

ICLEI – Local Governments for Sustainability – Africa
Climate Change Projections for Walvis Bay: Adding value through downscaling



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***Abstract:**

This project addresses knowledge, resource, capacity and networking gaps on the theme: 'Strengthening urban governments in planning adaptation.'

The main objective of this project is to develop an adaptation framework for managing the increased risk to African local government and their communities due to climate change impact. The ultimate beneficiaries of this project will be African local governments and their communities. The guiding and well-tested ICLEI principle of locally designed and owned projects for the global common good, specifically in a developing world context, will be applied throughout project design, inception and delivery.

Additionally, the research will test the theory that the most vulnerable living and working in different geographical, climatic and ecosystem zones will be impacted differently and as such, will require a different set of actions to be taken. Potential commonalities will be sought towards regional participatory learning and wider applicability. The five urban centres chosen for this study, based on selection criteria, include: Cape Town, South Africa, Dar es Salaam, Tanzania; Maputo, Mozambique; Windhoek, Namibia; and Port St. Louis, Mauritius.

Through a participatory process, this project will carry out a desk-top study, long-term, multi-discipline, multi-sectoral stakeholder platforms in five Southern African cities comprising of academics, communities and the local government in order to facilitate knowledge-sharing, promote proactive climate adaptation and resource opportunities available for African cities, develop five tailor-made Adaptation Frameworks and explore regional applicability. A network of stakeholders within each urban centre will be established, feeding into a larger regional network of local authorities and partners in Sub-Saharan Africa, and globally through existing ICLEI global (e.g. the ICLEI Cities for Climate Protection programme), ICLEI Africa and UCLG-A members and networks, ensuring global best practice, roll-out, and long-term sustainability.

Key words: Adaptation, Africa, Climate Change, Local Governments, Participatory Action Research, Policy.

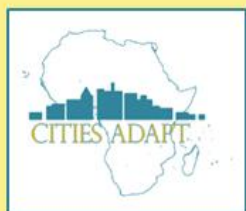
Sub-Saharan African Cities: A Five-City Network to Pioneer Climate Adaptation through participatory Research and Local Action.

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Climate change projections
for Walvis Bay:
Adding value through
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Climate Change Projection for Walvis Bay: Adding value through change

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Preface

Climate change is expected to have severe physical, social, environmental and economic impacts on cities worldwide, both directly and indirectly. Although there are some uncertainties surrounding the understanding of earth's complex systems, there is strong evidence in current literature and climatic measurements to demonstrate that, as a result of increasing green house gas emissions, atmospheric, land and sea surface temperatures are rising. Global model projections have demonstrated that temperature and rainfall changes throughout Africa, increased frequency of storms and sea-level rise in sub-tropical Oceans, will expose current vulnerabilities of coastal (and other) cities, whilst also potentially heightening risks associated with food security and water resources.

Global Climate Model projections of change are presented and discussed in 'the baseline climate report for southern African countries including: Namibia, South Africa, Mozambique, Tanzania and Mauritius'.¹ This report shows the results from applying a downscaling methodology developed at the University of Cape Town to nine GCMs and the observed rainfall and temperature data from stations near Walvis Bay. The downscaling relates daily weather systems to the observed rainfall and temperature at each location on each day (to a point-scale).

Projections are described as being manifested as certain impacts, depending on the region, amongst others;

- changes in rainfall and precipitation patterns (flooding and drought),
- increases in temperature and associated desiccation effects,
- increasing frequency and intensity of storm surges or extreme events,
- increasing average global sea levels due to melting glaciers and thermal expansion (permanent and non-permanent inundation) and,
- changes in wind speed.

This report will outline impacts and vulnerabilities that the available model results typically imply for Walvis Bay, whilst also discussing constraints, given the paucity of available climatological data (there were only 3 stations from which data was available for the area around Walvis Bay) and the limitations of the current methods. It must be noted that sea-level rise is NOT presented here, as it does not feature in downscaled projections and has been dealt with in more detail elsewhere².

¹ Tadross and Johnston, 2011. **Projected Climate Change Over Southern Africa; Namibia, South Africa, Mozambique, Tanzania and Mauritius, Report for ICLEI, February 2011**

² Brundrit, G B (1995). Trends of southern African sea level: statistical analysis and interpretation. South African Journal of Marine Science 16: 9-17.

1 Historical observations and trends from Walvis Bay and Windhoek

Historical observations of weather during the recent past from weather stations in the vicinity of Walvis Bay are required in order to understand the current climate context of the city. They also assist in the determination and identification of any historical trends in climate that may be associated with anthropogenic climate change (usually trends in the short term (decades) are indicative of a changing climate, whereas changes over the longer (centuries) are part of a planetary/sun cycle). For this study local rainfall and temperature data from Walvis Bay were made available from local sources and the baseline climate and trends (as well as the future downscaled climates) were taken from these data and those available through the GHCN (Global Historical Climatology Network). Figure 1 shows the location of the 4 stations available through these data sources (Windhoek, Swakopmund, Walvis Bay and Gobabeb).

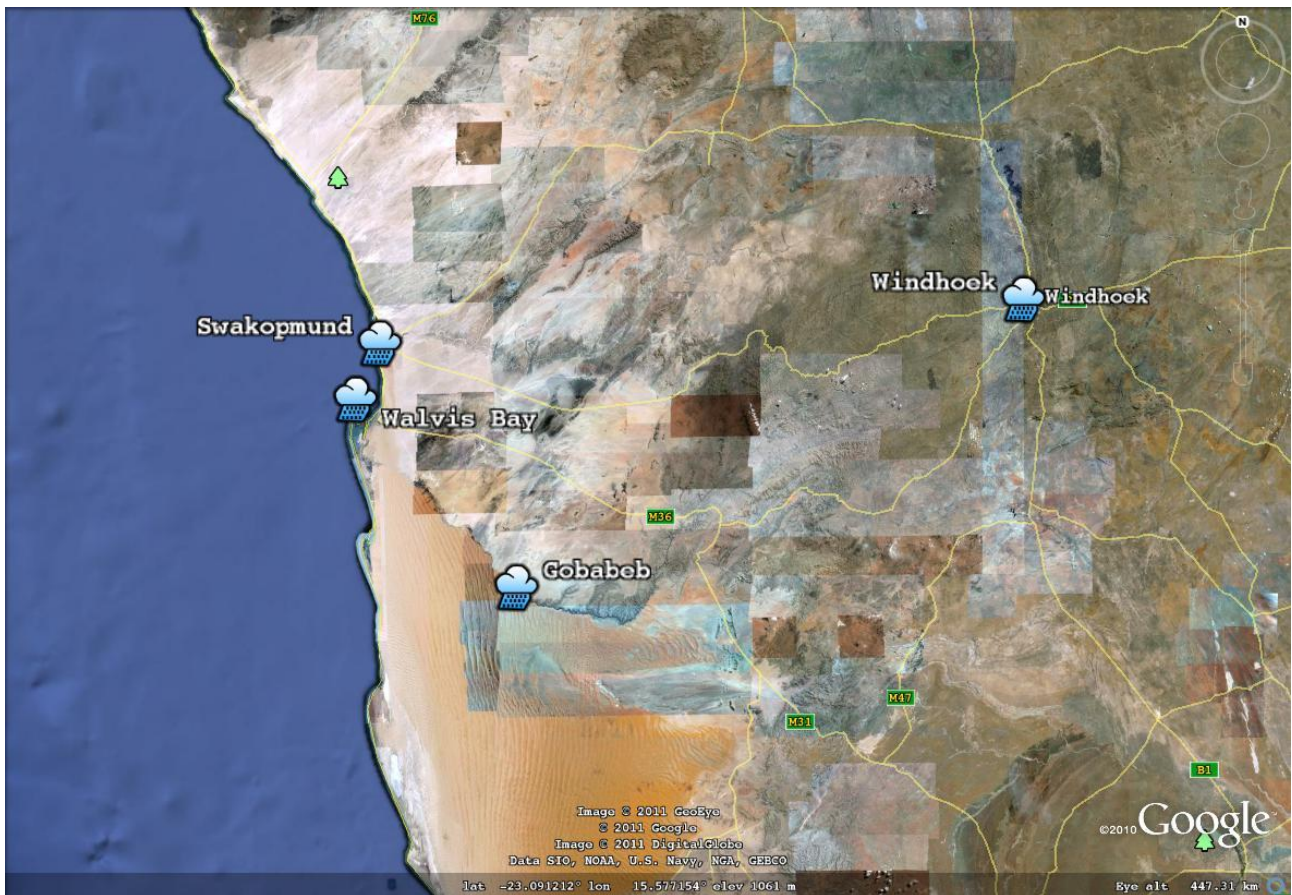


Figure 1: Available weather stations.

Unfortunately records available through the Global Historical Climatology Network (GHCN) have a smaller selection and no temperature data (except Windhoek), so this report concentrates on the Walvis Bay data, using other station data when appropriate for the discussion.

1.1 Climate of Walvis Bay

Walvis Bay has an arid climate and has a mean annual precipitation of around 13 mm. Though it is close to the Namib Desert, Walvis Bay has a mild climate due to the relatively cool Benguela ocean current. Average maximum temperatures occur during midsummer, in January and February and peak at around 23 °C, while winter minima drop to 9° C in August.

