

Elaboration of a “Climate Change Hazard, Vulnerability and Risk Assessment” Study to the benefit of the City of Cape Town

Vulnerability and Hazard Assessment Report

Réf. AFD/DOE/EBC/CLD | ACH-2017-026



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PROJECT BACKGROUND

This report is submitted under the French Development Agency (AFD) project: Elaboration of a "Climate Change Hazard, Vulnerability and Risk Assessment" Study to the benefit of the City of Cape Town. The project falls under the CICLEIA Framework Agreement for Studies and Technical Assistance for the Cities and Climate Change Initiative in Sub-Saharan Africa, funded by the French Development Agency (AFD), EU and the Swiss State Secretariat for Economic Affairs (SECO). This report is submitted on the back of the outcomes of Phase 2 and the Participatory Analysis Workshop with the City of Cape Town (CCT) held on the 18th of January 2019, in accordance with the requirements of the Contract for Réf. AFD/DOE/EBC/CLD | ACH-2017-026. As such, this report constitutes Deliverable 2 under this contract and includes: i) a summary of preliminary findings; ii) climate change projections and hazard assessment; iii) risk and vulnerability assessment; iv) thematic assessment of key risks and vulnerabilities and v) a brief discussion on the way forward.

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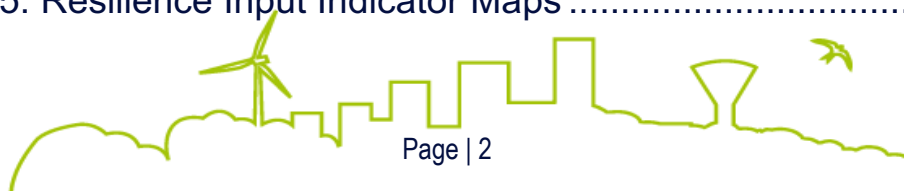


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Abbreviations and Acronyms

AAO	Antarctic Oscillation
ACCESS1-0	Australian Community Climate and Earth System Simulator
AFD	French Development Agency (Agence Française de Développement)
AMO	Atlantic Meridional Overturning
AR5	Assessment Report 5
CBD	Central Business District
CCAM	Conformal-Cubic Atmospheric Model
CCSM	Community Climate System Model
CCT	City of Cape Town
CNRM-CM5	National Centre for Meteorological Research Coupled Global Climate Model, version 5
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DM	District Municipality
ENSO	El Niño Southern Oscillation
FFDI	Forest Fire Danger Index
FGD	Focus Group Discussion
GCM	Global Climate Model
GFDL-CM3	Geophysical Fluid Dynamics Laboratory Coupled Model
GIS	Geographic Information Systems
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
MPI-ESM-LR	Max Planck Institute Coupled Earth System Model
NorESM1-M	Norwegian Earth System Model
R&V	Risk and Vulnerability
SAM	Southern Annular Mode
SST	Sea Surface Temperature
WCWSS	Western Cape Water Supply System



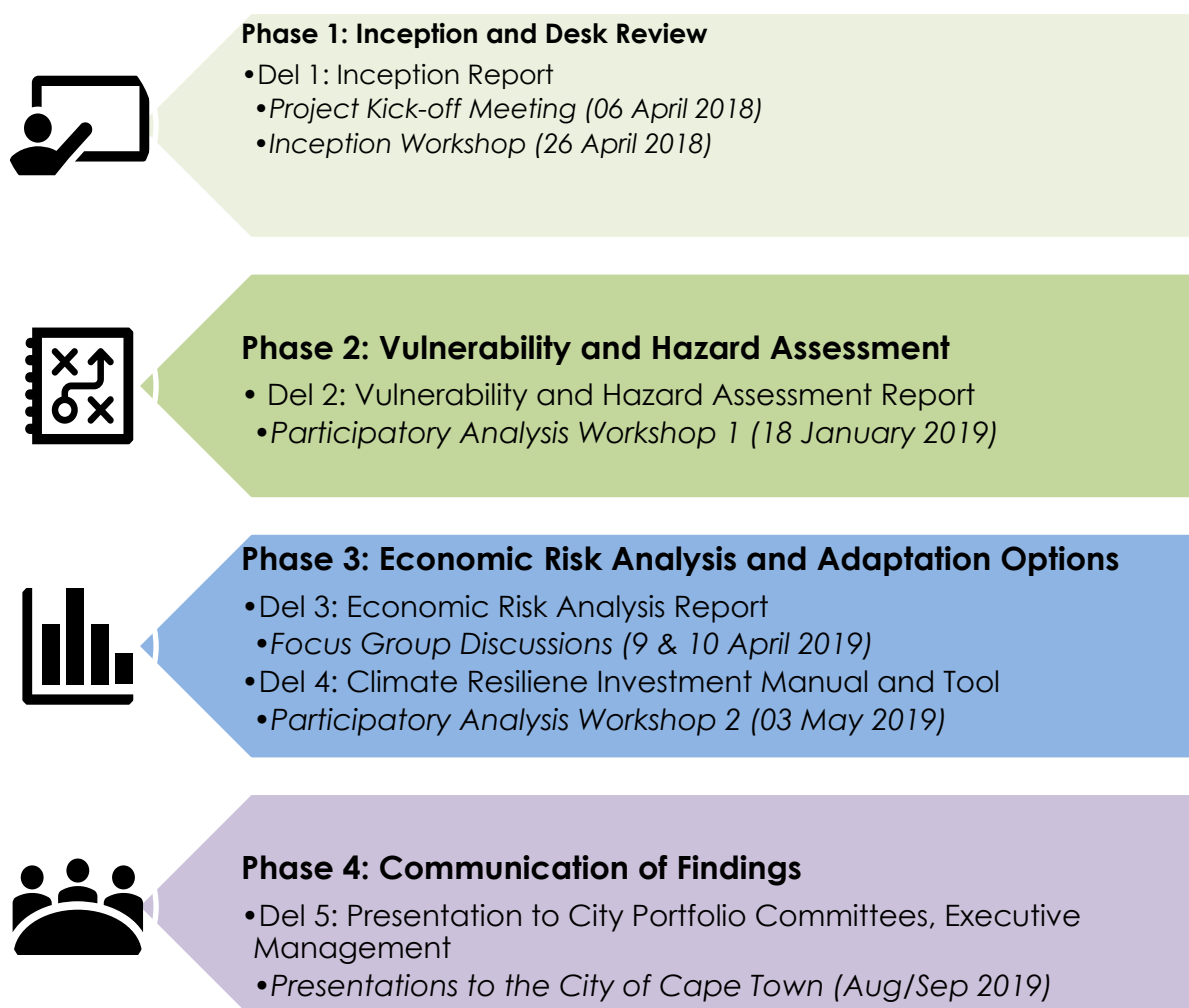
A. Introduction

This report is Deliverable 2 of the project **Elaboration of a “Climate Change Hazard, Vulnerability and Risk Assessment” Study to the benefit of the City of Cape Town**, commissioned by the French Development Agency (AFD).

Réf. AFD/DOE/EBC/CLD | ACH-2017-026.

The project is being delivered in line with a four-phased approach, with key deliverables and fieldwork activities under each phase, as illustrated in Figure 1. Building on the outcomes of Phase 1 and the Participatory Analysis Workshop with the City of Cape Town (CCT) held on the 18th of January 2019, this report includes: i) a summary of preliminary findings; ii) climate change projections and hazard assessment; iii) risk and vulnerability assessment; iv) thematic assessment of key risks and vulnerabilities and v) a brief discussion on the way forward.

Figure 1: Phased Project Approach



A.1 Summary of Key Findings

Cape Town is expected to experience a drier and significantly warmer future. Changes in these first order climate parameters have widespread impacts throughout biophysical, social and economic systems in around the City. The key climate-related hazards that pose the greatest risk to Cape Town are:

1. Drought
2. Fire
3. Heatwaves
4. Floods
5. Strong Winds

The Western Cape Water Supply System is highly exposed to drought, which poses direct risks to the economy of Cape Town, the natural environment and livelihoods of residents. The indirect impacts of drought are also far reaching and pose risks both within and beyond the City boundaries. Fires pose significant threats to human life, livelihoods and both low- and high-value properties. The areas most at risk within the City are those that have limited access to services and resources to buffer the impacts of shocks and respond to incremental challenges of long-term stressors.

The risks associated with these climate hazards are significant and manifest through multiple pathways that impact people, the economy and the environment. Complex interlinkages and cumulative impacts between the thematic areas of livelihoods, poverty and inequality, the built environment and disaster risk highlight that **building resilience is the key to reducing vulnerability in Cape Town.**



B. Climate Change Projections and Hazard Assessment

B.1 Background and Overview

Climate change is projected to impact drastically in southern Africa during the 21st century under low mitigation futures (Niang *et al.*, 2014). African temperatures are projected to rise at ~1.5 to 2 times the global rate of increase (James and Washington, 2013; Engelbrecht *et al.*, 2015). Moreover, the southern African region is projected to become generally drier under enhanced anthropogenic forcing (Christensen *et al.*, 2007; Engelbrecht *et al.*, 2009; James and Washington, 2013; Niang *et al.*, 2014). These changes in climate will have a range of impacts on the South African environment and economy, including impacts on energy demand (in terms of achieving human comfort within buildings and factories), water security (through reduced rainfall and enhanced evapotranspiration) and agriculture (in terms of changes in crop yield) (Engelbrecht *et al.*, 2015). Box 1 defines the notions of hazard and risk and differentiates between them.

Box 1: Definitions of hazard and risk

Hazard - The potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources (IPCC, 2012: 560). For example: floods, droughts and fires.

Risk - The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. (IPCC, 2012: 1772). For example, drought poses different types and levels of risk through different pathways affecting multiple people, assets, etc., in different ways.

However, climate change impacts will not only manifest through changes in average temperature and rainfall patterns, but also changes in the intensity and frequency of extreme weather events. For the southern African region, generally drier conditions and the more frequent occurrence of dry spells are likely over most of the interior (Christensen *et al.*, 2007; Engelbrecht *et al.*, 2009). Tropical cyclone tracks are projected to shift northward, bringing more flood events to northern Mozambique and fewer to the Limpopo province in South Africa (Malherbe *et al.*, 2013; Muthige *et al.*, 2018). Flood events related to cut-off lows are also projected to occur less frequently over South Africa (Engelbrecht *et al.*, 2013) in response to changes in the wind regime and displacement of frontal systems towards the south pole. Intense thunderstorms are likely to occur more frequently over South Africa in a generally warmer climate (e.g. Engelbrecht *et al.*, 2013).

Recent climate change risk and hazard research (Brundrit, 2016; Fairhurst, 2008; Cartwright, 2008; Jack *et al.*, 2016) indicates that Cape Town is currently facing four key climate change challenges:

- A decrease in annual average rainfall and a change in the seasonality of rainfall;
- An increase in mean annual temperature: higher maximum temperatures, more hot days, and more frequent and intense heat-waves;
- An increase in average wind strength; and
- An increase in both the intensity and frequency of storms: short, high intensity rainfall events and increased size and duration of coastal storms.

These changes, already observed to some or other extent, will continue to occur, in addition to sea level rise. This climate change induced sea level rise will further exacerbate the severity of storm surges and therefore their impact (Brundrit, 2009). As with other extreme events, the recovery period between storm events is expected to shorten, leaving economies and livelihoods more vulnerable than they already are.



B.1.1 Section and Methodological Overview

This section presents the climate change projections and accompanying hazard assessment. These build on the findings of existing studies related to climate change risks in Cape Town (discussed above), using the most recent and most detailed projections of future climate change available for the southwestern Cape in South Africa.

The analysis is based on the Assessment Report Five (AR5) of the Intergovernmental Panel on Climate Change (IPCC), and complemented by the recent IPCC Special Report on Global Warming at 1.5°C (SR1.5). We have based the spatial analysis of high impact climate events on the most spatially detailed projections of climate change over southern Africa obtained to date, through the Centre for High Performance Computing (CHPC) of the Meraka Institute of the CSIR in South Africa. The findings corroborate and contrast the existing body of evidence and latest insights into future changes in the frequency and intensity of extreme events over the southwestern Cape in South Africa, with a focus on extreme events that impact directly on Cape Town. See Box 2 for an outline of the specific experimental design for the climate change projections.

Box 2: Experimental design of climate change projections

The OneWorld team analysed an ensemble of high-resolution climate model simulations of present-day climate and future climate change projections over southern Africa, over the southwestern Cape. The regional climate model used is the conformal-cubic atmospheric model (CCAM), a variable-resolution global climate model (GCM) developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) (McGregor 2005; McGregor and Dix 2001, 2008). CCAM runs coupled to a dynamic land-surface model CABLE (CSIRO Atmosphere Biosphere Land Exchange model). Six GCM simulations of the Coupled Model Intercomparison Project Phase Five (CMIP5) and AR5 were obtained for the low-mitigation emission scenario described by the Representative Concentration Pathway 8.5 (RCP8.5).

The simulations span the period 1960-2100 and the project team initially downscaled them to 50 km resolution globally. The GCMs downscaled include the Australian Community Climate and Earth System Simulator (ACCESS1-0); the Geophysical Fluid Dynamics Laboratory Coupled Model (GFDL-CM3); the National Centre for Meteorological Research Coupled Global Climate Model, version 5 (CNRM-CM5); the Max Planck Institute Coupled Earth System Model (MPI-ESM-LR); the Norwegian Earth System Model (NorESM1-M) and the Community Climate System Model (CCSM4). In these simulations CCAM was forced with the bias-corrected daily sea-surface temperatures (SSTs) and sea-ice concentrations of each host model, and with carbon dioxide, sulphate and ozone forcing consistent with the RCP8.5 scenarios.

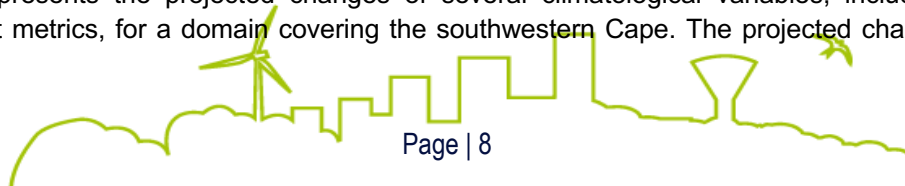
Several reports have extensively demonstrated the model's ability to realistically simulate present-day southern African climate (e.g. Engelbrecht et al., 2009; Engelbrecht et al., 2011; Engelbrecht et al., 2013; Malherbe et al., 2013; Winsemius et al., 2014; Engelbrecht et al., 2015). Most current coupled GCMs do not employ flux corrections between atmosphere and ocean, which contributes to the existence of biases in their simulations of present-day SSTs – greater than 2 °C along the West African coast. The bias is computed by subtracting the Reynolds (1988) SST climatology (for 1961-2000) from the corresponding CGCM climatology for each month. The bias-correction is applied consistently throughout the simulation. Through this procedure the climatology of the SSTs applied as lower boundary forcing is the same as that of the Reynolds SSTs. However, the intra-annual variability and climate-change signal of the CGCM SSTs are preserved (Katzfey et al., 2009).

A multiple-nudging strategy was followed to obtain the 8 km resolution outputs. After completion of the 50 km resolution simulations described above, CCAM was integrated in stretched-grid mode over southern Africa, at a resolution of about 8 km (0.08° degrees in latitude and longitude). The high-resolution part of the model domain was about 2000 x 2000 km² in size and centred at 28°E, 25°S. The higher resolution simulations were nudged within the quasi-uniform global simulations, through the application of a digital filter using a 600 km length scale. The filter was applied at six-hourly intervals and from 900 hPa upwards.

The model integrations performed at a resolution of 8 km over South Africa offer a number of advantages over the 50 km resolution simulations. Firstly, the influence of convective rainfall is partially resolved in the 8 km simulations, implying that the model is less dependent on statistics to simulate this intricate aspect of the atmospheric dynamics and physics. Secondly, important topographic features such as the eastern escarpment and Cape Fold mountains are significantly better resolved in the 8 km resolution simulations, indicating that the topographic forcing of temperatures, wind patterns and orographic rainfall can be simulated more realistically. The 8 km resolution results represented here may therefore be regarded as potentially providing new insights into the futures of extreme weather events over South Africa under a changing climate.

B.2 Regional Climate Change Projections

This section presents the projected changes of several climatological variables, including extreme weather-event metrics, for a domain covering the southwestern Cape. The projected changes in each



metric are subsequently shown for the time periods 2021-2050 (mid-future) and 2070-2099 (far-future) relative to the baseline period 1961-2000 for the low-mitigation scenario (RCP 8.5). Three maps are presented for each climate metric, for both mid-future and far-future periods. These maps show the 10th, 50th (median) and 90th percentiles of projected changes for the entire ensemble of projections outlined in Box 2. In this way, it is possible to gain some understanding of the uncertainty range that is associated with the projections. Finally, the projections are shown for the region 35 °S to 31 °S and 17 °E to 23 °E, that is, for a domain covering the southwestern Cape. A list of the climate and hazard metrics analysed in this report is provided in Table 1.

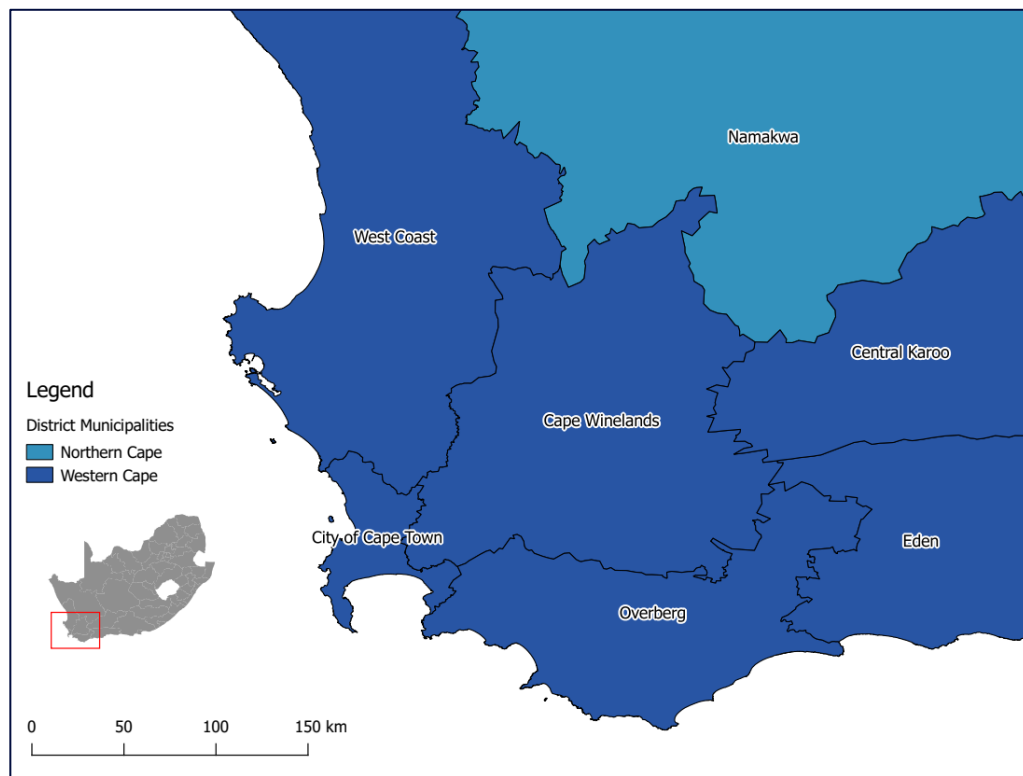
Table 1: Key Climate and Hazard Metrics

Metric	Description and/or units
Average, maximum and minimum temperature	°C (Degrees Celsius)
Very hot days	A day when the maximum temperature exceeds 35 °C. Units are number of events per grid point per year.
Heat-wave days	The maximum temperature exceeds the average temperature of the warmest month of the year by 5 °C for at least 3 days.
High fire-danger days	McArthur fire-danger index exceeds a value of 24. Units are number of events per grid point per year.
Rainfall	mm (Millimetres)
Extreme rainfall	More than 20 mm of rain falling within 24 hrs over an area of 64 km ² . The occurrence of extreme convective rainfall is used as a proxy for the occurrence of storms that produce lightning. Units are number of events per grid point per year.
Windspeed	Annual average windspeed, metres per second (m/s)

Figure 2 illustrates the locations of the district municipalities (DMs) in the southwestern Cape region, for reference when analysing the spatial distribution of the metrics above.



Figure 2: District Municipalities of the Southwestern Cape



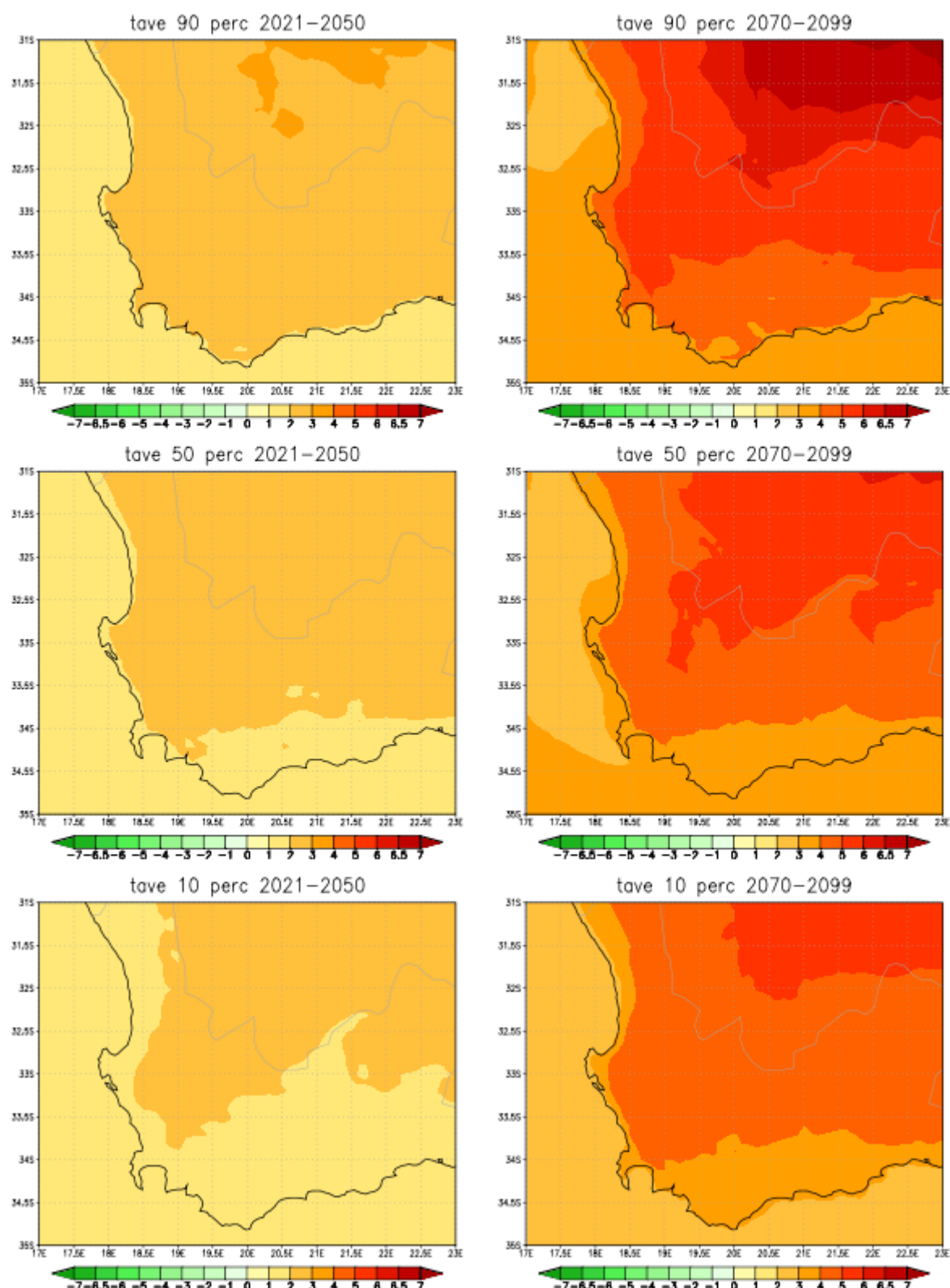
B.2.1 Average, maximum and minimum temperature

Projected changes in annual average temperature, as well as average maximum and average minimum temperatures are shown in Figures 3, 4 and 5, respectively. The following is evident from these figures, in conjunction with the AR5 assessment of Niang et al. (2014), Engelbrecht et al. (2015) and the SR1.5 assessment of Hoegh-Guldberg et al. (2018):

- Rapid rises in the annual average, maximum and minimum near-surface temperatures are projected to occur over the northern interior (Namakwa DM) of the Western Cape during the 21st century – temperature over this region is projected to rise at about 1.5 to 2 times the global rate.
- **For the mid-future period**, temperature increases of 2 to 3 °C may plausibly occur over most of the Western Cape. Over Cape Agulhas and further to the east along the Cape south coast (southern Overberg and Eden DMs) it is likely that temperature increases will be slightly less, in the order of about 2°C. These relatively smaller increases are due to the moderating effects of the ocean. Cape Town DM shows a variable 0-2 °C increase throughout the municipality.
- **For the far-future period**, temperature increases of more than 4°C are projected to occur over the northern interior regions (Namakwa DM) of the Western Cape, with increases of about 3°C projected for the southern coastal regions (southern Overberg and Eden DMs). Maximum temperatures are projected to rise faster than minimum temperatures over the south-western Cape (Cape Town DM). Temperature projections vary from 2-4 °C from the southern to the northern parts of the Cape Town DM.

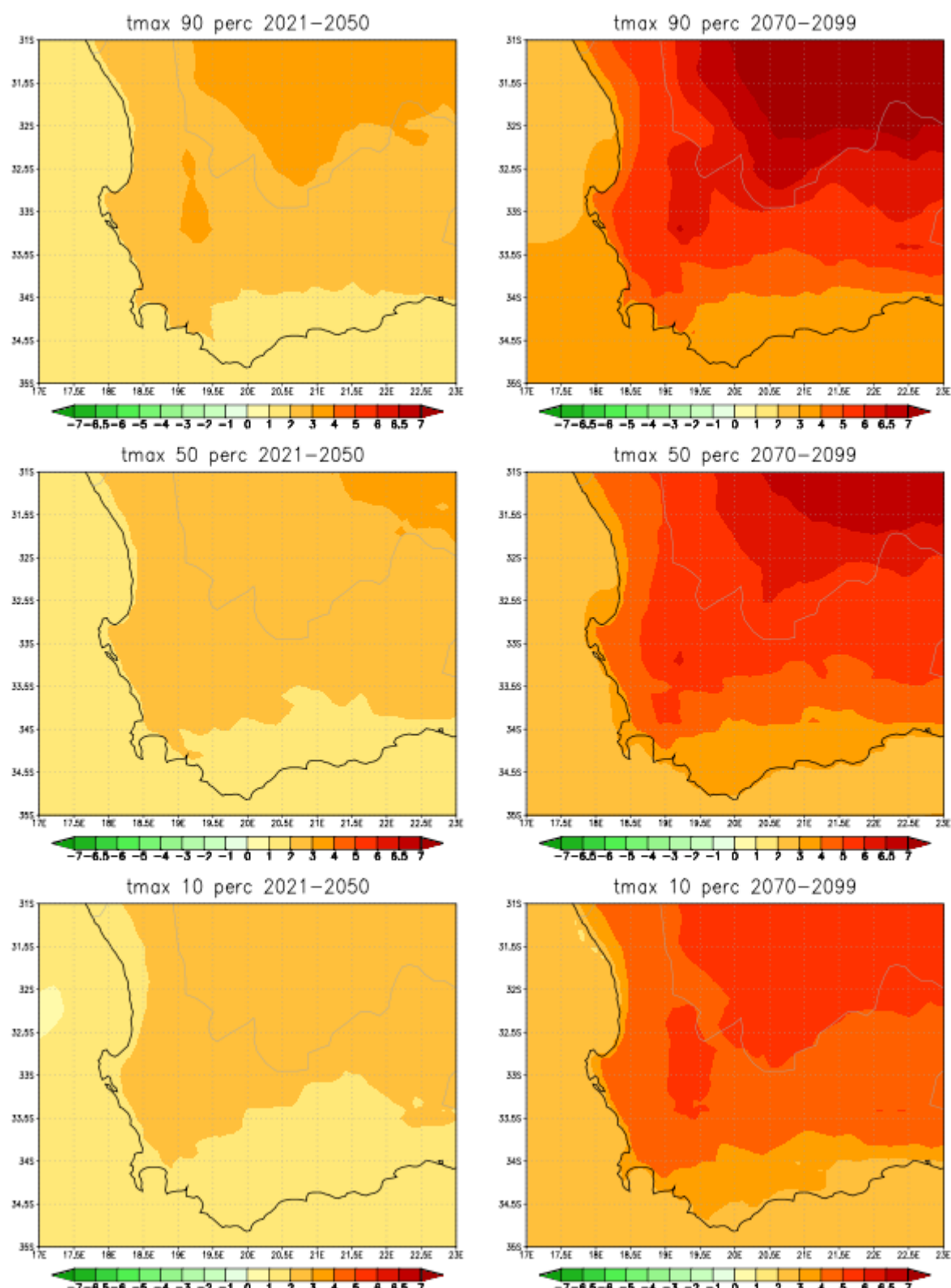
Impacts: Such drastic temperature increases will have significant impacts on numerous sectors, including agriculture, water and energy. Increasing temperatures, already by the mid-future, and more so by the far-future, would contribute to enhanced evaporation of soil-moisture and also from surface water resources. Associated increases in temperature extremes are likely to impact directly on human health, crop yield, livestock, the household demand for energy, as well as migration and general fire risk.

