conflict between rural and urban land governance in Isiolo and this reflects the tension of having dual systems of governance (traditional and local government) allocating and managing land. In the rural areas the elders are responsible for allocation of land and land conflicts at the local scale and this small-scale governance has positive outcomes. In the urban areas this traditional system of land allocation and law making is eroded and this results in the Department of Land making land allocation decisions based on urban laws, which results in social conflict as people from different ethnic groups and social systems live together in one urban space. This system, which creates the need for a hybrid from of governance, is typical of the peri-urban areas of Durban, where the land is governed under both the traditional authority and the municipality (Sim and Sutherland, 2017). However, this dual form of governance is not present in Quarry Road West informal settlement as it is in the urban core of the city.

The role of NGOs and CBOs. In Isiolo there is a wide range of NGOs and CBOs that have been created to address the development challenges of the area, such as the Al Hamduh Women's Group and the Faiya Cultural Women's Group. Many of these organisations have been established to address the needs of women, poverty and safeguard the culture and skills of people from the area. These organisations attempt to access resources from NGOs and aid organisations as well as the government but find it very difficult to obtain support in any form. Residents were concerned that NGOs and CSOs were not meeting the development needs of people in the area in relation to drought and the pastoral system and now communities are really suffering. They felt that NGOs were providing more support to rural areas, with a focus on infrastructure development rather than immediate crises like the drought. However a government official explained that NGOs could only work in areas that they were prescribed to work in and hence they were constrained. Some respondents stated that it is in the urban areas that support is really needed. Some felt that the outcomes of development decisions were distorted by politics and that NGOS did not deal with everyday critical challenges. Most respondents including the government official stated that it is important to have more conversations between the county government and NGOs which would enable more flexible and productive partnerships. If this happens then the County government can play a stronger role in influencing what NGOs invest in in local areas.

In Quarry Road West informal settlement there is an absence of NGOs operating in the settlement. The university has played an interesting role as being the interface or 'bridge' between the local state and the community through the PRP and this has led to transformation of these relations.

Political patronage and corruption. Corruption is a major challenge in the governance of both Isiolo and Quarry Road West informal settlement, although this happens at different scales in the two settlements. In Isiolo the national government does provide some food assistance but it has been reported that county commissioners will use this for their own gain. There is mismanagement of resources and this is always worse at election time. In Durban and South Africa corruption and political patronage is pervasive and it undermines socially just development in the city. Informal settlers are probably the group of society that are most adversely affected by corruption as much needed resources are channelled elsewhere.

Gender issues. Gender inequality is a major problem in Isiolo with women not having the same access to decision making processes as men. If women want to raise an issue at a meeting they usually did this through a male intermediary. Women also carry the development burden in Isiolo as men work away from home, they leave their families and many die in conflicts and so women are left at home to deal with all the challenges the lack of development brings.

In Quarry Road West informal settlement women are the leaders and have been critical to the outcomes and success of the PRP project and the U-Res mapping project. Many gender issues, such as the abuse of women are prevalent in Quarry Road West informal settlement but the strong women leaders in the settlement have ensured that women have rights and a voice in the community. Many households in Quarry Road West informal settlement are female headed households and so woman play an active and important role in the life of the community and also bear the burden of development as is the case in Isiolo.

Addressing disaster risk management. The response to disaster risk management is still very fragmented in Kenya and Isiolo. National and regional governments have been working on a drought risk policy, but these processes have not taken hold or been implemented in Isiolo. Some counties have disaster risk units and directors but this has not taken place in Isiolo as other major conflicts, such as land disputes and security issues have dominated discussions and overridden the need to develop climate change policies.

In Durban and Quarry Road West informal settlement the Disaster Risk Management Department of the Municipality is responsible for managing disasters, such as fires and flooding in the settlement. The response of this department is good, and is evident in the support the municipality provides after fires. While flooding is a major risk, the response of the department is more fragmented and ad hoc as it is difficult to respond to the variable outcomes of a flood in the settlement. However this department works in conjunction with other departments such as the Coastal, Stormwater and Catchment Management Department in eThekwini Municipality. This department is currently developing an early flood warning system for the Palmiet River based on the data obtained from a radar system at UKZN. This more accurate storm warning system is now working in conjunction with the locally established early flood warning system of the PRP, where middle income community member from Riverwatch in Westville, a community based organisation in the PRP, monitor rainfall and river levels on the Palmiet River.

Knowledge and information. The Foucauldian argument that' knowledge is power' is strongly supported in the empirical research for WP3. Both in Isiolo and Quarry Road West informal settlement, leaders have argued that ordinary citizens need to be empowered through education and knowledge sharing, particularly in relation to climate risk. In both cases it is evident that residents are not always aware of their rights, particularly in terms of how they can interact with local government. Residents also need to understand what rights and services they are entitled to. Access to knowledge and the co-production of knowledge builds social cohesion and therefore has other positive governance and development outcomes. The biggest challenge is in translating climate knowledge, information and data in to practice and this requires resources, collaboration, knowledge sharing and negotiation and the political will to ensure that change takes place. The translation and downscaling of global scale data in to a short report on climate change impacts on Durban as part of U-RES (see Appendix) has proven to be particularly useful.

1.1 III.3b. Using and integrating data from different scales

The value of mapping processes at different scales formed the second goal of WP3. Participatory maps were produced in both Isiolo and Quarry Road West informal settlement. The participatory GIS mapping that was undertaken in Quarry Road West where 20 mapmakers from the community co-produced the GIS risk maps and GIS maps of the settlement with the U-Res researchers was a significant learning process. The map of the settlement is being completed and ongoing research on its impact on the future of the community is being undertaken by the community and the researchers. This was an extremely valuable process that was supported by U-Res. More comparative work on the participatory mapping of Isiolo town and Quarry Road West informal settlement and the benefits of the risks maps produced hopefully will be undertaken in the future.

Bahle Mazeka has written a draft paper on urbanisation, mapping and changing green spaces in Durban as a result of his exchange to University of Newcastle and this ongoing work will therefore provide insights around mapping urbanisation at the scale of the city, which is aligned with the work of Alistair Ford at the University of Newcastle.

The historical archaeology and settlement change work being undertaken (see part I) will be developed further in partnership with Cathy Sutherland and Mark Tebboth, as it has become evident that understanding the history of African settlement and the evolution of African urbanism is critical to building resilience in African cities in the future.

III.4. Ground truthing principles of resilient urban development

The role of WP3 in relation to the principles was to reflect back on the principles and to highlight some of the challenges and issues with the principles, when confronted with complex governance systems, constrained budgets, inefficient and politicised decision-making processes etc. For example, the principles talk about the importance of density and hard infrastructure. These issues may well lead to a sustainable urban form but it will not be practical in the African context. Densification is already taking place in many urban areas, but this is occurring not through 'formal design', but in informal settlements or in locations governed by traditional authorities where land is more readily available when compared to land that is controlled by municipal government. The extent to which these universal principles travel from a 'developed world' context, and how applicable they are within the context of African urbanisation, requires further investigation. This was not fully developed due to the time constraints in U-Res and the way in which research networks formed within the broader team, but this work could be developed more fully in the future

References

Andrews, O., C. Le Quéré, T. Kjellstrom, B. Lemke, and A. Haines (2018). Implications for workability and survivability in populations exposed to extreme heat under climate change: a modelling study. The Lancet Planetary Health, 2, e540-e547

Broto, V.C., 2017. Urban Governance and the Politics of Climate change. World Dev. 93, 1–15.