Precipitation occurs during summer, with only January, February and March recording long term means of more than 2 (3) days with some rain per month. Occasionally intense rainfall (of around 10-20mm) can occur in the basin of the Kuiseb and the runoff can cause floods in the city, which has no storm water drainage.

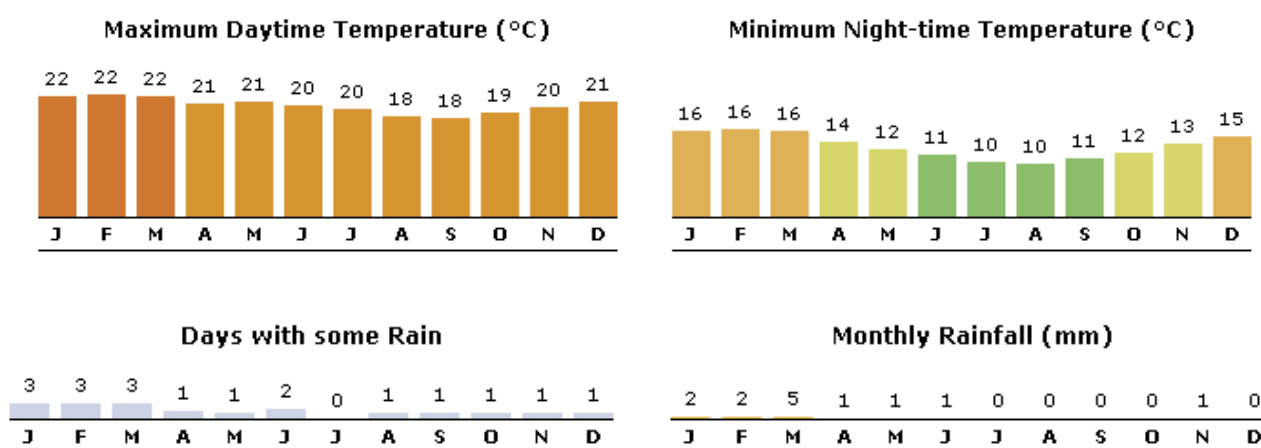


Figure 2: Minimum and maximum temperatures (°C), number of rain days and average monthly rainfall at Walvis Bay.

Source www.worldclimateguide.co.uk

Through the GHCN network, daily rainfall data were available for the Windhoek station between 1920 and 2000 and temperature data between 1960 and 2003. The Walvis Bay station data was available between 1958 and 2011 (though temperature was only available between 1994 and 2011). Figures 2 and 3 show the daily climatology (average over all years) of rainfall, temperature and reference evapotranspiration³ at the two sites. It can be seen that the seasonal variation in climate is similar at the two sites, though rainfall and evapotranspiration is significantly less at Walvis Bay compared to Windhoek (rainfall is almost zero on average for much of the year at Walvis Bay which makes detecting any trend of downscaling any future change very difficult). Temperatures at Windhoek are slightly higher and the seasonality is higher. In both cases evapotranspiration is higher than rainfall at all times of the year, which limits agriculture and water resources in the different areas.

³ Reference evapotranspiration (ET₀) indicates the amount of water that would be lost due to evaporation and transpiration if it were available. If ET is higher than rainfall it means that the soil and vegetation will dry out.

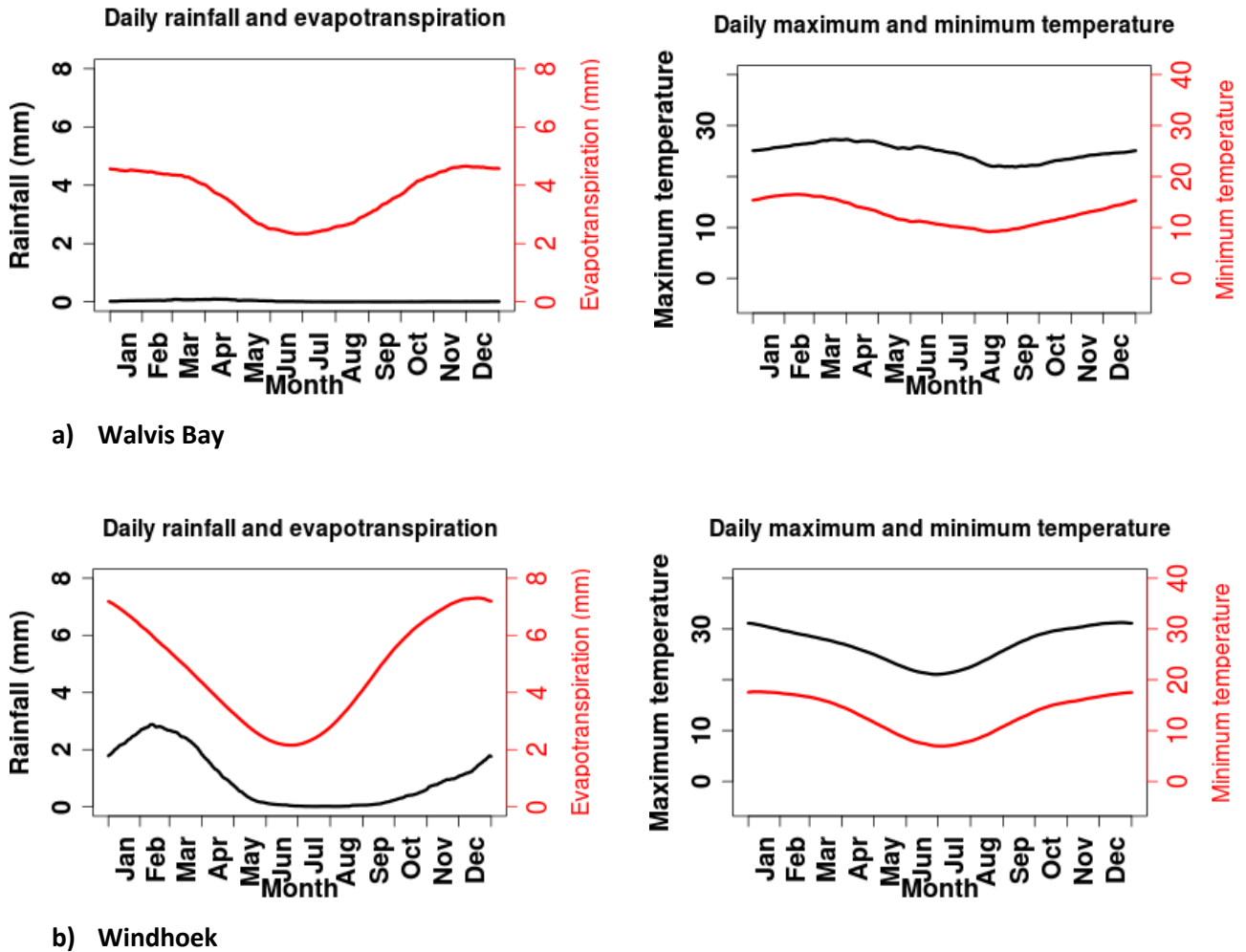


Figure 3: Daily climatology of rainfall (mm day⁻¹), minimum and maximum temperatures (°C) and reference evapotranspiration (mm day⁻¹) at (a) Walvis Bay and (b) Windhoek.

1.2 Historical trends in climate data at Walvis Bay

Unfortunately many of the records for the stations are patchy and only include data for a limited number of years, which makes calculating and detecting trends very difficult. Additionally rainfall near the coast (at Swakopmund, Walvis Bay and Gobabeb) is extremely low and erratic, making any detected trends dependent on a limited number of events.

Any data collected at a weather station must undergo quality control procedures. Such quality control procedures are generally flexible and there are no hard and fast guidelines as to what should be implemented. For example, complex statistical techniques that detect discontinuities in time-series (usually indicating the relocation or deterioration of a sensor) can be used with historical data, though these do not work as well for rainfall data. In this analysis it was decided to use the following simple tests and data was removed if it failed any of them:

- check for duplicate or missing records;
- check for negative rainfall (an impossibility in reality);
- check for rainfall > 500 mm in one day (also impossible);
- remove data more than 6 standard deviations from the mean (this would indicate an error in reading);

- remove data where minimum temperatures are greater than maximum temperatures (non-sensical).

The remaining data was then also used to calculate extreme rainfall indices, both on an annual and seasonal basis utilising software distributed by the ETCCDMI⁴ and STARDEX⁵ projects.

The only trends consistently detectable (significant at the 90% confidence level⁶) at all locations were those for increasing temperatures, though in most cases (with the exception of Windhoek) the time-series is too short to make definitive statements about the long term trend. Figure 4 shows the trend in maximum daily temperatures for Windhoek, which is consistent with those shown in the IPCC 4th assessment report⁷.