Figure 3: Projected change in the annual average temperature (°C)



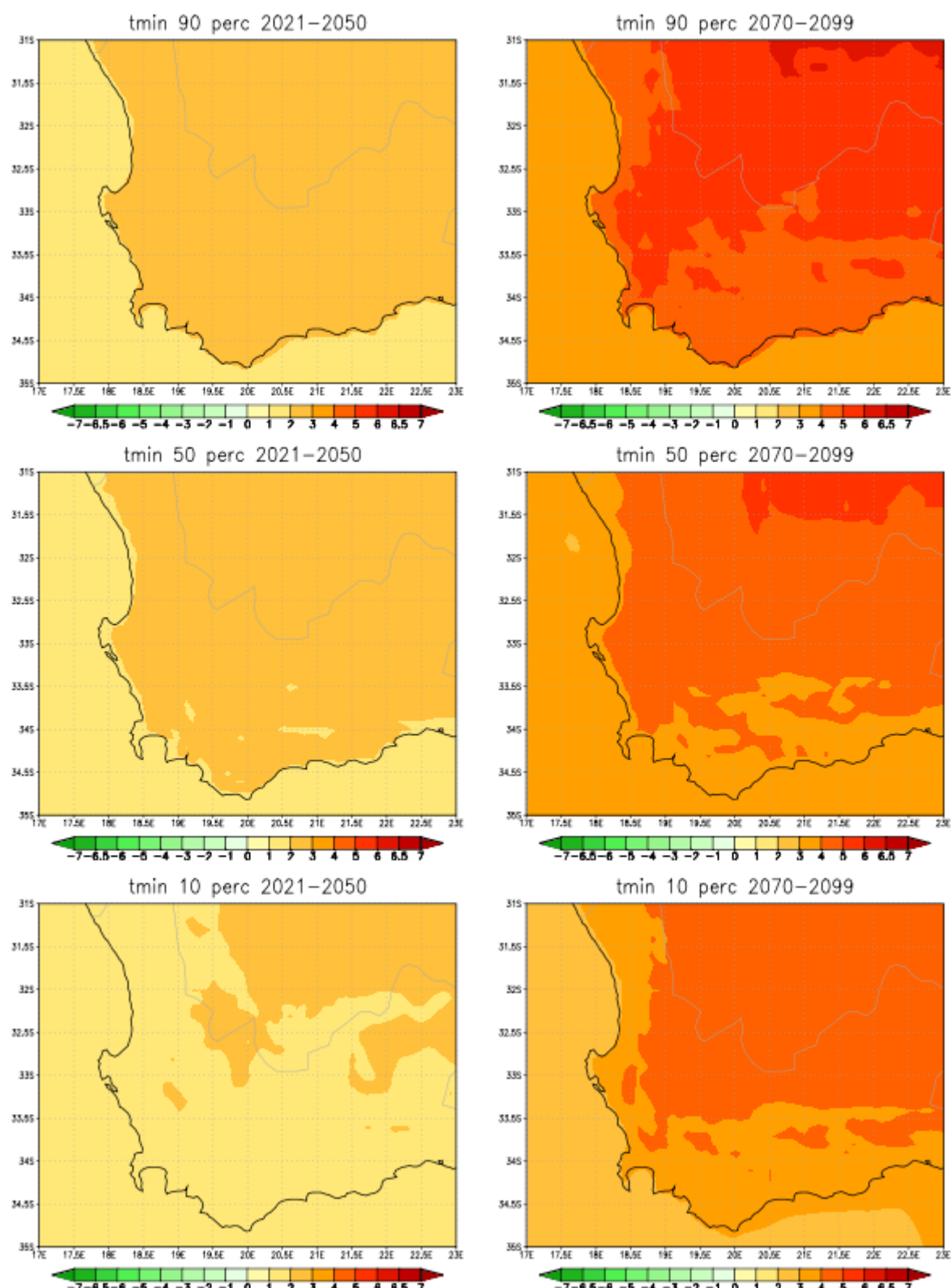
Projected change in the annual average temperature (°C) over the southwestern Cape in South Africa at 8 km resolution, for the time period 2021-2050 relative to 1961-1990 (left) and for 2070-2099 relative to 1961-1990 (right). The 10th, 50th and 90th percentiles are shown under a low-mitigation scenario (RCP8.5).

Figure 4: Projected change in the annual average maximum temperature (°C)



Projected change in the annual average maximum temperature (°C) over the southwestern Cape in South Africa at 8 km resolution, for the time period 2021-2050 relative to 1961-1990 (left) and for 2070-2099 relative to 1961-1990 (right). The 10th, 50th and 90th percentiles are shown under a low-mitigation scenario (RCP8.5).

Figure 5: Projected change in the annual average minimum temperature (°C)



Projected change in the annual average minimum temperature (°C) over the southwestern Cape in South Africa at 8 km resolution, for the time period 2021-2050 relative to 1961-1990 (left) and for 2070-2099 relative to 1961-1990 (right). The 10th, 50th and 90th percentiles are shown under a low-mitigation scenario (RCP8.5).

B.2.2 Very hot days

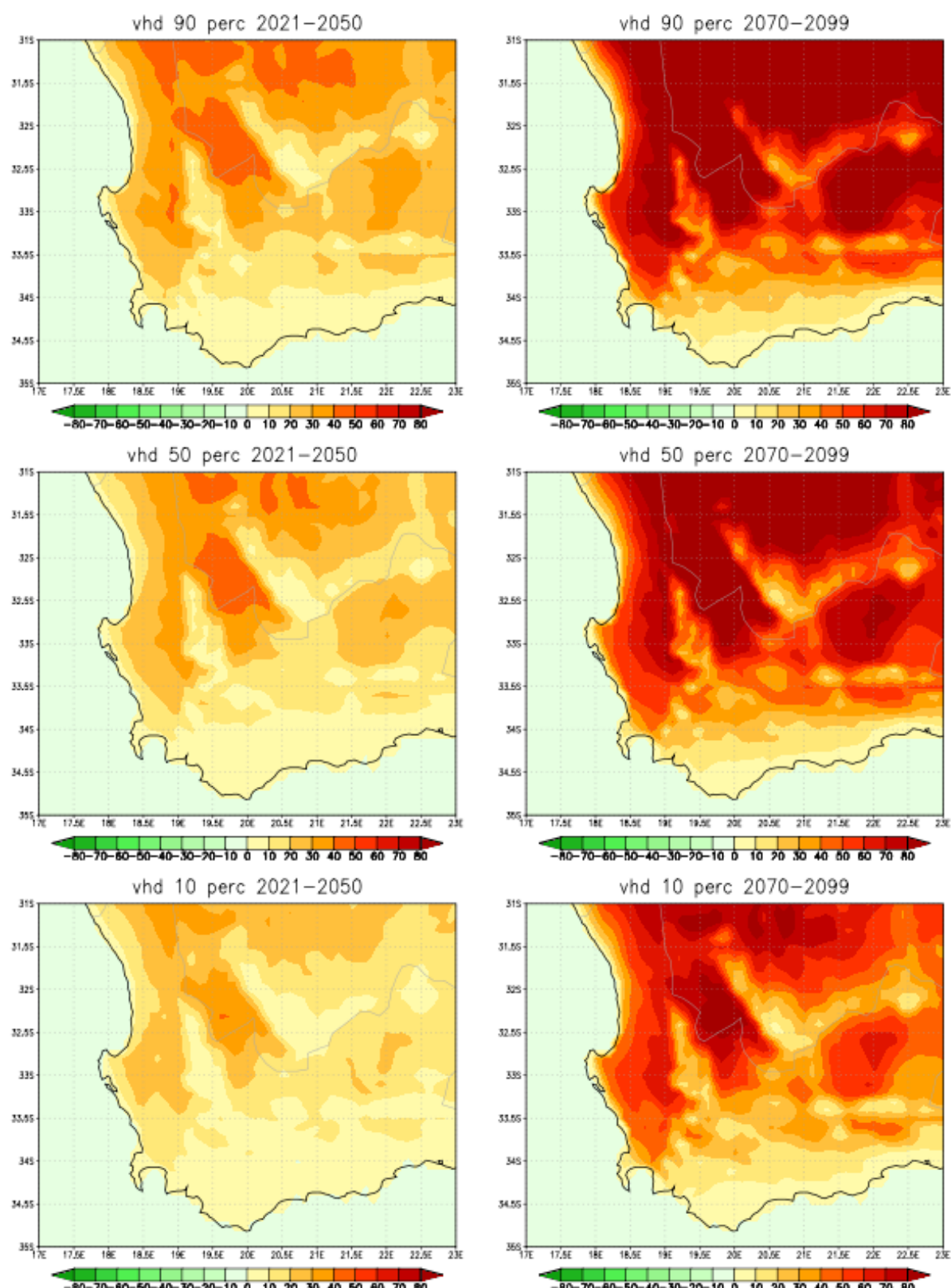
Projected changes in the annual average number of very hot days are shown in Figure 6. The following is evident from the figure, in conjunction with the AR5 assessment of Niang et al. (2014), Engelbrecht et al. (2015), Garland et al. (2015) and the SR1.5 assessment of Hoegh-Guldberg et al. (2018):

- In association with drastically rising maximum temperatures (Figure 5) the frequency of occurrence of very hot days is also projected to increase drastically under climate change.
- **For the mid-future period**, very hot days are projected to increase by about 10 days per year over the southern coastal areas (southern Overberg and Eden DMs) and in a narrow strip along the west coast, by 10-20 days per year over the central parts of the province (Cape Winelands and Central Karoo DMs) and by more than 30 days per year over the northern parts of the southwestern Cape (Namakwa DM). Projected increases in very hot days vary from 0-20 from the southern to the northern parts of the Cape Town DM.
- **For the far-future period**, very hot days are projected to increase by about 10 days per year in the narrow strip along the Cape south coast (southern Overberg and Eden DMs). A meridional (north-south) gradient exists in the projected increase in the number of very hot days across the province, with an increase of 80 or more such days per year projected for the northern interior regions (Namakwa DM) – a drastic and potentially devastating increase. Projected increases in very hot days vary from 0-50 from the southern to the northern parts of the Cape Town DM.

Impacts: Increases in the occurrence of very hot days occur in association with projected increases in the frequency of occurrence of heat-wave days and high fire-danger days (see Appendix 1). These changes may impact on human and animal health through increased heat stress and are likely to impact negatively on crop yield. They are also likely to increase the probability of veld and forest fires.



Figure 6: Projected change in the annual average number of very hot days



Projected change in the annual average number of very hot days (units are days per grid point per year) over the southwestern Cape in South Africa at 8 km resolution, for the time period 2021-2050 relative to 1961-1990 (left) and for 2070-2099 relative to 1961-1990 (right). The 10th, 50th and 90th percentiles are shown under a low-mitigation scenario (RCP8.5).

B.2.3 Heat-wave days

A heat-wave is defined as an event when the maximum temperature at a specific location exceeds the average maximum temperature of the warmest month of the year at that location by 5 °C, for a period of at least three days. The total number of days occurring within a heat-wave is referred to as "heat-wave days". Heat-waves are rare events in terms of South Africa's present-day climate, with very few locations experiencing more than 10 heat-wave days on the average per annum.

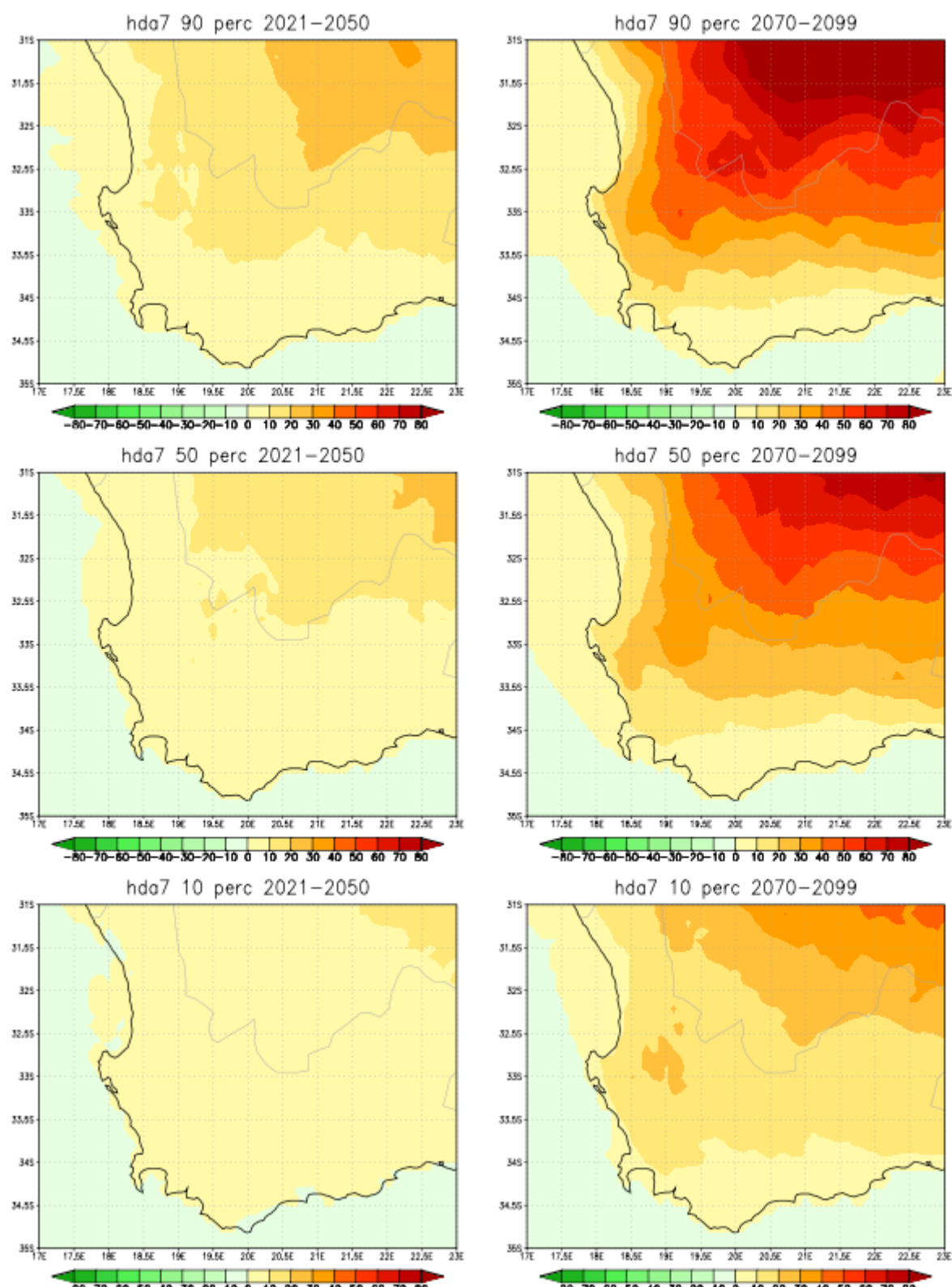
Projected changes in the annual average number of heat-wave days are shown in Figure 7. The following is evident from the figure, in conjunction with the AR5 assessment of Niang et al. (2014), Engelbrecht et al. (2015), Garland et al. (2015) and the SR1.5 assessment of Hoegh-Guldberg et al. (2018):

- In association with drastically rising maximum temperatures (Figure 5), the frequency of occurrence of heat-wave days is also projected to increase drastically under climate change.
- **For the mid-future period**, heat-wave days are projected to increase by less than 10 days per year over most of the Western Cape and plausibly by 10-20 days per year over most northern parts of the province (Namakwa DM). Projected increases in heat-wave days vary from 0-10 from the southern to the northern parts of the Cape Town DM.
- **For the far-future period**, heat-wave days are projected to increase drastically and with a south-north gradient across the province, reaching increases of 40-50 days per year over the northern parts of the Western Cape (Namakwa DM). Projected increases in heat-wave days vary from 0-20 from the southern to the northern parts of the Cape Town DM.

Impacts: Significantly increased numbers of heat-wave days will impact on human, plant and animal health through increased heat stress. Increased numbers of such days are also likely to impact negatively on crop yield and increase the likelihood of veld and forest fires.



Figure 7: Projected change in the annual average number of heat-wave days



Projected change in the annual average number of heat-wave days (units are days per grid point per year) over the southwestern Cape in South Africa at 8 km resolution, for the time period 2021-2050 relative to 1961-1990 (left) and for 2070-2099 relative to 1961-1990 (right). The 10th, 50th and 90th percentiles are shown under a low-mitigation scenario (RCP8.5).

B.2.4 High fire-danger days

Projected changes in the annual average number of high fire-danger days are shown in Figure 8. Fire danger is a combination of factors that affect initiation, spread and the ease of controlling fires. High fire-danger days are days when the [McArthur Forest Fire Danger Index \(FFDI\)](#) exceeds a value of 12, where units are the number of days per model grid point. Note that the FFDI has been used extensively to study Fynbos Fire risk over the southwestern Cape and Cape south coast regions (e.g. Van Wilgen et al., 2010). The following is evident from the figure, in conjunction with the AR5 assessment of Niang et al. (2014), Engelbrecht et al. (2015), Garland et al. (2015) and the SR1.5 assessment of Hoegh-Guldberg et al. (2018):

- In association with drastically rising maximum temperatures (Figure 5), the simulation shows that the frequency of occurrence of high fire-danger days is also projected to increase drastically under climate change.
- **For the mid-future period**, high fire-danger days are projected to increase by up to 10 days per year along the southern coastal regions (southern Overberg and Eden DMs), with larger increases to the north (Namakwa and West Coast DMs), reaching values of 20-30 days per year over the northern parts of the south-eastern Cape. Projected increases in high fire-danger days vary from 0-20 from the southern to the northern parts of the Cape Town DM.
- **For the far-future period**, high fire-danger days are projected to increase, with more than 80 days per year over the far northern parts of the province (Cape Winelands, West Coast and Namakwa DMs). Substantial increases are projected in the Fynbos regions of the Cape Fold mountains. It is only along the Cape south coast regions (southern Eden and Overberg DMs), under the moderating influence of the ocean, where increases are likely to be restricted to about 10 days per year. Projected increases in high fire-danger days vary from 0-60 from the southern to the northern parts of the Cape Town DM.

Impacts: Notable increases in high fire-danger days will impact directly on human, plant and animal health, as well as threaten physical and natural infrastructure. This could impact significantly on crop yields, tourism, property values, emergency services, etc.

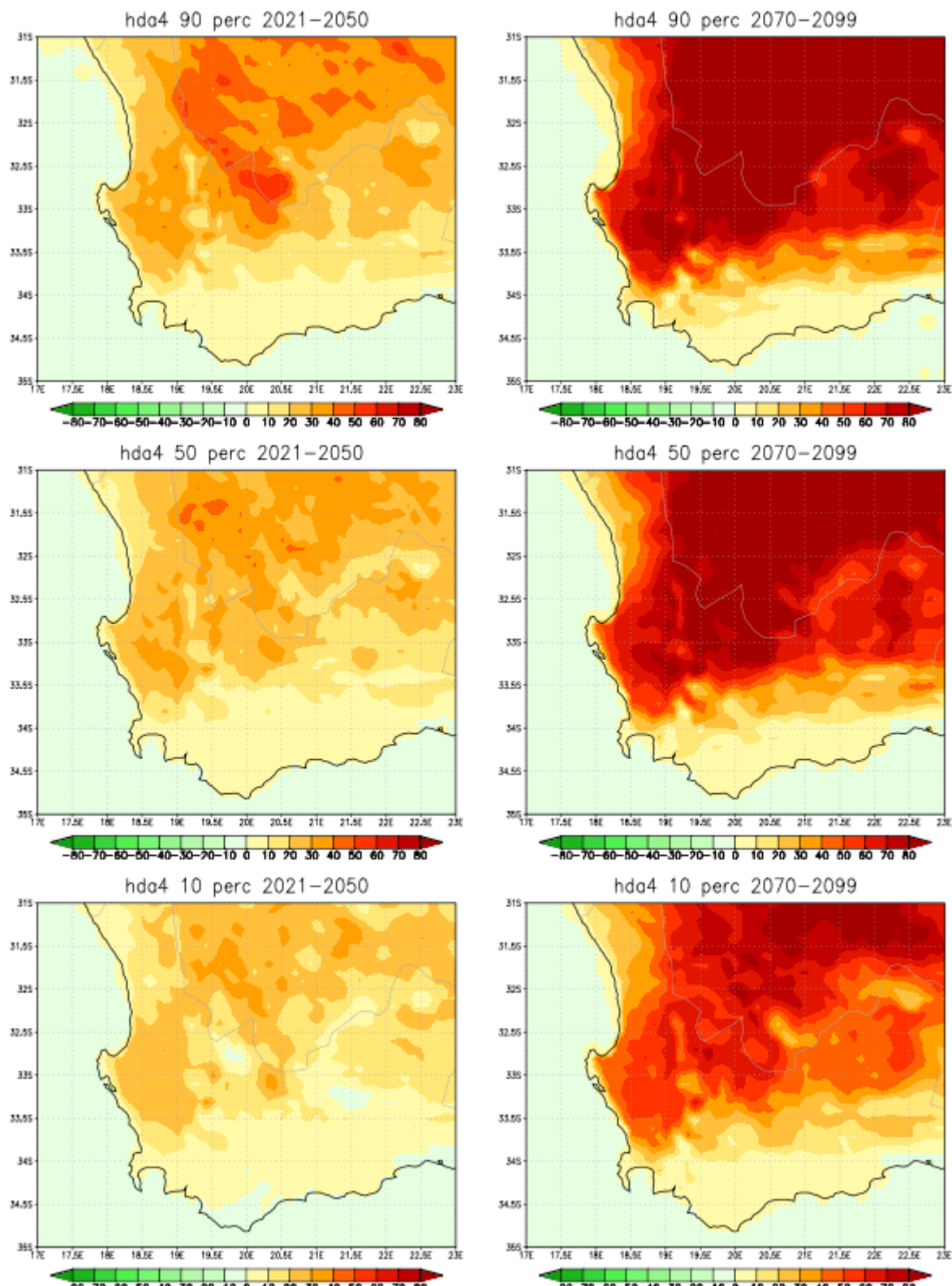
B.2.4.1 Seasonality of fire risk

High fire-danger days have a seasonal cycle, which is related to the increasing risk for runaway veld and forest fires. The Fynbos biome has evolved over hundreds of thousands of years in the cool, wet winters and dry, warm summers of South Africa's winter rainfall region. Fire thus occurs as a natural phenomenon in the Fynbos biome during the dry summer months, following the production of biomass during the wet seasons. However, climate change is projected to significantly alter the seasonal cycle in rainfall over the southwestern Cape.

Appendix 1 provides an examination of the projected changes in the seasonal cycle of the number of high fire-danger days for two cases, of Cederberg, in the south-west, and Vermaaklikheid (on the Cape south coast). These cases illustrate two contrasting examples of projected change in fire risk in the southwestern Cape. At Vermaaklikheid along the Cape South coast region, the FFDI is indicative of a notably smaller change in fire risk than over the Cederberg region to the north. Although projections indicate high fire risk days will increase over the mid- and far-future periods for both regions, the Cederberg will experience more high-risk days. Projected changes in temperature, wind speed, relative humidity and drought conditions influence the future fire risk. Thus, based on the temperature (Section B.2.1), wind (see Section B.2.7) and rainfall (Section B.2.5) projections, Cape Town will experience up to 20-60 more high fire risk days per year (see Section B.3). It should be noted that the FFDI is focused on assessing risk of wildfires. Although the underlying climate conditions that influence the likelihood of urban fires are largely the same, the physical pathways through which fire risk manifests are different (discussed further in Section D.).



Figure 8: Projected change in the annual average number of high fire-danger days



Projected change in the annual average number of high fire-danger days (units are days per grid point per year) over the southwestern Cape in South Africa at 8 km resolution, for the time period 2021-2050 relative to 1961-1990 (left) and for 2070-2099 relative to 1961-1990 (right). The 10th, 50th and 90th percentiles are shown under a low-mitigation scenario (RCP8.5).

B.2.5 Rainfall

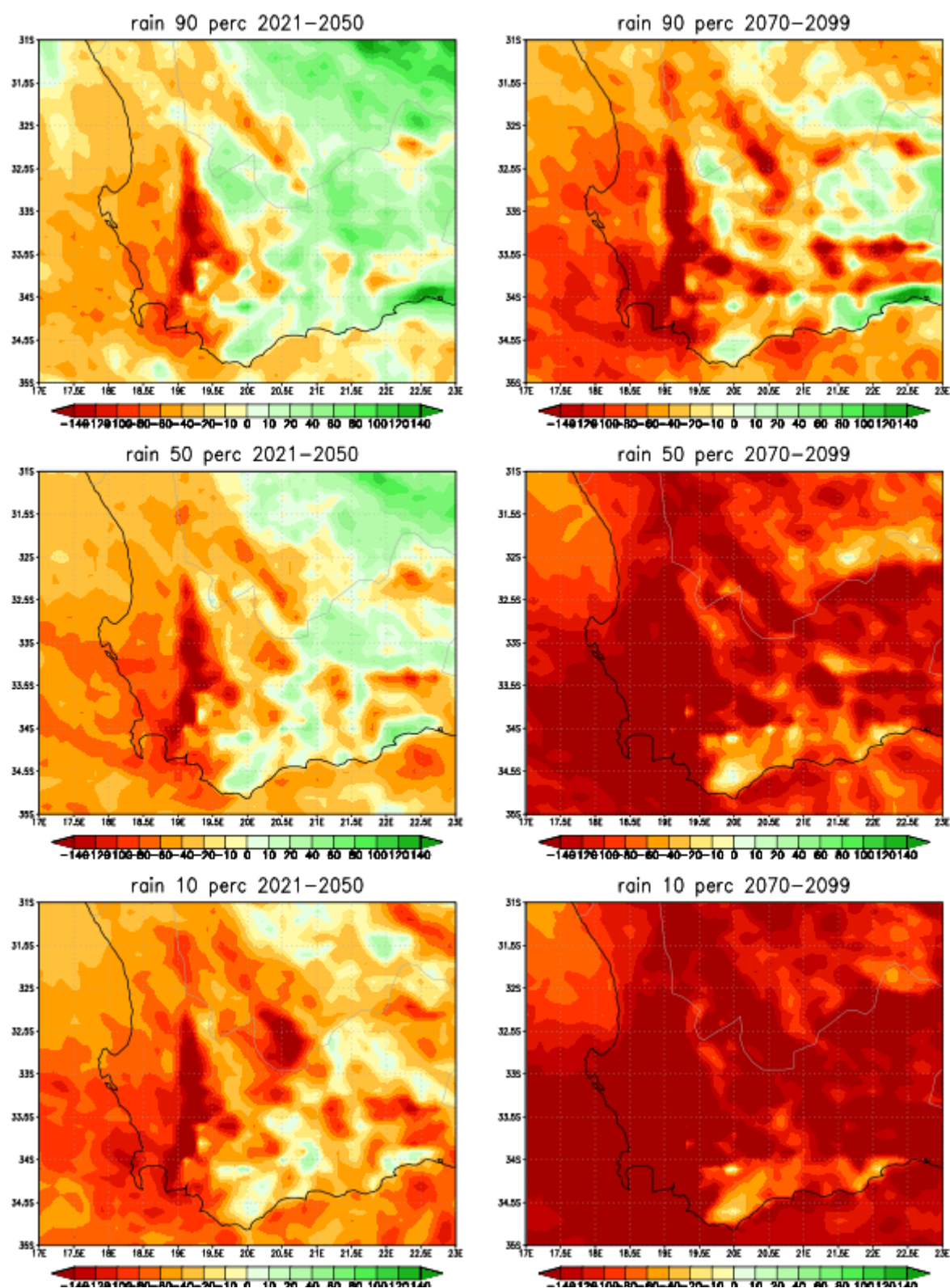
Projected changes in annual average rainfall are shown in Figure 9. The following is evident from the figure, in conjunction with the AR5 assessment of Niang et al. (2014), Christensen et al. (2007), Engelbrecht et al. (2009), Engelbrecht et al. (2015) and the SR1.5 assessment of Hoegh-Guldberg et al. (2018):

- A general decrease in average rainfall is likely to occur over the winter rainfall region of South Africa under enhanced and continued human-induced climate change.
- **For the mid-future period**, rainfall is projected to decrease substantially along the south-north aligned Cape Fold mountains north of Cape Town (West Coast and Cape Winelands DMs), including over the important catchment areas of the Cape Town dams. Over the eastern interior (Cape Winelands, Central Karoo and Eden DMs), rainfall increases are projected by some projections. This results from an increase in the occurrence of convective storms over this region. Projected decreases in rainfall vary from 60-120mm from the northern to the southern parts of the Cape Town DM.
- **For the far-future period**, rainfall is projected to decrease substantially across the Western Cape. The largest decreases are projected to occur over the meridionally aligned and zonally aligned Cape Fold mountains (West Coast, Cape Winelands and Overberg DMs). The displacement of frontal systems towards the South Pole under low mitigation futures is the main dynamic mechanism underpinning the projected decreased in rainfall. Increases in the strength of the subtropical high pressure reduce the signal of increasing convective rainfall in the east, so that this signal is weaker compared to the mid-future period. Projected decreases in rainfall vary from 80-160mm from the northern to the southern parts of the Cape Town DM.
- Reductions in rainfall will manifest as soon as the 2021-2050 (mid-future) period. Nevertheless, the rainfall projections display more uncertainty than in the case of projected changes in temperature. This implies that adaptation policy makers need to take into account a range of different rainfall futures (i.e. drier and wetter), in particular for the eastern interior of the Western Cape.

Impacts: Notable reductions in annual average rainfall will have a myriad of impacts on all sectors within and around Cape Town. Long term water supplies will be compromised and negatively impact water and food security. This will have a number of ripple effects throughout the economic, social and environmental systems.



Figure 9: Projected change in annual average rainfall totals (mm)



Projected change in annual average rainfall totals (mm) over the southwestern Cape in South Africa at 8 km resolution, for the time period 2021-2050 relative to 1961-1990 (left) and for 2070-2099 relative to 1961-1990 (right). The 10th, 50th and 90th percentiles are shown under a low-mitigation scenario (RCP8.5).

B.2.6 Extreme rainfall events

Projected changes in extreme rainfall events are shown in Figure 10. Here an extreme rainfall event is defined as 20 mm of rain occurring within 24 hours over an area of 64 km². The following is evident from the figure, in conjunction with the AR5 assessment of Niang et al. (2014), Engelbrecht et al. (2009), Engelbrecht et al. (2013) and the SR1.5 assessment of Hoegh-Guldberg et al. (2018):

- **For the mid-future period**, consistent with the projected decreases in rainfall, extreme rainfall events are projected to decrease in frequency over most of the southwestern Cape. This is true in particular for the south-north aligned Cape Fold mountains region (West Coast and Overberg DMs), and the catchment regions of the Western Cape Water Supply System (WCWSS) dams. A number of projections show increases in extreme rainfall events over the eastern parts of the interior of the Western Cape (Central Karoo and Eden DMs), as a consequence of convective rainfall increasing over this region. Projected decreases in extreme rainfall events vary from 0-3 days throughout the Cape Town DM.
- **For the far-future period**, extreme rainfall events are projected to decrease further in frequency over the Western Cape. This signal of decreasing extreme events also extends to the eastern interior regions of the Western Cape (Central Karoo and Eden DMs), implying that in the far-future the strengthening of the subtropical high-pressure belt and associated subsidence will be the dominant change in circulation. The relatively large decreases in extreme rainfall events projected for the Cape Fold mountains are important from the perspectives of run-off and water security. Projected decreases in extreme rainfall events vary from 0-5 days throughout the Cape Town DM.

Impacts: Extreme rainfall events, such as those occurring over the eastern part of the Western Cape interior, are mostly caused by intense thunderstorms, which often also cause lightning, hail, damaging winds and flash floods. Adaptation policies therefore need to take into account the possibility that extreme rainfall events may increase in frequency, in the mid-future, over the eastern interior regions of the Western Cape. Box 3 explores the uncertainties in projections of extreme rainfall in the Western Cape.

Box 3: Understanding Extreme Rainfall Projections

As the air temperature rises, the air can hold more water. This amount is about 7% more water vapour per 1°C rise in air temperature per unit volume of atmosphere at ambient conditions, according to the Clausius-Clapeyron equation (Trenberth et al., 2003). This means that with global warming and more moisture in the atmosphere, storms will become more energetic (the extra water condensing into rainfall releases additional latent heat). It also means that convection storms will become more intense, releasing greater amounts of water.