Chen, Y., Zhou, H., Zhang, H., Du, G., Zhou, J., 2015. Urban flood risk warning under rapid urbanization. Environ. Res. 139, 3–10. https://doi.org/10.1016/j.envres.2015.02.028

Golden, J.S., 2017. The Built Environment Induced Urban Heat Island Effect in Rapidly Urbanizing Arid Regions – A Sustainable Urban Engineering Complexity Island Effect in Rapidly Urbanizing Arid 3430. https://doi.org/10.1080/15693430412331291698

Idris, S., Dharmasiri, L.M., 2016. Development of built environment and its implication on flood risk in Gombe Metropolis , Nigeria 10, 111–116. https://doi.org/10.5897/AJEST2015.2041

Israel, A.O., 2017. Nature , the built environment and perennial fl ooding in Lagos , Nigeria : The 2012 fl ood as a case study. Urban Clim. 21, 218–231. https://doi.org/10.1016/j.uclim.2017.06.009

Levermore, G., Parkinson, J., Lee, K., Laycock, P., Lindley, S., 2017. Urban Climate The increasing trend of the urban heat island intensity. Urban Clim. 2–10. https://doi.org/10.1016/j.uclim.2017.02.004

Lucon, O., Ürge-Vorsatz, D., Zain Ahmed, A., Akbari, H., Bertoldi, P., Cabeza, L.F., Eyre, N., Gadgil, A., D Harvey, L.D., Jiang, Y., Liphoto, E., Mirasgedis, S., Murakami, S., Parikh, J., Pyke, C., Vilariño, M. V, 2014. Buildings. In: Mitigation. Working Group III contribution to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change. [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge.

Müller, D.B., Liu, G., Løvik, A.N., Modaresi, R., Pauliuk, S., Steinhoff, F.S., Brattebø, H., 2013. Carbon Emissions of Infrastructure Development. Environ. Sci. Technol. 47, 11739–11746. https://doi.org/10.1021/es402618m

Revi, A., Satterthwaite, D., Corfee-morlot, J., Robert, B., Kiunsi, R., Pelling, M., Roberts, D., Gajjar, S.P., Sverdlik, A., Satterthwaite, D., Roberts, D., 2014a. Towards transformative adaptation in cities : the IPCC ' s Fifth Assessment 26, 11–28. https://doi.org/10.1177/0956247814523539

Revi, A., Satterthwaite, D.E., Aragón-Durand, F., Corfee-Morlot, J., Kiunsi, R.B.R., Pelling, M., Roberts, D.C., Solecki, W., 2014b. Urban areas. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, . Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 535-612. 535.

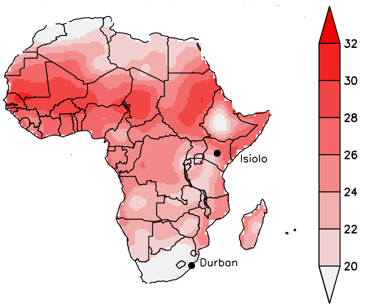
Soo, H., Rakhmat, A., Kubota, T., Iizuka, S., 2017. Impacts of land use changes from the Hanoi Master Plan 2030 on urban heat islands : Part 2 . Influence of global warming. Sustain. Cities Soc. 31, 95–108. https://doi.org/10.1016/j.scs.2017.02.015

Appendix: **Analysis of climate change projections and extremes over Africa**

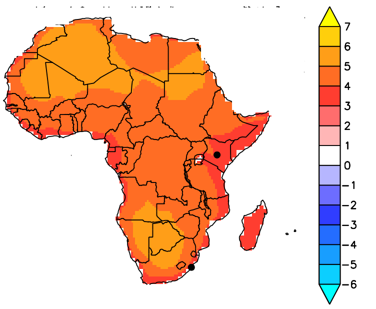
Pan-Africa analysis

The results are based on an average of multiple models as used by the World Health Organization in the Climate and Health Country Profiles (http://www.who.int/globalchange/resources/countries/en/; see Methods below). The last decade is taken as 2006-2015, while the end of this century is 2090-2099 under a high emissions scenario. The maps indicate the location of the two case studies discussed in this report, Isiolo in Kenya and Durban (eThekwini municipality) in South Africa. Detailed climate change risk profiles for these two locations follows.

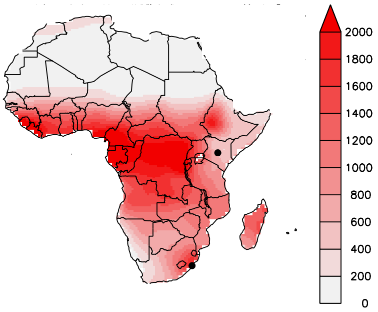
Mean temperature for the last decade (degrees Celsius).



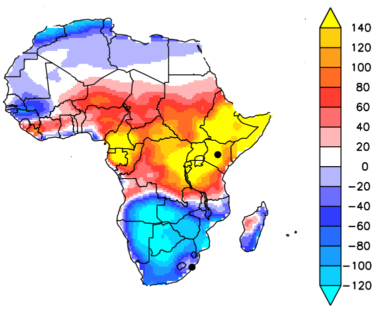
Projected change in temperature at the end of this century for a high emissions scenario (°Celsius).



Mean precipitation rate for the last decade (mm per year)



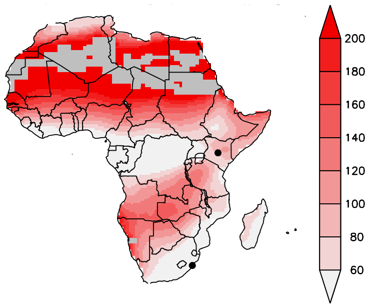
Projected change in mean precipitation at the end of this century.



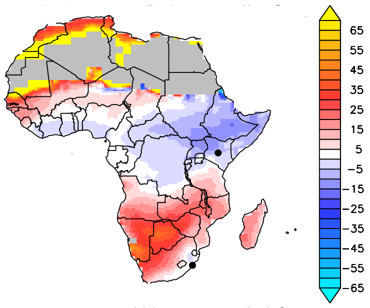
The mean annual temperature is highest in the tropics as expected, with the change in projected temperatures highest both in the tropics and in the southern region. The temperature change is therefore larger in Durban, while more extreme temperatures will be encountered in Isiolo. The combination of temperature and humidity means some regions of tropical Africa could have severe issues of habitability, with daily humidity-combined temperature indicator exceeding 36°C for a month in a row, and possibly even survivability, where the same indicator exceed 40°C three days in a row (Andrews et al. 2018).

The mean precipitation rate (mainly rainfall but with some snowfall) is highest in the tropical sub-Saharan Africa, much lower in southern Africa, and near zero in the Sahara. The projected changes are for a general pattern of wet-getting-wetter and dry-getting-dryer. Hence for more rainfall in the tropics, an extension of the desert area around the Mediterranean, and drier conditions in southern Africa in general. The projected changes in Isiolo and Durban are smaller than surrounding regions. However note that both these locations (Durban in particular) are near regions with large projected changes, and therefore the projections can be less accurate due to the difficulty of representing frontal regions in global models.

Mean number of consecutive dry days for the past decade, an indicator of droughts.

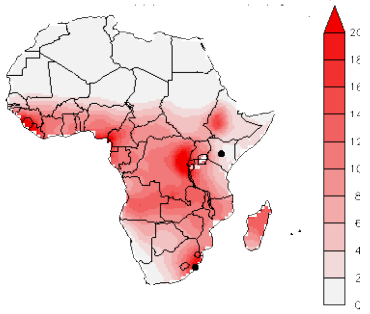


Projected change in consecutive dry days at the end of this century.