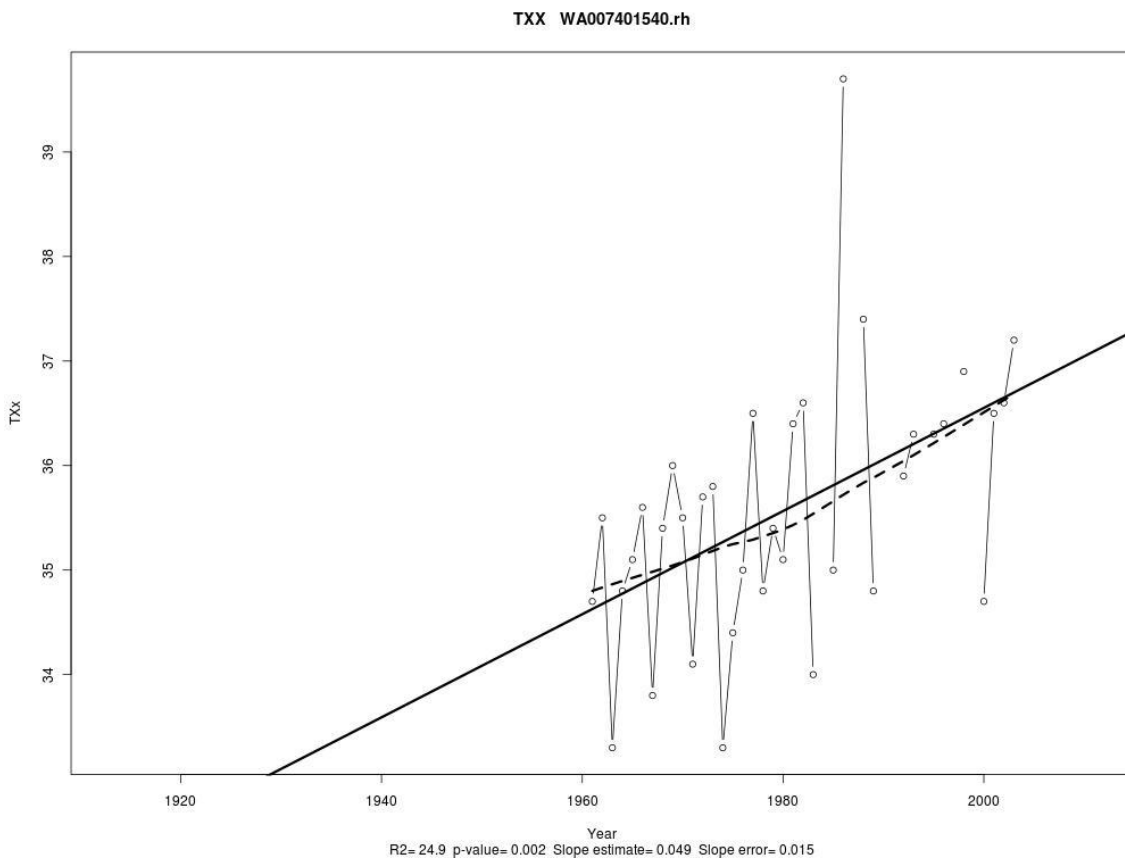


Figure 4: Trend in maximum daily temperatures at Windhoek.

There were significant trends (at the 90% confidence interval) in rainfall at Walvis Bay, showing decreases in average rainfall and total rainfall falling in 3 and 5 day periods. However, these negative trends were largely due to one or two high rainfall events recorded during the 1970's, with later events being of smaller magnitude. It was thus deemed to be highly improbable that these trends could be extrapolated into the future.

⁴ <http://cccma.seos.uvic.ca/ETCCDMI/software.shtml>

⁵ <http://www.cru.uea.ac.uk/projects/stardex/>

⁶ The confidence level is a statistical term for how willing one is to be wrong. With a 90 percent confidence interval, there is a 10 percent chance of being wrong

⁷ IPCC, 2007. IPCC Fourth Assessment Report (AR4) [online]: Available: <http://www.ipcc.ch/>

It is recommended that if climate data for a longer period, especially including later years (particularly rainfall data) becomes available in the future then this data should be further tested for trends in both extreme (e.g. using software from the ETCCDMI and STARDEX programmes) and mean climate characteristics. This could give greater insight into the expected rainfall averages as well as frequency and nature of extreme rainfall.

2 GCM projections of future change (for 2050)

GCM projections of change were presented in the baseline climate report for southern Africa⁸ and are shown here with a focus on the region around Walvis Bay.

2.1 Rainfall

Figure 5 demonstrates how rainfall is expected to change under both a B1 and A2⁹ emissions scenario; for each season, both the median¹⁰ change (15/13 GCMs for the A2/B1 scenario) and percentage of models agreeing on the sign (i.e. increase or decrease) of the change is shown. The median of the models (i.e. the most common outcome) suggests the most likely change for each period, whereas the percentage of models can be taken as an indication of the confidence in whether a positive or negative change is consistently simulated across the GCM models (values less than 50% suggest most models are simulating a negative change, whereas greater than 50% suggest most models simulate a positive change).

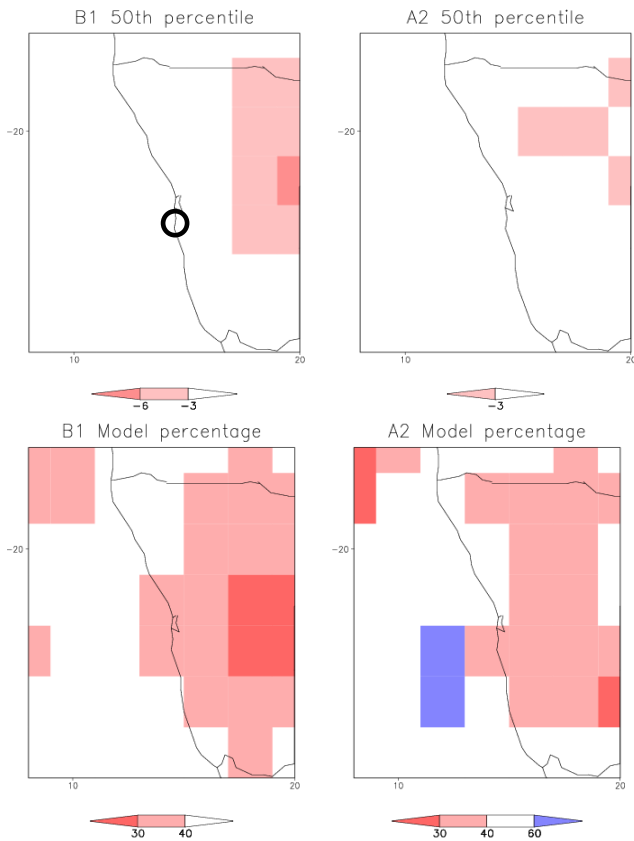
If one seeks consistency across GCM models (which could be defined as more than 60% of models agreeing on the sign of change) as well as consistency across both the A2 and B1 scenario, then the most obvious changes are for simulated decreases in rainfall during all 4 seasons. During the December-February period the simulations are perhaps less consistent in the region of Walvis Bay, with equal numbers of positive and negative changes simulated across the GCM models under an A2 emissions scenario. The magnitude of the simulated changes is small as the baseline rainfall is very low.

⁸ Tadross and Johnston 2011, Projected Climate Change Over Southern Africa; Namibia, South Africa, Mozambique, Tanzania and Mauritius, Report for ICLEI, February 2011

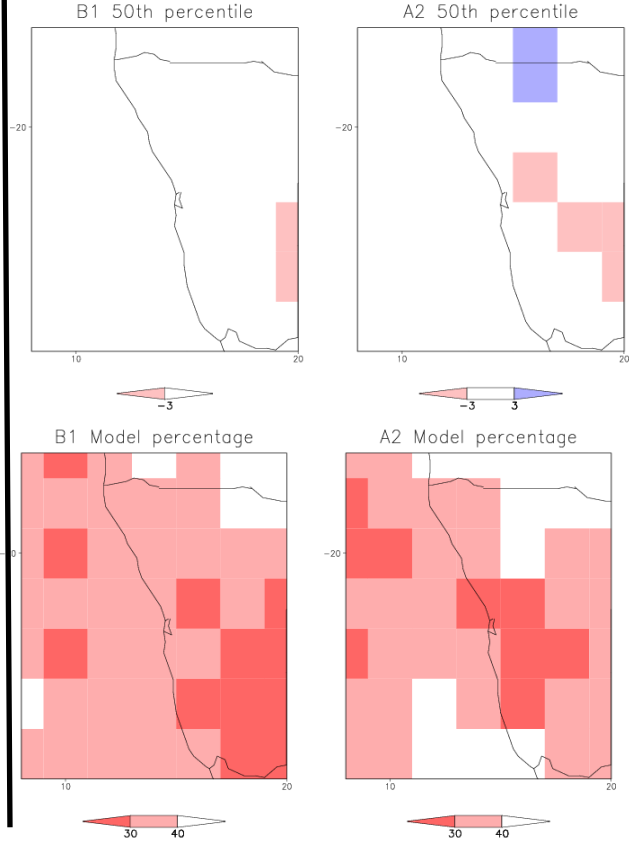
⁹ Emissions Scenarios were constructed to explore future developments in the global environment with special reference to the production of greenhouse gases and aerosol precursor emissions. The A2 scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. The B1 scenario family describes a convergent world with the emphasis on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

¹⁰ The median is the midpoint of a frequency distribution of observed values, sometimes reflected as the most common result.