These effects are not always seen in climate models because many do not resolve convective clouds and rely on statistical methods to describe the probability of convective precipitation occurring across model cells (Lenderink et al., 2017). Convection-permitting models also often show stronger precipitation responses than models in which convection is parameterised, but must be run at much finer scales (Kendon et al., 2014). For example, climate models with inter-nodal distances of 1.5 km usually show increases in intensities of short-duration rainfall at the high thresholds that lead to localised flooding.

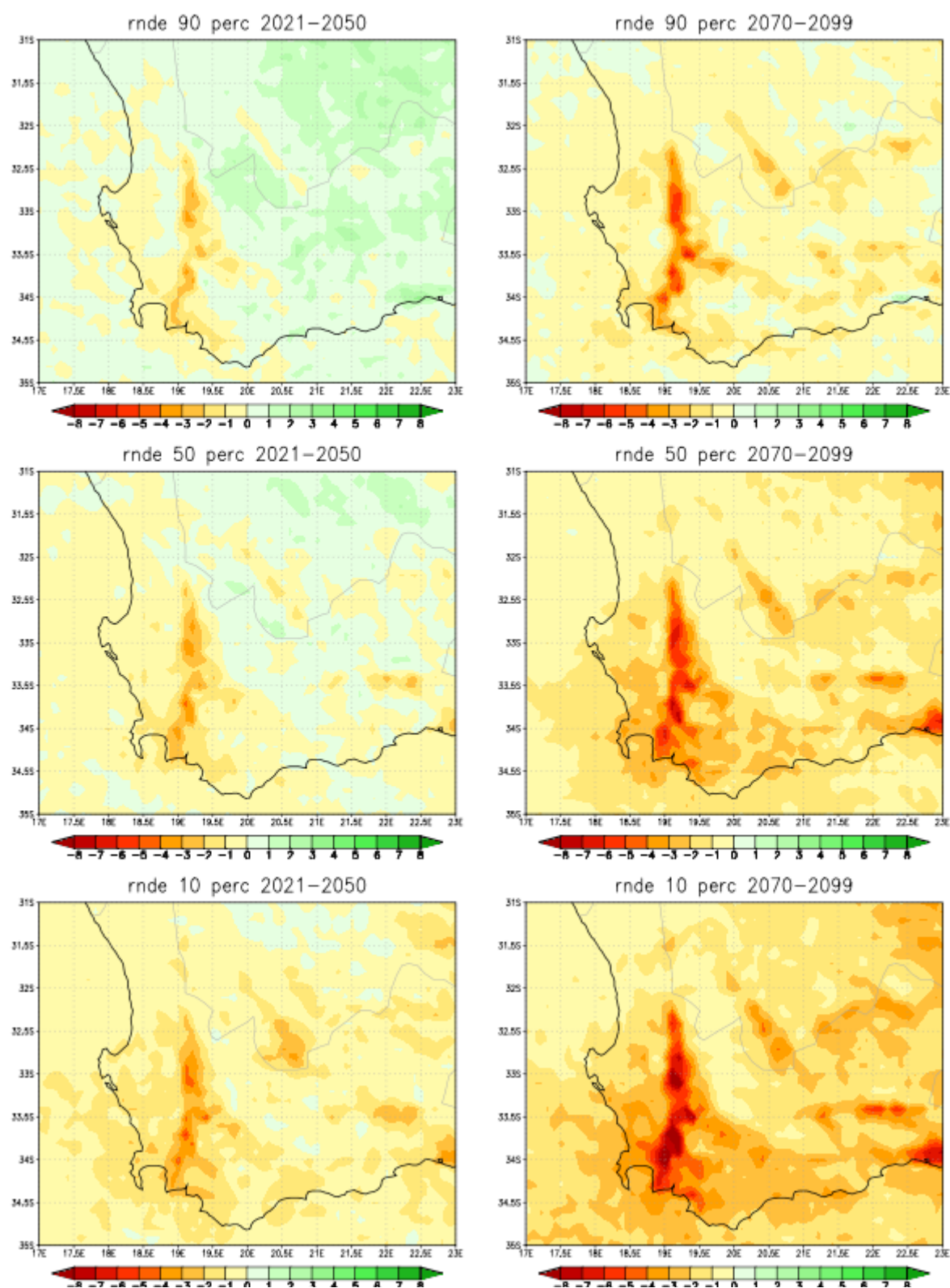
Larger-scale models or those with larger inter-nodal distances are less able to represent local-scale storm dynamics. Modelling convection systems at significantly finer scales leads to a higher number of convective extremes and rainfall intensities increase as a result of warming (Kendon et al., 2014). *The implications are that climate models at the larger model inter-nodal distances can underestimate convection intensity with rising atmospheric temperatures.*

Increased intensities of rainfall with a warming atmosphere have already been observed in Australia by Wasko and Sharma (2015) and Guerreiro et al. (2018). This same phenomenon has tentatively been identified over the Western Cape by Pharoah et al. (2016), in which cut-off low storm systems in summer have caused more damage than those in winter because rainfalls were more intense. Further, de Waal et al. (2017) have shown recent increases in storm intensity in the Western Cape based on observed trends.

In summary, climate modelling shows a reduction in extreme rainfalls over the Western Cape and Cape Town over time, but local observations support the notion that increasing intensities of rainfall have fallen in recent years. Objectively, warming air masses will be able to hold more water and this must precipitate somewhere. Prudence will dictate that the City of Cape Town concern itself also with a possible future of increasing intensity of extreme rainfall, and all that that entails with respect to infrastructure and the management of storm water and settlement patterns.



Figure 10: Projected change in the annual average number of extreme rainfall days



Projected change in the annual average number of extreme rainfall days (units are days per grid point per year) over the southwestern Cape in South Africa at 8 km resolution, for the time period 2021-2050 relative to 1961-1990 (left) and for 2070-2099 relative to 1961-1990 (right). The 10th, 50th and 90th percentiles are shown under a low-mitigation scenario (RCP8.5).

B.2.7 Wind Speed

Projected changes in annual average wind speed are shown in Figure 13, following after Box 4. The following is evident from the figure, in conjunction with the AR5 assessment of Niang et al. (2014), Engelbrecht et al. (2009), Engelbrecht et al. (2013) and the SR1.5 assessment of Hoegh-Guldberg et al. (2018):

- **For the mid-future period**, slight to moderate windspeed increases are projected fairly uniformly across the City of Cape town, with the southern Peninsula expected to experience slightly higher increases in annual average wind speed. However, these moderate increases in annual average windspeed are not uniform over the broader southwestern Cape, with small pockets of higher windspeed increases in the Cape Winelands DM and significant areas projected to experience slight decreases in windspeed towards the northwest and southeastern parts of the region (West Coast, Eden and Central Karoo DM).
- **For the far-future period**, variable increases in windspeed are projected across the City of Cape town, with the southern parts of the City expected to experience higher increases in annual average wind speed. However, these increases in annual average windspeed are not uniform over the broader southwestern Cape, with small pockets of higher windspeed increases in the Cape Winelands DM and significant areas projected to experience moderate decreases in windspeed towards the northwest and southeastern parts of the region (West Coast, Eden and Central Karoo DM).

Impacts: Increased average wind speeds will have a variety of ripple effects on other climate-related hazards such as fires and coastal storms (discussed in Box 4). Strong wind events can cause damage to infrastructure, most notably informal structures that aren't designed to withstand strong gusts of wind. Moreover, increased windspeeds will influence the overall evaporation rates of the dams and rivers in the region. Box 4 discusses wind as a climatic driver for extreme events and conditions.

Box 4: Wind as a climatic driving force for extreme conditions

High wind speeds and gust velocity are important factors in posing a hazard to exposed assets. In a limited number of examples referenced below across the southern Cape, strong winds have been important contributory factors in creating severe social and economic loss, including death and injury (Table 2). The average and 1-hour gust wind speeds are data from the Global Forecast System (GFS), abstracted from the weather modelling system Ventusky. Over the years, Cape Town has experienced many destructive fires driven by strong winds and the data presented in Table 2 is only a small sample of these.

Table 2: Recent fire damage in the southern Cape, enhanced by high wind speeds.

Incident	Damage	Date	Avg. Wind Speed (km/h)	1hr Gust Wind Speed (km/h)	Reference
Franschoek pass closed	Road closed to travel	19-Feb-19	7	20*	(Seleka, 2019)
Betty's Bay	31 houses destroyed, 28 damaged, 1 injured	11-Jan-19	54	90	(Ngqakamba, 2019)
Karwyderskraal	Commercial property threatened	26-Dec-18	41	60	(Mitchley, 2019)
Cape St Francis	12 houses destroyed, 21 damaged	18-Dec-18	47	61	(Sicetsha, 2018)
Karatara, Southern Cape	8 dead, 2 women, 6 children	30-Oct-18	30	76	(Pijoos, 2018)
Capricorn Park, Cape Town	500 informal dwellings destroyed	26-Oct-18	18	35	(Isaacs, 2018)
Khayelitsha, Cape Town	4000 displaced, 1 dead	20-Oct-18	37	50	(Head, 2018)
Knysna, Southern Cape	9 dead, 900 houses destroyed, 2000 jobs lost, R2+ billion in damages	08-Jun-17	50	82	(Forsyth et al., 2019)

* Steep and variable topography creates funnel systems which dramatically increase local wind speeds

Current fire danger rating systems used by the South African Weather Service (SAWS), as a means of predicting



impending fire danger, are not sufficiently representative of the various local weather conditions that give rise to extreme fire danger (Forsyth et al., 2019; Kraaij et al., 2018).

Hourly wind run (the distance wind has travelled over a period of an hour) observed at Cape Town airport for the period 1960 – 2001 indicates not only increasing wind runs but also increasing 1-hour gust speed (Figs 11 and 12). Figure 11 shows the trends in average wind run increase for every month of the year and particularly in the high fire danger months of January, February and March. Figure 12 shows that the trend in maximum annual 1-hour gust velocity has increased substantially during the observation period. If this trend is valid through to 2019 and beyond, the trend has significant implications for increasing fire danger on windy days, or for the increased possibility of structural damage as a result of very strong winds. Most damage occurs during the extreme conditions, not during average conditions. Other research supports these observed increases in wind speed with observations from the surrounding oceans (Young and Ribal, 2019). Wind speeds in the coastal areas are substantially affected by oceanic wind speeds.

Figure 11: Mean increases in wind run at Cape Town airport over the period 1960-2001.

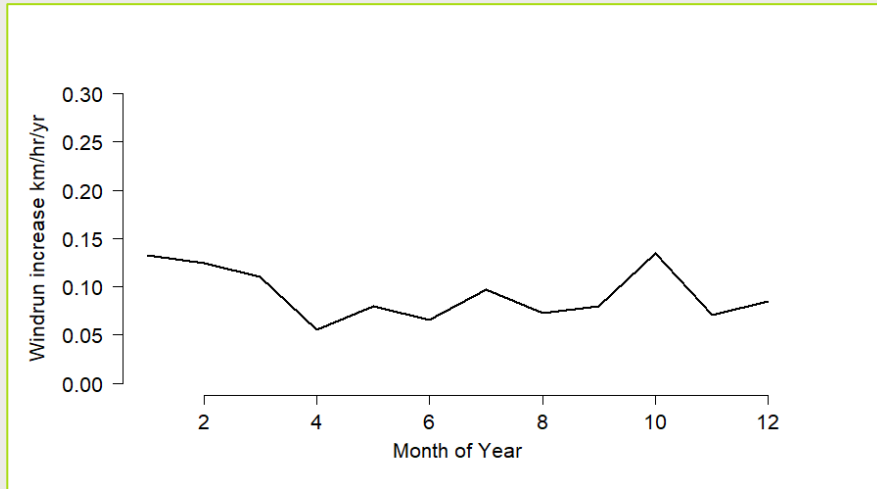


Figure 12: The trend in 1-hour gust wind speed at Cape Town airport for the period 1960-2001

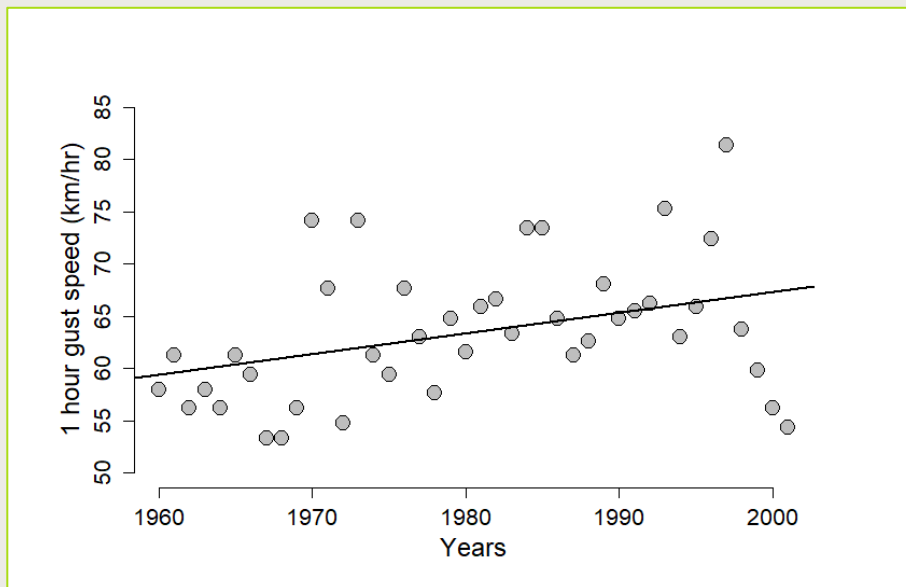
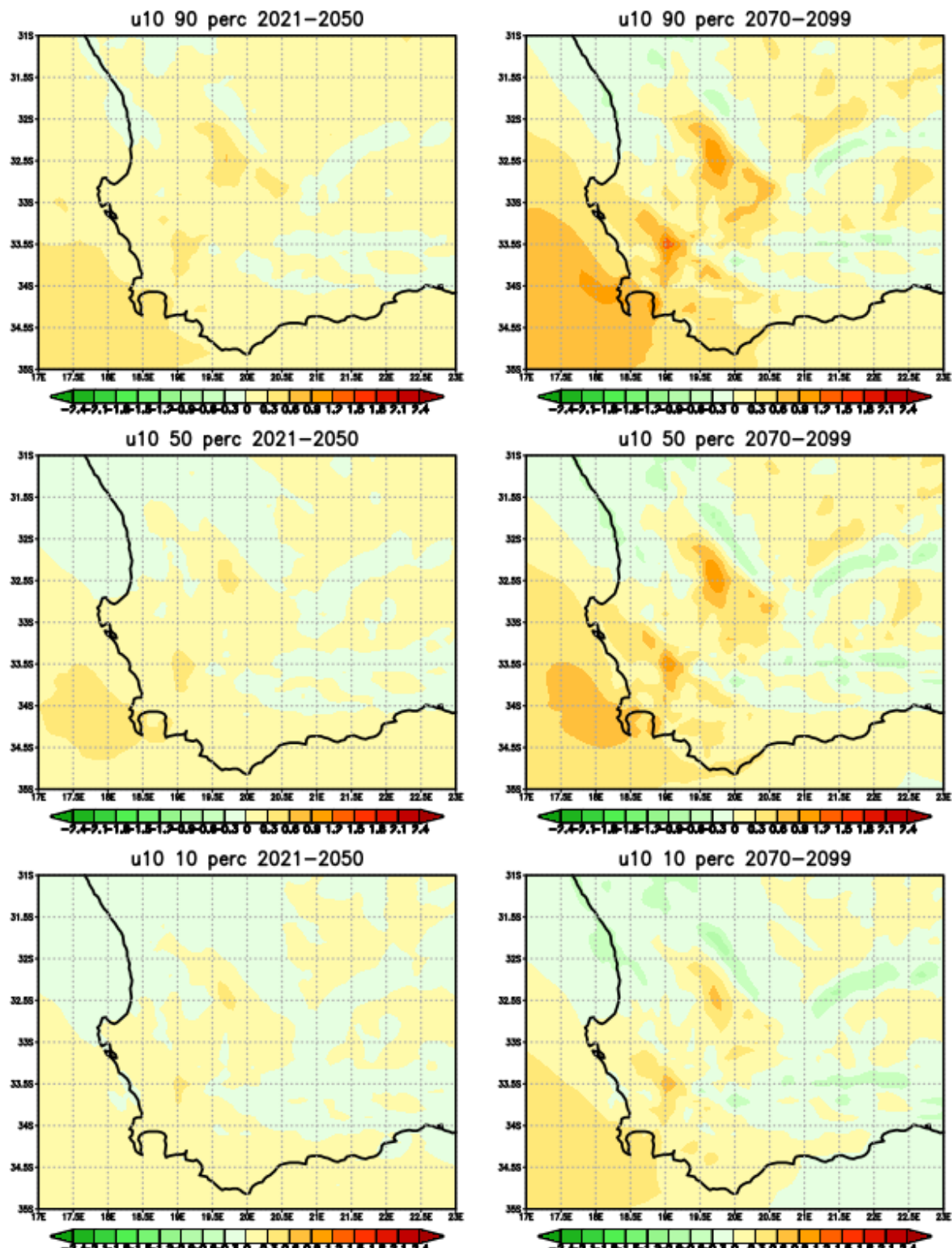


Figure 13: Projected change in the annual average wind speed (m/s)



Projected change in the annual average wind speed (m/s) over the southwestern Cape in South Africa at 8 km resolution, for the time period 2021-2050 relative to 1961-1990 (left) and for 2070-2099 relative to 1961-1990 (right). The 10th, 50th and 90th percentiles are shown under a low mitigation scenario (RCP8.5).

B.2.8 Sea-level Rise and Coastal Storms

South Africa's Third National Communication on Climate Change (2018) states that the observed rate of sea-level rise along the west coast of South Africa over the last few decades was recorded to be 1.87 mm/year, with a rate of +1.48 mm/year recorded on the south coast. These values are somewhat lower than the global rate of sea-level rise. However, both the global rate of sea-level rise and the regional rates of sea-level rise along the South African coastline are likely to increase during the 21st century under enhanced levels of global warming.

A general southward displacement in the Southern Hemisphere westerlies is projected under low mitigation climate change futures. This change is to occur in association with a southward displacement of the Southern Hemisphere storm tracks, including the frontal systems that bring rain to the southwestern Cape and the Cape south coast of South Africa (Engelbrecht et al. 2009). It is this poleward displacement of the Southern Hemisphere westerlies that is the main reason for the expected decreases in rainfall over the winter rainfall region of South Africa (e.g. Christensen et al. 2007; Engelbrecht et al. 2009; Niang et al. 2014; Hoegh-Guldberg et al. 2018). A further consequence of the poleward migration of the Southern Hemisphere westerlies is a projected decrease in the number of cold-core cut-off low pressure systems occurring over southern Africa (Engelbrecht et al. 2013).

A consequence of these changes is that coastal erosion events caused by wind-waves and swells associated with deep low-pressure systems occurring close to the west coast or Cape south coast may plausibly occur less frequently under climate change. However, this does not imply that the risks for coastal erosion will diminish in a changing climate. In fact, under a systematic poleward displacement of the westerlies, southeasterly winds are to occur more frequently over the southwestern Cape, which may lead to slight increases in annual average wind speed over the region (Figure 13, on the previous page). Such a change in average synoptic circulation would also imply changes in the prevailing directions of wind waves and swell impacting on the west coast and Cape south coast. In fact, a recent study based on altimeter readings detected increases in wave height along the west coast and south coast of the southwestern Cape over the period 1985-2018 (Young and Ribal, 2019). The magnitude of these changes is in the order of 2 cm/s/yr and 4 cm/s/yr for average and extreme winds, respectively. Corresponding increases can be detected on the Cape south coast in average significant wave height and extreme values of significant wave height, with the trends being in the order of 0.33 cm/yr and 1 cm/yr, respectively (Young and Ribal, 2019). Given that these increases in significant wave height are also to occur in conjunction with changes in the prevailing direction of wind-waves and swell, the associated impacts on coast erosion and also on sedimentation in harbours need to be investigated rigorously. Numerical projections of the quantitative changes in wind waves and swells (periodicities and amplitudes) under climate change and associated impacts (coastal erosion, sedimentation and operations) remain largely unexplored for all South African harbours.

Sea-level rise inundation projections that were derived from basic contour inundation models are used to provide greater spatial distribution of sea-level rise risk across the City of Cape Town. These projections are captured in the Risk and Vulnerability Assessment in Section C.



B.3 Climate Hazard Assessment: Cape Town

Climate-induced hazards or high-impact weather events pose a significant risk to Cape Town in the context of climate change under a low-mitigation future. Impacts will be both direct (e.g. human health impacts of increasing temperatures and heat-waves; water security impacts of increasing drought frequencies) and indirect (e.g. food security impacts of increasing temperatures and decreasing rainfall in agricultural areas; increased in-migration resulting from threats to rural livelihoods). These indirect impacts or knock-on effects will manifest both within and beyond the boundaries of Cape Town, thus understanding future climate change projections within and beyond City limits is critical. Especially considering some of the projected impacts of climate change are partially moderated in the City region due to the influence of the near-proximity to the ocean.

Based on the assessment of projected changes in climate and associated hazards for the southwestern Cape (Section B.2), specific impacts on Cape Town can be summarised as shown in Table 3, noting that there is notable variation within the City boundaries (discussed further in Section C).

Table 3: Impact of projected climate change and associated hazards on Cape Town

Climate Variable	Projected Impact on Cape Town	
	Mid-Future Period (2021-2050)	Far-Future Period (2070-2099)
Average, maximum and minimum temperature	↑ 1-3 °C	↑ 3-4 °C
Very hot days	↑ 0-20 Days	↑ 0-50
Heat-wave days	↑ 0-10 Days	↑ 0-20 Days
High fire-danger days	↑ 0-20 Days	↑ 0-60 Days
Mean Annual Rainfall	↓ 60-120 mm	↓ 80-160+ mm
Extreme Rainfall days	↓ 0-3 Days	↓ 0-5 Days
Average Wind Speed	↑ 0-0.3 m/s	↑ 0.6-0.9 m/s

For the most part, this assessment corroborates the research findings related to climate change risks for Cape Town (discussed in Section B.1). Specifically:

- a decrease in annual average rainfall;
- a change in the seasonality of rainfall, as the primary winter rainfall generating mechanism becomes weaker;
- an increase in mean annual average, maximum and minimum temperatures;
- more hot days, heat-waves and high fire-danger days; and
- an increase in average wind speeds.

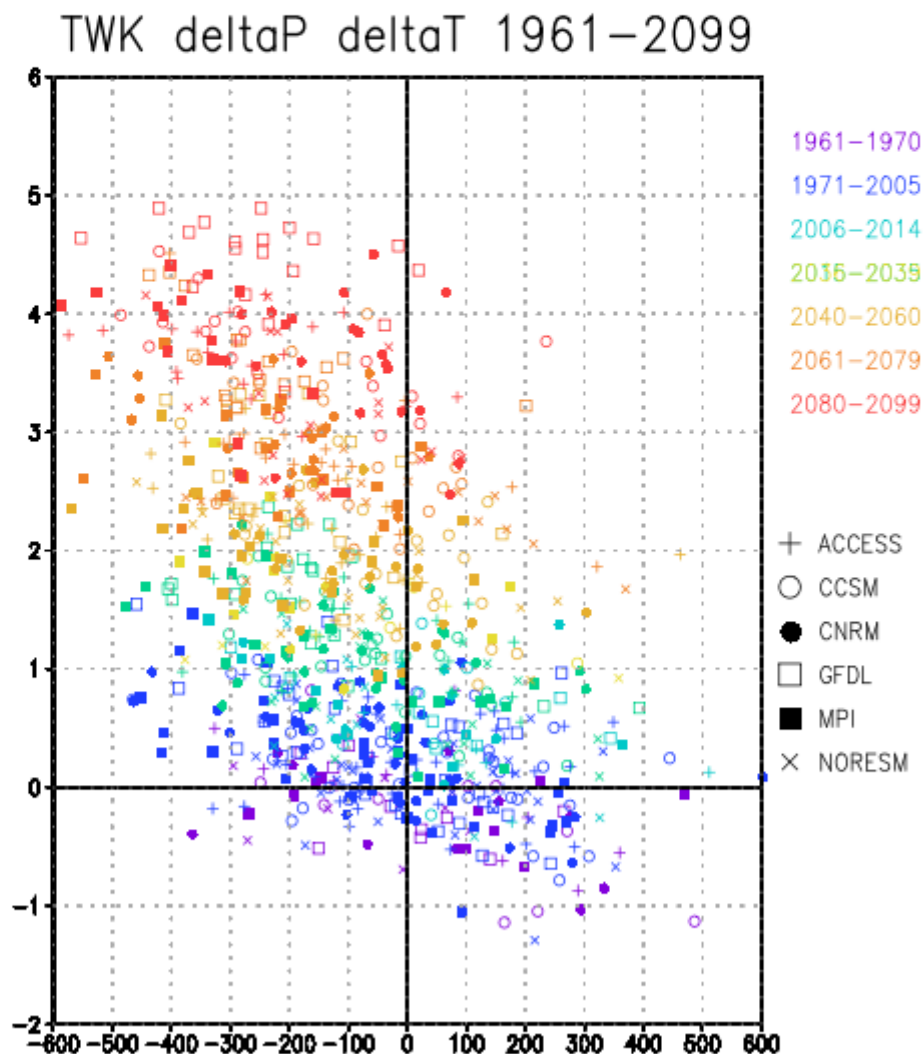
However, these findings reveal that over the City area, the frequency of heavy rainfall events is expected to systematically decline as we progress through the 21st century. Our research finds no evidence to support the notion that heavy rainfall events are likely to become more frequent over time. It is essential to understand how these projected changes in climate translate into potential hazards when assessing risk and vulnerability and planning for both resilience-building and disaster response investments.



B.3.1 Combined Temperature and Rainfall Stressors

Figure 14 illustrates the combined projected changes in rainfall and temperature over time for the southwestern Cape. These multiple ensembles show the projected trends towards lower rainfall and higher temperatures in the future. Of particular importance is the rate at which average rainfall and temperature is changing and the relative levels of uncertainty between model projections. Overall, the general trend is towards a significantly hotter and somewhat drier future, which will influence multiple climate-related hazards that may threaten Cape Town in one way or another.

Figure 14: Simulated trends in anomalies in average annual rainfall (x-axis) and temperature (y-axis)



Simulated trends in average annual temperature anomalies (y-axis) and annual rainfall anomalies (x-axis) for the historical period 1961-2099 (bias-corrected using observations) and projected trends until 2099, under a low-mitigation scenario (RCP8.5).

B.3.2 Drought

Meteorological drought, or lower than average rainfall over an extended period of time, is the primary first order climate-related hazard threatening Cape Town. Moreover, decreases in extreme rainfall events, typically the types of rainfall events that induce large amounts of run-off and thereby drive streamflow, are projected. It is likely that the return period of multi-year droughts such as the 2015-2017 drought in Cape Town will decrease during the 21st century, including the mid-future period of 2021-2050. In other words, the likelihood of these multi-year droughts occurring in the future is increasing (i.e. it is likely they will occur more often going into the mid and late periods of the 21st century).

These meteorological drought conditions are compounded by increasing temperatures which increase evapotranspiration and evaporation, leading to decreased overall water supplies and streamflow (i.e. hydrological drought), as well as soil water deficiencies and resulting plant water stress (i.e. agricultural drought). Moreover, these combined stressors on natural available water supplies lead to **multiple stressors across ecosystems** (i.e. ecological drought).

The vulnerability of the City of Cape Town to the occurrence of multi-year droughts has recently been seen, in the 2015-2017 drought, which came close to causing the city to run out of water (the so called "day zero"). Figure 14, on the previous page, indicates significantly enhanced risks of day zero events occurring over the next 30 years, and increasingly so deeper into the 21st century. It has been estimated that the probability of such severe droughts occurring has already increased by a factor of 3 as a consequence of anthropogenic induced climate change (Otto et al., 2018). Box 5 below outlines some of the key global and regional climate drivers that influence the likelihood of drought in the Western Cape Region.

Box 5: Global and Regional Climate Drivers

Oceanic oscillations are large-scale changes in sea-level air pressure, sea temperature and wind direction, over time scales of several months up to several decades. These changes tend to oscillate between one state and another (hence the term oscillation) and be characterised by shifts of cool and warm (relatively) pools of ocean water. These oscillations are associated with changes in weather over land elsewhere and of importance to southern Africa, control the intensity of wet and dry seasons.

El Niño Southern Oscillation (ENSO), the Indian Ocean Dipole (IOD), the Southern Annular Mode (SAM) or Antarctic Oscillation (AAO) - these two are essentially the same, and the Atlantic Meridional Overturning (AMO), are the ocean-climate oscillations that have an influence on the seasonal weather of southern Africa.

Of all the oscillations, winter rainfall in the south-western Cape region is likely most strongly related to the state of the AAO (Reason and Rouault, 2005). For the period 1948 – 2004, six of the eighth driest winters occurred during a positive AAO phases, which are negative pressure anomalies over the Antarctica and positive pressure anomalies over the mid-latitudes. The state of the AAO has the strongest effects on south-western Cape weather because it is related to shifts in the sub-tropical jet, to changes in fluxes of atmospheric moisture above the surrounding oceans and which in turn alters low-level convergence, mid-level atmospheric lift and vorticity, all of which control the amount of moisture available in the atmosphere for precipitation (Reason and Rouault, 2005).

There is some hint of an effect on Western Cape droughts by the IOD and AMO (Richman and Leslie, 2018), but this relationship is relatively weak. The El Niño phase of ENSO has a negative relationship to Western Cape rainfall, such that during an El Niño, the Western Cape tends to get increased rainfall (Philippon et al., 2012).

Using proxy records Abram et al. (2014) show that the AAO is at its strongest positive point for a millennium and has been increasingly positive for the last 500 years, the trends being attributed to anthropogenic climate forcing. The increasingly positive the AAO index implies declining rainfalls in the Western Cape.

Smoothed AAO indices and annual rainfall values in the Western Cape have a relatively strong correlation, which is strengthened if the AAO index leads rainfall by two years, indicating the possibility of using the AAO as a leading indicator of possible multi-year droughts and thus providing forewarning to water resource managers (Reason and Rouault, 2005). More work is required on this promising relationship.

To directly link the projected changes in rainfall to future dam levels, state-of-the art hydrological modelling of streamflow in combination with water yield modelling of the Theewaterskloof and Berg River dams should be applied, with these simulations forced by detailed projections of future rainfall and temperature patterns over the catchments. Such a modelling system also needs to include different options for decision making in terms of managing dam levels, human behaviour in terms of water use, water allocation strategies and future population and urban growth of the City of Cape Town. Although such a modelling endeavour falls outside the scope of this project, the basic concepts may be illustrated through the application of a first order statistical model that links future dam levels to streamflow.