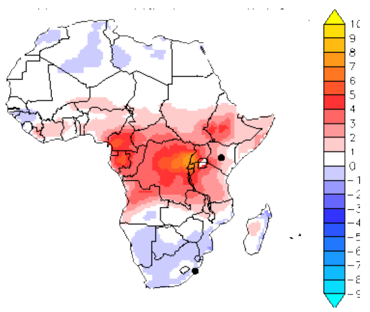


The number of consecutive dry days is a common indicator for the duration of droughts. Large regions spend more than 3 months without receiving any rainfall. Therefore changes in these regions are particularly critical. The projected changes are for an increase in the duration of droughts in southern African countries and in the belt around the Sahara regions. Again Isiolo and Durban are near frontal regions and therefore the specific projections for these regions are more uncertain.

Mean number of very heavy rainfall days for the past decade, an indicator of flood risk.



Projected change in very heavy rainfall days at the end of this century.



The number of very heavy rainfall days is significant over most of sub-Saharan Africa, indicating high flood risks. The year-to-year variability in this indicator is also high, meaning that some years will see high flood risks and others not. The general pattern of change projected by models is for increasing risks of floods over most of central Africa, and constant or possibly slightly decreasing risks in southern Africa. However the model spread is large and several models project increasing risks (up to around +20% of days) also in southern Africa.

Climate model analysis method. We present here results from a multi-model ensemble, using all available models of the Coupled Model Intercomparison Project Phase 5 (CMIP5) archive, as used for the preparation of the World Health Organisation (WHO) Climate and Health Country Profiles. For most indicators, 18 models were available. We show here a high emissions scenario (RCP8.5), which leads to warming of 4.3°C [range of 3.2 to 5.4°C]. Most effects are proportional to the global warming level, so that if global warming was limited to 2°C above pre-industrial, the corresponding effect would be lower. The variables are (1) the mean temperature, (2) the mean precipitation, including rainfall and snowfall, (3) the number of consecutive dry days, which is the maximum number of consecutive days when precipitation is less than 1mm, and (4) the number of very heavy precipitation days, which is the annual number of days when precipitation exceeds 20 mm. The extremes indicators were taken from Sillman et al. 2013; 10.1002/jgrd.50203.

DURBAN – Climate change risk profile

Key messages and implications for climate change risk assessment for Durban

- The Durban climate is subject to large year-to-year variability particularly for rainfall. Thus even in the absence of anthropogenic climate change, this major city needs to be resilient to the natural variability observed over the last few decades.

- Observed records for the Durban region show emerging trends in temperature over the last few decades – in particular a clear trend towards higher temperatures and more frequent high temperature extremes.

- Climate projections show a strengthening of the observed temperature trends, particularly with higher greenhouse gas emissions.

- There is no clear evidence of changes in annual mean total rainfall or the annual frequency of rainfall extremes in the CMIP5 global climate models analysed here, whereas the earlier generation of CMIP3 models indicated increases in rainfall. However, the annual projections presented here may mask more complex and contrasting seasonal changes. Statistically-downscaled projections for Durban and a high emissions scenario suggest a tendency towards increased total monthly rainfall from September to February and a stronger tendency towards decreased rainfall from March to August. There is somewhat less agreement between models with respect to rainfall extremes, though a few statistically-downscaled models indicate more frequent high rainfall events (days > 5mm and > 20mm) from September to February. Given the range of model projections, a robust resilient strategy would plan for increases in heavy rainfall and drought days by around 20%.

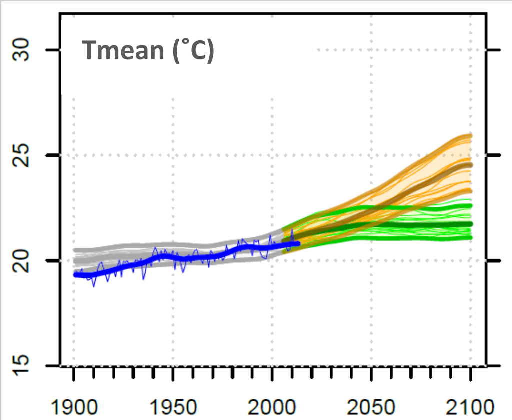
- If global warming can be constrained to 2°C or less with respect to preindustrial conditions, the impacts of climate change would be substantially reduced for Durban, particularly in the second half of the century.

Projected climate changes	Potential impacts and risks for Durban
Warmer conditions, including more intense and frequent high temperature extremes and heat wave days, for the Durban area	• Human heat stress and other negative health effects including potential increases in mortality, particularly if air quality also decreases • Negative impacts and constraints on labour productivity, particularly for outdoor workers • Greater heat stress and discomfort, particularly during the summer months, with negative impacts for tourism • Potential increased demand for air conditioning – which would increase energy demand • Potential impacts on water demand and quality (e.g., due to effects of increased evaporation under warmer conditions)
Uncertain changes in precipitation, particularly extreme daily heavy rainfall events for the Durban area	• Earlier work based on the CMIP3 models indicated increased flood risk in the Durban urban area and recommended that an increase of ~15% should be applied to design rainfalls and 20% to design streamflows. On the basis of the CMIP5-based projections shown here it is difficult to determine whether these risk assessments remain valid. • Results emerging from the CORDEX initiative indicate added value of dynamical downscaling for southern Africa. Thus it is recommended that the impacts and risks associated with extremes of rainfall should be explored using CORDEX outputs as well as consideration of the underlying large- and local-scale physical processes which influence precipitation in the Durban area (as in the FRACTAL project http://www.fractal.org.za/).
Warmer conditions, including more extremes, across southern Africa. Drier conditions in winter and spring across southern Africa. Increases in extremes in both	• Increased migration to urban areas • Changes in the attractiveness of tourism areas and in tourist flows • Impacts on food production and security • Impacts on transportation networks • Impacts on energy supply

directions (i.e. increased droughts as well as heavy rainfall events).	• Impacts on water supply (quality and quantity)

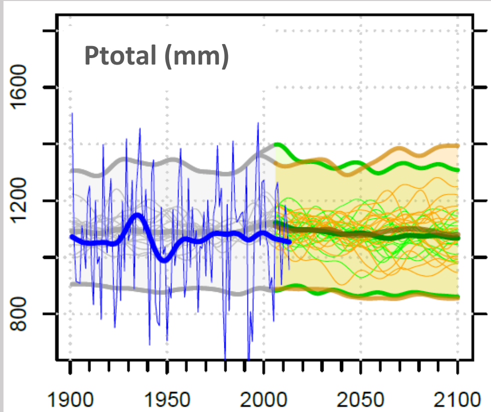
Observed changes and future projections of annual temperature and rainfall

Rising temperature



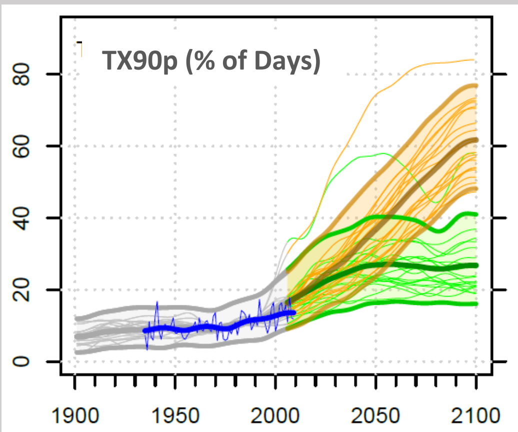
Both observations and simulations show an **upward trend in mean annual temperature.** Under a high emissions scenario, this trend is projected to continue until the end of the century, with **a rise of 3.4°C on average** from 1981-2010 to 2071-2100. If emissions decrease rapidly, this rise is limited to about 1.1°C on average.