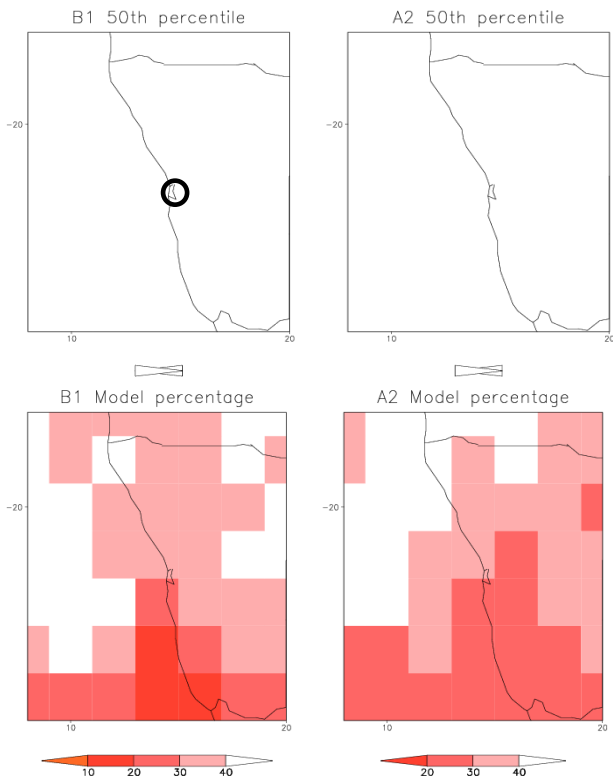
December-February



March-May



June-August



September-November

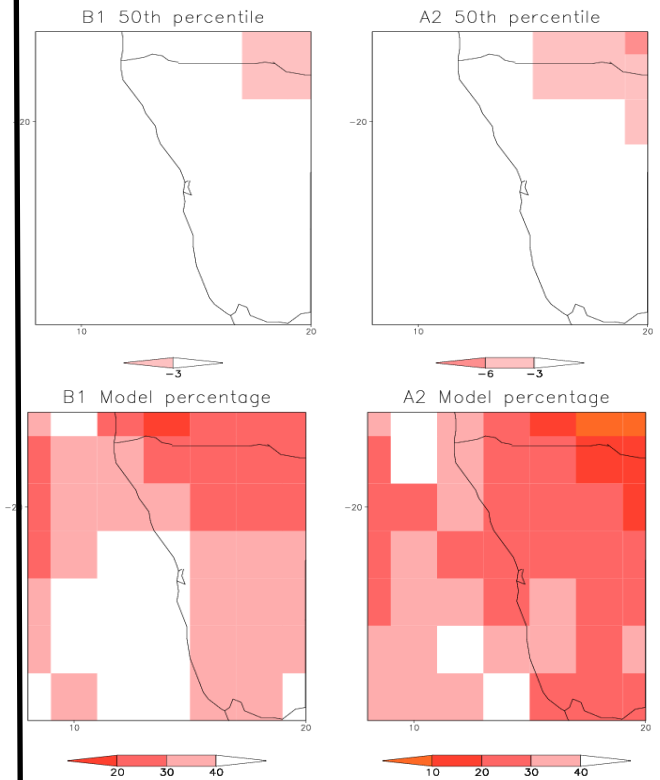


Figure 5: Median GCM simulations of rainfall change in mm per month by 2050 under A2 and B1 emissions scenarios for each season. The confidence of the model ensemble simulations is indicated by the percentage of models simulating a positive/negative change, indicated by the percentages where less than 40% (lower agreement) is in red shades and more than 60% (greater agreement) is in shades of blue..

2.2 Temperature

All GCMs simulate an increase in temperature which results in the median changes shown in figure 6 for both scenarios and for each season. Increases are similar for each season depending on the scenario used; 1.0-1.75°C for the B1 scenario and 1.5-2.5°C for the A2 scenario at Walvis Bay. Increases inland are significantly more than near the coast, as the cool ocean has a moderating influence. These are median changes and incorporate a range of projected increases, all positive, in each case.

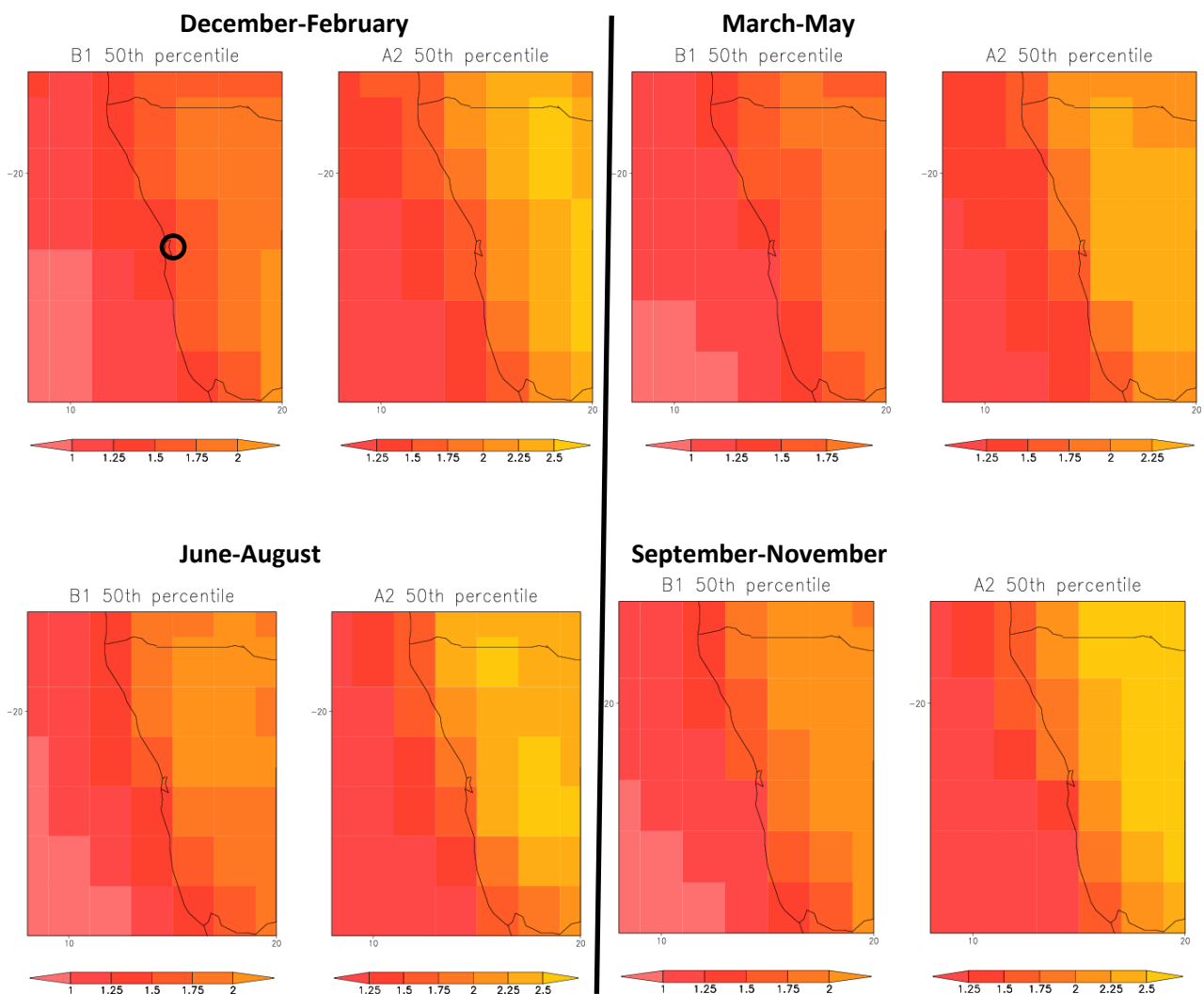
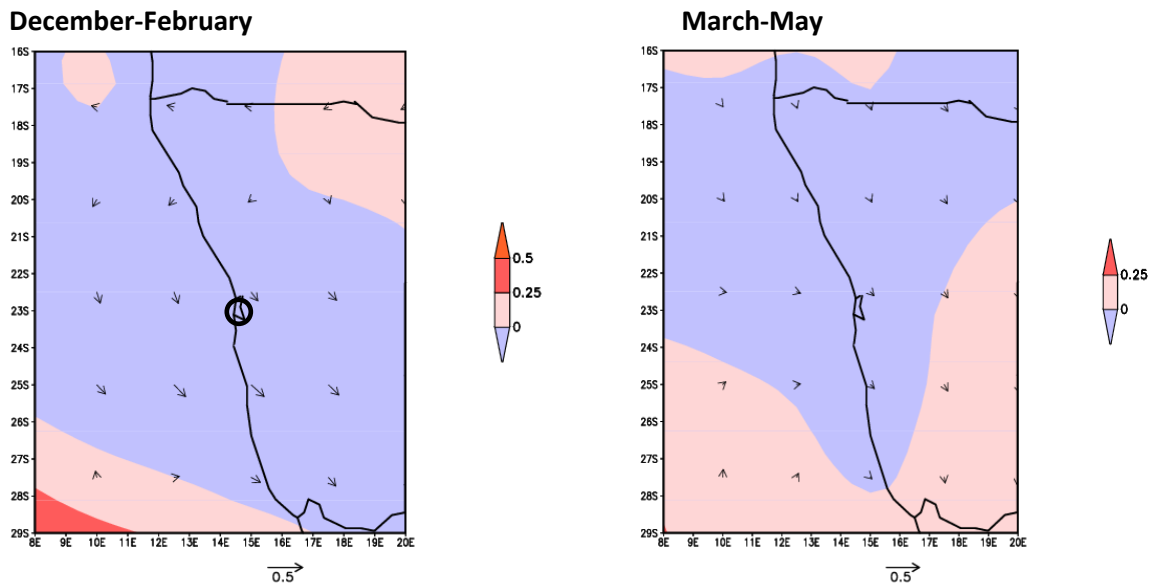


Figure 6: Median GCM simulations of change by 2050 under A2 and B1 emissions scenarios for each season.