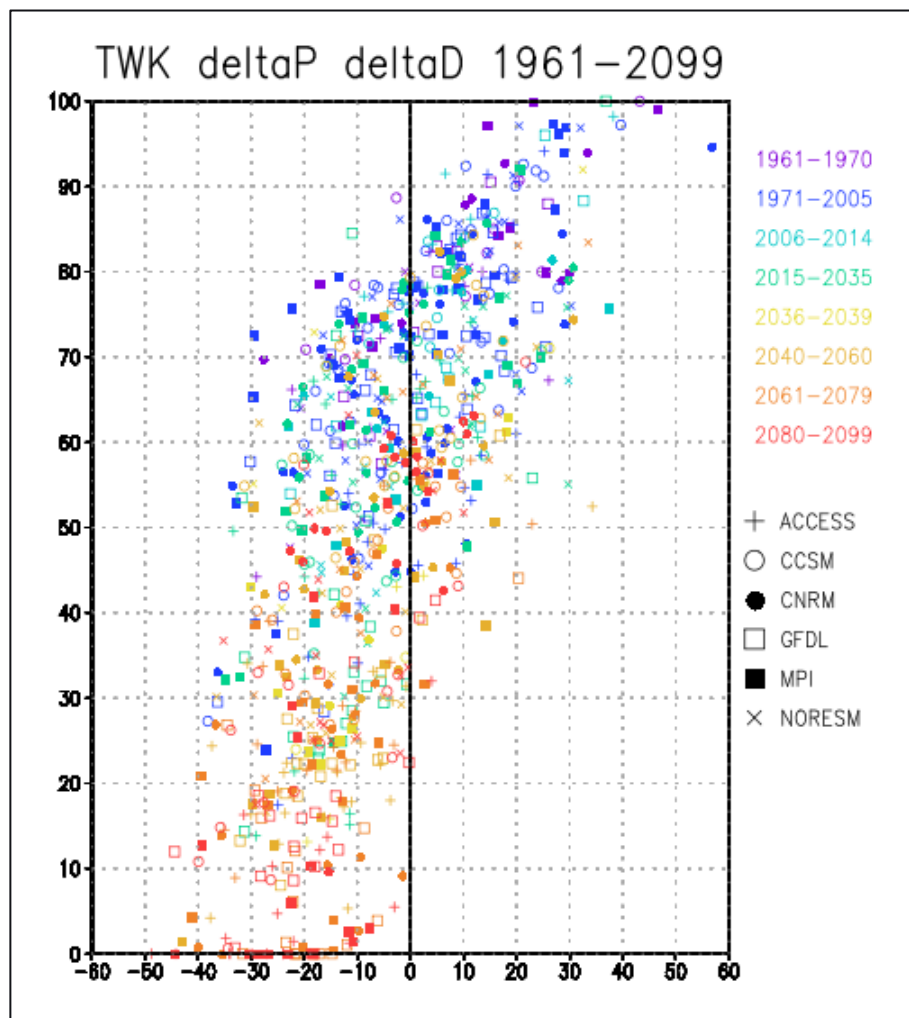
Projected future Theewaterskloof Dam levels for the period 1961-2100 (y-axis) as a function of annual rainfall anomalies (x-axis) are shown in Figure 15. The rainfall anomalies are based on the 1961-1990 baseline period, as before. This statistical model is comprised of three basic responses of Theewaterskloof dam level to rainfall:



- i) when the dam level is high with no immediate threat of drought, dam levels fall or rise in linear correlation to rainfall, as observed during such years;
- ii) when dam levels approach the full capacity, water usage increases; and
- iii) when dam levels drop to below 50%, water usage greatly decreases.

Under such straightforward modelled responses of dam level to rainfall and the existing state of water security, the statistical model suggests the possible occurrence of day zero events (where dam levels drop to below 20%) already for the period 2015-2035. Such events are projected to occur with increasing frequency deeper into the 21st century. Although this first order statistical model should not be applied for quantitative planning, it serves to demonstrate the sobering realisation that the CCT is in the need of transformational adaptation in terms of its future water security.

Figure 15: Simulated trends in anomalies in rainfall (x-axis) and dam levels (y-axis): Theewaterskloof



Model simulated trends in average annual Theewaterskloof dam levels (y-axis) and annual rainfall anomalies (x-axis) for the historical period 1961-2099 (bias-corrected using observations) and projected trends until 2099 (RCP8.5 emission scenario).

B.3.3 Fires

Fires are another major climate-related hazard threatening Cape Town. The drastic increases projected in the number of high fire-danger days are to a large extent driven by increases in temperature. Both natural fires (veld fires) and urban fires are likely to become more frequent as a direct result of a changing climate. High temperatures, low humidity or available moisture and high windspeeds all contribute towards higher risks of fire. Greater wind strength and prolonged winds create further

challenges for fighting and containing fires that have started, which ultimately will influence the potential damage fires can cause. Apart from the obvious risk to human life and health, and to properties and informal settlements and public infrastructure, fires present a significant environmental risk to the Cape Floral Kingdom. Moreover, heatwaves are a significant climate hazard projected to increase throughout the 21st century, which presents further risks to human, plant and animal health, as well as increased demand for water and electricity, among others.

B.3.4 Extreme rainfall events and flooding

On the other hand, extreme rainfall days are projected to systematically decline as a result of climate change. This finding diverges from previous findings that projected an increase in the intensity and frequency of high-intensity rainfall events. It is important to note that this finding is based on the change in the primary rainfall-generating mechanism (i.e. mid-latitude cyclones bringing frontal rainfall moving southward). This is despite observed data in extreme rainfall events throughout the Western Cape Province showing a slight positive trend from the first to the second half of the 20th century (De Waal et al. 2017). Figure 14 above further emphasises the relative uncertainty of the future rainfall projections. Nevertheless, it is critical to incorporate the most advanced scientific knowledge available to date when planning adaptation investments, especially in the rapidly advancing field of climate science.

Based on these projected reductions in extreme rainfall days, it is plausible that all types of flooding are likely to systematically decrease within Cape Town as we move further into the 21st century. However, the extent and magnitude of flood events – be it fluvial (riverine), coastal or pluvial (surface water) – are influenced by numerous biophysical, infrastructural and meteorological factors aside from rainfall. Moreover, a decrease in extreme rainfall days and the storm events associated with them, will likely reduce coastal erosion impacts that result from coastal storm conditions. However, if observed trends continue and extreme rainfall days continue to increase slightly, these all types of flooding events are likely to have greater impacts. Again, it is critical to acknowledge the multiplicity of environmental and human influences on the extent and magnitude of coastal erosion aside from rainfall.

For example, changes in wind and swell direction and strength were cited as factors that have increased impacts of coastal erosion in recent years at the Participatory Analysis Workshop with CCT. Ultimately this highlights the complex environmental and biophysical interlinkages between changes in climate phenomena and their associated influences on hazards that threaten the City. It is out of the scope of this study to develop and include a detailed wave and swell model or integrated flood model, which attempt to account for the myriad of causal pathways of effect through complex systems. Therefore, the role of flooding, sea-level rise and changes in wind patterns and strength will be further assessed through the following R&V assessment (Section C), whether through empirical data or expert analysis of the key risks and associated causal impact pathways.



C. Risk and Vulnerability Assessment

C.1 Overview

The assessment of climate change risk and vulnerability in and around Cape Town builds directly off the hazard assessment and climate change projections. Based on the overarching adaptive management approach adopted to undertake this study, the technical approach towards assessing climate change risk and vulnerability has evolved.

Vulnerability to climate change is assessed as a function of **exposure** to climate impacts, and the level of **resilience** of the impacted systems. These terms are explained under the relevant sections that follow. The resilience assessment is a combination of relative **adaptive capacity** and **sensitivity indicators**. This is for two main reasons:

- The concept of resilience is well developed and entrenched in CCT (the City will launch its Resilience Strategy in 2019 and has already adopted the 100 Resilience Indicators, developed by the Rockefeller Foundation);
- The notion of resilience is better suited to urban environments where there are overlaps between many indicators of sensitivity and adaptive capacity (as discussed in the project Inception Workshop).

This section presents and discusses the initial outcomes of the R&V assessment. Relative levels of exposure, resilience and vulnerability are presented graphically in maps extending over the broader southwestern Cape region, focusing on Cape Town. Box 6 below explains how to interpret these maps.

Box 6: Interpreting the risk and vulnerability maps

For the **exposure summary maps** (see Figures 16, 17 and 18), yellow reflects relatively high exposure and purple indicates relatively low levels of exposure. This is despite the fact that all areas within the project extent are projected to be exposed to negative changes in climate. The exposure summary maps are scaled from low to high across the three different time periods (current, mid-future and far-future). Hence, exposure over the region is seen to systematically increase over time as the effects of anthropogenic climate change take hold. The same colour scheme applies for the **vulnerability hotspot maps** (see Section C.4, Vulnerability Assessment: Figures 21, 22 and 23).

In the **resilience summary map** (see Figure 20): blue reflects high levels of resilience, whereas red indicates relatively lower levels. It is important to note that the extent of the exposure assessment is greater than the City boundaries, whereas the resilience assessment was limited to the spatial limits of the Cape Town Municipality.

The scoring and associated colour gradients affect the relative intensity of colours, so that areas of deep blue or red cannot be directly compared with each other in terms of intensity, between different indicators. For example, even though certain areas show up as dark red for low levels of the 'access to electricity' indicator, the absolute level of access to electricity might still be considered generally high. It is only low in relation to other areas of the City. The relative levels of exposure, resilience or vulnerability can only effectively be compared within an individual map and through the assessment of the underlying drivers (i.e. different indicators that contribute to resilience and exposure). Moreover, the R&V summary maps do not illustrate absolute levels of vulnerability in relation to global benchmarks. This means that even though some areas may appear less vulnerable than others to climate change, they are likely vulnerable to different impacts of climate change in one way or another, and vice-versa.

Note: Maps of Cape Town's Major Suburbs are shown in Appendix 2 for reference throughout this section.

This section presents and describes how the project team carried out the cumulative risk assessment in terms of overlaying the different indicators of exposure and resilience. Moreover, the ranking of risks and most vulnerable areas is discussed in relation to the outcomes of the R&V assessment.



C.2 Exposure Assessment

Exposure is defined as the presence (location) of people, livelihoods, environmental services and resources, infrastructure, or economic, social, or cultural assets in places that could be adversely affected by physical events and which, thereby, are subject to potential future harm, loss, or damage (Lavell et al., 2012: 32).

All the summary maps including exposure (current, mid-future and far-future), resilience and vulnerability hotspots, together with their respective algorithms can be found in Appendix 3.

Figures 16, 17 and 18 illustrate the composite exposure assessment maps for the current, mid-future and far-future time period.

These composite exposure maps show the following:

- Areas further inland from the coast are more exposed in general to current climate variability and climate-related hazards, particularly areas to the east and northeast of the City.
- Within the City boundaries, the northern and eastern extremities show the highest levels of combined exposure, covering areas such as Mamre, Stellenbosch Farms and Strand. Smaller pockets of high relative exposure can be found in central areas of the City going into the far-future.
- Other smaller areas showing relatively high levels of exposure include Paarden Island, Observatory, Pinelands, Stellenbosch Farms, Brooklyn, Maitland, Sir Lowry's Pass and Gordon's Bay.
- Areas that demonstrate relatively low levels of exposure include Cape Point, Simon's Town, Kommetjie, Noordhoek, Camps Bay, Sea Point, Signal Hill / Lions Head, Green Point, Pelikan Park, Mitchell's Plain, Kalk Bay and Melkbosstrand.

However, to understand the underlying drivers of these relative levels of exposure, the various indicators of exposure need to be explored in greater depth, in the following section (see Section C.2.1).



Figure 16: Exposure to Harms Summary Map (Current Conditions)

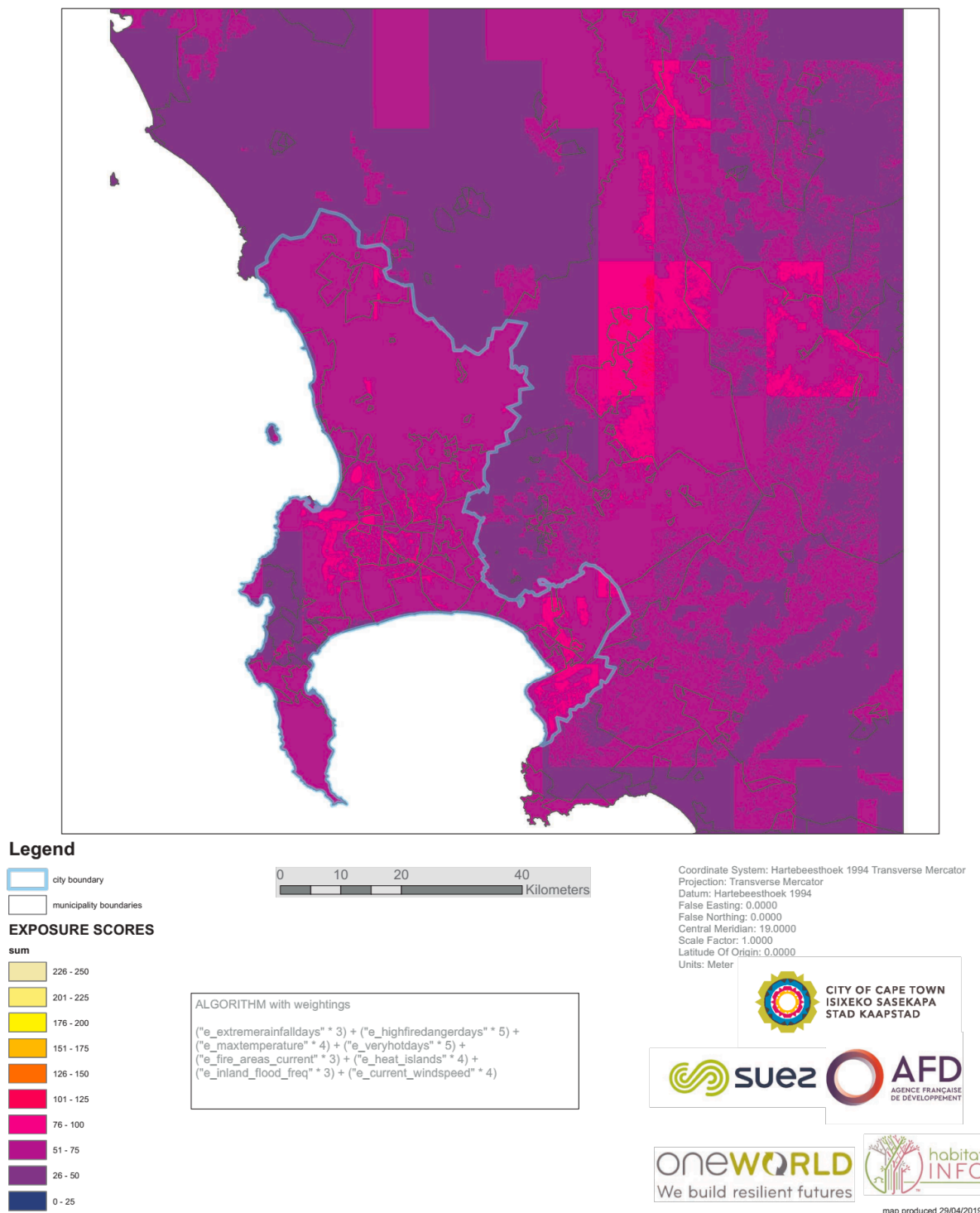


Figure 17: Exposure to Harms Summary Map (Mid-future Conditions).

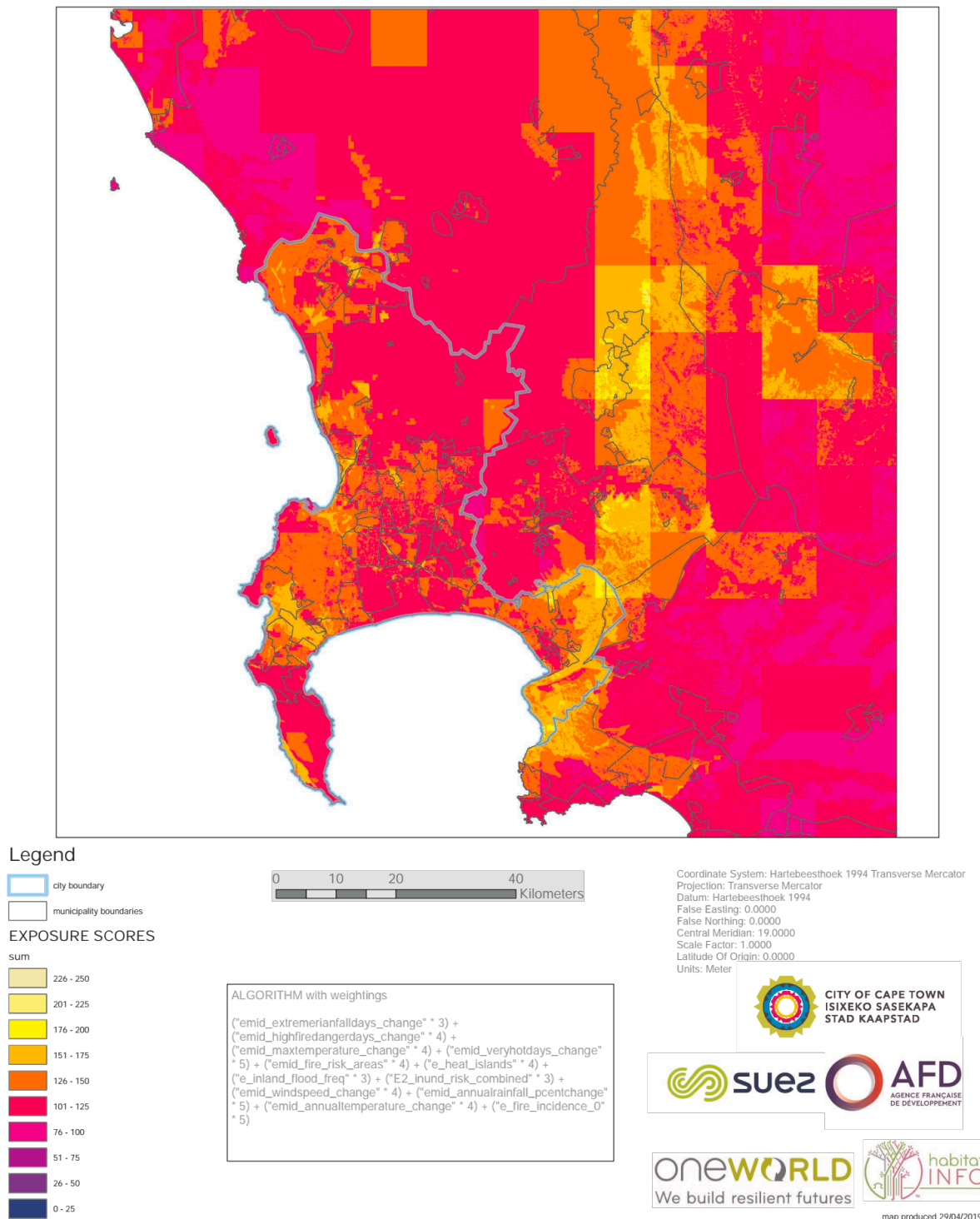
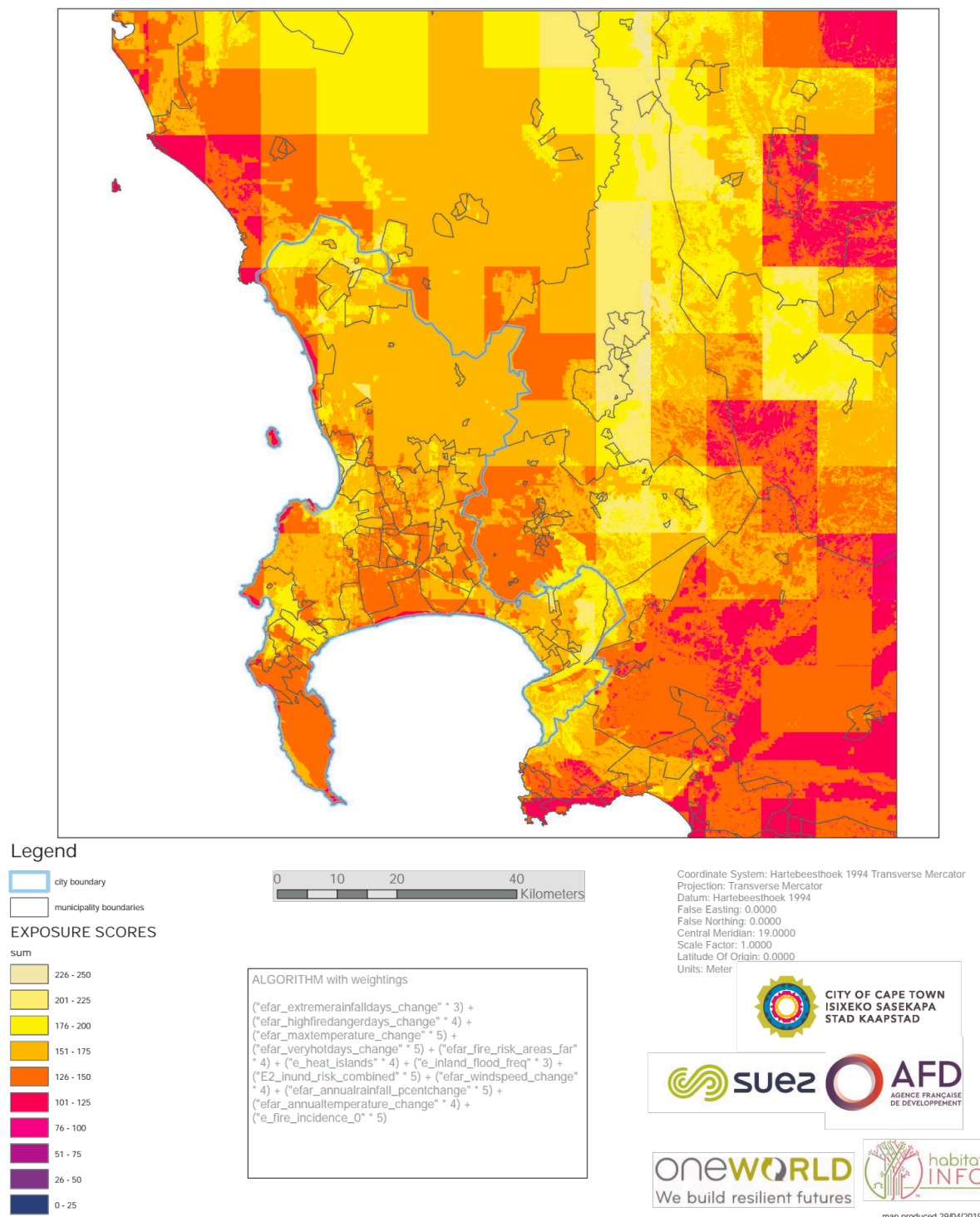


Figure 18: Exposure to Harms Summary Map (Far-future Conditions)



C.2.1 Indicators of Exposure

Table 4 outlines the various indicators of exposure and their associated weightings for the three different time periods of assessment. The table therefore illustrates how the climate projections have been interpreted into the R&V model, amongst other key indicators. The maps showing the spatial distribution of these various input indicators of exposure are provided in Appendix 4.

The weighting scale ranges from 1 (lowest weighting) to 5 (highest weighting) for each indicator that makes up exposure (and resilience discussed below). These weightings are determined by three key aspects, as informed by the background research and stakeholder engagement:

- Relevance to the region/area
- Confidence in the accuracy of the data
- The spatial resolution of the data

Exploring these underlying indicators reveals the different drivers of exposure and their associated causal pathways, which ultimately demonstrate the cumulative nature of the assessment and how cumulative exposures to different climate-related harms manifest within the model, to generate the composite exposure summary maps (Figures 16, 17 and 18).

Drivers of exposure differ for different areas. This can be seen in the case of the Malmesbury Farms on one hand, and Observatory area on the other. Although both these areas exhibit relatively high levels of exposure to harms, the underlying drivers of exposure are different and thus the risks manifest through different causal pathways. From examining the input maps in Appendix 4, it is evident that high levels of overall exposure in the Malmesbury Farms area are primarily being driven by relatively high numbers of high fire-danger days, high maximum temperatures and high numbers of very hot days. By contrast, exposure to harms in Observatory is largely being driven by strong heat island effects, moderately high numbers of extreme rainfall days and high maximum temperatures.

Table 4: Indicators of Exposure.

Time Period	Indicator	Description	Weighting
Current	Extreme Rainfall Days	Number of days with >20mm of rainfall within 24 hrs over an area of 64 km ² per year.	3
	Fire Risk Areas	Correspondence of combustible fuel load with number of high fire-danger days per year.	4
	Fire Incidence	Incidence of urban and wildfires from 2009-2016.	5
	Heat Islands	Heat island intensity determined by ranking and combining land cover type, solar irradiation and wind speed.	4
	High Fire Risk Days	Number of days McArthur fire-danger index exceeds a value of 24 per year.	5
	Inland Flood Frequency	Combined flood frequency data from 2014-2018.	3
	Maximum Temperature	Mean annual maximum temperature.	4
	Very Hot Days	Number of days when the maximum temperature exceeds 35 °C per year.	5
	Average Windspeed	Average annual windspeed in meters per second (m/s).	4
Mid-Future (2021-2050)	Sea-level Rise Inundation Risk	Combined Shuttle Radar estimates and CCT sea-level rise modelling data showing projected areas of inundation from different levels of sea-level rise.	3
	Rainfall Change (%)	Relative (percentage) decline or increase in rainfall relative to current period.	5
	Mean Temperature Increase	Mean annual temperature increase relative to current period.	4

	Extreme Rainfall Days	Projected number of days with >20mm of rainfall within 24 hrs over an area of 64 km ² per year, relative to current period.	3
	Fire Risk Areas	Correspondence of combustible fuel load with number of high fire-danger days per year.	4
	High Fire Risk Days	Projected number of days McArthur fire-danger index exceeds a value of 24 per year, relative to current period.	4
	Maximum Temperature	Projected mean annual maximum temperature relative to current period.	4
	Very Hot Days	Projected number of days when the maximum temperature exceeds 35°C per year relative to current period.	5
	Average Windspeed	Projected average increase in wind speed relative to current period (m/s).	4
Far-Future (2070-2099)	Rainfall Decline (%)	Relative (percentage) decline in rainfall relative to current period.	5
	Mean Temperature	Mean annual temperature increase relative to current period.	4
	Extreme Rainfall Days	Projected number of days with >20mm of rainfall within 24 hrs over an area of 64 km ² per year, relative to current period.	3
	Fire Risk Areas	Correspondence of combustible fuel load with projected number of high fire-danger days per year relative to current conditions.	4
	High Fire Risk Days	Projected number of days McArthur fire-danger index exceeds a value of 24 per year, relative to current period.	4
	Maximum Temperature	Projected mean annual maximum temperature relative to current period.	5
	Very Hot Days	Projected number of days when the maximum temperature exceeds 35°C per year relative to current period.	5
	Average Windspeed	Projected average increase in wind speed relative to current period.	4

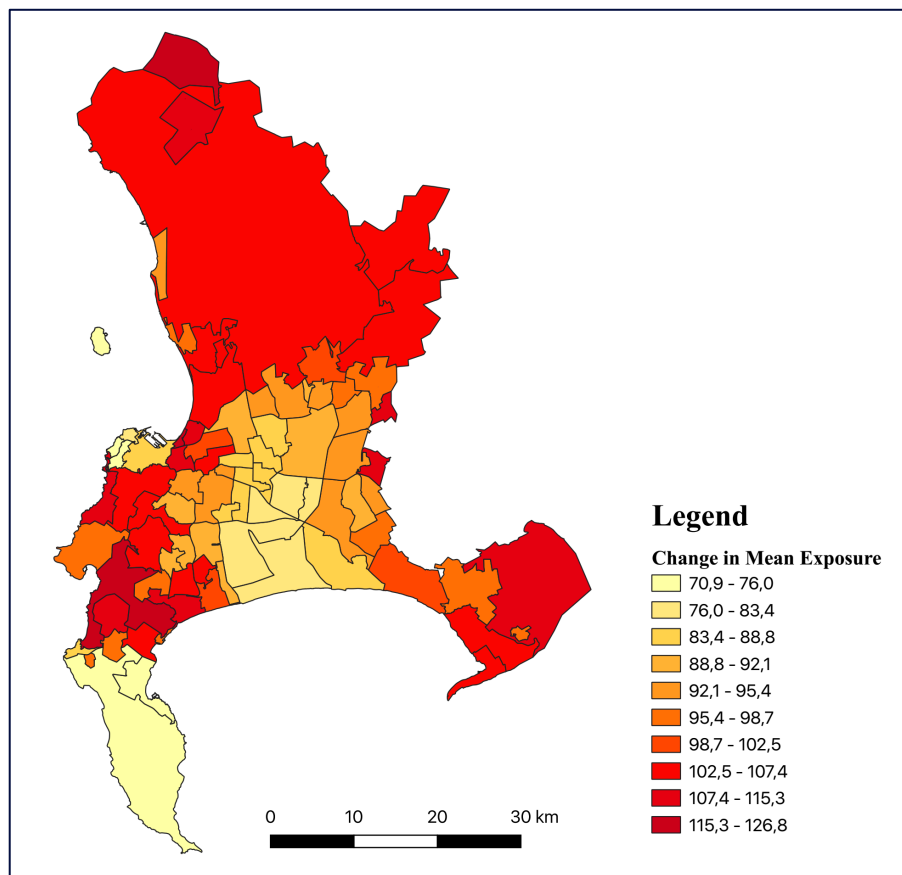
C.2.2 Future Exposure

Effective responses to climate change risks necessitate both an understanding of current risks, as well as projected changes in future risk. Figure 19 shows the change in mean exposure from the current to the projected far-future period for Cape Town's Major Suburbs. Although all areas within Cape Town are projected to become relatively more exposed to harms going into the future, exposure in some areas will increase moderately more than others.

For example, when assessing the underlying drivers of far-future exposure (see Figure 19), the differences between the underlying drivers of high levels of future exposure in Constantia and Malmesbury Farms (both appear as dark red in Figure 19) are clear. Exposure in Constantia is largely being driven by extreme rainfall days, fire risk and windspeeds, rainfall decline and temperature increase. By contrast, the main drivers of future exposure for the Malmesbury Farms area are increases in mean and maximum temperatures, increases in high fire-danger days, a high percentage decline in rainfall and increases in very hot days.