No clear changes in total rainfall



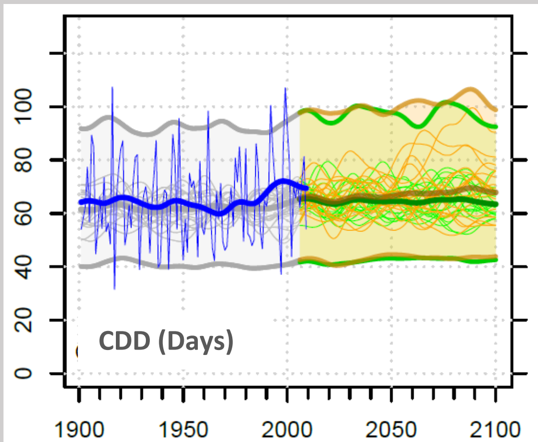
The observations are dominated by **large decade-to-decade and year-to-year variability.** This variability continues into the future. There is no clear indication of changes in average rainfall, but there is a suggestion of increasing days with high rainfall.

More high temperature extremes and heat waves



The observations and simulations are consistent in indicating **more high temperature extremes** (warm days and warm nights, days of heat wave) and fewer cold temperature extremes (cold days and cold nights, days of cold wave). The percentage of warm days (shown here), for example, is projected to **increase by about 40% on average** from 1981-2010 to 2071-2100 under a high emissions scenario (and the number of heat wave days to increase by around 90 days on average). If emissions decrease rapidly, the rise in warm days is limited to about 12% on average (and the rise in heat wave days is about 10 days on average).

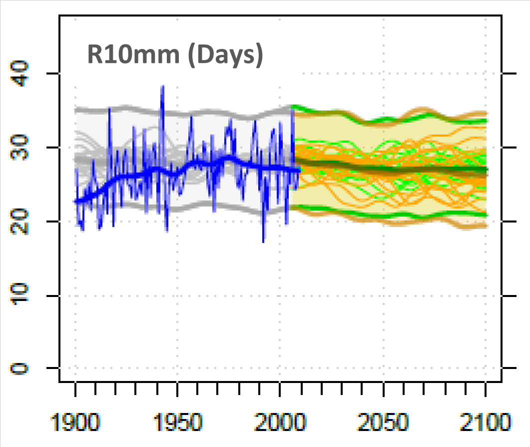
Little change in dry spell length



The observations of rainfall extremes (such as heavy rainfall days – see next page) and number of consecutive dry days – shown here - show large year-to-year and decade-to-decade variability. This variability continues into the future. There is **no clear indication of major changes** in the length of dry spells, although **more models indicate an increase** than a decrease.

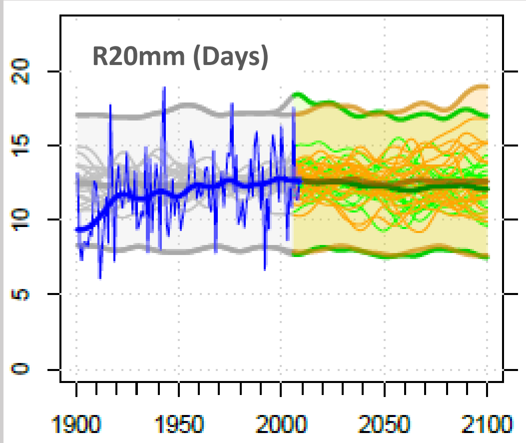
The time series plots above and on the next pages show simulated changes across about 20 different CMIP5 global climate models under a 'business as usual' high emissions scenario (RCP8.5 - thick orange line) compared to projections under a 'two degree scenario' with rapidly reducing emissions (RCP2.6 - thick green line). Each model is also shown individually (thin lines) as well as the 90% model range (shaded) as a measure of uncertainty. Observations are shown in blue (grid-box scale).

Little change in heavy rainfall days



The observations of rainfall extremes such as heavy rainfall days shown here, show large year-to-year and decade-to-decade variability. This variability continues into the future. There is **no clear indication of changes** in the number of heavy rainfall days.

Little change in very heavy rainfall days



The observations of rainfall extremes such as very heavy rainfall days shown here, show large year-to-year and decade-to-decade variability. This variability continues into the future. There is **no clear indication of major changes** in the future although some models indicate an increase.

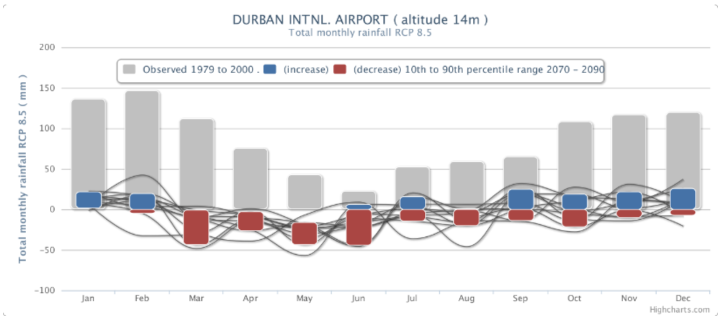
Projected changes in 30 year averages

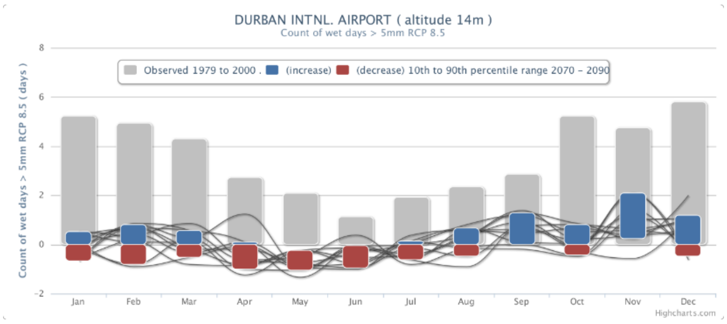
	Observed 1981-2010	2030s - RCP8.5	2050s - RCP8.5	2080s - RCP8.5	2080s - RCP2.6
Temperature					
Mean temperature	20.7°C	+1.2 (0.9 to 1.8) °C	+1.7 (1.2 to 2.3) °C	+3.4 (2.4 to 4.4) °C	+1.1 (0.6 to 1.6) °C
Warm days	12 days	+16 (9 to 23) %	+23 (14 to 32) %	+42 (33 to 53) %	+12 (7 to 19) %
Warm nights	12 days	+20 (14 to 30) %	+31 (21 to 42) %	+57 (44 to 68) %	+16 (10 to 24) %
Rainfall					
Total rainfall	1080 mm	-1 (-9 to +4) %	-2 (-11 to +4) %	-1 (-12 to +10) %	-3 (-9 to +3) %
Heavy rainfall days (>10mm)	27 days	-1 (-3 to +1) days	-1 (-4 to 0) days	-1 (-5 to +4) days	-1 (-3 to +2) days
Heavy rainfall days (>20mm)	12 days	0 (-1 to +1) days	0 (-2 to +2) days	0 (-3 to +2) days	0 (-1 to +1) days
Consecutive dry days	68 days	+3 (-4 to +15) days	+4 (-5 to +16) days	+6 (-9 to +22) days	+1 (-4 to +9) days

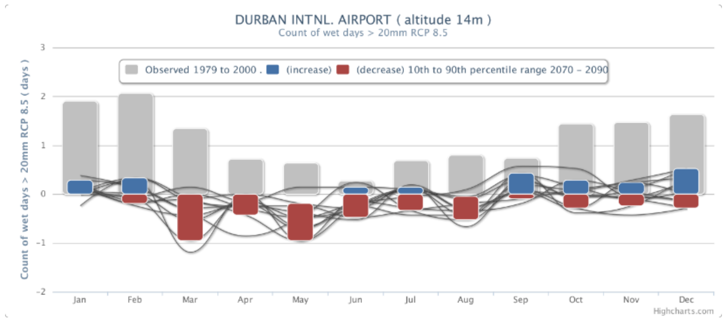
This table shows the projected changes in 30 year averages, with respect to a present-day baseline of 1981-2010, for the '2030s' (2021-2050), the '2050s' (2035-2064) and the '2080s' (2071-2100). The average of gridded observations is also shown for 1981-2010 (note that since this is a grid-point average based on station observations, it will differ somewhat from values for a single station).