The city of Walvis Bay is bounded by a few different grid cells, but the overall temperature increases in the region ensure that the expected temperature increases will be of the order shown, that is between 1.00 and 1.75 degrees for the B1 scenario and between 1.5 and 2.5 degrees for the A2 scenario by 2050. Considering that the current trend of greenhouse gas emissions is closer to or exceeding those for the A2 scenario, it can confidently be expected to be around 2 degrees warmer by 2050 than today. This is valid for all temperatures, minima, maxima and means.

2.3 Winds

Figure 7 shows the median changes in surface (actually 10m above the surface) winds simulated under an A2 scenario; the arrows indicate the changes in direction¹¹ and the magnitude of that change, while shading shows the changes in net speed of the wind - red shading indicates that median wind speed increases whereas dark blue shading indicates that wind speeds decrease. Wind speeds increase from the south during June-November, whereas they decrease and become more northerly during December-May. Changes during June-November reflect a strengthening of the anticyclonic atmospheric circulation over the southern Atlantic Ocean during winter and early spring, as depicted in the IPCC 4th assessment report. The changes during summer may indicate the potential for the advection of tropical air from the north, though this would depend on winds at higher elevations.



¹¹ Arrows indicate the movement of the wind – e.g. an arrow pointing south indicates a wind coming from the north.

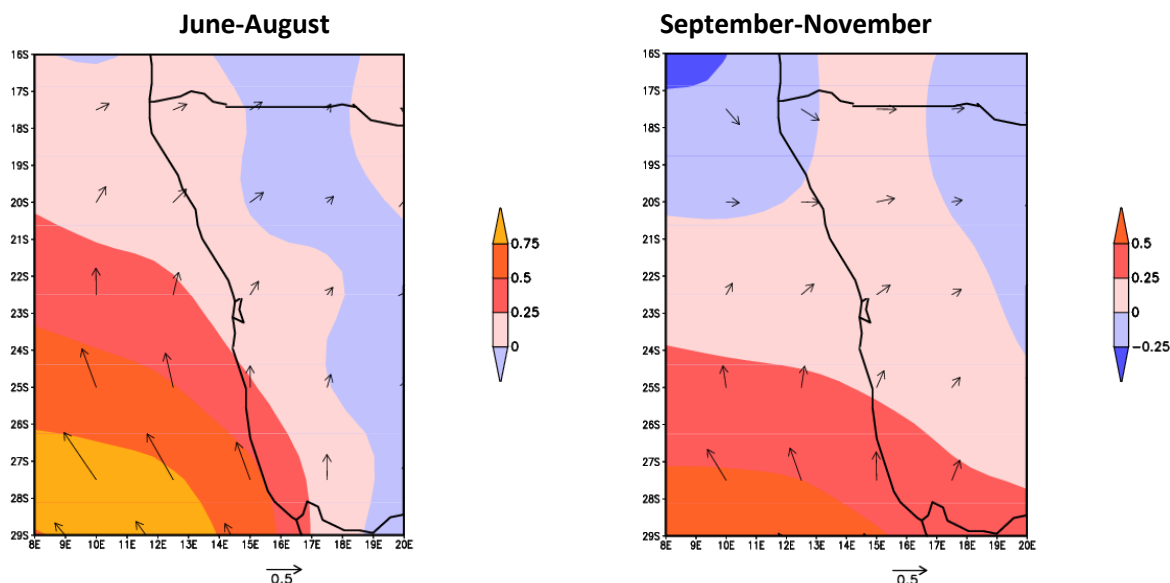


Figure 7: Median changes in 10m wind directions simulated under an A2 emissions scenario; shading indicates changes in wind speed (in m/s).

The implications of a increased wind strength during June-November must be considered in terms of any existing vulnerabilities that Walvis Bay may face. The impact on harbour activity and wave action on the lagoon must be assessed in terms of this projection.

3 Statistically downscaled projection of future changes in rainfall, temperature and evaporation

The following sections show the results from applying a downscaling methodology developed at the University of Cape Town to nine suitable GCMs¹² (forced with the A2 emissions scenario) and the observed rainfall and temperature data from the Walvis Bay and Windhoek stations. The downscaling relates daily weather systems to the observed rainfall and temperature at each location on each day. Taking the simulated changes in daily weather systems from each GCM we can then simulate the expected changes in daily rainfall and temperature at each location. We use the Priestly-Taylor method to calculate reference evapotranspiration (ET_0) based on simulated temperatures, solar radiation and altitude.

3.1 Rainfall

Figure 8 below compares the downscaled GCM control climates¹³ (1961-2000) with the observed climates for Walvis Bay and Windhoek. In both cases the GCM control climates are close to the observed, replicating the observed seasonal cycle and peak rainfall during February as well as capturing the higher rainfall at Windhoek. This gives us confidence that the downscaling methodology applied to these GCMs is simulating the local climates correctly.

¹² The suitability of GCMs depends on the frequency of data and the type of variable

¹³ A Control climate is the current climate as determined by the model – the degree of difference between the control and the observed climate gives an indication of the skill of the model

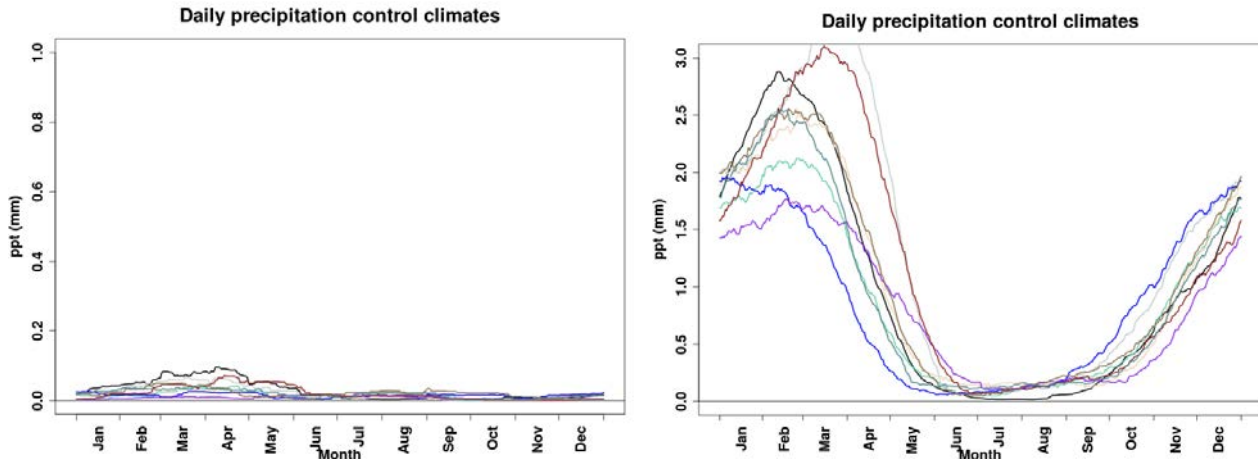
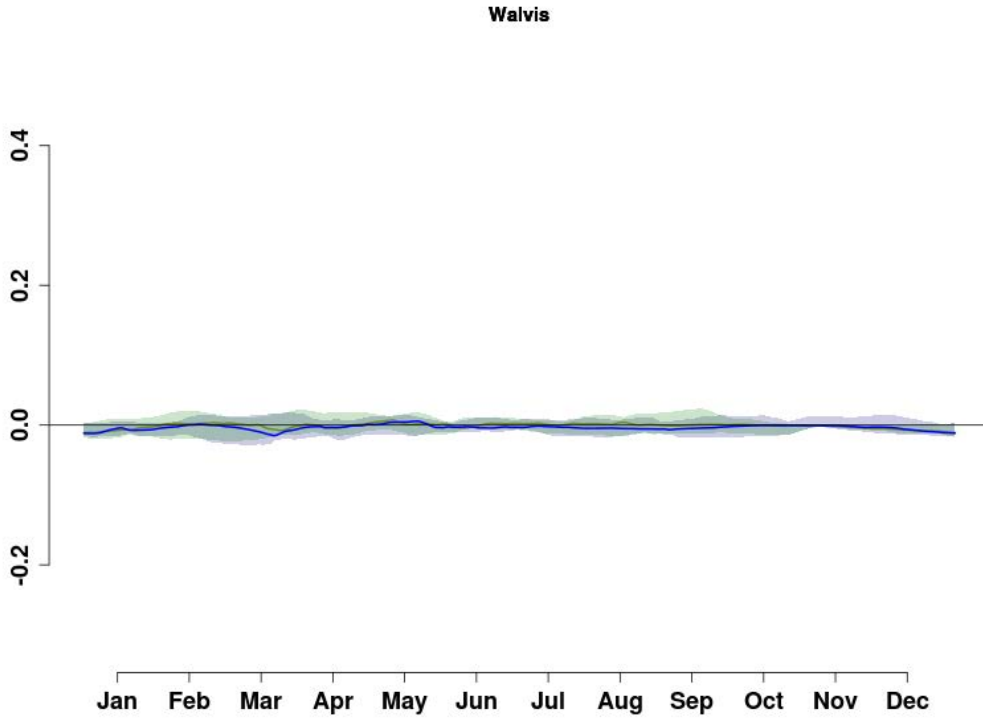