Figure 19: Change in mean exposure from the current to the far-future period



C.3 Resilience Assessment

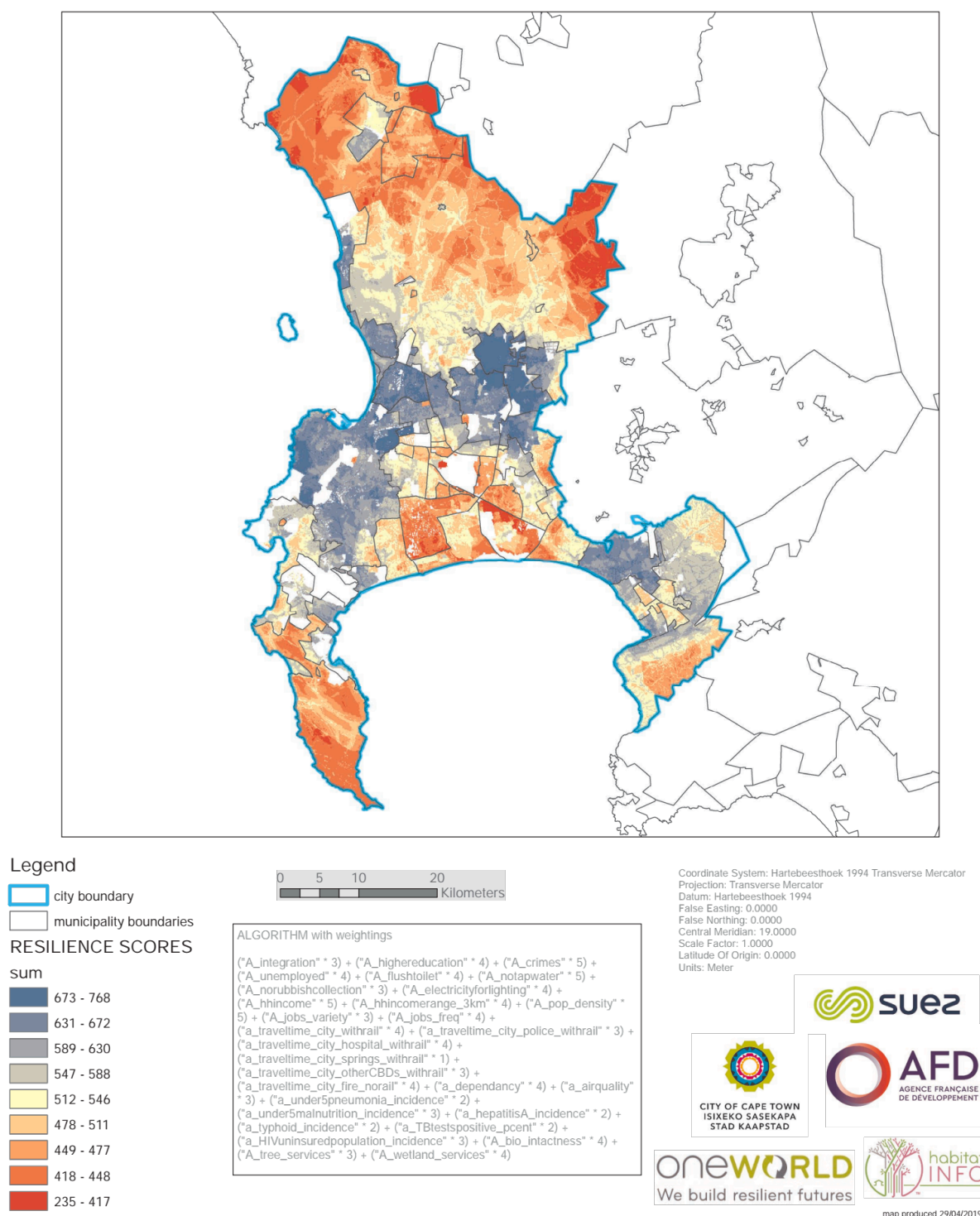
Resilience is defined as 'the capacity of individuals, communities, institutions, businesses and systems within a city to survive, adapt and grow no matter what kind of chronic stresses and acute shocks they experience' (100RC, 2019).

All the summary maps, including exposure (current, mid-future and far-future), resilience and vulnerability hotspots, together with their respective algorithms can be found in Appendix 3. Figure 20 illustrates the composite resilience assessment map.

This composite map shows:

- The spatial distribution of relative levels of economic, social and environmental resilience throughout Cape Town.
- The least resilient areas are found in the northern regions of the City, the 'Cape Flats' and informal settlements, and the southern peninsula to a lesser extent. Specific hotspots of low resilience occur in the suburbs of Philippi, Delft, Blue Downs, Guguletu, Mamre, Langa, Epping, Kalksteentfontein, Khayelitsha, Airport, Bishop Lavis, Cape Farms North, Mitchells Plain, Manenberg, Joostenberg Vlakte and Malmesbury Farms.
- Whereas areas of relatively high resilience occur largely in the higher income residential areas. Specific high-resilience suburbs include: Durbanville, Vredeklloof, Eversdal, Pinelands, Newlands, Fish Hoek, Tokai, Kenridge, Brackenfell, Bergvliet, Camps Bay, Somerset West, Wynberg, Melkbos Strand, Kalk Bay, Brooklyn and Muizenberg.

However, as for exposure, to understand the underlying drivers of these relative levels of resilience, the various indicators of resilience need to be explored, in the following section (see Section C.3.1.).

Figure 20: Resilience Summary Map


C.3.1 Indicators of Resilience

Table 5 outlines the various indicators of resilience and their associated weightings. The maps showing the spatial distribution of these various input indicators of resilience are provided in Appendix 5. Exploring these underlying indicators reveals the different drivers of and barriers to resilience and their associated causal pathways. The underlying indicators ultimately demonstrate the cumulative nature of the assessment and how cumulative indicators of resilience manifest within the model to generate the composite summary maps (see resilience summary map in Figure 20).

It is important to note that aside from the differential weighting, not all input indicators are necessarily combined equally to generate the summary map. Where indicators represent the same resilience pathway, these are initially combined into composite indicators and then included in the algorithm as individual treatments. For example, Table 5 shows there are two indicators representing access to potable water ('tap water' and 'tap water inside houses'). Although the indicators are technically measuring different things, they both represent the same resilience pathway (i.e. access to potable water improves resilience to climate shocks and stressors).

An example of different areas with relatively low resilience being driven by different indicators can be seen with Epping and Joostenberg Vlakte. Analysing the underlying drivers of resilience (input maps in Appendix 5) reveals that the relatively low levels of resilience in Epping are being primarily driven by high crime rates, high population density, low access to electricity services, low coverage of flushing toilets, low levels of access to water, poor levels of higher education and poor access to municipal services such as refuse collection. By contrast, the relatively low resilience scores in the Joostenberg Vlakte area are being driven by low diversity of job opportunities, high levels of income inequality and moderate access to municipal services, tap water and electricity.

Table 5: Resilience Indicators.

Indicator	Description	Weighting
Air Quality	Combined average of nitrogen oxide, ozone, sulphur dioxide, carbon monoxide and particulate matter.	3
Crime Rate	Total number of crimes by police precinct area.	5
Dependency	Dependency ratio calculated as the population of non-working age divided by the population of working age.	4
Electricity for Lighting	Percentage of households with access to electricity for lighting.	4
Flushing Toilets	Percentage of households with flush toilets (main sewerage connection and septic tanks).	4
Hepatitis Rate	Incidence of hepatitis in 2017.	2
Median Household Income	Median household income.	5
Range of Household Income within 3km	Measure of income disparity in different neighbourhoods: maximum minus minimum household income within a 3km radius.	4
Higher Education	Percentage of people over the age of 20 with higher education.	4
HIV Rate	Incidence of HIV in 2017.	3
Social Integration	Relative integration of different population groups.	3
Employment Opportunities within 1km	Measure of employment opportunities: ranked zoning areas by potential formal employment opportunities assessed within 1km radius.	4
Employment variety within 1km	Measure of job diversity opportunities: distance from multiple zoning areas related to employment opportunities assessed within 1km radius.	3
Education (no education)	Percentage of the population aged 20+ without any education.	5
Refuse Collection	Percentage of households without municipal refuse collection services.	3
Tap Water	Percentage of households without access to tap water facilities.	5
Toilet Facilities	Percentage of households without access to any toilet facilities.	5
Population Density	Number of people living in an area relative to the size of the area.	5
Tap Water Inside Houses	Percentage of households with tap water inside their house.	4
TB Rate	Incidence of Tuberculosis.	2

Access to Fire Stations	Estimated time required to travel to the nearest fire station.	4
Access Time to Hospitals	Estimated time required to travel to the nearest hospital.	4
Access to Police Stations	Estimated time required to travel to the nearest police station.	3
Access to Freshwater Springs	Estimated time required to travel to the nearest freshwater spring.	1
Access to CBD	Estimated time required to travel to the Central Business District (Cape Town City Centre).	4
Access to All CBDs	Estimated time required to travel to a central employment node within the City of Cape Town.	3
Typhoid Rate	Incidence of Typhoid in 2017.	2
Malnourishment Rate	Incidence of malnourishment in children under 5 years of age.	3
Pneumonia Rate	Incidence of pneumonia in children under 5 years of age.	2
Employment Rate	Percentage of people unemployed in the formal sector.	4
Weekly Solid Waste Collection	Percentage of households with weekly municipal solid waste collection services.	3
Jobs: Population Balance	Measure of job opportunities relative to population densities: combination of job frequency assessment and population densities.	5
Biodiversity Services	Measure of functionality of biodiversity related ecosystem services.	4
Forest and Upper-storey Services	Measure of functionality of forest, tree and upper-story vegetation ecosystem services.	3
Wetland and Watercourse Services	Measure of functionality of wetland and watercourse ecosystem services.	4

C.4 Vulnerability Assessment

Vulnerability is defined as the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including exposure to harm and lack of capacity to cope and adapt (IPCC Glossary, 2014).

Figures 21, 22 and 23 show the composite vulnerability assessment maps, or 'hotspots' maps for the current, mid-future and far-future periods respectively. All the summary maps including exposure (current, mid-future and far-future), resilience and vulnerability hotspots (current, mid-future and far-future), together with their respective algorithms and meta-data can be found in Appendix 3.

The current configuration of the R&V model depicts the north eastern regions of the City to be the most vulnerable to current conditions, with other hotspots occurring around the centre of the Cape Town Municipality and in the far north. The least vulnerable areas are seen in the southern peninsula, southern coast, Table Mountain area and up the west coast.

The future vulnerability hotspots maps show little variation in spatial distribution of vulnerability within Cape Town. It is important to note that these assessments assume a 'business-as-usual' scenario for resilience indicators, that is, that they will remain the same as the current status-quo. Areas that are projected to become more exposed in the future are slightly more vulnerable (specifically in the north eastern parts of the City) and accordingly some areas in the centre of the City area become relatively less vulnerable. However, in absolute terms the entire City will become more vulnerable for both the mid- and far-future periods.



Figure 21: Vulnerability Summary Map (Current Conditions)

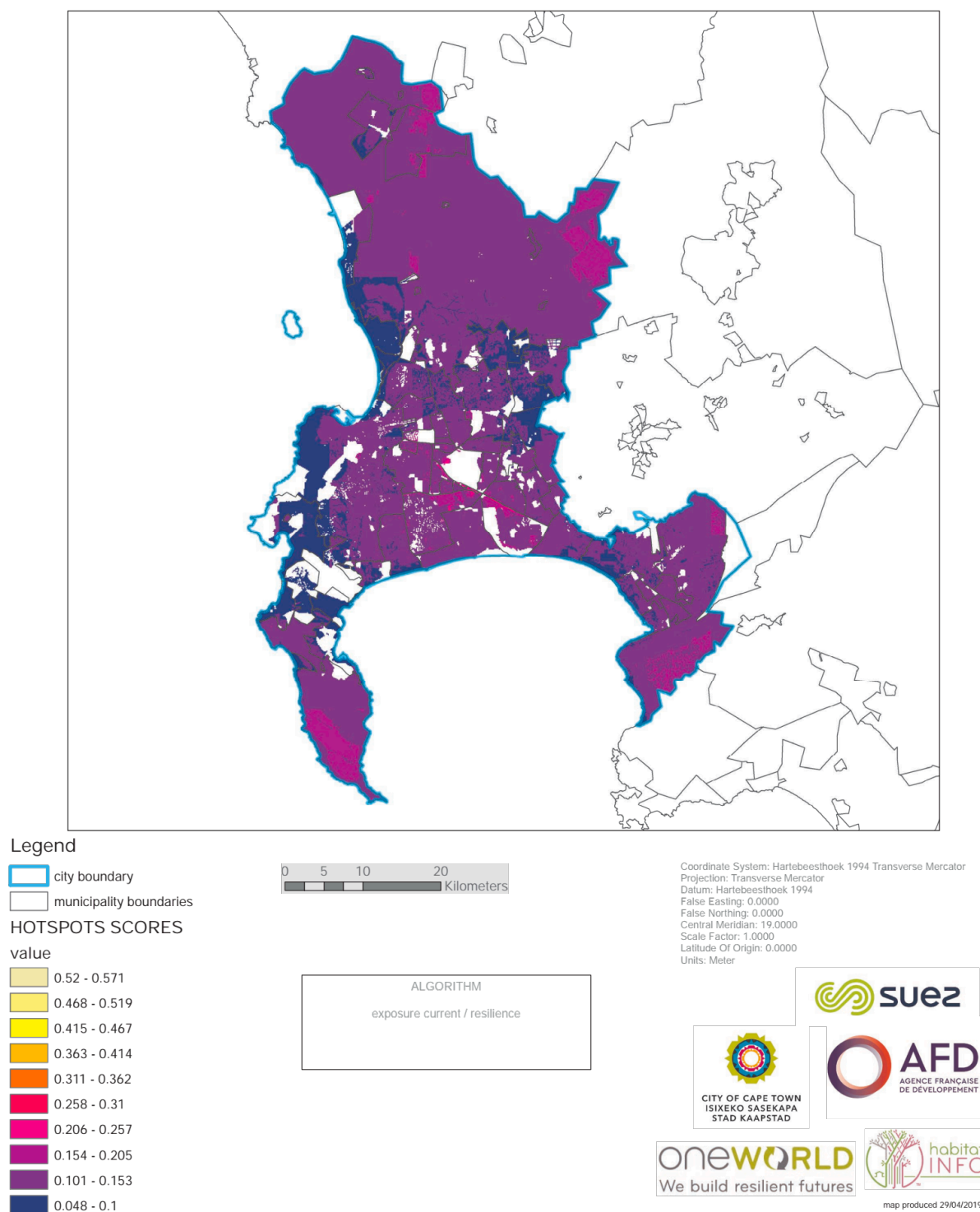


Figure 22: Vulnerability Summary Map (Mid-Future Conditions)

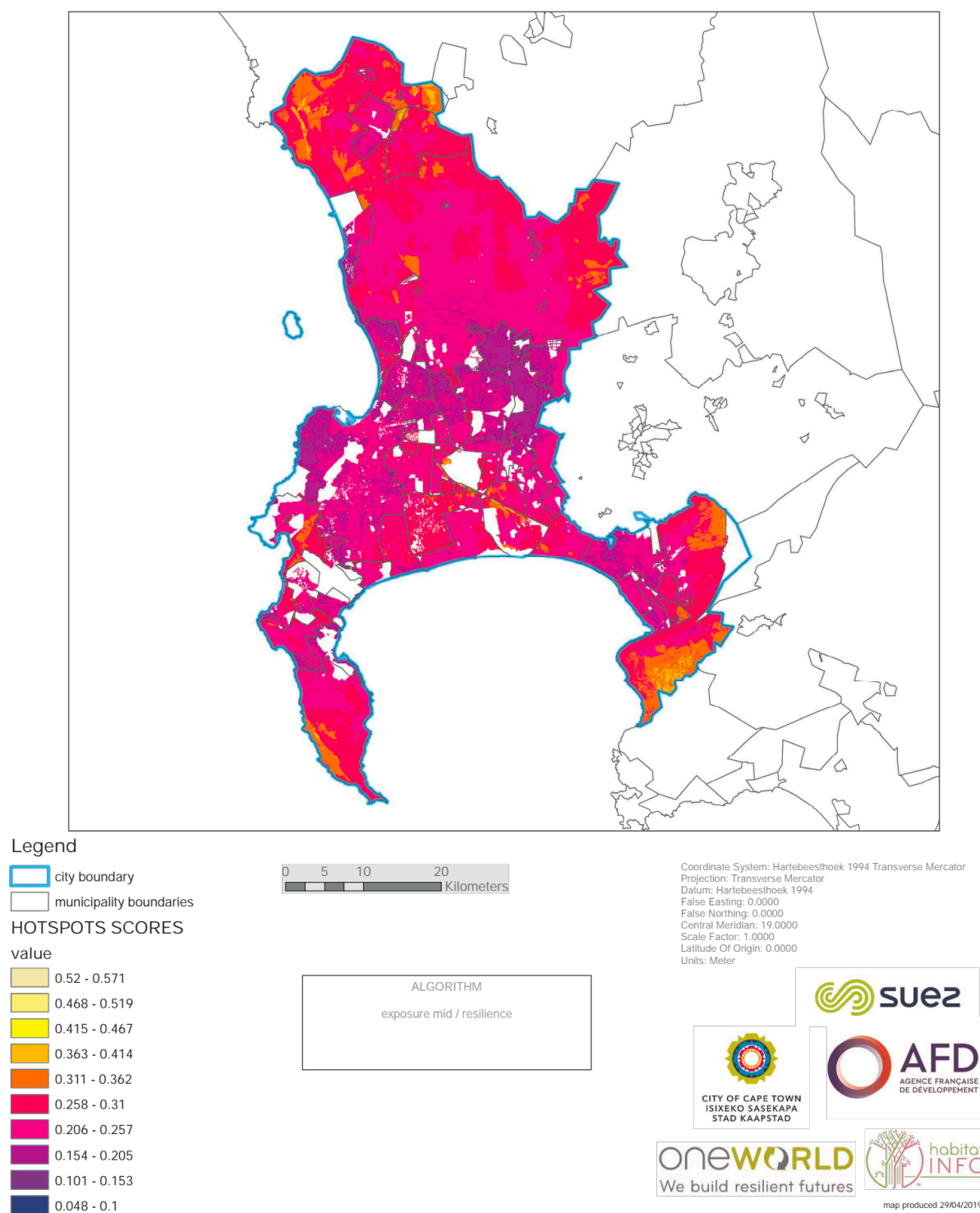
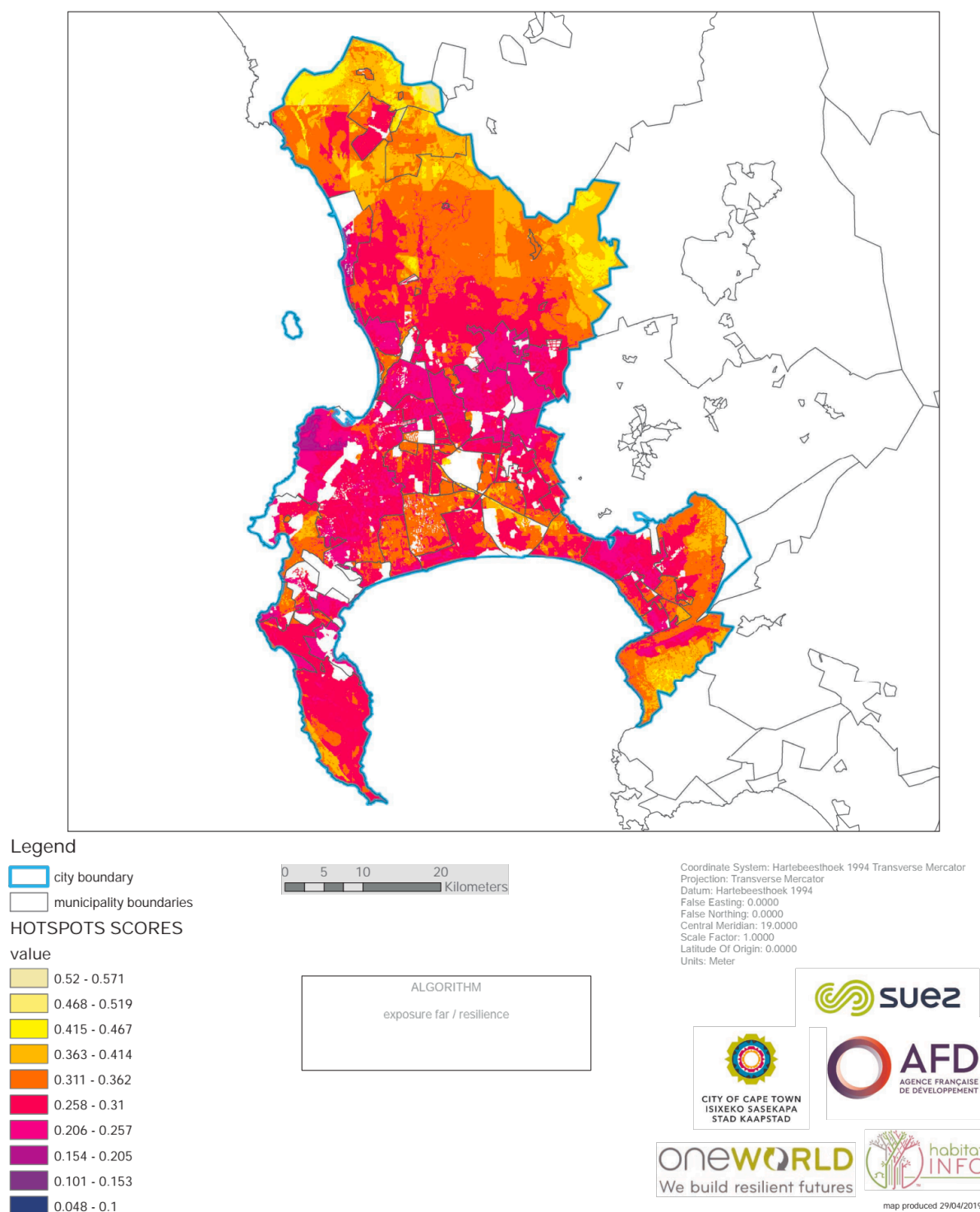


Figure 23: Vulnerability Summary Map (Far-Future Conditions)

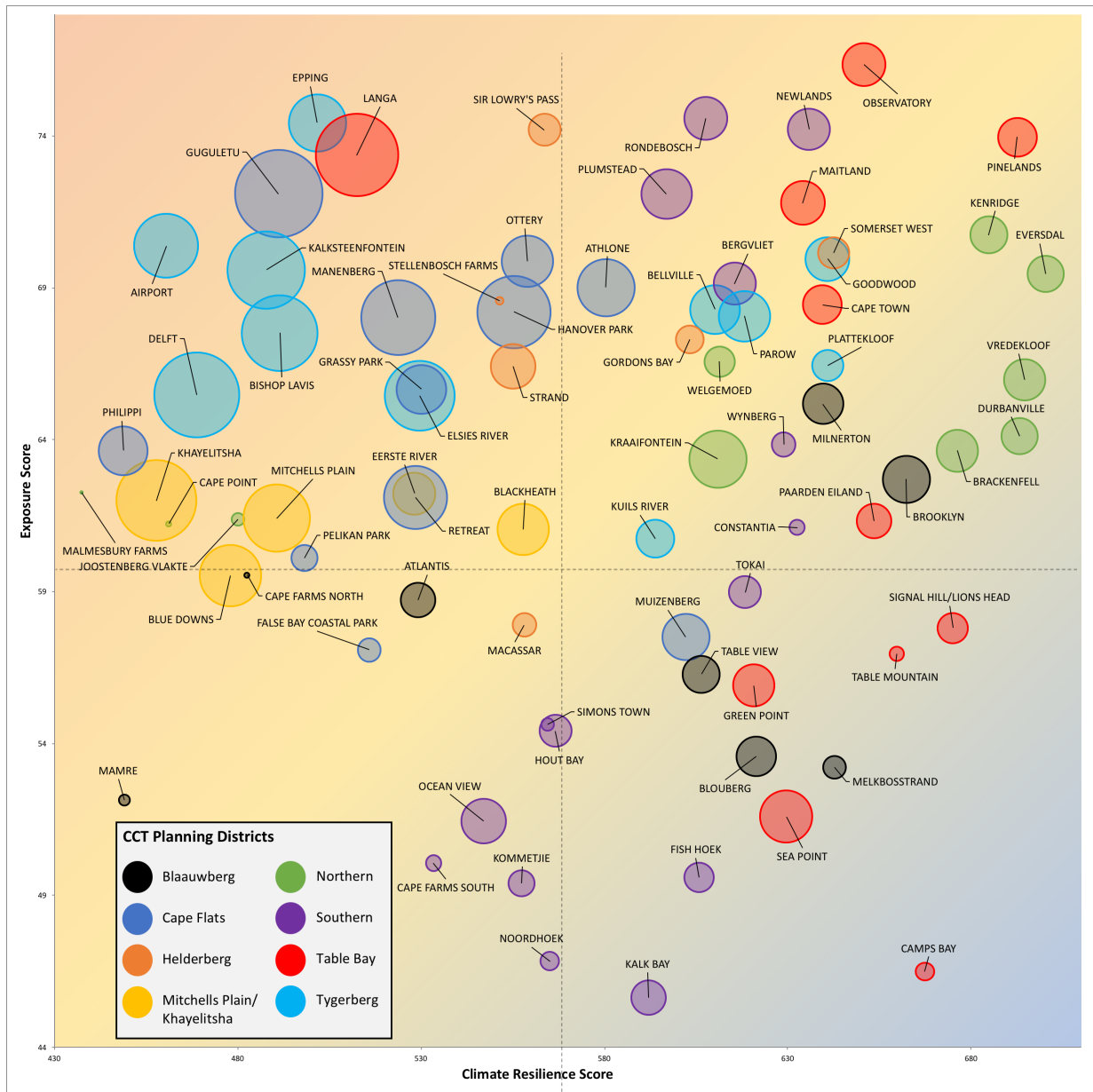


C.4.1 Disaggregating Vulnerability by Major Suburb

Figure 24 presents a vulnerability scatter plot by major suburb in Cape Town, with relative population densities indicated by the size of the bubbles (greater population density = larger bubble). By plotting relative levels of resilience and exposure against one another at the suburb level, it is possible to identify key spatial trends in vulnerability and understand the key drivers of vulnerability in different locations.

Analysing varying levels of vulnerability at this scale has a number of pros and cons. The biggest strength of this analysis is that it allows for spatial differentiation of resilience and exposure for a large number of spatial units, making it easier to identify, rank and prioritise risks and response pathways. Finer resolution spatial units (e.g. census 'small-place' areas) would render the uncertainty of the results too high to be accurately assessed, because much of the input data is captured at a courser resolution. Using any courser resolution units (e.g. CCT's 'master planning districts') would render the analysis too broad to determine the nuanced spatial differences in vulnerability.

Figure 24: Vulnerability Scatter Plot (Current Conditions)



Identifying key trends in vulnerability by investigating the underlying causal pathways is critical for developing context and risk specific adaptation investments. For example, the vulnerability scatter plot in Figure 24 highlights a clear inverse correlation between population density and resilience, even though population density is an indicator of resilience in the model. Although areas such as Observatory, Pinelands and Newlands are relatively exposed to climate change and related hazards, the area is also relatively resilient and is thus not highly vulnerable. On the other hand, suburbs such as Mitchells Plain, Philippi and Khayelitsha score poorly on resilience but are not highly exposed either. Thus, the role of expert input and qualitative analysis is key to untangling the primary causal pathways of vulnerability to

identify strategic entry points for adaptation that maximise impact and minimise cost. This process necessitates an understanding of how different risks manifest within a system to be able to rank them.

C.4.2 Ranking Key Climate Change Hazards and Risks

The notion of risk is generally determined as a function of the magnitude of the occurrence, and the likelihood that it will occur. For both acute climate shocks such as floods and fires, and chronic climate stressors such as drought, complex system interactions make it difficult to calculate risk. The multiplicity of impacts and associated knock-on effects further complicate the determination of magnitude. On the other hand, the relative uncertainty of climate models limits the ability to determine likelihood, most notably for rainfall projections (as discussed in Section B).

Risks manifest differently within different sectors, themes (such as livelihoods, poverty, the built environment) and segments of society (discussed in Section D). Therefore, in ranking climate-related hazards in terms of the risk they pose to Cape Town, we use a combined approach that draws on the quantitative outcomes of the R&V assessment, coupled with qualitative expert assessment. Based on this combined assessment, the key climate-related hazards that pose the greatest risk to Cape Town are:

1. Drought
2. Fire
3. Heatwaves
4. Floods
5. Strong Winds



D. Thematic Risk and Vulnerability Assessment

D.1 Overview and Key findings

This section presents a discussion of the findings of the R&V assessment in terms of thematic areas of impact, namely livelihoods (section D.2), poverty and inequality (section D.3), the built environment (section D.4) and disaster risk (section D.5). The analysis focuses on the key risks identified in Section C.4.2 and highlights the different pathways through which these risks manifest under each theme, drawing on key examples from Cape Town. The systemic interlinkages and cumulative impacts of multiple risks are also discussed in relation to key examples. The thematic assessment is deepened through the Economic Risk Analysis (Deliverable 3 for this project) to reflect key economic risks related to human, social, manufactured, financial, natural and intellectual capital.

The analysis in this report highlights the main sources of vulnerability as being drought, heatwaves, fires, floods and strong winds. Sea level rise is also a factor in some parts of the City. The interactions between the drivers of these risks, primarily temperature, wind and rainfall, are likely to manifest in a sharp increase in extreme drought events and fires.

D.2 Livelihoods

Livelihood strategies in Cape Town are highly variable in terms of their vulnerability to current and future climate-related hazards. High levels of unemployment correlate strongly with low levels of resilience, indicating that the informal sector faces the highest risks of climate stressors and shocks. Understanding the risks faced by workers in the informal sector is challenging because of the lack of reliable data, however the importance of their contribution to the economy cannot be ignored. Herrera et al. (2012) argue that as much as 80% of those who work in developing cities are employed in the informal economy. The Quarterly Labour Force Survey (QLFS) for Quarter 3 of 2018 indicates that from July-September 2018 the total number of jobs in Cape Town was ~1,606,000. The informal sector component of this (non-agriculture) makes up ~179,000 jobs or ~11% of people employed, while agriculture accounts for ~1% of people employed. Moreover, private household employment (e.g. domestic workers) comprises more than 5%, while formal employment (non-agriculture) makes up the majority of ~82%.