The average change is shown in each case together with an indication of the uncertainty range across the models (in brackets – the 90% range). For temperature, the lower end of the range is always positive – indicating a robust pattern of change towards higher temperatures. For rainfall, the lower end of the range is negative, with slightly larger negative changes at the lower end of the range for total rainfall and heavy rainfall days, and larger positive changes at the upper end of the range for consecutive dry days. This indicates greater uncertainty in both the direction and magnitude of rainfall change than is the case for temperature, with overall no very clear signal of future changes in rainfall. A robust resilient strategy would plan for increases in heavy rainfall and drought days by around 20%.

For the 2030s and 2050s only projections for the higher RCP8.5 emissions scenario are given. As the time series plots on the previous page and above show, there is very little difference between the two scenarios for the next couple of decades. By the 2080s, changes under the lower RCP2.6 emissions scenario, particularly for temperature, (final column) are considerably reduced compared with the high emissions scenario.







The projections shown on the previous pages are based on CMIP5 global climate models which have a rather coarse spatial resolution (see Appendix). All are annual projections so may mask differential seasonal changes.

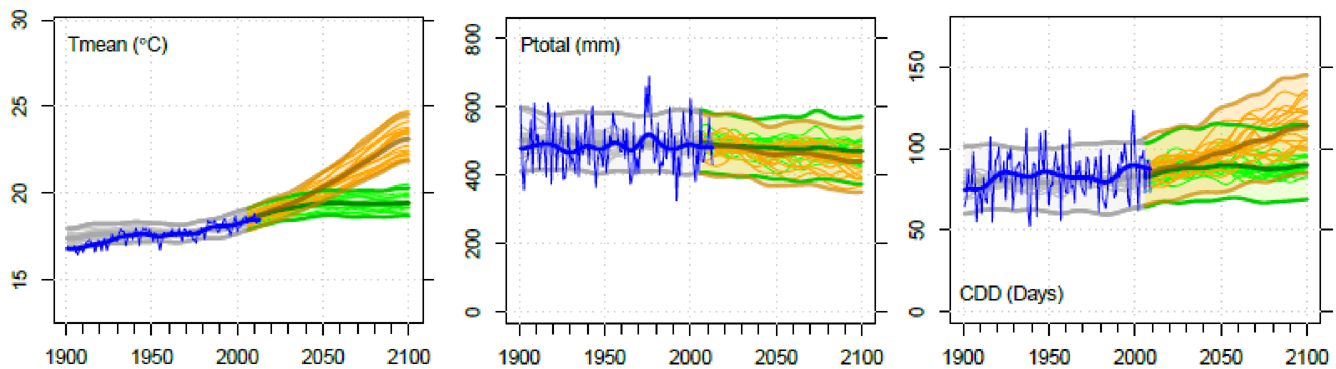
The figures on the left show statistically-downscaled projections for 10 of the CMIP5 models (black lines), for the high RCP8.5 emissions scenario. Station data for Durban international airport (grey bars) were used to construct the statistical models. Projected changes are shown as the difference between 2070-2090 and 1979-2000. The coloured bars show the 90th percentile range in red (decrease) and blue (increase).

Top: Total monthly rainfall (mm)
Middle: Number of wet days >5mm
Bottom: Number of very heavy rainfall days >20mm

Graphs produced and downloaded from the Climate Information Portal, CSAG, University of Cape Town cip.csag.uct.ac.za (also provides access to the earlier CMIP3 projections).

Issues requiring further consideration:

- The projections presented here focus on temperature and rainfall – but Durban is also potentially vulnerable to changes in sea level and the frequency and/or intensity of tropical cyclones.
- The projections do not incorporate urban heat island effects. How might climate change and/or changes in the city itself influence the evolution of the Durban urban heat island?
- The projections shown here are based on global climate models at relatively coarse spatial scale whereas downscaled information, in particular from regional climate models, may provide added value and more reliable projections for the Durban area. Thus analysis is recommended of a multi-model ensemble from the CORDEX initiative to better understand changes in extreme rainfall events. These models do not however provide direct information about sub-daily rainfall extremes which are important for flash flood risk in urban areas.
- Will climate change and its impact in other parts of the region and more widely across South Africa have consequences for Durban? Analysis of the global model data indicates increasing temperature (Tmean), a small decrease in total rainfall (Ptotal) and an increase in consecutive dry days (CDD) for **South Africa** as a whole:



Appendix: Climate projections – models, scenarios and uncertainties

The climate projections presented here are based on the output from global climate models (GCMs). These models represent the physical processes driving weather and climate at the grid-box level (typically at a resolution of a few hundred kilometres) using numerical equations and parameterisations in a similar way to the numerical weather prediction models from which they have evolved. They are forced by greenhouse gas emission or concentration pathways which reflect different assumptions about future socioeconomic and technological developments. Here, two Representative Concentration Pathways (RCPs) are used to span the range considered in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC):

- RCP8.5: a 'business as usual' high emissions scenario, with concentrations of greenhouse gases by the end of the century that are almost four times preindustrial levels. The expected rise in global mean temperature for RCP8.5 is somewhat higher than that projected for Durban at the end of the century.
- RCP2.6: effective national action and international cooperation limit carbon emissions to a lower pathway, which would keep the rise in global temperature compared with preindustrial conditions to 2°C or lower (consistent with the 2015 Paris agreement).

The reliability of GCMs can be assessed, in part, by considering how well they reproduce observations (using grid-box averages rather than point or station values to ensure a like-with-like comparison). **Assessment of the ~20 models indicates that they underestimate mean temperature values for the Durban region but simulate temperature extremes somewhat better. Mean total precipitation and heavy rainfall extremes are consistently overestimated, while consecutive dry days are underestimated.** In all the non-downscaled time series plots shown here a simple bias adjustment is used to bring models and observations into line over a baseline period of 1961-1990. For mean annual temperature, the adjustment factors required range from -1.3°C to +3°C across the models, with an average adjustment of +1°C. For total annual precipitation, ratios are used to make the adjustment and range from 0.5 to 1.2, with an average value of 0.7. The analyses presented here could be improved by further work on model assessment, for which additional observations would be sought. If particularly poorly-performing GCMs are identified they could be excluded from the analysis and the projections updated.

In addition to inevitable uncertainty concerning which emissions scenario society will follow, there are inherent climate modelling uncertainties associated with the response of the models to greenhouse gas forcing. Thus it is good practice to use a number of models from different modelling centres, as is done here – and to consider the range of responses (therefore the 90% range is shown on the time series plots) as well as the average multi-model ensemble response (thick line on the non-downscaled plots). This is particularly important for rainfall and especially rainfall extremes which tend to be more spatially and temporally variable than temperature.

Data sources:

- Observed mean temperature and rainfall: CRU-TSv3.22 http://catalogue.ceda.ac.uk/uuid/3f8944800cc48e1cbc29a5ee12d8542d
- Observed indices of temperature and rainfall extremes: HadEX2 http://www.metoffice.gov.uk/hadobs/hadex2/.
- Simulated mean temperature and rainfall from the CMIP5 archives http://pcmdi9.llnl.gov and simulated indices of extremes calculated from CMIP5 model runs http://www.cccma.ec.gc.ca/data/climdex/
- See Goodess et al., Country-level time series (1900-2100) of temperature and precipitation extremes for health and other impact studies, *Nature Scientific Data*, in preparation, for further details of data sets and processing.
- The indices of extremes used here are defined as follows: Warm days (TX90p) – percentage of days when Tmax > 90th percentile; Warm nights (TN90p) – percentage of days when Tmin > 90th percentile; Number of heavy rainfall days (R10mm) – annual count of days when rainfall ≥10mm; Number of very heavy rainfall days (R20mm) – annual count of days when rainfall ≥20mm; Heat wave days (WSDI) – annual count of days with at least 6 consecutive days when Tmax >90th percentile.
- Statistically downscaled rainfall projections for Durban from Climate Information Portal, CSAG, University of Cape Town cip.csag.uct.ac.za

Additional information on CORDEX simulations: Pinto et al., 2016: Evaluation and projections of extreme precipitation over Southern Africa from two CORDEX models, Climatic Change 135, 655-668; Abiodun et al., 2017: Potential impacts of climate change on extreme precipitation over four African coastal cities, Climatic Change 143, 399-413; Omar & Abiodun, 2017: How well do CORDEX models simulate extreme rainfall events over the East Coast of Africa? Theor. Appl. Climatol. 128, 453-464.