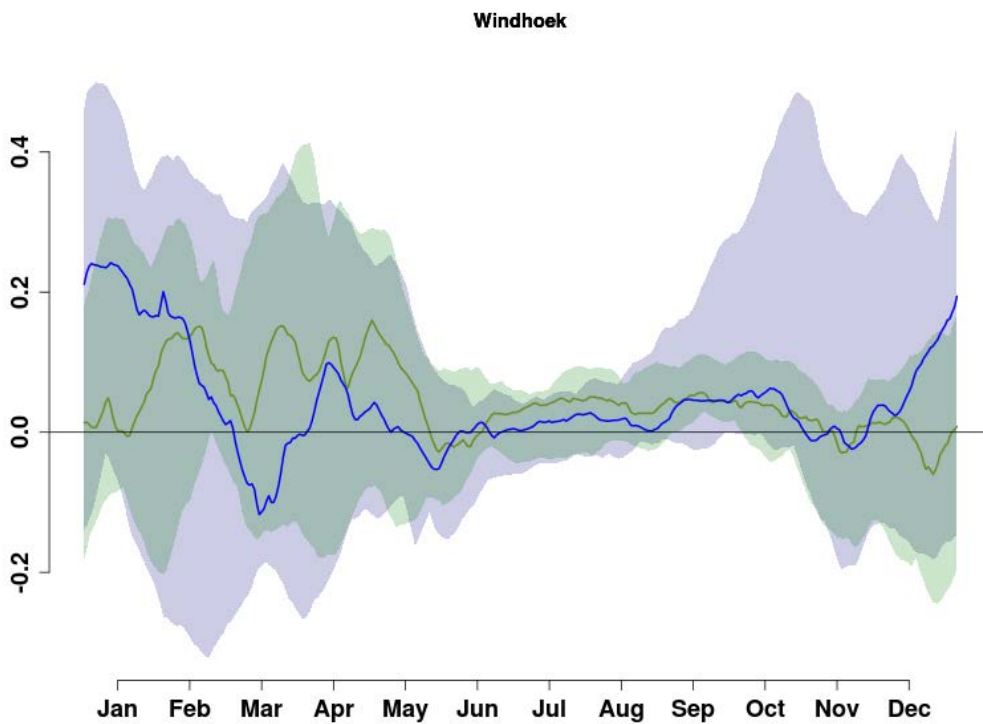
Figure 8: GCM downscaled control rainfall climates (mm per day), for the period 1961-2000; Walvis bay (left) and Windhoek (right). Black line is observed climate and coloured lines are downscaled GCM climates.

Figure 9 presents the simulated changes (or anomalies¹⁴) in rainfall for both Walvis Bay and Windhoek. The solid lines indicate the median of the downscaled models and the shaded regions the spread between the different downscaled GCMs. Green colouring is for the change simulated for the 2046-2065 period and blue for the 2081-2100 period (all relative to the control period of 1961-2000). Changes at Walvis Bay are very small with some GCMs suggesting positive and some negative changes, whereas at Windhoek the median models suggest an increase in rainfall, though with a reasonable spread between models, indicating relative uncertainty. The implications of this are discussed in 3.3.

¹⁴ An anomaly is the difference between the current climate and a future climate as projected by a model.



a) Walvis Bay



b) Windhoek

Figure 9: Downscaled rainfall anomalies (mm day⁻¹) for the 2046-2065 period (green) and 2081-2100 period (blue). Shading indicates the spread of results for the various models and solid lines the median model response.

3.2 Temperature

The downscaled changes in temperature are similar to those from the GCMs presented earlier and are similar for both minimum and maximum temperatures. Maximum temperature changes are summarised for both stations in figure 10. Highest increases are during the drier winter period, with median changes for the 2081-2100 period as high as 3.5°C at Walvis Bay and 5°C at Windhoek.

The implications of this are discussed in 3.3.

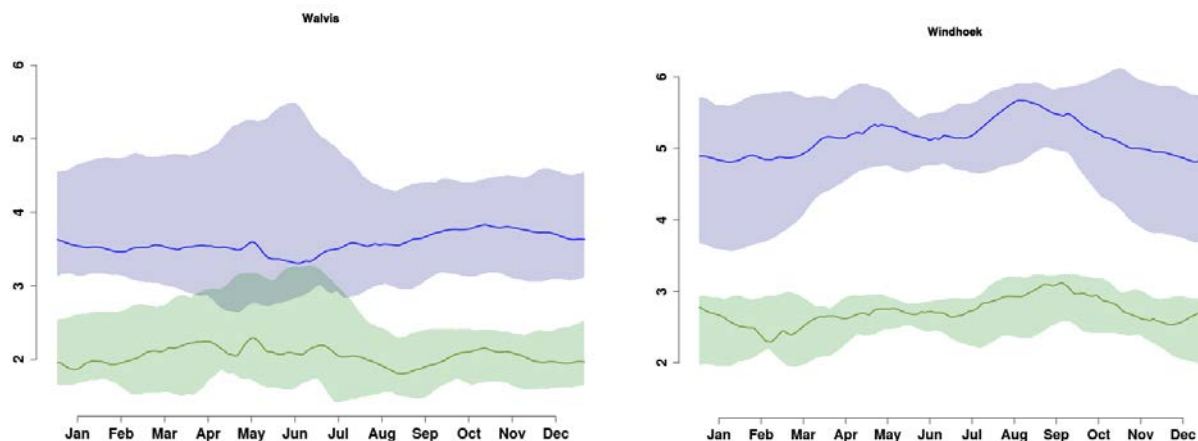


Figure 10: Downscaled minimum temperature anomalies (°C) for the 2046-2065 period (green) and 2081-2100 period (blue). Shading indicates the spread of results for the various models and solid lines the median model response.

3.3 Evaporation and effective rainfall

One major consequence of the changes in temperature is the resultant increase in reference evapotranspiration (ET_0) which is summarised for both stations in figure 11. Increases in ET are highest during November and December, with highest increases of 0.5-0.6 $mm\ day^{-1}$ during the 2081-2100 period at Walvis Bay. Increases in ET_0 at Windhoek are higher and easily reach $1mm\ day^{-1}$ during the 2081-2100 period.

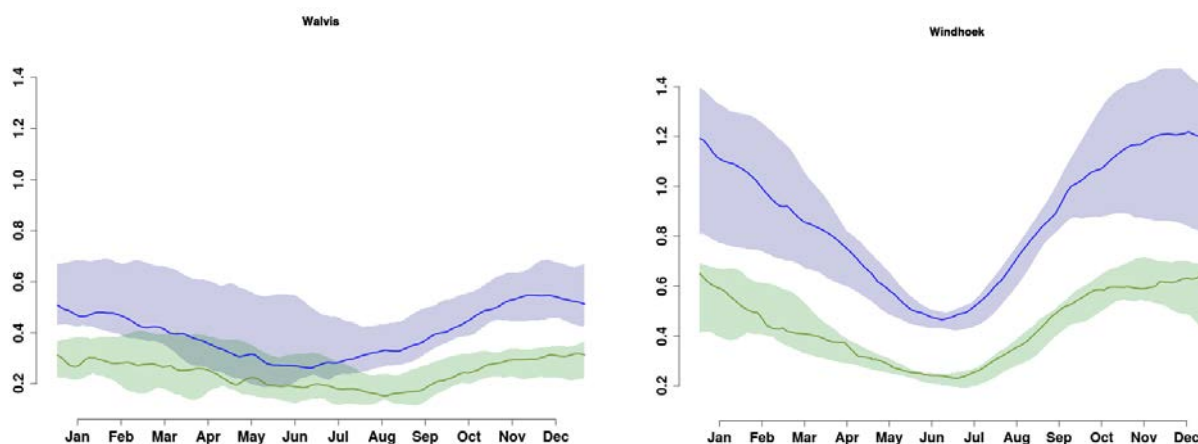


Figure 11: Downscaled reference evapotranspiration (ET_0) anomalies (mm day^{-1}) for the 2046-2065 period (green) and 2081-2100 period (blue). Shading indicates the spread of results for the various models and solid lines the median model response.

One consequence of these increases in ET_0 is that effective rainfall (rainfall less evaporation) becomes less, even without a decrease in rainfall. Assuming that evaporation occurs at the reference level (typical of a surface covered in short grass– for hard surfaces 100% runoff is assumed), figure 12 shows the change in effective rainfall. Comparing with figure 9 it can be seen that the change in evaporation dominates the change in rainfall resulting in reductions in effective rainfall in nearly all simulations and all months. This implies less surface water available for water storage and provision, flora and fauna. The reduction in effective rainfall has no bearing on flood frequency as the intensity of rainfall is not reflected here.