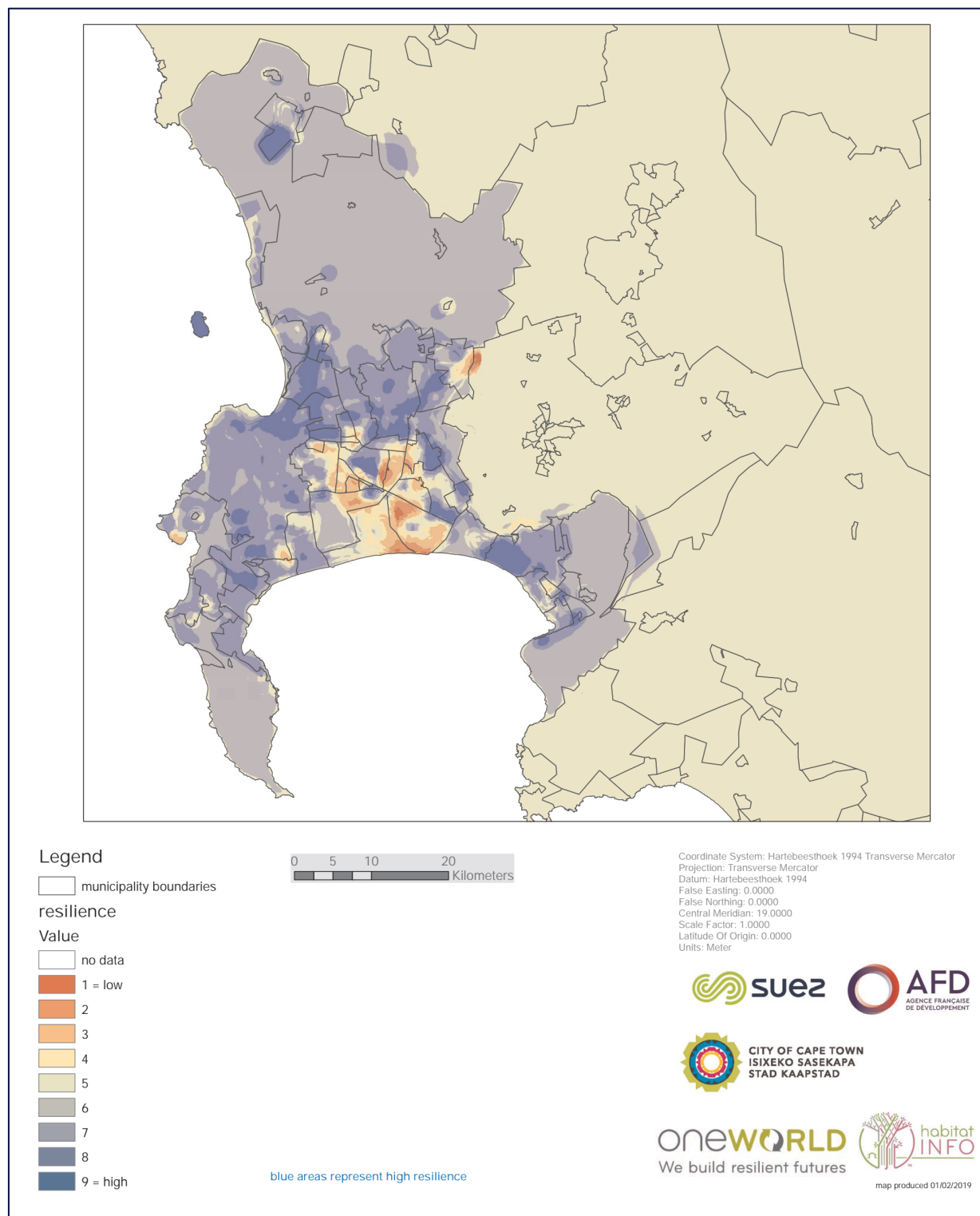
Although individual incomes from the informal economy are low, cumulative contributions to the national economy are significant. Moreover, the informal economy provides low-cost inputs and services to and both formal and informal sectors, especially within poorer areas. At the household level, informal activities are often what sustain families living in poorer areas and informal settlements, thus sustaining these activities is central to building resilience and alleviating poverty (Skinner, 2014). Moreover, traditional gender roles and livelihoods are more entrenched in social norms in the informal sector, and women are often more reliant on informal sector income and are thus more vulnerable to climate risks.

Figure 25 illustrates the analysis of job opportunities and population balance in Cape Town. Red areas provide relatively limited job opportunities in relation to the population density compared to blue areas (See Appendix 5). These areas largely correlate with low income areas and informal settlements, where the informal economy plays the strongest role in maintaining livelihoods.

Although these areas are not highly exposed to changes in rainfall, drought is a serious risk to informal livelihoods because of the location of key dams in the WCWSS. One key example can be drawn from the recent multi-year drought in the Western Cape, which resulted in significant water use restrictions. These restrictions disproportionately impacted the informal economy as many businesses such as informal car washes and cleaning services had to be scaled down or closed, which in turn was reported to have knock-on effects for crime as more people are forced into illegal income generation activities (Saal, February 2018). Moreover, there is limited financial and social redundancy in informal systems as insurance coverage is extremely low and households are forced to get by with limited resources. Thus, when chronic stressors such as a drought limit the water availability of a household through increased tariffs and/or through direct restrictions, these households cannot afford to use much less than they already do. Although the 'free basic allowance' of water for 'indigent households' may buffer these impacts to a certain

degree, these households remain trapped in a cycle of poverty; and water consumption by these households remains very low (discussed further in Section D.3).

Figure 25: Job opportunities and population balance in Cape Town



Similar risks threaten the informal economy from shocks such as fires, heatwaves and floods. Without insurance, informal businesses and households face significantly higher relative losses from fires or floods that damage or destroy their home or business infrastructure. Threats to human health and life from heatwaves are likely to disproportionately impact the informal economy as informal sector workers are often exposed to the elements and lack the financial resources to continue working productively in

extreme heat (i.e. working outside or without air conditioning, etc.). Heatwaves experienced in Europe in recent summers have also highlighted the particular vulnerability of the aged to extreme heat (Herrmann and Sauerborn, 2018). Again, this affects the poor, who are least able to afford air conditioners.

On the other hand, many water-intensive formal sector livelihoods are threatened by climate-related shocks and stressors. The most obvious interaction is between drought and agricultural jobs. WWF (2018) estimates that ~30,000 jobs were lost in the agricultural sector in the Western Cape as a direct result of the recent drought. Although the majority of these jobs are probably not within the Cape Town Municipality, the ripple effects in the regional economy can be significant for the City, being the economic hub of the province. In-migration to the City is thus a significant driver of vulnerability linked to both in-situ and broader regional impacts of climate change. People moving to Cape Town predominantly settle in the low-income areas and informal settlements, where vulnerabilities are already high. These complex interlinkages between livelihoods, poverty, the built environment and disaster risk further highlight how climate change is a threat multiplier for Cape Town.

D.3 Poverty and Inequality

Poverty and inequality are both drivers of climate change vulnerability, and are results of it. The roles of poverty and inequality, which are inextricably linked in South Africa, are central to understanding vulnerability in the context of Cape Town because, as mentioned above, climate change acts as a threat multiplier that exacerbates existing human, social, economic and environmental vulnerabilities through multiple causal pathways. South Africa's high levels of inequality coupled with endemic poverty, mean that the impacts of climate change pose serious challenges for development (ACDI, 2015).

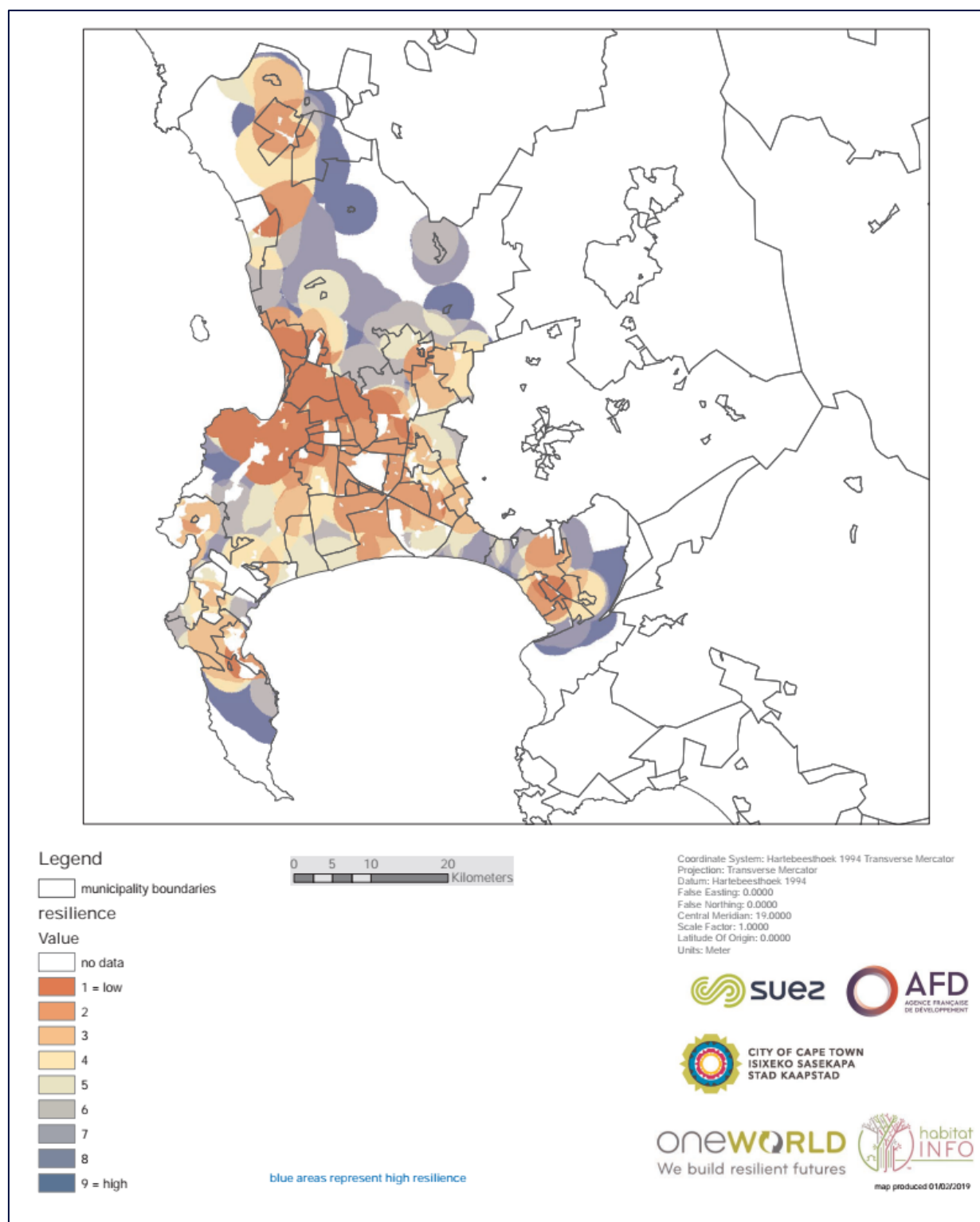
The distribution of poverty within Cape Town is largely contiguous, as evidenced through key resilience input indices such as mean household income, and access to electricity and water services (see Appendix 5). Spatial distributions of high ranges in income inequality underline the inextricable linkages between livelihood opportunities (Figure 26) and poverty and inequality. The relatively high levels of vulnerability of the informal sector is strongly linked to inequality and cycles of poverty, crime and violence in specific areas within the City.

Figure 26 illustrates relative levels of income inequality within a 3km radius of each household income level in Cape Town. In other words, this indicator reveals areas where there are significant differences in household income (red areas), which are often drivers of illegal activity such as crime (Kriegler, 2018) and other activities that limit resilience. Poverty and inequality are multi-dimensional and multi-generational, highlighting the complex causal pathways of vulnerability. For example, Khambule and Siswana (2017) argue that social and economic inequalities undermine social cohesion in South Africa, which ultimately reduces resilience to shocks and stressors. Communities that are able to collectively respond to shocks such as fires, droughts and heatwaves are more resilient. Ultimately, poorer households are less likely to have adequate resources to adapt to change, which are further undermined by the stark levels of inequality that limit social cohesion.

High levels of vulnerability in poorer areas also result in a myriad of City-wide and regional socio-economic impacts that have negative knock-on effects on general levels of vulnerability. For example, resource poor households are more dependent on natural resources from surrounding ecosystems when climate stressors limit livelihood activities. Over-dependence on natural systems may threaten the sustainability of these systems to continue providing essential ecosystem services such as water provision. These cycles further entrench City-wide vulnerabilities by placing increasing pressure on social support systems and economic redistribution mechanisms, further eroding social cohesion in communities and negatively impacting economic sentiment and investment. All of these factors may further contribute to poverty and overall poor levels of resilience.



Figure 26: Range of household income within 3km in Cape Town



D.4 Built Environment

The built environment in Cape Town refers to the vast range of public and private infrastructure and residential households that make up the human-made environment in which the people of Cape Town live, work and travel. The built environment directly and indirectly influences levels of vulnerability through both exposure and resilience aspects. For example, roads and public transport infrastructure provide ease of access to and from critical infrastructure such as hospitals and fire stations.



Moreover, these components of the built environment also face risks from climate shocks and stressors to their overall structural integrity and functional capacity. For example, more intense and frequent heat waves, extreme temperatures and floods present physical risks to critical public infrastructure such as roads, which are constructed to specific thermal and hydrological codes (in relation to heat and stormwater runoff).

Impacts of urban heat island effects are intensified by both increasing temperatures and physical building density, ultimately increasing heatwave risks impacts and the overall risks associated with increasing temperatures in highly built-up areas.

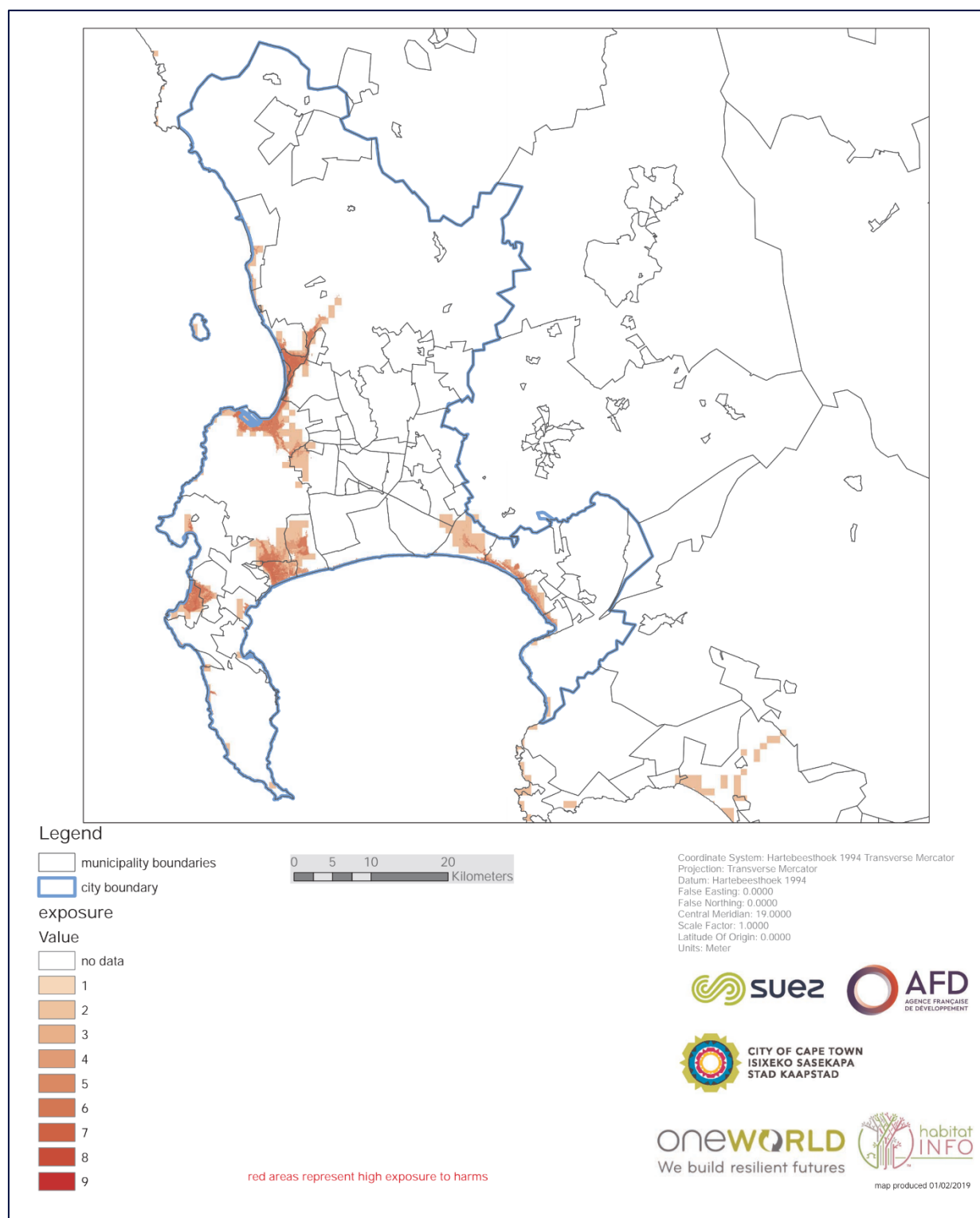
Urban fires, often exacerbated by climate change impacts such as increased wind strength and frequency, present significant risks to residential housing, particularly in the areas with high population densities, and informal settlements. Wildfires also present significant risk to residential properties and public infrastructure facilities, including a significant proportion of middle to high income housing developments built in or adjacent to wilderness areas.

As previously discussed, low-income areas are less resilient for a number of reasons and are thus more socially vulnerable to climate-related hazards, signalling the importance of prioritising these areas in terms of investing in resilience. However, the nature of re-distributional taxation in South Africa provides an argument for protecting high value properties from the impacts of climate change. Household municipal rates are based on property value, and a proportion of rates paid to CCT is used to cross-subsidise low-income areas, thus contributing directly to their resilience. Thus, if climate-related shocks and stressors pose a threat to high value properties, these may negatively influence property values and reduce the cross-subsidisation that contributes to resilience in low-income areas. While this argument has merit, it must be balanced with the increasing need to invest in areas of low resilience, noting that reducing resilience inequalities may reduce the pressure on cross subsidisation from property rates over time.

Figure 27 demonstrates the areas at highest risk of inundation from future sea-level rise in Cape Town. Darker red shows the areas that are the most exposed to sea-level rise. Although the direct impacts of sea-level rise are likely going to occur slowly over many years, associated effects on changes in coastal erosion and coastal flooding may exacerbate risks to coastal infrastructure in these areas. Risks particularly to public infrastructure are important because of the resultant knock-on effects and interrelationships with social and economic vulnerabilities. For example, damaged roads or rail infrastructure limits human mobility in time of crisis (for example to reach a hospital, etc.), and access to economic opportunities, which result in lower overall resilience. Furthermore, risks of sea-level rise and coastal flooding to high value property, for example in the low-lying Green Point and Milnerton areas, and continuous erosion of the Sea Point seawall, will have knock-on impacts for tourism and the broader economy.



Figure 27: Sea-level rise inundation risk in Cape Town



D.5 Disaster Risk

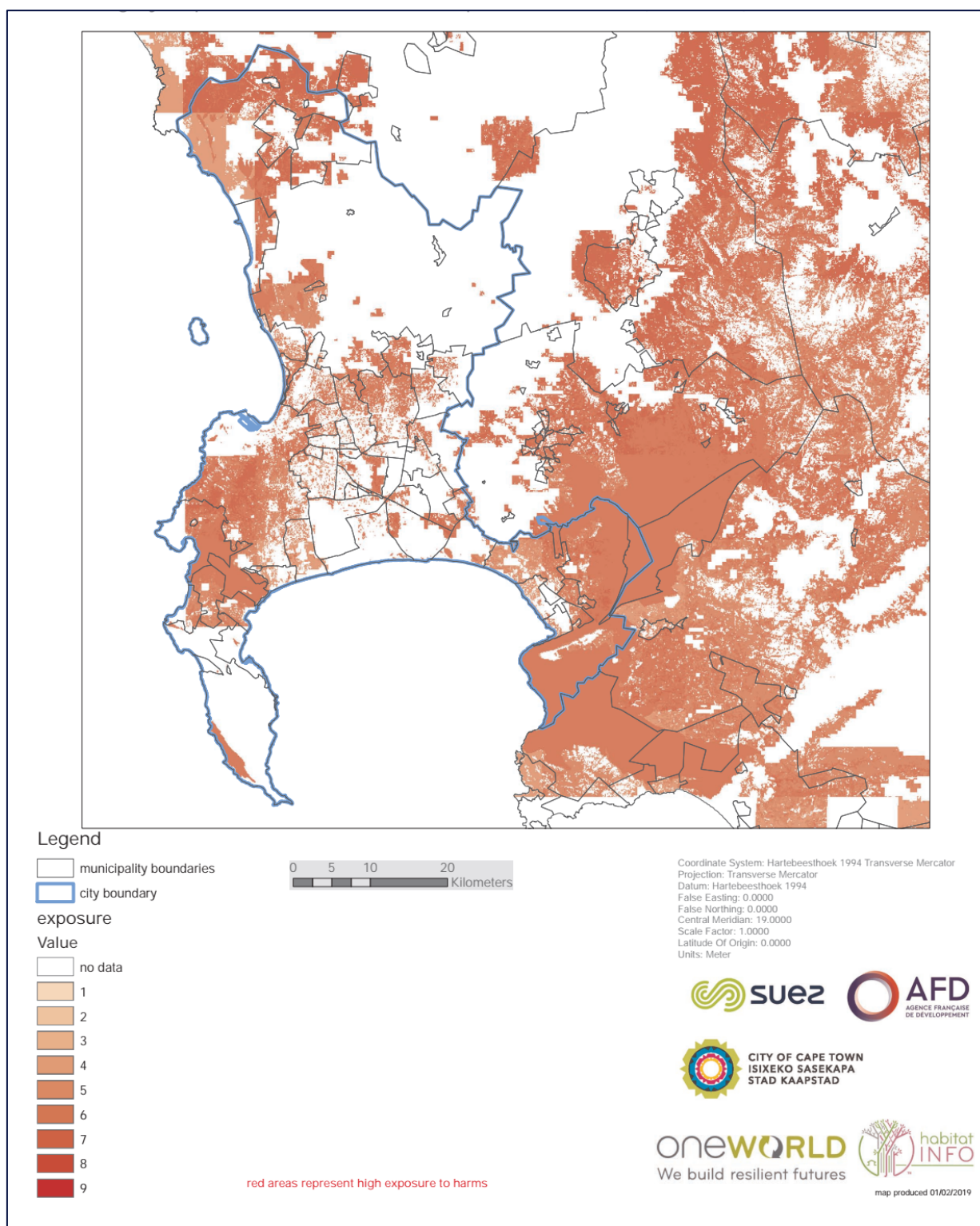
Disaster risk response and preparedness, both important adaptation responses, contribute directly to relative levels of vulnerability throughout the City. The obvious relationships are directly related to resilience, for example a residential area with a shorter travel time to and from a fire station, a hospital, police station or freshwater spring is likely to be more resilient to climate-related shocks than one further away from such amenities. However, disaster risks manifest through different pathways, many of which will have cumulative impacts and will result in increasing vulnerability to future climate-related hazards. As such, disaster risk, although articulated as a fourth cross cutting theme, is also a direct threat to livelihoods, poverty and inequality and the built environment.

Figure 28 demonstrates future high fire risk areas in and around Cape Town. The darker red areas show areas at highest risk of fire in the future because of changes in climatic conditions. The risks associated with high fire danger are extensive, and include human, social, environmental and infrastructural risks. In relation to risks to human life and health, densely populated areas in informal areas that have limited access to municipal disaster response services will experience the greatest risk from fire disasters. Other related impacts include deterioration in in-situ and down-wind air quality as a result of higher numbers of fires. Furthermore, the risk from fire for natural areas with high biodiversity and those yielding high-value ecosystem services, represents considerable risks to society, as loss of these areas has a variety of ripple effects for different sectors such as tourism, agriculture and water.

Fire disaster risk is closely interwoven with water security risks for Cape Town, partly because of the biophysical impacts of alien invasive species. The Status of Biological Invasions and their Management in South Africa Report (SANBI, 2017) highlights that alien plants use up to 30% of the water supply in major cities such as Cape Town. Moreover, alien species change the structure and biomass of vegetation, adding fuel and increasing the severity of wildfires, making them more difficult to control and more destructive.



Figure 28: Future fire risk areas in Cape Town region



E. The Way Forward

Although the findings presented in this report will be subject to continued development and refinement through participatory analysis, this marks the end of Phase 2 of the project. From here on out, the project team is carrying out the Economic Risk Assessment and prioritisation of adaptation investments in parallel. The increasingly nuanced R&V assessment continues to add nuance. Additionally, Phase 3 of the project will incorporate a variety of in-depth engagement activities to create the platform for the final Phase: Communication of Findings. Specifically, upcoming engagement activities are envisioned to include:

- Focus Group Discussions with key participants of the reference group and key informants within CCT;
- The second participatory analysis workshop once preliminary findings from the Economic Risk Analysis and Adaptation Options Assessment have been collated;
- Project presentations to key CCT corporate structures such as the relevant portfolio committee and selected Executive Directors.
- Attendance of workshop/s for the AFD funded 'low-income household energy study' being undertaken by OneWorld, which has various synergies with this project, and are currently being explored.

In addition, and to further inform the Economic Risk Assessment, while also deepening the R&V analysis contained in this report, the following 'deep dive' assessments are about to commence:

- Rainfall and flooding assessment to validate and refine the findings contained in this report;
- Land use assessment, integrating and deepening the associated risks across the four themes discussed in the previous section;
- Fire risk assessment, detailing the interactions between increased fire risk, common drivers of fires in informal settlements, risks for property investments and for land uses in general;
- Coastal risk dynamics assessment to deepen the understanding of the extent of the risks of coastal erosion and the interactions with wind and storm surges.

Based on the outcomes of this report and the above assessments, the Economic Risk Assessment will be focused on assessing the economic risks associated with both immediate climate shocks and more gradual climate stressors through a broad 'capital theory' approach. The logic follows that different forms of capital provide different flows of benefits (or services) to society such as human capital, social capital, natural capital, intellectual capital and manufactured capital. Baseline indicators for these various forms of capital will be drawn from the R&V assessment and other relevant data sources. Thereafter, the project team will carry out a systematic cost-benefit analysis for priority adaptation investment options, which have been scrutinised and verified through multiple stakeholder engagements.

This overarching approach to understanding broader economic risks is consistent with the notion of risk manifesting through multiple pathways and is centred around managing the trade-offs within complex socio-economic and biophysical systems.



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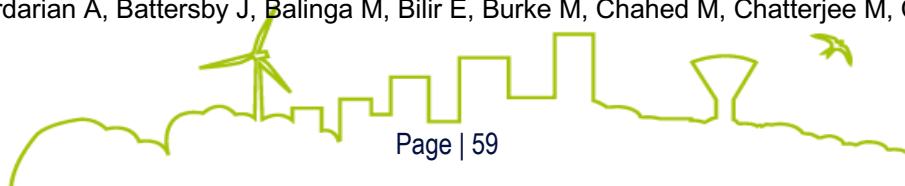
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Appendix 1: Seasonality of fire risk

Winter rainfall, and well as the frontal rain that occurs during the transition seasons of autumn and spring, are projected to decrease significantly under enhanced anthropogenic forcing. This is due to the strengthening of the subtropical high-pressure belt over the southern African region and the southward displacement of the westerly wind regime (and cold fronts) under climate change (Christensen et al., 2007; Engelbrecht et al., 2009). Moreover, temperatures are projected to increase over the southwestern Cape across all seasons. This implies that fire risk is to increase across all seasons in the southwestern Cape. Of particular importance is the potential of more frequent occurrence of fires during winters that are projected to increasingly become drier and warmer, upsetting the natural seasonal cycle of fire in the Fynbos Kingdom and posing severe threats to biodiversity. Also important is the potential for more frequent mega-fires to occur within the longer burning season, with implications for biodiversity and disaster events impacting on human mortality and property. Figures 29 to 32 show the projected changes in the seasonal cycle of the number of high fire-danger days for two cases of Cederberg and Vermaaklikheid (along the Cape south coast).

Cederberg

Model-projected changes in the annual cycle of the number of days per month when the FFDI value is rated as high, very high or extreme ($\text{FFDI} > 12$) is shown in Figure 29 (top panel), for the future time period 2021-2100 and the baseline period 1961-1990, for the Cederberg region (32.5°S and 19.25°E). For each time period, the simulated cycles for all six ensemble members are shown. The projected changes in the annual cycle of high fire danger days are shown in Figure 29 (lower panel). The same quantities are displayed in Figure 30 but for the period 2070-2099 relative to 1961-1990. The present day (1961-1990) annual cycle in the number of high fire danger days shows a distinct peak in the late summer (January to March), which forms part of the dry season over the region. During this time of the year, about 10-12 days per month are associated with a high fire risk according to the FFDI.

For the far-future period of 2070-2099, the projected increases in days with high fire risk are drastic for late spring to autumn – increases range between 8 and 18 days per month (Figure 30). High fire danger days are also projected to occur regularly during the winter months (very low fire risk is simulated for the region for the present-day climate in winter). The projected increases in high fire-risk are also substantial for the mid-future period of 2021-2050, with increases for the late spring autumn period projected to range between 2 and 10 days per month. These results suggest the potential of a future expansion of the length of the fire season over the Cederberg region, with a significant increase in risk during an important part of the fire season, namely the late summer.

Vermaaklikheid

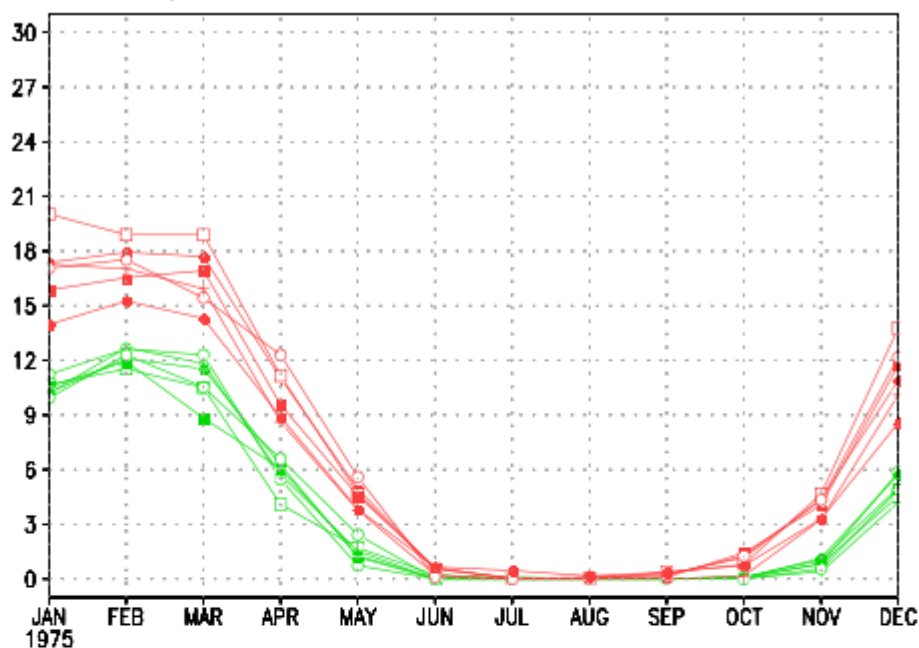
At Vermaaklikheid along the Cape South coast region, the FFDI is indicative of relatively smaller fire risk than over the Cederberg to the north. Over this region the number of high fire-danger days is simulated to range between 2 and 4 days per month during the late spring to autumn period (Figure 31, top panel). Increases are projected to range between 0 and 1 days by the mid-future period of 2021-2050 (Figure 31, lower panel), and by 4-8 days by the far-future period of 2070-2099 (Figure 32, lower panel).