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ISIOLO – Climate change risk profile

Key messages and implications for climate change risk assessment for Isiolo

- The semi-arid Isiolo climate is subject to large year-to-year variability, particularly for rainfall. Thus even in the absence of anthropogenic climate change, the city and surrounding region needs to be resilient to this natural variability and the occurrence of alternating drought and flood.

- Climate projections show a clear trend towards higher mean temperatures and more frequent warm days and nights and fewer cold days and nights, particularly with higher greenhouse gas emissions.

- The projections for rainfall are more uncertain, but show a tendency towards higher rainfall totals and a general tendency towards more intense and frequent rainfall extremes. These projections are not consistent with recent observed trends in the region which indicate drying within the long-rain period (March to May). This East African rainfall paradox is the subject of ongoing research by the climate science community.

- Given the uncertainties in rainfall projections, it is suggested that the city should plan for resilience to ongoing fluctuations between drought and flood. For the planning of major infrastructure with long life times, the implications of more intense rainfall and higher flood risk should be considered.

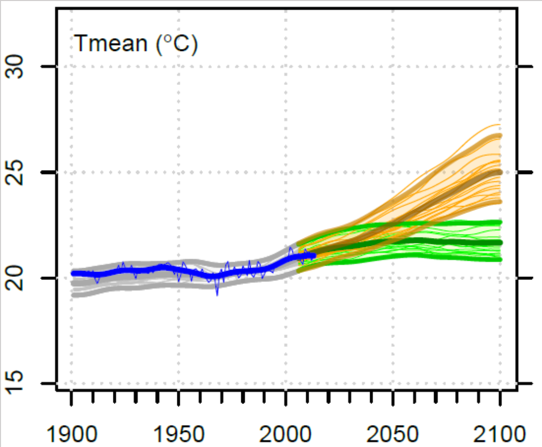
- More locally-focused research and analysis is needed on the potential impacts of climate change in the region, including hydrological and flood risk modelling – taking account of infrastructure changes in the region such as dam construction. Whilst downscaling cannot overcome large-scale shortcomings in global climate models, there is nonetheless likely to be some added value in using statistical and/or dynamical downscaling approaches to assess potential future climate changes in this region.

- If global warming can be constrained to 2°C or less with respect to preindustrial conditions, the impacts of climate change would be substantially reduced for Isiolo, particularly in the second half of the century.

Projected climate changes	Potential impacts and risks for Isiolo
Warmer conditions, including more intense and frequent high temperature extremes and heat wave days	• Human heat stress and other negative health effects including potential increases in mortality, particularly if air quality also decreases in areas of intense urban development • Negative impacts and constraints on labour productivity, particularly for outdoor workers in the agricultural and construction sectors • Greater heat stress and discomfort leading to potential increased demand for air conditioning, particularly for the tourism sector – which would increase energy demand • Transport disruption (e.g., rail buckling and melting of road surfaces) and passenger discomfort
Higher annual rainfall totals and more frequent/heavy rainfall events	• Increased surface erosion and runoff, with a potential increase in flood risk, particularly in areas of urban and transport development with an increase in non-permeable surfaces • Increased risks to transport infrastructure • Possible implications for water quality
Continuing long dry spells and periods of drought, set against a backdrop of rising temperatures	• Increased evaporation with warmer conditions leading to lower soil moisture and higher potential evapotranspiration • Implications for water quantity and quality, as well as demand
Combined effects of changes in temperature and rainfall across the wider region	• Impacts on ecosystems including national reserves and parks • Impacts on rain-fed agriculture and pastoralism • Impacts on human health, including malaria occurrence

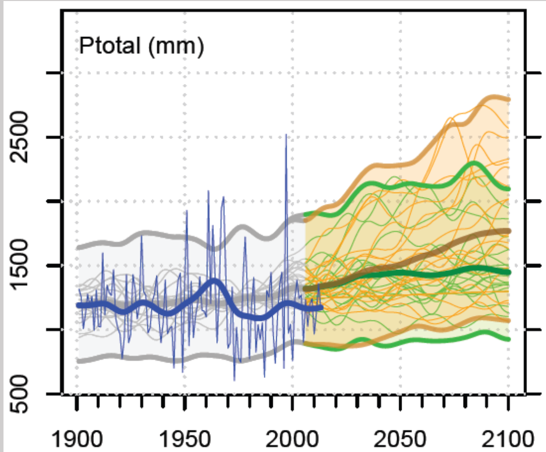
Observed changes and future projections of temperature and rainfall

Rising temperature



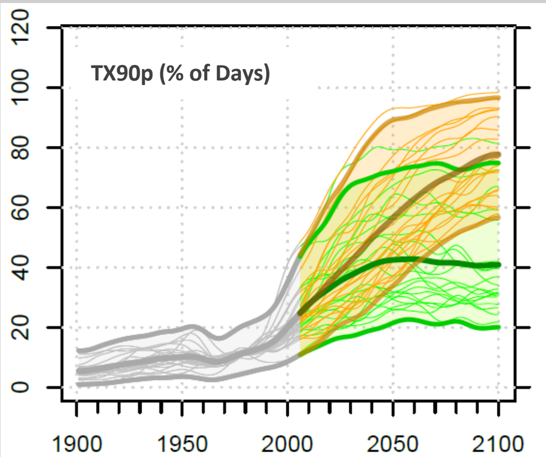
Both observations and simulations show an **upward trend in mean annual temperature.** Under a high emissions scenario, this trend is projected to continue until the end of the century, with **a rise of 3.9°C on average** from 1981-2010 to 2071-2100. If emissions decrease rapidly, this rise is limited to about 1.1°C on average.

Increasing future rainfall



The observations are dominated by large decade-to-decade & **year-to-year variability.** The simulations show a **tendency towards increasing total annual rainfall**, although **variability is large**. Under a high emissions scenario, total annual rainfall is projected to **increase by about 35%** on average from 1981-2010 to 2071-2100. If emissions decrease rapidly, this rise is limited to about ~15% on average.

More high temperature extremes and heat waves



The simulations indicate **more high temperature extremes** (warm days and warm nights, days of heat wave) and fewer cold temperature extremes (cold days and cold nights, days of cold wave). The percentage of warm days (shown here), for example, is projected to **increase by about 55% on average** from 1981-2010 to 2071-2100 under a high emissions scenario (and the number of heat wave days to increase by around 215 days on average). If emissions decrease rapidly, the rise in warm days is limited to about 25% on average (and the rise in heat wave days is about 70

The East African rainfall paradox

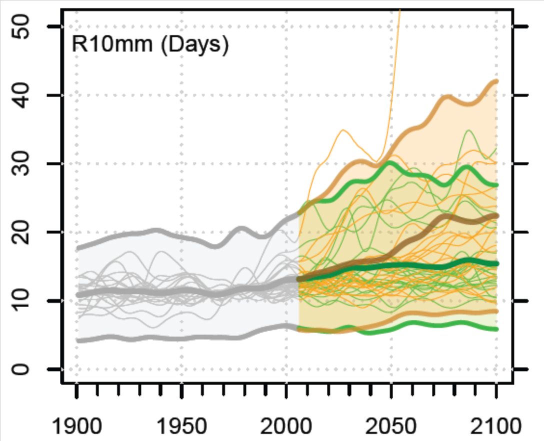
The rainfall observations in the figure above (blue lines) show decadal variability as well as large year-to-year variability including a large spike associated with the 1997 El Niño event. There is, however, no indication of any overall trend in the observations. Whereas the projections for both emission scenarios show a clear trend towards higher total rainfall.