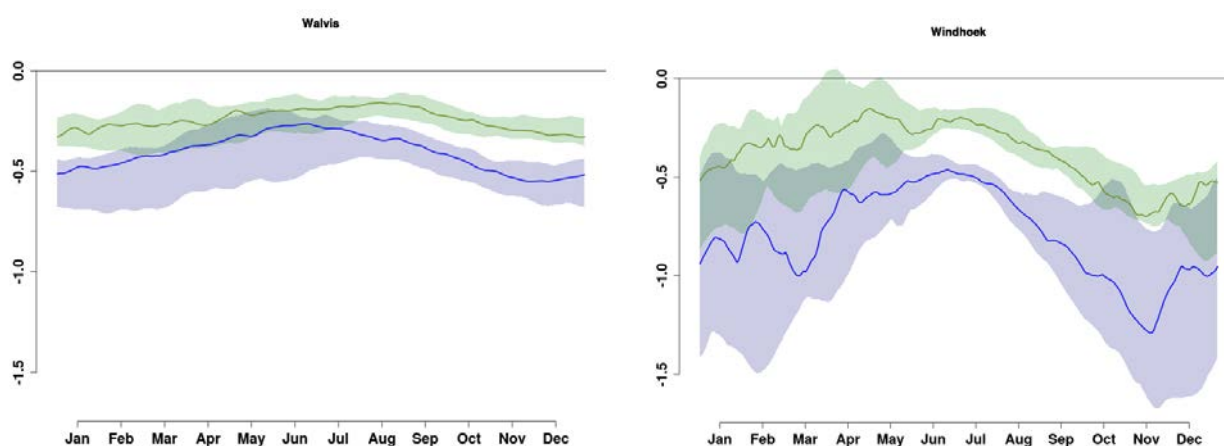


Figure 12: Downscaled effective rainfall ($\text{ppt} - ET_0$) anomalies (mm day^{-1}) for the 2046-2065 period (green) and 2081-2100 period (blue). Shading indicates model spread (10th and 90th percentiles) and solid lines the median model response.

4 Changes in climate extremes

Climate extremes (or extreme events) are harder to simulate than changes in the mean climate, largely because GCMs are low resolution parameterised versions of the real climate and may fail to capture important mechanisms e.g. intense and localised convective rainfall. Whilst the downscaling here relates the large scale atmospheric GCM fields to observed rainfall and temperature, and is therefore good at projecting realistic climate on average, it still relies on the GCM simulations to model the change in atmospheric dynamics. This, and the infrequent nature of extreme events (poor sampling in the historical record,) means that it is difficult to project future changes.

Until there are fundamental improvements in the GCMs, improved estimates of extreme climate events will be difficult; new simulations from the CORDEX programme will offer some high resolution dynamic simulations from multiple regional climate models (RCMs) for the first time, and these simulations may be able to better simulate the complex dynamics of extreme events leading to improved estimates of change.

4.1 Changes in extreme temperatures

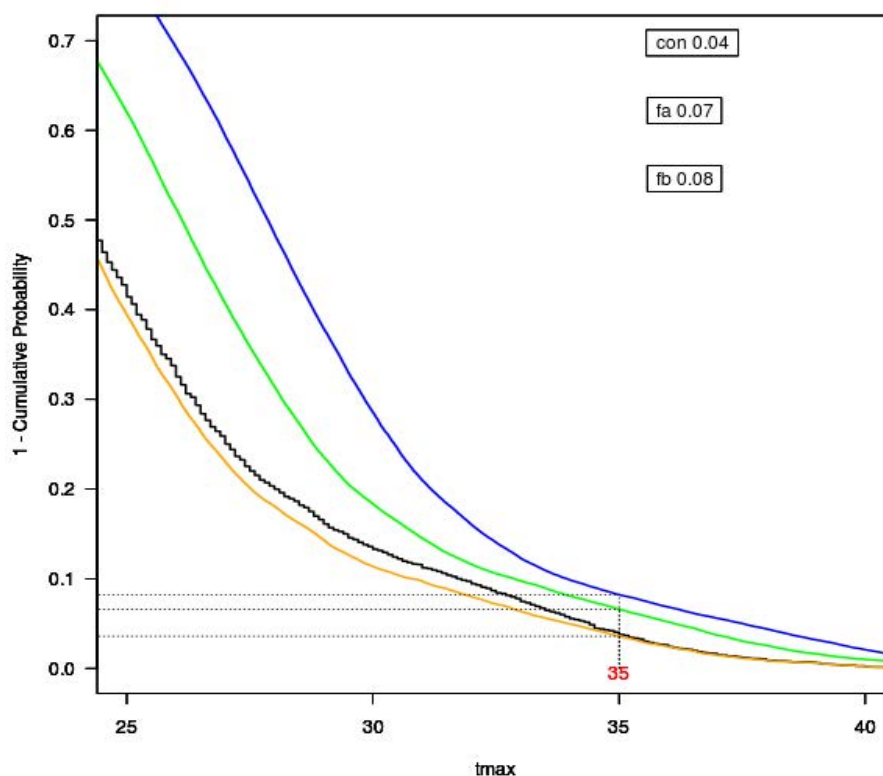
Changes in extreme temperatures are positive (meaning increases in maximum temperatures and the frequency of days with extremely high temperatures) in all simulations from GCMs and the statistical downscaling used here. Figure 13 indicates the cumulative probability of exceeding different maximum daily temperatures for different periods at Walvis Bay and Windhoek under an assumed A2 emissions scenario. The risk of exceeding high values (e.g. 35°C) is higher during future periods at each location, with

the change in probability higher at Windhoek than at Walvis Bay; this reflects the higher increases in temperature simulated for inland locations in the GCM data noted previously. The table below shows the probability of exceeding 35°C for each location and period.

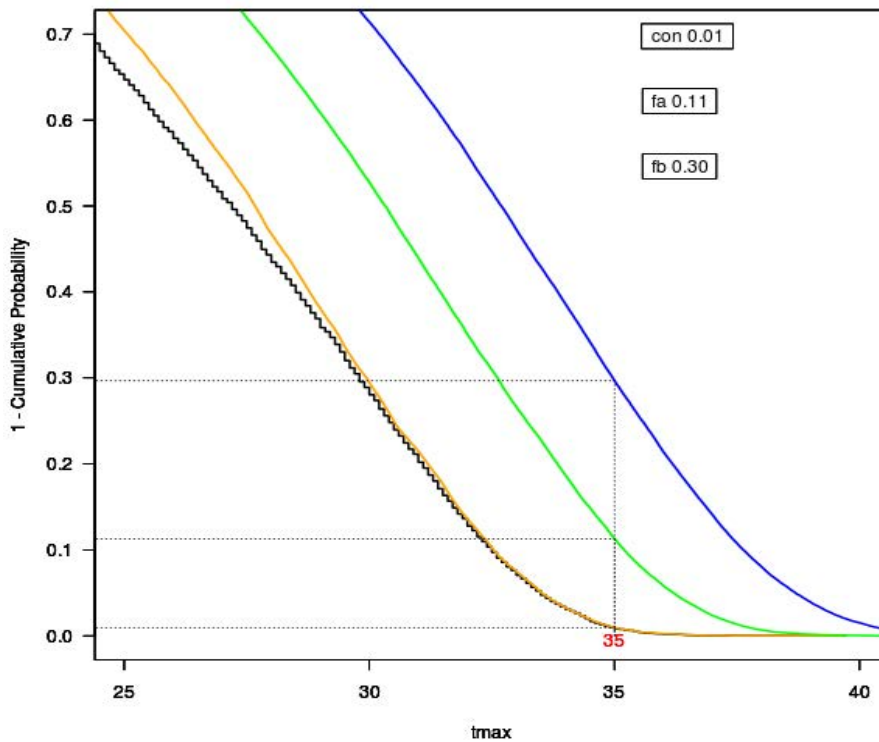
Location	Probability of exceeding 35°C under present climate (1960-2000)	Probability of exceeding 35°C under future climate (2046-2065)	Probability exceeding 35°C under future climate (2081-2100)
Windhoek	1%	11%	30%
Walvis bay	4%	7%	8%

Table 1. Probability of the occurrence of very hot days.

Whilst the chance of exceeding 35°C is higher than Windhoek under present conditions at Walvis Bay, the increase in probability for the future is less than at Windhoek. Even so we can expect the frequency of days exceeding 35°C at Walvis Bay to nearly double by 2055 (from 4% to 7%).



a) Walvis Bay



b) Windhoek

Figure 13: Cumulative probability of exceeding maximum temperatures under current (black), downscaled control (orange), downscaled 2046-2065 (green) and downscaled 2081-2100 (blue) periods. Walvis Bay (a) and Windhoek (b).

One improvement on these estimates of change for the future would be to downscale using a higher resolution RCM which would be better able to resolve gradual temperature changes in regions of steep topography (although this is not applicable in Walvis Bay), something that the GCMs and statistical downscaling used here is not able to do. The multiple RCM simulations generated as part of the CORDEX programme could be used in this regard.

4.2 Changes in extreme rainfall

Changes in extreme rainfall are, at least partly, difficult to estimate due to the problems in simulating extreme atmospheric conditions mentioned earlier. Additionally the statistical downscaling technique used here can only simulate daily rainfall values seen in the historical record. This means that it may underestimate increases in rainfall due to increases in intensity, especially at the extreme end of the distribution. Given that increases in intensity are possible in a hotter climate with more moisture available for rainfall, this is a shortcoming of the downscaling methodology employed here. Using RCMs (which are not restricted by such limits) is currently not an option as there are not enough RCM simulations for multiple GCMs available for the region (in order to construct envelopes of change and assess the probability/risk of particular changes). Again this may change when the CORDEX data becomes available. .