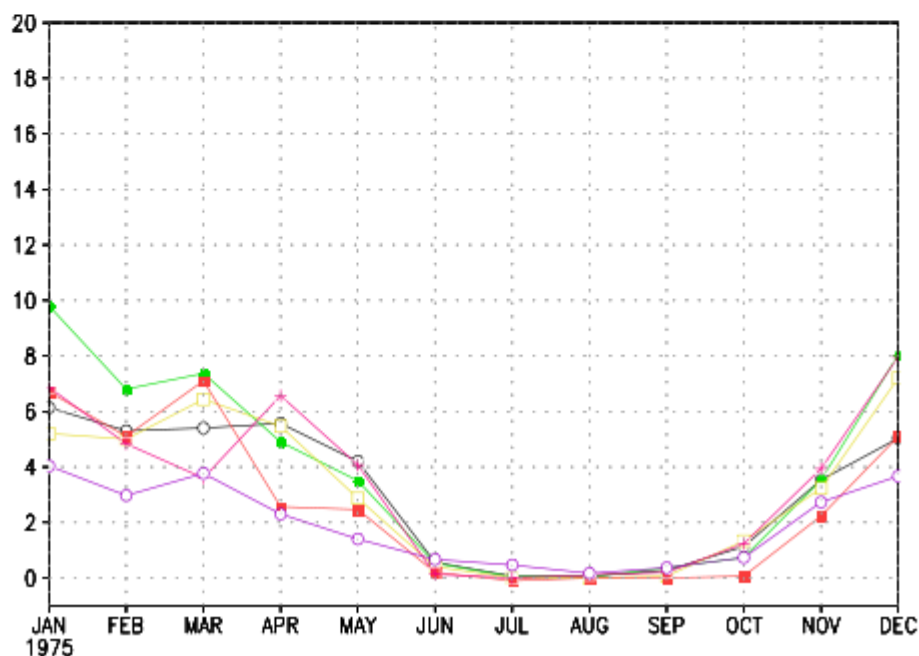


Figure 29: Projected changes in the number of high fire-danger days per month: Cederberg

hda3 cycle 1961–1990 and 2021–2050

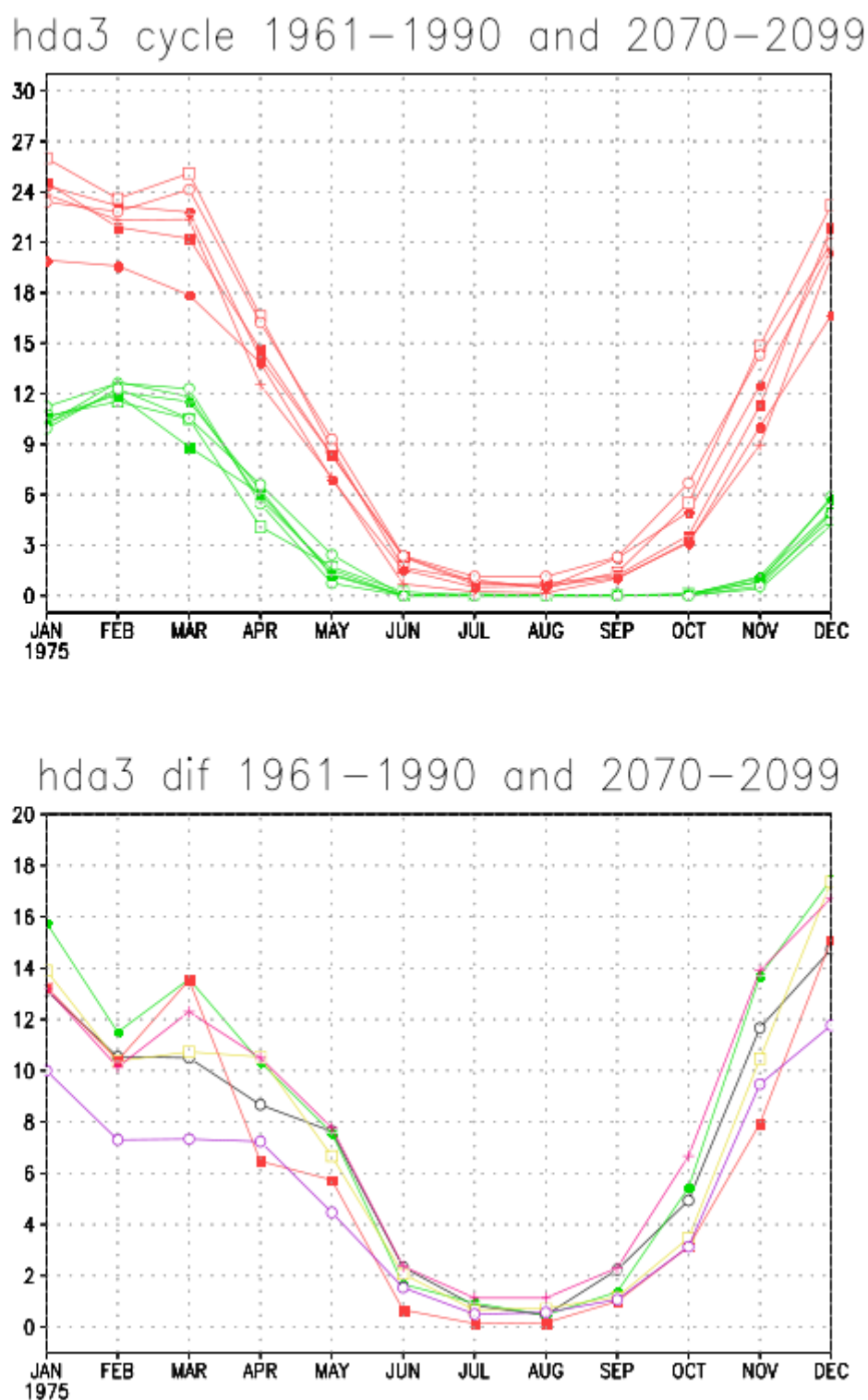


hda3 dif 1961–1990 and 2021–2050



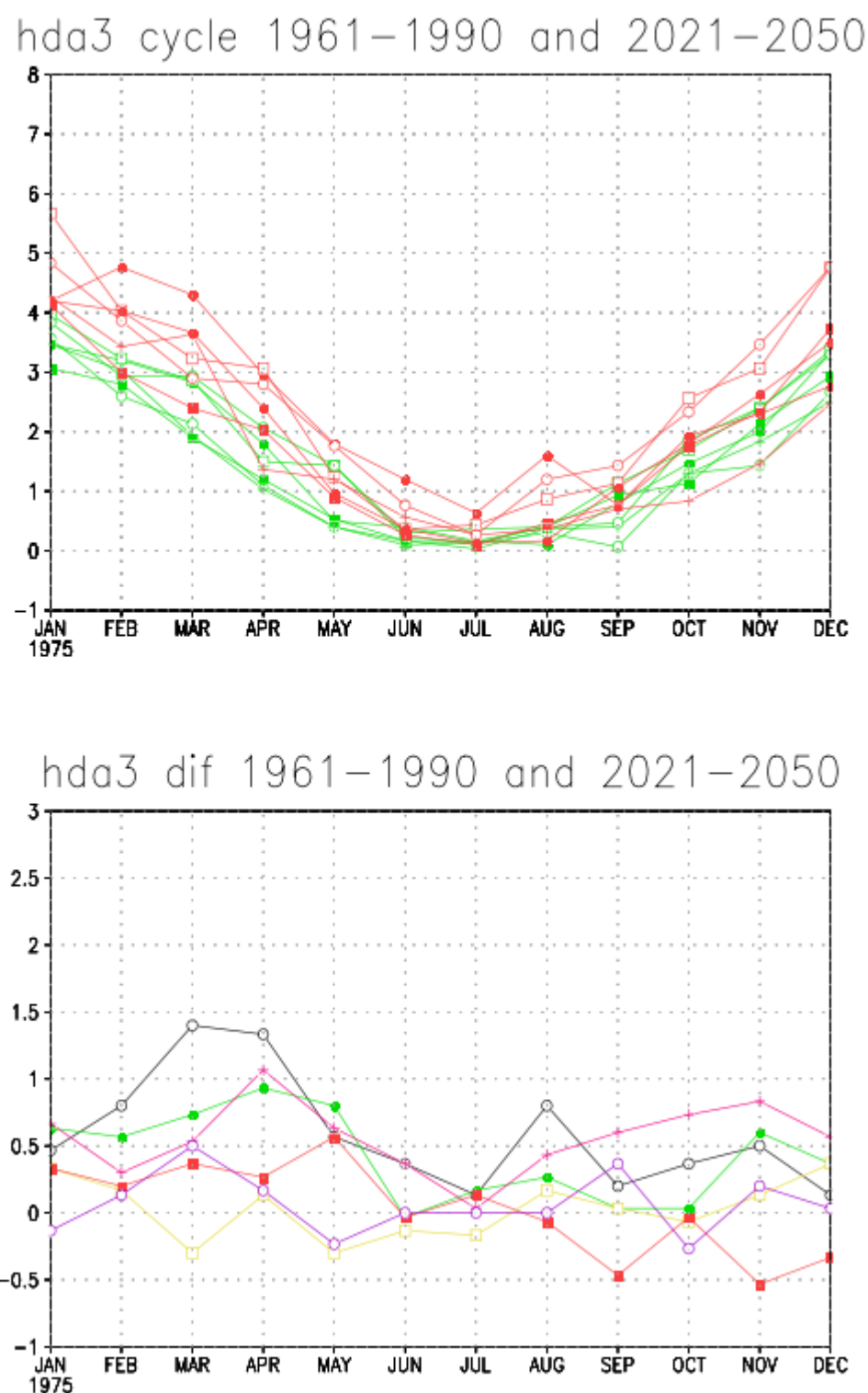
Projected changes in the annual cycle of the number of days per month when the FFDI value is rated as high, very high or extreme (FFDI > 12) over the Cederberg region, for the future time period 2021-2050 and the baseline period 1961-1990. For each time period, the simulated cycles are shown (top panel) for **present-day climate (green lines)** and **far-future climate (red lines)**. The bottom panel shows the projected monthly differences in the number of high fire danger days for 2021-2050 relative to 1961-1990.

Figure 30: Projected changes in the number of high fire-danger days per month: Cederberg



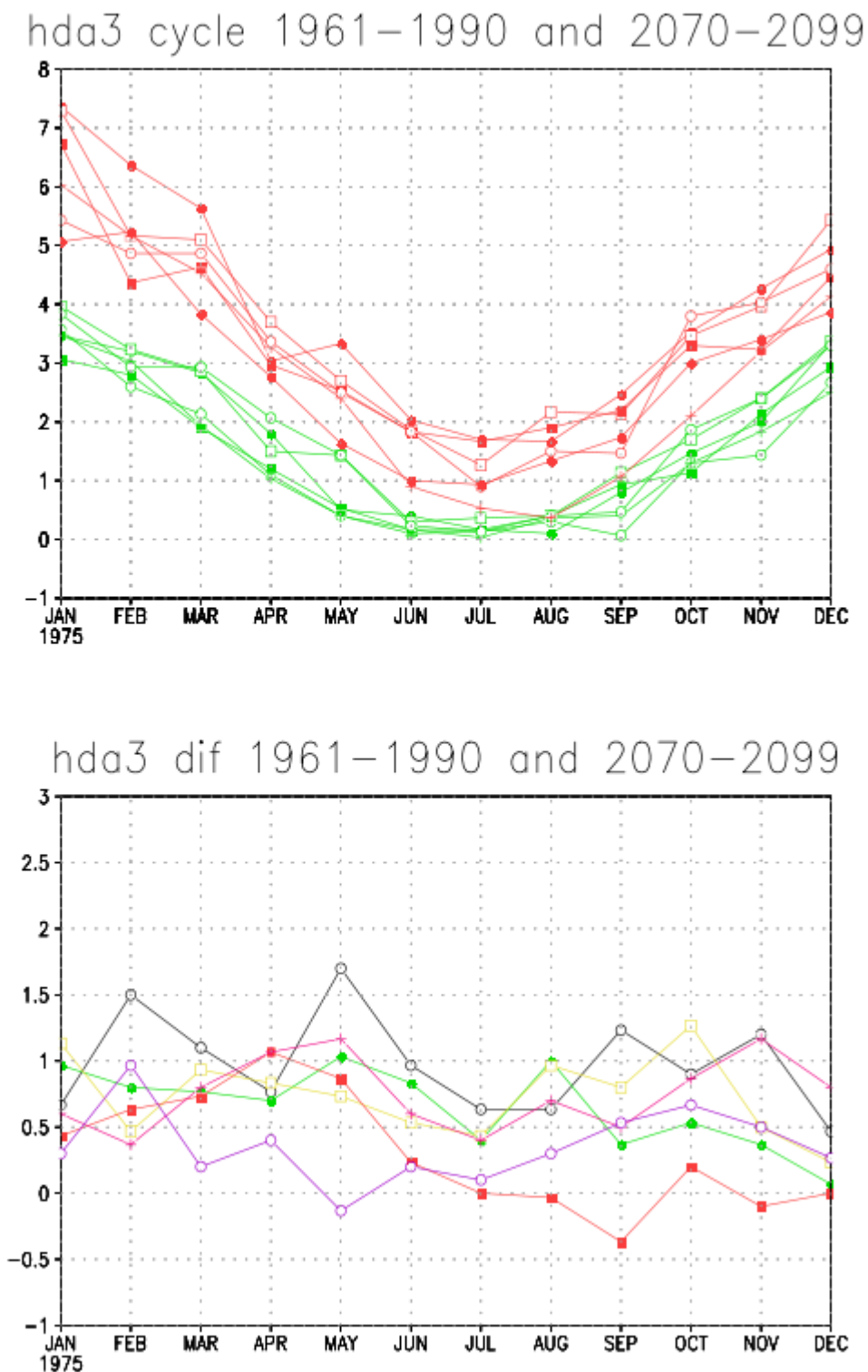
Projected changes in the annual cycle of the number of days per month when the FFDI value is rated as high, very high or extreme ($FFDI > 12$) over the Cederberg region, for the future time period 2070–2099 and the baseline period 1961–1990. For each time period, the simulated cycles are shown (top panel) for **present-day climate** (green lines) and **far-future climate** (red lines). The bottom panel shows the projected monthly differences in the number of high fire danger days for 2070–2099 relative to 1961–1990.

Figure 31: Projected changes in the number of high fire-danger days per month: Vermaaklikheid



Projected changes in the annual cycle of the number of days per month when the FFDI value is rated as high, very high or extreme (FFDI > 12) at Vermaaklikheid along the Cape south coast, for the future time period 2021-2050 and the baseline period 1961-1990. For each time period, the simulated cycles are shown (**top panel**) for **present-day climate (green lines)** and **far-future climate (red lines)**. The bottom panel shows the projected monthly differences in the number of high fire danger days for 2021-2050 relative to 1961-1990.

Figure 32: Projected changes in the number of high fire-danger days per month: Vermaaklikheid



Projected changes in the annual cycle of the number of days per month when the FFDI value is rated as high, very high or extreme (FFDI > 12) at Vermaaklikheid along the Cape south coast, for the future time period 2070–2099 and the baseline period 1961–1990. For each time period, the simulated cycles are shown (**top panel**) for **present-day climate (green lines)** and **far-future climate (red lines)**. The bottom panel shows the projected monthly differences in the number of high fire danger days for 2070–2099 relative to 1961–1990.

Appendix 2: Maps of Major Suburbs of Cape Town



Appendix 3: Risk and Vulnerability Assessment Summary Maps

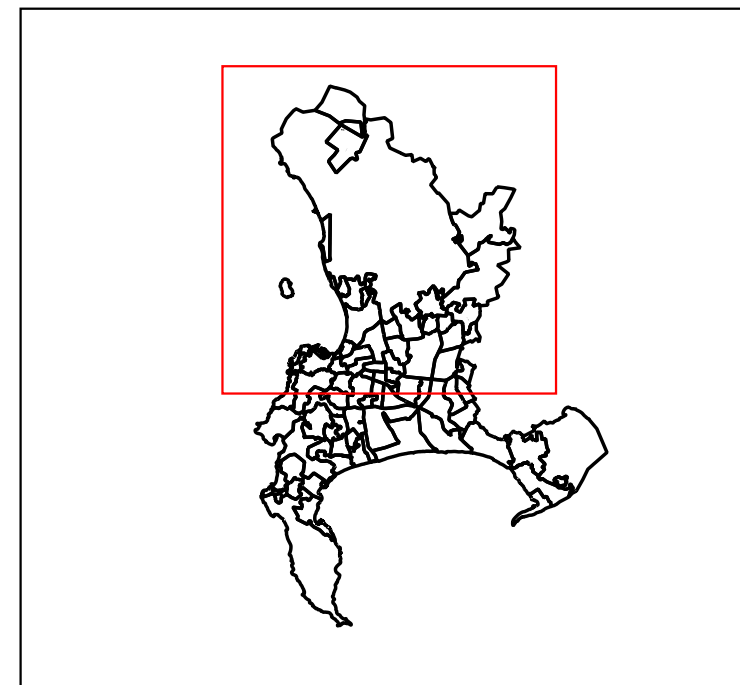
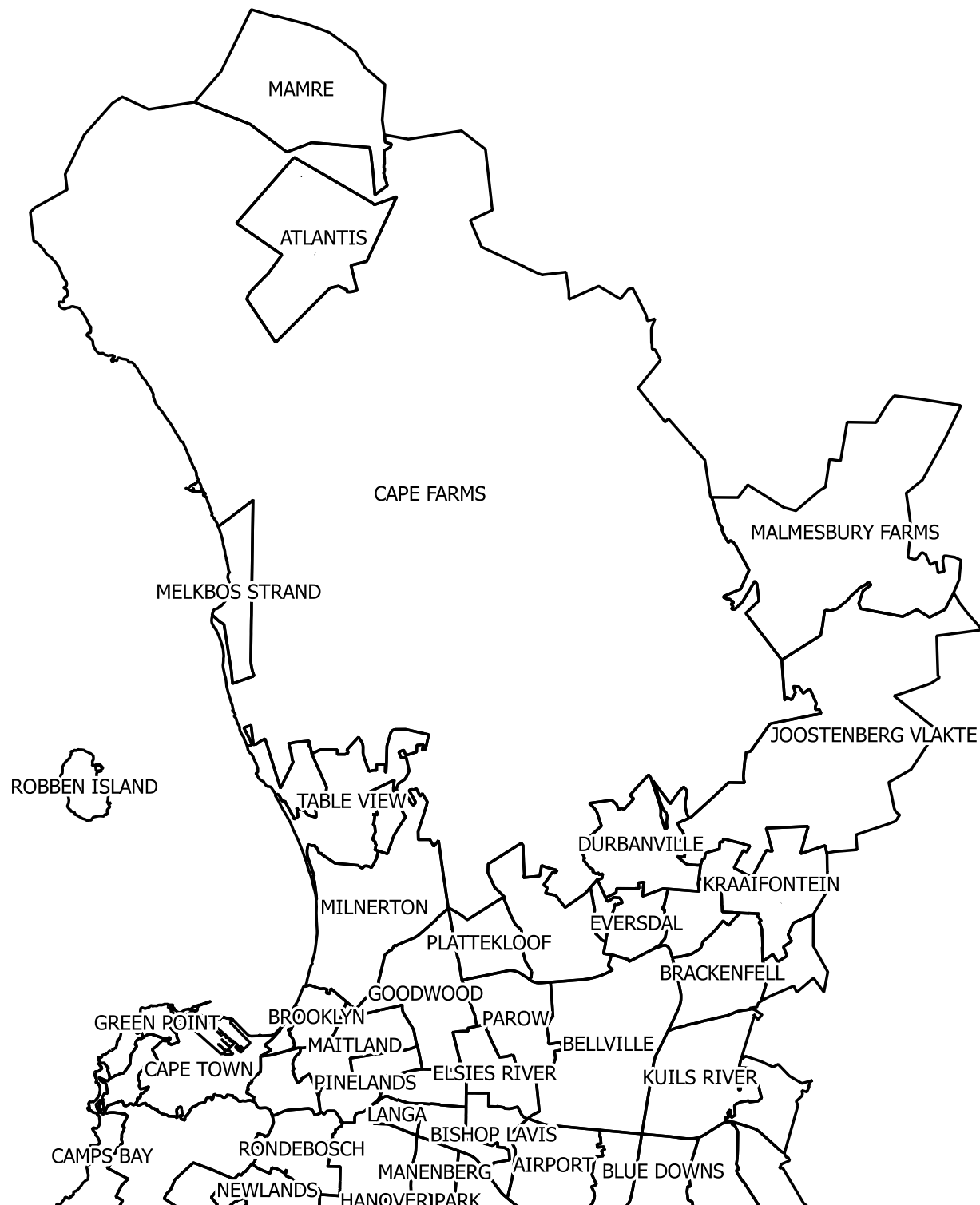


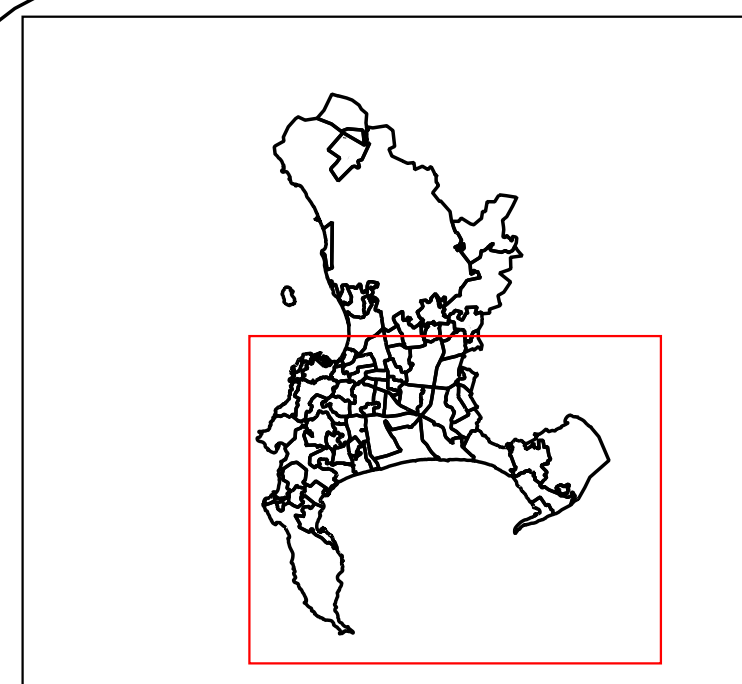
Appendix 4: Exposure Input Indicator Maps

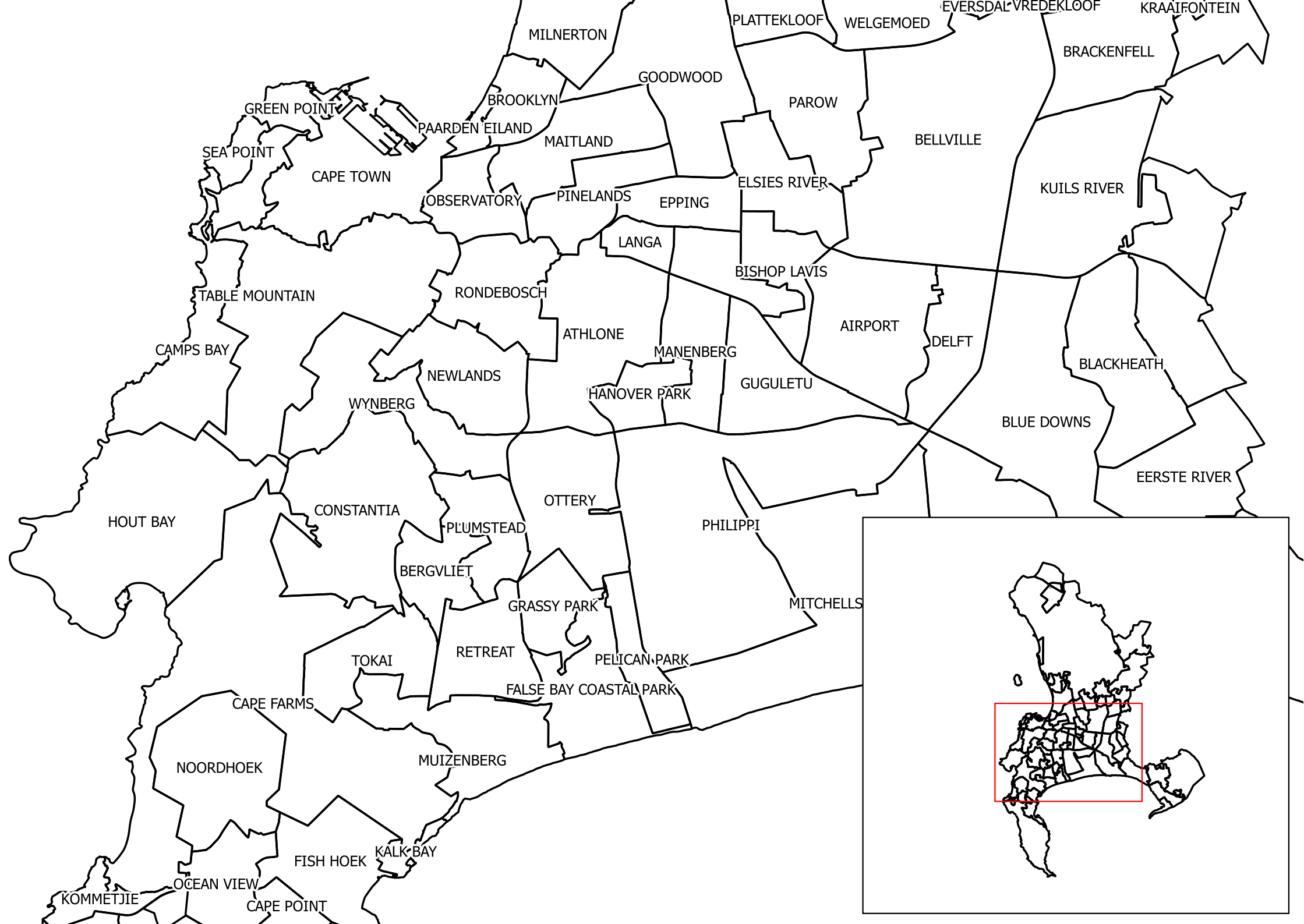


Appendix 5: Resilience Input Indicator Maps



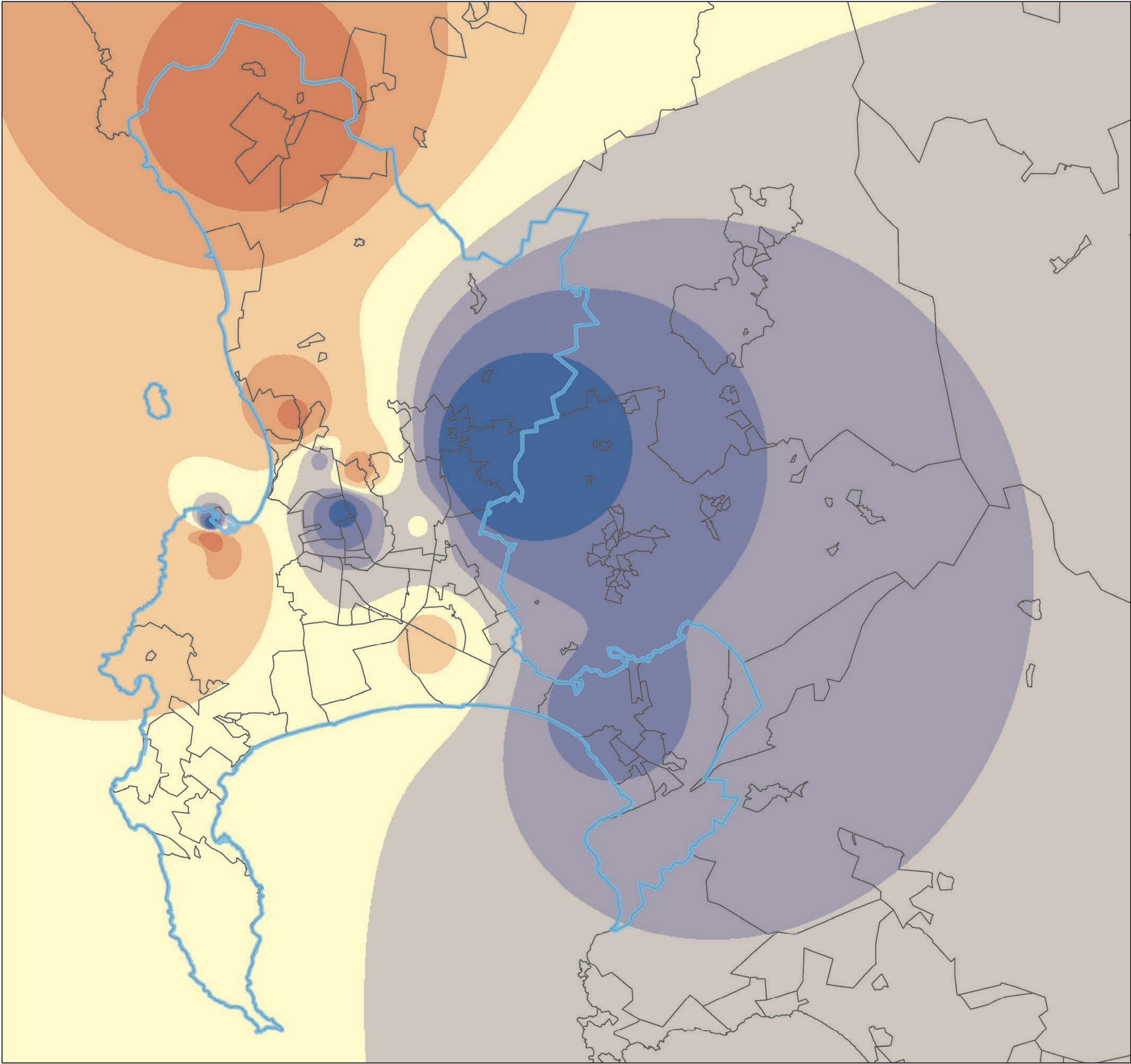






Air Quality

category: resilience time period: current conditions weighting 3



Legend

- city_boundary
- municipality boundaries

resilience

- Value
- no data
 - 1 = low
 - 2
 - 3
 - 4
 - 5
 - 6
 - 7
 - 8
 - 9 = high



Air quality (2016). Raw values of Nitrogen oxide, Ozone, Sulphur dioxide, Carbon monoxide and particulate matter (PM10 and PM2.5) were combined. Air quality monitoring station locations sourced from CoCT. The data were converted to raster and then reclassified to 1-9 using a natural breaks method. The reclassified values were inverted such that high values represented high Resilience. Cells with no data were assigned a value of 0. Original resolution: n/a. Credits: City of Cape Town