This discrepancy between observed and projected rainfall trends (which is also seen in the extremes – see next page) is well known and is referred to as the 'East African rainfall paradox'. A number of theories have been proposed for this paradox, but it is not considered to be due to issues with the quality or reliability of the observed data or to land-use changes. Plausible theories relate to patterns of sea surface temperature natural variability, the co-action of global warming with El Niño Southern Oscillation like (ENSO-like) variability, and changes in anthropogenic aerosols, as well as issues related to model reliability.

Further process-based analysis of the East African climate model outputs and projections is needed in order to better understand these issues and to hopefully resolve the East African rainfall paradox.

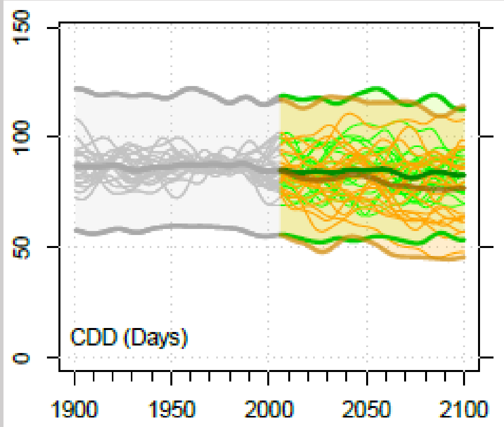
These time series plots show simulated changes across about 20 different global climate models under a 'business as usual' high emissions scenario (thick orange line) compared to projections under a 'two degree scenario' with rapidly reducing emissions (thick green line). Each model is also shown individually (thin lines) as well as the 90% model range (shaded) as a measure of uncertainty. Observations are shown in blue (grid-box scale).

More heavy rainfall events



The projections show a general tendency towards **more frequent heavy rainfall events**. The number of days per year with rainfall greater than 10mm (shown here), for example, is **projected to increase by about 10 days on average** from 1981-2010 to 2071-2100 under a high emissions scenario. Some models indicate increases well outside the range of observed variability, **indicating even greater increase in risk**.

Small decrease in dry spell length



There is indication of a **small decrease in dry spell length** (CDD: maximum number of consecutive dry days) under a high emissions scenario – a decrease of less than 10 days on average from 1990 to 2100. For a low emissions scenario, there is no indication of change.

The projected patterns of change in both heavy rainfall events (left) and dry spell length (right) contrast with observed trends in the region over the last decades. The observations indicate a decrease in rainfall and an increase in dry spell length during the long rains (March to May) with a tendency in some regions to increased rainfall and shorter dry spell length during the short rains (October to December). These discrepancies are further illustration of the East African rainfall paradox (see previous page).

Projected changes in 30 year averages

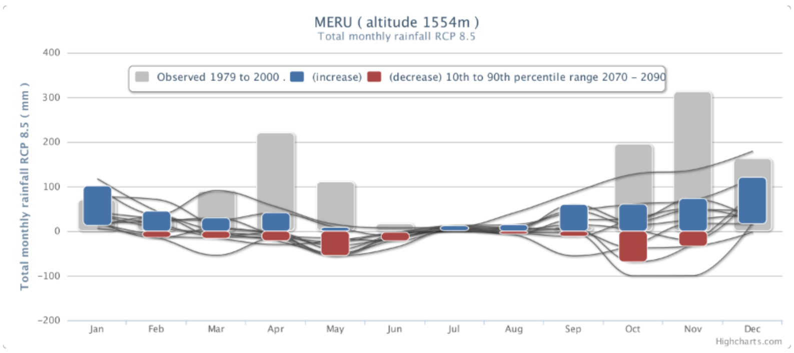
	Observed *	2030s - RCP8.5	2050s - RCP8.5	2080s - RCP8.5	2080s - RCP2.6
Temperature					
Mean temperature	20.7°C	+1.4 (1.0 to 1.9) °C	+2.0 (1.4 to 2.8) °C	+3.9 (2.9 to 5.3) °C	+1.1 (0.5 to 1.8) °C
Warm days	N/A	+28 (16 to 51) %	+37 (23 to 60) %	+56 (42 to 70) %	+23 (10 to 46) %
Warm nights	N/A	+39 (28 to 48) %	+55 (38 to 64) %	+77 (66 to 85) %	+31 (14 to 50) %
Rainfall					
Total rainfall	1147 mm	+14 (-4 to +35) %	+19 (-5 to +49) %	+37 (-2 to +77) %	+14 (-3 to +36) %
Heavy rainfall days	N/A	+3 (0 to +13) days	+5 (0 to +17) days	+10 (0 to +25) days	+3 (0 to +11) days
Consecutive dry days	N/A	-4 (-21 to +8) days	-4 (-18 to +4) days	-8 (-30 to +8) days	-3 (-10 to +4) days

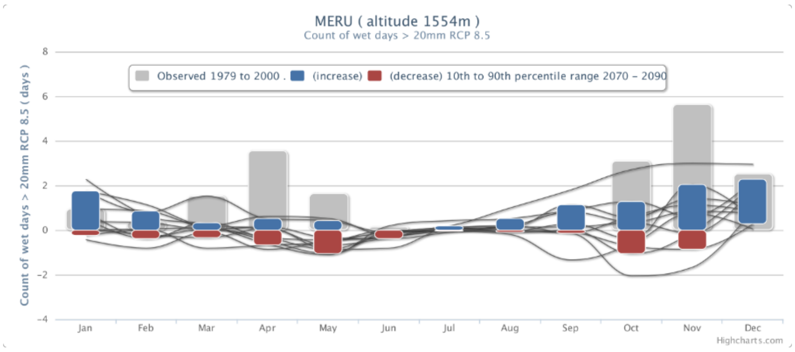
This table shows the projected changes in 30 year averages, with respect to a present-day baseline of 1981-2010, for the '2030s' (2021-2050), the '2050s' (2035-2064) and the '2080s' (2071-2100).

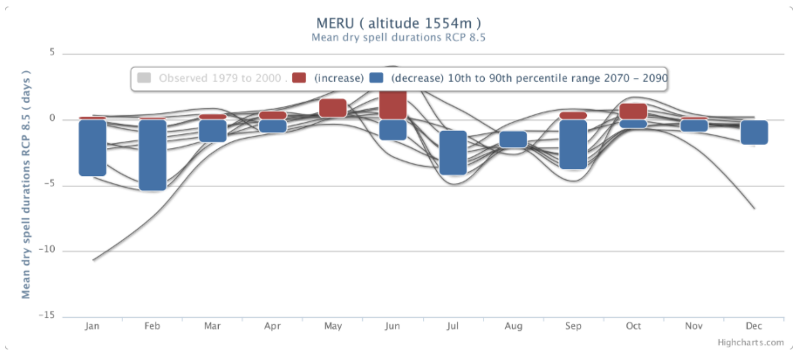
The average of CRU-TS gridded observations is also shown for 1981-2010 for mean temperature and total rainfall. This is a grid-point average based on station observations. Grid-point averages will always differ somewhat from values for a single station. The Isiolo region has a strong rainfall, and to a lesser extent temperature, gradient reflecting the regional topography and the influence of Mount Kenya. The observed total rainfall given in the table above is notably higher than expected on average in this region (300-650 m in the arid/semi-arid regions of Isiolo County) , indicating that the stations available for the gridding are not fully representative of Isiolo. For this reason projected rainfall changes are given as % rather than absolute values in the table above. The observed temperature appears a little on the low side – suggesting the stations used come from higher altitudes. These grid-point observations are used to bias adjust the models so will affect the projections (see Appendix).