Given these limitations, Generalised Extreme Value (GEV) distributions were fitted to the annual maximum 1, 3 and 5 day total rainfall simulated by the downscaled GCMs for both the control and future climate simulations. From these GEV distributions the 10, 20 and 50 year return levels of extreme rainfall were

calculated, as well as their 95% confidence intervals. The results are indicated in the table below for the annual maximum 1 day total rainfall and 5 GCMs (indicated by different colour bands).

Return period	1960-2000 return level (mm)			2046-2065 return level (mm)		
	lower 95%	Estimate	upper 95%	lower 95%	Estimate	upper 95%
10 year:	5.85	8.59	19.15	9.29	18.57	53.69
20 year:	7.85	12.85	39.1	23.91	47.83	57.39
50 year:	10.84	20.84	50.43		161.63	
10 year:	6.05	8.12	13.39	5.29	8.33	29.15
20 year:	7.82	11.07	21.98	6.8	11.67	37.91
50 year:	10.12	15.92	41.27	8.63	17.25	38.81
10 year:	9.16	15.52	49.17	11.72	23.44	58.61
20 year:	13.4	26.8	71.64	27.18	54.37	54.37
50 year:	26.49	52.97	73.87		159.9	
10 year:	9.3	15.75	41.12	3.74	7.47	33.48
20 year:	14.2	27.65	70.36	6.43	12.86	35.37
50 year:	28.01	56.03	72	12.65	25.3	37.95
10 year:	7.72	12.44	27.72	7.43	14.85	51.98
20 year:	11.32	20.76	57.08	17.92	35.84	53.76
50 year:	19.7	39.4	59.09	55.56	111.12	65.95

Table 2. The probability ranges of extreme 1 day rainfall for the present and for the 2046-2065 period.

Although these GCMs converged on appropriate GEV distributions, there is a wide range of estimates within the 95% probability space, or bounds. These bounds are often overlapping between the current and future climate estimates, indicating that these estimates are not significantly different at the 95% confidence interval. This is likely a limitation of the statistical downscaling technique used to generate the future rainfall; it is constrained by historical observations and so is unable to fully represent changes in high intensity rainfall events. The only way to address this would be to use either other statistical downscaling techniques which represent these changes or multiple Regional Climate Models (RCMs) which can simulate these changes. Neither of these data were available for the present study – even these techniques may fail as predicting these rare events with any level of statistical significance is extremely difficult..

5 Walvis Bay: impacts and vulnerabilities

Walvis Bay is home to around 60 000 inhabitants, and is well developed, with significant infrastructure and industrial investment and is economically highly dependent upon shipping, fishing and large salt production companies. The city is located about two metres above sea level and hosts the only port in the country suitable for import and export trade, acting too as a national and regional economic import/export access point for surrounding landlocked countries such as Botswana, Zambia and Zimbabwe. The import of liquid fossil fuel in particular is of vital importance to the city's economy.

As a coastal town, Walvis Bay is exposed to risks and impacts associated with intense rainfall events, resultant flooding, coastal erosion and direct damage to infrastructure, services and property. The city has already experienced such impacts, though not frequently.

It is the vulnerability of Walvis Bay to the impacts of sea level rise that contributes most to the World Bank ratings of concern on Namibia. Low-lying Walvis Bay, with an elevation of less than 2m above mean sea level, is the most vulnerable to sea level rise and extreme tidal characteristics. An earlier study on the impacts of climate change indicates the possibility of inundation, water logging and flooding of the town, particularly if the protection from the Pelican Point sand spit is reduced¹⁵. The projected rise in sea levels due to global warming is likely to affect parts of Walvis Bay and also the entire marine and fishing industry and the coastal economy¹⁶. However, it must be noted that the downscaling study in the report does not add any further insight into the already identified vulnerabilities of sea-level rise. In this report the most significant impact is found to be decreases in the amount of rainfall, but likely increases in rainfall intensity, with increase in temperature and a higher frequency of very hot days.

These impacts may increase or decrease specific threats and vulnerabilities to specific local government sectors which were identified in the baseline report¹⁷. A recent assessment on threats associated with climate change in Walvis Bay indicated the following vulnerabilities¹⁸:

- Increased number of extreme weather events;
- Increasing mean sea level rise;
- Coastal erosion;
- Contaminated and decreased water resources;
- Loss of biodiversity, ecosystems, natural and marine resources;
- Damage to residential, key industrial and municipal infrastructure;
- Change in local temperature and precipitation, and
- Increased health problems due to heat stress

The risks and impacts upon sectors such as water and sanitation, energy, transport and health ultimately and inherently affect livelihoods. Thus risks and impacts associated with sea level rise (both storm-driven intermittent and permanent inundation) will also embody impacts upon livelihoods.

¹⁵ Brundrit, G B (1995). Trends of southern African sea level: statistical analysis and interpretation. South African Journal of Marine Science 16: 9-17.

¹⁶ Mfunne, John Kazgeba Mfunne and Birga Ndombo. 2005. An assessment of the capacity and needs required to implement Article 6 of the United Nations Framework Convention on Climate Change (UNFCCC) in Namibia

¹⁷ Priscilla Rowswell and Lucinda Fairhurst (2011) Sub-Saharan African Cities: A five-City Network to Pioneer Climate Adaptation through Participatory Research & Local Action Draft Baseline Study (February 2011)

¹⁸ UNHABITAT 2010. Walvis Bay, Namibia: Cities and Climate Change .

Both current and future risks are summarised in the tables below. Increased risks in the future are highlighted in yellow.

5.1 Water and Sanitation

Impacts upon Water and Sanitation	Impact on livelihoods
<ul style="list-style-type: none"> • Salt water intrusions into freshwater systems in coastal zones are anticipated to increase. • Increased salinity levels of recycled water. • Increased temperatures and evaporation will decrease availability of freshwater for domestic and industrial use <ul style="list-style-type: none"> • Increased pressure and stress on fresh water supply. • Water treatment capacity will increase. • Water sanitation in the poorer, vulnerable areas will be affected • Cascade effect on health as a result of increased changes of contamination of fresh water sources. 	<ul style="list-style-type: none"> • Increased need for maintenance, upgrades or replacement/installation of infrastructure (e.g. storm water facilities) • Some water supplies /dams offline and thus increasing pressure on remaining water sources and potential water restrictions • Knock on effect on health as a result of increased changes of contamination of fresh water sources. • After sea storm surge events or heavy rainfall water may not be able to disperse / run-off and water may become stagnant leading to disease outbreaks

5.2 Transport

Type	Impacts upon Transport	Impact on livelihoods
Road	<ul style="list-style-type: none"> • Damage of infrastructure • Blockage of roads (fallen trees, debris) • Coastal Flooding causes diversions • Accidents • Inundation of roads 	<ul style="list-style-type: none"> • Limits access routes • Work hours lost– reducing income • Risk to public safety
Port	<ul style="list-style-type: none"> • Damage of infrastructure • Erosion to coastal infrastructure and equipment • Damage of boats • Erosion to harbour wall • Damage to anchored boats 	<ul style="list-style-type: none"> • Days at sea lost • Work hours lost – reducing income, if the port is rendered unworkable then there is no income stream until the damage has been cleared. • Delay in exports/imports • Increased insurance premiums

5.3 Health

Impacts upon Health (see also water above)	Impact on livelihoods
<ul style="list-style-type: none"> • Sea level rise will impact upon the health sector as a result of increased deaths from: <ul style="list-style-type: none"> ○ Drowning ○ Electrocutation • Increased pressure on emergency services. • Service delivery backlogs in clinics and hospitals • Chemical Hazards: contamination of flood water with oil, diesel, pesticides, fertilisers etc. • Spread of infectious diseases: skin and respiratory diseases and stomach ailments. • Increased temperatures will affect heat stroke occurrence 	<ul style="list-style-type: none"> • increased deaths from: <ul style="list-style-type: none"> – Drowning – Electrocutation • Poor and limited water supply to residents • Dehydration • Loss of shelter • Likely to affect vulnerable communities (young, woman and elderly) most at risk to impacts associated with severe extreme events, such as extreme heat.

5.4 Energy

Impacts upon Energy	Impact on livelihoods
<ul style="list-style-type: none"> • Damage and losses to energy production facilities and infrastructure (power stations, high voltage lines etc) through flooding. • May cause an increased demand for energy for upgrades and adaptation <ul style="list-style-type: none"> • Clean up operations • Rebuilding of infrastructure and housing. • Increased demand for air conditioning 	<ul style="list-style-type: none"> • Chances of electrocution by livewires being submerged in floodwater • Limited water supply if water sector does not have backup generators

The risks and impacts upon water and sanitation, transport, health, and energy as shown and highlighted above, ultimately affect human livelihoods. Local authorities need to analyse associated and projected impacts and adapt and plan accordingly to strategically build resilience. There is a need for ongoing vulnerability assessment and the development of adaptation strategies and preparedness in protecting local communities and the environment on which they depend upon for their livelihoods and well-being. It is increasingly important to gauge the value of pre-emptive adaptation strategies that increase resilience and decrease vulnerability, against the cost of damages if these measures are not put in place.