The average change is shown in each case together with an indication of the uncertainty range across the models (in brackets – the 90% range). For temperature, the lower end of the range is always positive – indicating a robust pattern of change towards higher temperatures. For rainfall, the lower end of the range is negative (or zero), with larger positive changes at the upper end of the range for total rainfall and heavy rain days. This indicates greater uncertainty in both the direction and magnitude of rainfall change than is the case for temperature.

For the 2030s and 2050s only projections for the higher RCP8.5 emissions scenario are given. As the time series plots above show, there is very little difference between the two scenarios for the next couple of decades. By the 2080s, changes under







The projections shown on the previous pages are based on CMIP5 global climate models which have a rather coarse spatial resolution (see Appendix). All are annual projections so may mask differential seasonal changes, including different changes in the long and short rains.

The figures on the left show statistically-downscaled projections for 10 of the CMIP5 models (black lines), for the high RCP8.5 emissions scenario. Station data for Meru (grey bars – the nearest available station, but somewhat less arid and at ~500m higher altitude than Isiolo) were used to construct the statistical models. Projected changes are shown as the difference between 2070-2090 and 1979-2000. The coloured bars show the 90th percentile range in red (decrease) and blue (increase).

Top: Total monthly rainfall (mm)
Middle: Number of very heavy rainfall days > 20mm
Bottom: Maximum number of consecutive dry days.

Graphs produced and downloaded from the Climate Information Portal, CSAG, University of Cape Town cip.csag.uct.ac.za

The downscaled monthly rainfall projections shown above indicate greater increases in rainfall totals and extremes for the short rains (October to December) than for the long rains (March to May). The largest increases are in December and there is some indication of decreased rainfall in May. Though not evident in all models, there is some suggestion of a possible earlier start to the short rains (higher rainfall in September) and an earlier end to the long rains (lower rainfall in May.

Issues requiring further consideration:

- The projections presented here focus on temperature and rainfall. While the temperature projections are reasonably robust, clearly indicating higher temperatures including more frequent high temperature extremes, there are considerable uncertainties associated with the rainfall projections. One major source of uncertainty is the discrepancy between recent observed rainfall trends and the projections, particularly for long-season rains.
- A greater focus on process-based evaluation of the global climate models focusing on aspects such as linkages between large-scale circulation features, such as ENSO and the Indian Ocean Dipole, and East African rainfall may help to address the East African rainfall paradox.
- Even if the global models are able to simulate these large-scale patterns and linkages, the complex topography and strong spatial gradients in this region of East Africa imply that there would be added value in downscaling (in particular using dynamical regional climate models) in order to better represent the arid/semi-arid conditions of the Isiolo region. Analysis of the reliability of the projections would also be facilitated by access to more local observations for the region – from stations as well as from satellites and reanalysis data.
- Analysis of rainfall variability and changes alone may not provide sufficient information for risk assessment, particularly impacts on ecosystems, agriculture, urban areas and infrastructure. The following types of modelling and indicators may also be relevant: agricultural drought, soil moisture, potential evapotranspiration, length and onset of rainy seasons, and hydrological and flood risk modelling (including impacts of urban development and dams).

Appendix: Climate projections – models, scenarios and uncertainties

The climate projections presented here are based on the output from global climate models (GCMs). These models represent the physical processes driving weather and climate at the grid-box level (typically at a resolution of a few hundred kilometres) using numerical equations and parameterisations in a similar way to the numerical weather prediction models from which they have evolved. They are forced by greenhouse gas emission or concentration pathways which reflect different assumptions about future socioeconomic and technological developments. Here, two Representative Concentration Pathways (RCPs) are used to span the range considered in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC):

- RCP8.5: a 'business as usual' high emissions scenario, with concentrations of greenhouse gases by the end of the century that are almost four times preindustrial levels. The expected rise in global mean temperature for RCP8.5 is broadly similar to that projected for Isiolo at the end of the century.
- RCP2.6: effective national action and international cooperation limit carbon emissions to a lower pathway, which would keep the rise in global temperature compared with preindustrial conditions to 2°C or lower (consistent with the 2015 Paris agreement).

The reliability of GCMs can be assessed, in part, by considering how well they reproduce observations (here using grid-box averages from CRU-TS rather than point or station values to ensure a like-with-like comparison). **Assessment of the ~20 models indicates that they overestimate mean temperature values from CRU-TS for the Isiolo region and underestimate mean total precipitation.** In all the time series plots shown here a simple bias adjustment is used to bring models and observations into line over a baseline period of 1961-1990. Where observations are not available the multi-model ensemble mean for 1961-1990 is used. For mean annual temperature, the adjustment factors required range from -4.7°C to -0.7°C across the models, with an average adjustment of -3°C. For total annual precipitation, ratios are used to make the adjustment and range from 0.6 to 9.6, with an average value of 3.1. **However, as noted earlier, the CRU-TS values do not capture the strong spatial climate gradients of the region and do not seem to be representative of the semi-arid location of Isiolo. Thus it is recommended that in any future work more local station data should be used to assess and potentially bias adjust the projections.**

In addition to inevitable uncertainty concerning which emissions scenario society will follow, there are inherent climate modelling uncertainties associated with the response of the models to greenhouse gas forcing. Thus it is good practice to use a number of models from different modelling centres, as is done here – and to consider the range of responses (therefore the 90% range is shown on the time series plots) as well as the average multi-model ensemble response (thick line on the plots). This is particularly important for rainfall and especially rainfall extremes which tend to be more spatially and temporally variable than temperature.

Data sources:

- Observed mean temperature and rainfall: CRU-TSv3.22 http://catalogue.ceda.ac.uk/uuid/3f8944800cc48e1cbc29a5ee12d8542d
- Simulated mean temperature and rainfall from the CMIP5 archives http://pcmdi9.llnl.gov and simulated indices of extremes calculated from CMIP5 model runs http://www.cccma.ec.gc.ca/data/climdex/
- See Goodess et al., Country-level time series (1900-2100) of temperature and precipitation extremes for health and other impact studies, *Nature Scientific Data*, in preparation, for further details of data sets and processing.
- The indices of extremes used here are defined as follows: Warm days (TX90p) – percentage of days when Tmax > 90th percentile; Warm nights (TN90p) – percentage of days when Tmin > 90th percentile; Number of heavy rainfall days (R10mm) – annual count of days when rainfall ≥10mm; Heat wave days (WSDI) – annual count of days with at least 6 consecutive days when Tmax >90th percentile.
- Statistically downscaled projections for Meru from Climate Information Portal, CSAG, University of Cape Town cip.csag.uct.ac.za

References on observed East Africa rainfall trends: Nicholson, 2016: An analysis of recent rainfall conditions in eastern Africa, Int. J. Climatol. 36, 526-532; Schmocker et al, 2016: Trends in mean and extreme precipitation in the Mount Kenya region from observations and reanalyses, Int. J. Climatol. 36, 1500-1514; Ongoma and Chen, 2017: Temporal and spatial variability of temperature and precipitation over East Africa from 1951 to 2010, Meteorol. Atmos. Phys. 129, 131-144.

References on the East Africa rainfall paradox: Rowell et al, 2015: Reconciling past and future rainfall trends over East Africa, J. Climate 28, 9768-9788; Hoell et al, 2017: Reconciling theories for human and natural attribution of recent East Africa drying, J. Climate 30, 1939-1957.

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