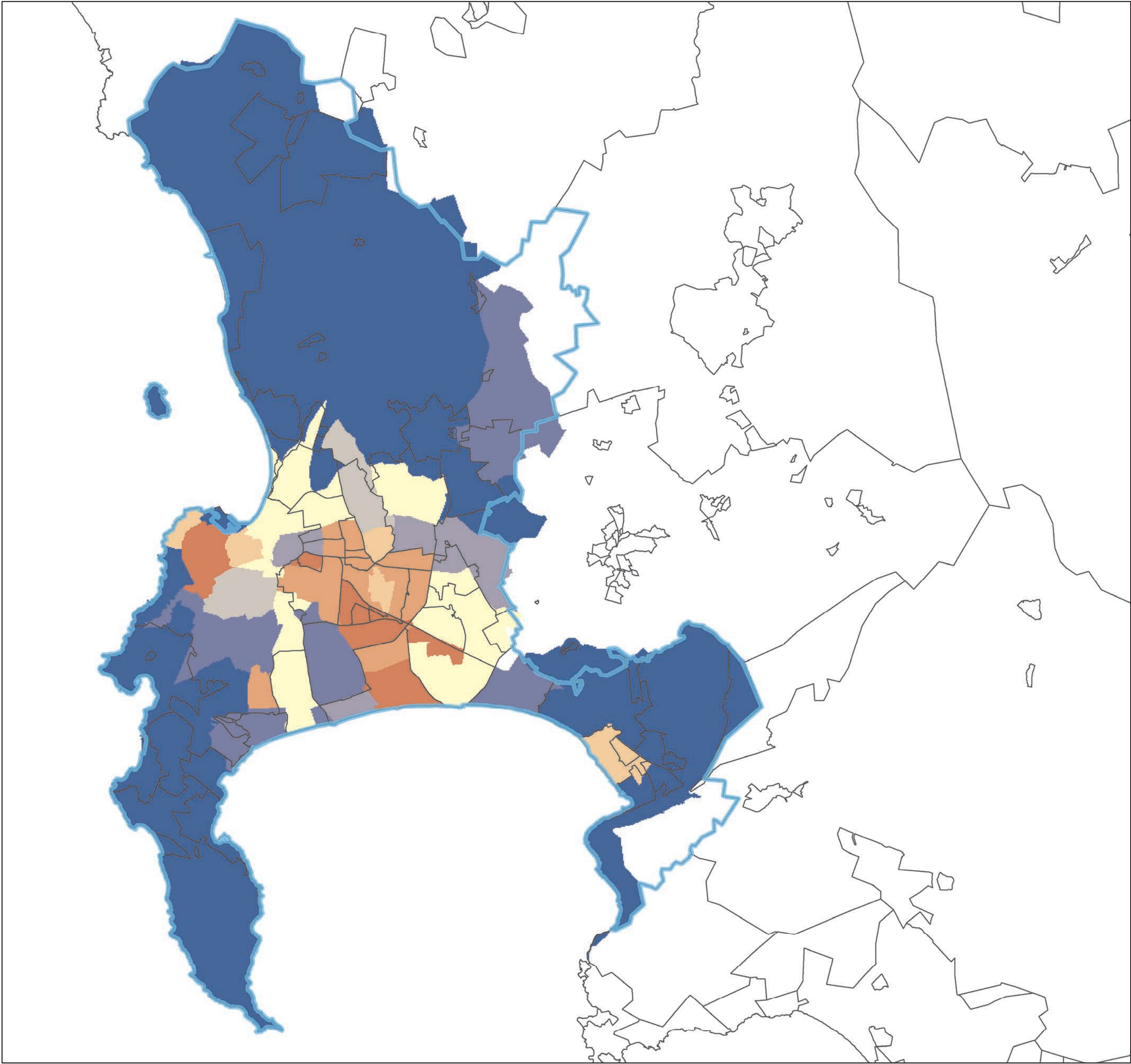
blue areas represent high resilience

Coordinate System: Hartebeesthoek 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: Hartebeesthoek 1994
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: 19.0000
Scale Factor: 1.0000
Latitude Of Origin: 0.0000
Units: Meter



Crime Rate

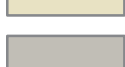
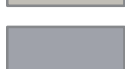
category: resilience time period: current conditions weighting 5



Legend

-  city_boundary
-  municipality boundaries

resilience

- Value
-  no data
 -  1 = low
 -  2
 -  3
 -  4
 -  5
 -  6
 -  7
 -  8
 -  9 = high



Total crimes per square km (April 2017-March 2018). Calculated by dividing Total Crimes by area (km). The data were converted to raster and then reclassified to 1-9 using a natural breaks method. The reclassified values were inverted such that high values represented high Resilience. Cells with no data were assigned a value of 0. Original resolution: Police Bound. Credits: City of Cape Town

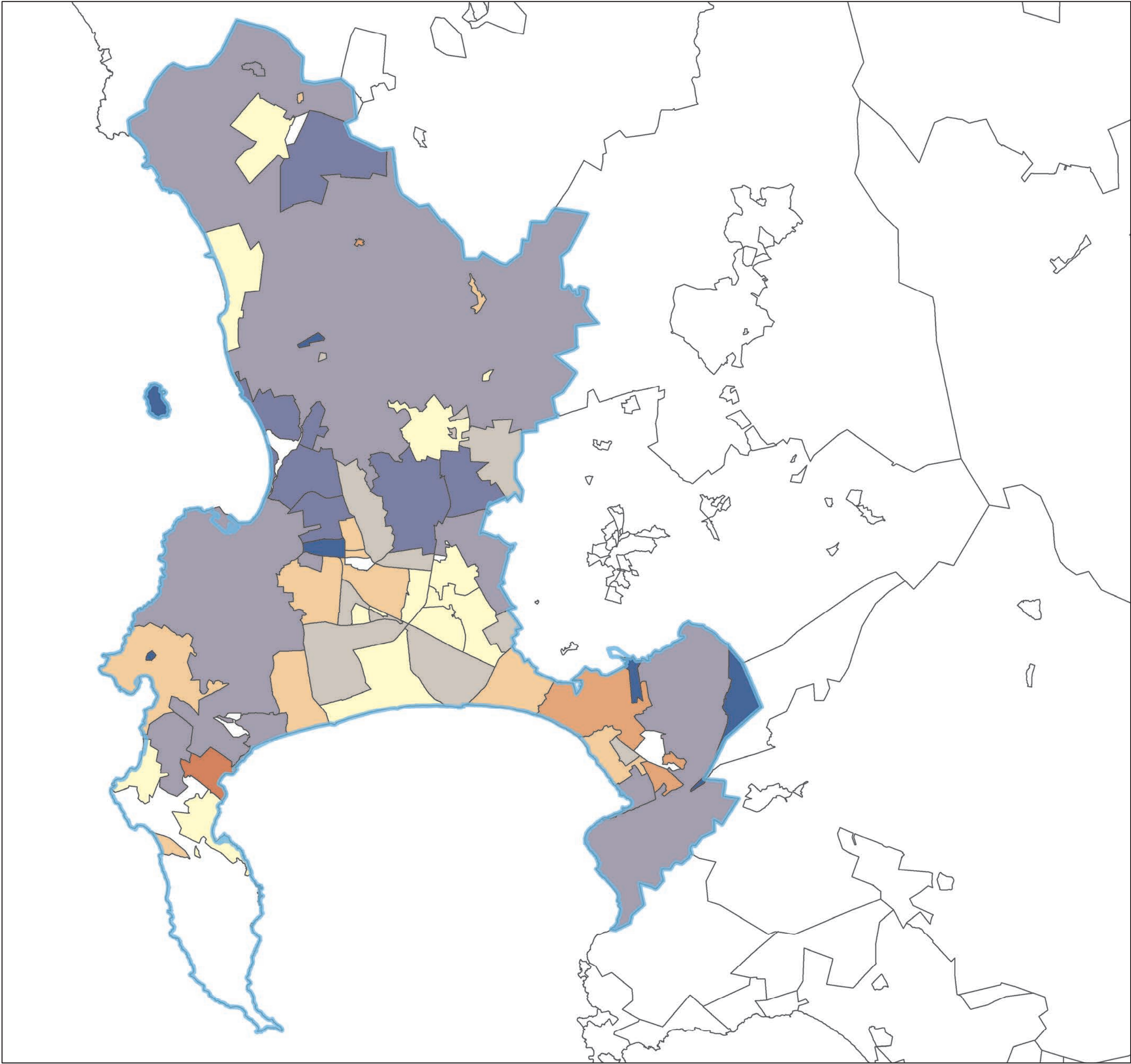
blue areas represent high resilience

Coordinate System: Hartebeesthoek 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: Hartebeesthoek 1994
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: 19.0000
Scale Factor: 1.0000
Latitude Of Origin: 0.0000
Units: Meter



Dependency

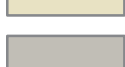
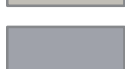
category: resilience time period: current conditions weighting 4



Legend

-  city_boundary
-  municipality boundaries

resilience

- Value
-  no data
 -  1 = low
 -  2
 -  3
 -  4
 -  5
 -  6
 -  7
 -  8
 -  9 = high



Dependency ratio (2011). Original raw data values used. The data were converted to raster and then reclassified to 1-9 using a natural breaks method. The reclassified values were inverted such that high values represented high Resilience. Cells with no data were assigned a value of 0. Original resolution: Main Place. Credits: City of Cape Town

Coordinate System: Hartebeesthoek 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: Hartebeesthoek 1994
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: 19.0000
Scale Factor: 1.0000
Latitude Of Origin: 0.0000
Units: Meter



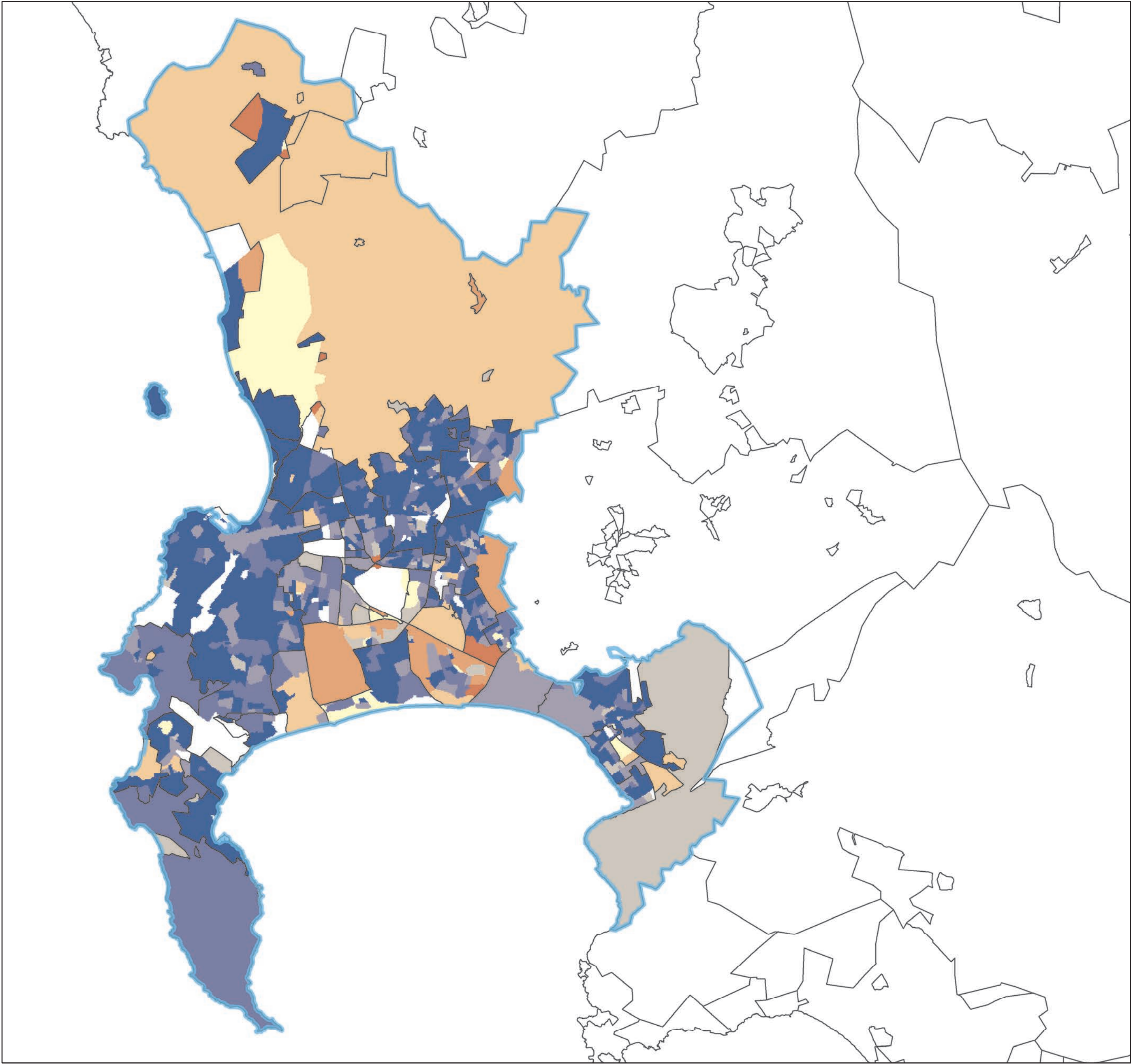
blue areas represent high resilience

Electricity for Lighting

category: resilience

time period: current conditions

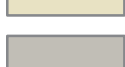
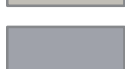
weighting4



Legend

-  city_boundary
-  municipality boundaries

resilience

- Value
-  no data
 -  1 = low
 -  2
 -  3
 -  4
 -  5
 -  6
 -  7
 -  8
 -  9 = high



Percentage of households with electricity for lighting (2011). Original raw data values used. The data were converted to raster and then reclassified to 1-9 using a natural breaks method. Cells with no data were assigned a value of 0. Original resolution: SP. Credits: City of Cape Town

Coordinate System: Hartebeesthoek 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: Hartebeesthoek 1994
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: 19.0000
Scale Factor: 1.0000
Latitude Of Origin: 0.0000
Units: Meter



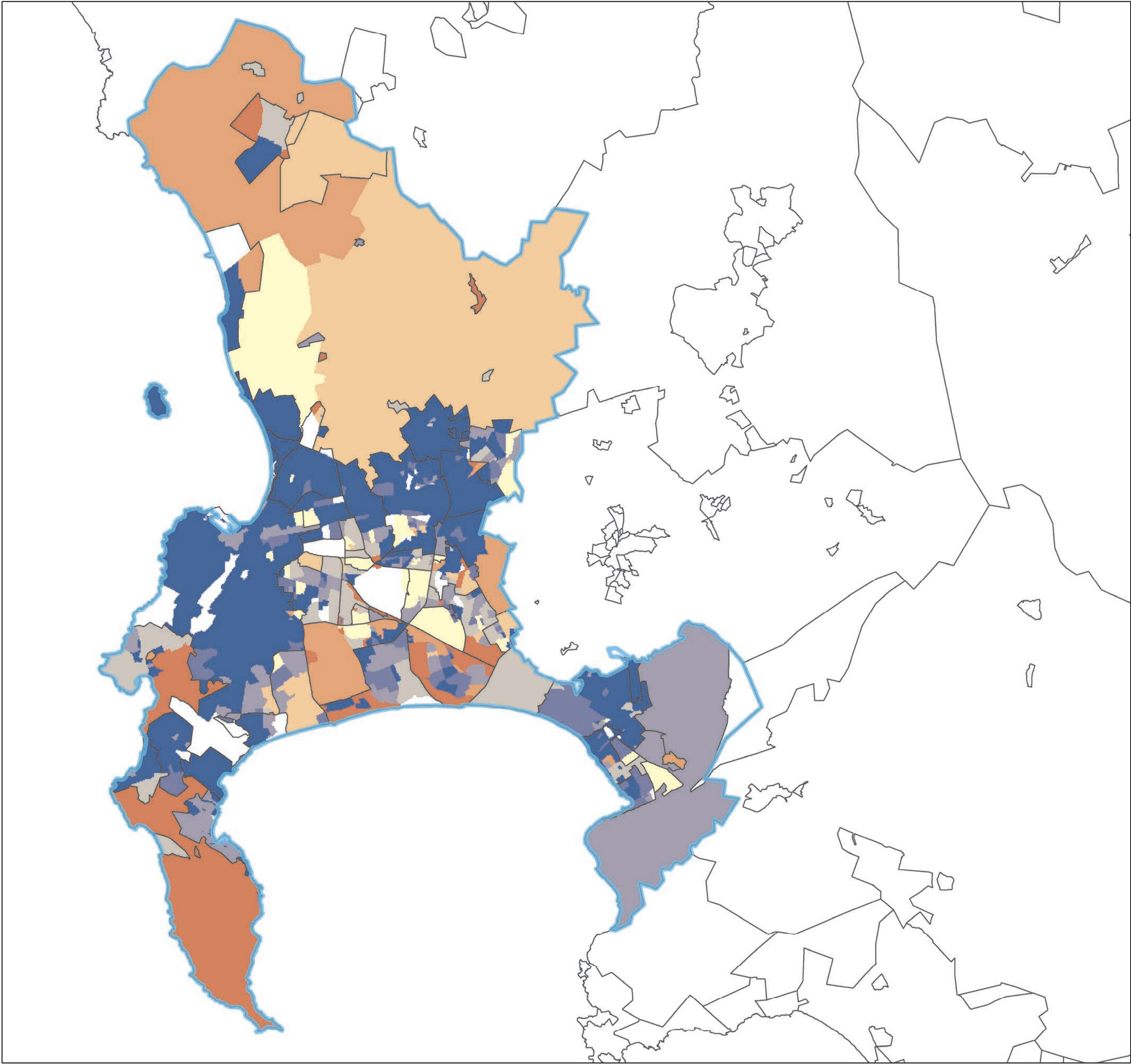
blue areas represent high resilience

Flushing Toilets

category: resilience

time period: current conditions

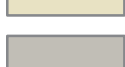
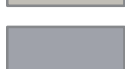
weighting 4



Legend

-  city_boundary
-  municipality boundaries

resilience

- Value
-  no data
 -  1 = low
 -  2
 -  3
 -  4
 -  5
 -  6
 -  7
 -  8
 -  9 = high



Percentage of households with a flush toilet (2011). Includes toilets which are both connected to main sewers and to septic tanks. The data were converted to raster and then reclassified to 1-9 using a natural breaks method. Cells with no data were assigned a value of 0. Original resolution: SP. Credits: City of Cape Town

blue areas represent high resilience

Coordinate System: Hartebeesthoek 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: Hartebeesthoek 1994
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: 19.0000
Scale Factor: 1.0000
Latitude Of Origin: 0.0000
Units: Meter

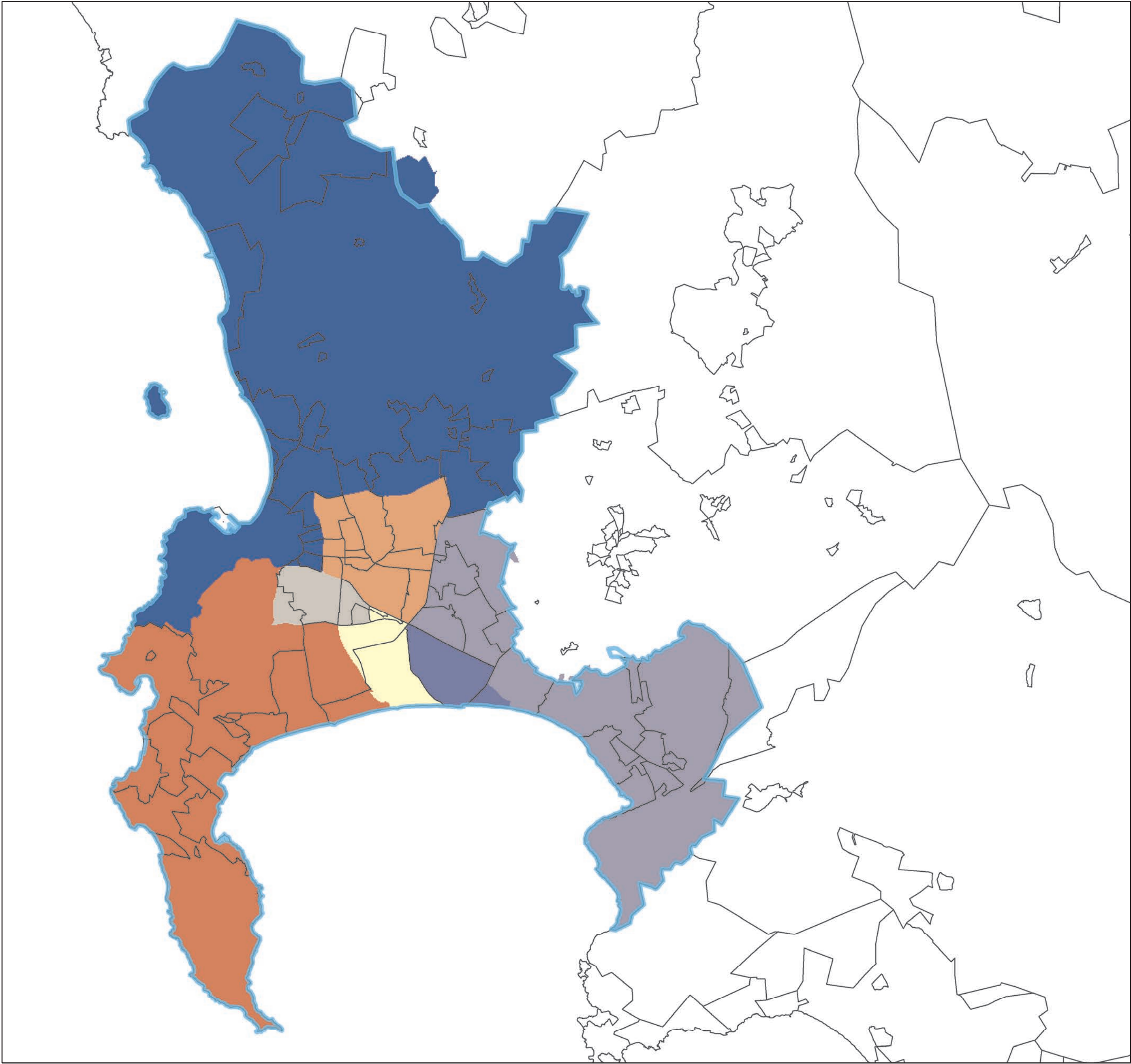


Hepatitis Rate

category: resilience

time period: current conditions

weighting2



Legend

- city_boundary
- municipality boundaries

resilience

- no data
- 1 = low
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9 = high



Number of people infected with Hepatitis A (2017). Original raw data values used. The data were converted to raster and then reclassified to 1-9 using a natural breaks method with some manual input. The reclassified values were inverted such that high values represented high Resilience. Cells with no data were assigned a value of 0. Original resolution: Health regions. Credits: City of Cape Town

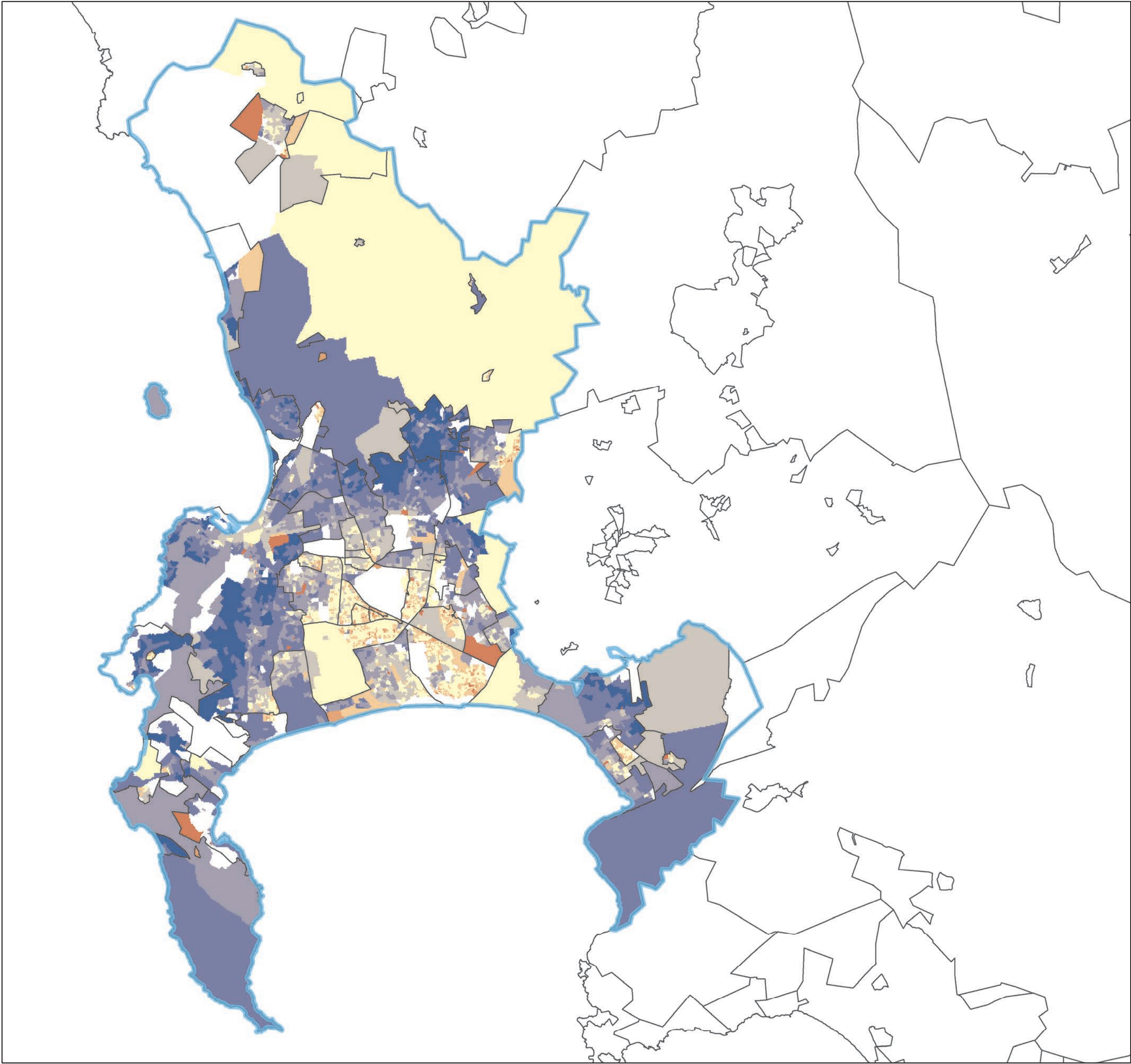
blue areas represent high resilience

Coordinate System: Hartebeesthoek 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: Hartebeesthoek 1994
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: 19.0000
Scale Factor: 1.0000
Latitude Of Origin: 0.0000
Units: Meter



Median Household Income

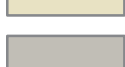
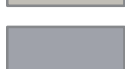
category: resilience time period: current conditions weighting 5



Legend

-  city_boundary
-  municipality boundaries

resilience

- Value
-  no data
 -  1 = low
 -  2
 -  3
 -  4
 -  5
 -  6
 -  7
 -  8
 -  9 = high



Median household income (2011). 0-10 values in raw data used. The data were converted to raster and then reclassified to 1-9 using a natural breaks method. Cells with no data were assigned a value of 0. Original resolution: SAL. Credits: City of Cape Town

Coordinate System: Hartebeesthoek 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: Hartebeesthoek 1994
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: 19.0000
Scale Factor: 1.0000
Latitude Of Origin: 0.0000
Units: Meter



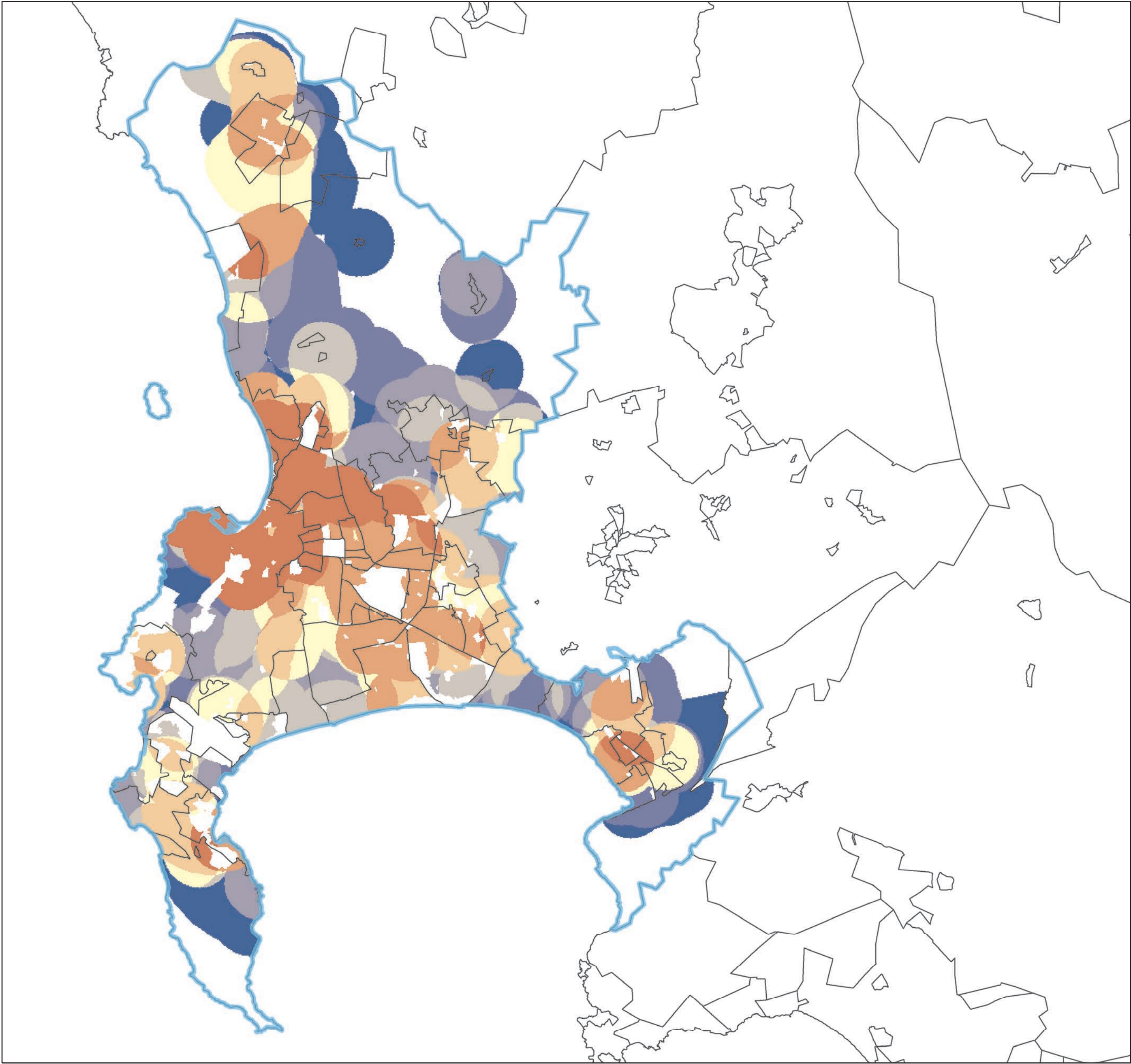
blue areas represent high resilience

Range of Household Income within 3km

category: resilience

time period: current conditions

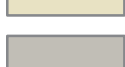
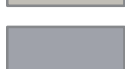
weighting 4



Legend

-  city_boundary
-  municipality boundaries

resilience

- Value
-  no data
 -  1 = low
 -  2
 -  3
 -  4
 -  5
 -  6
 -  7
 -  8
 -  9 = high



We ran focal statistics (ArcGIS Spatial Analyst: neighbourhood toolset) to measure the range (minimum to maximum value) of Median Household Income (2011) encountered within a 3km radius of each grid cell. This method is designed to contrast areas of high income disparity where crime may be more prevalent with areas where incomes are more equitable. Credits: City of Cape Town.

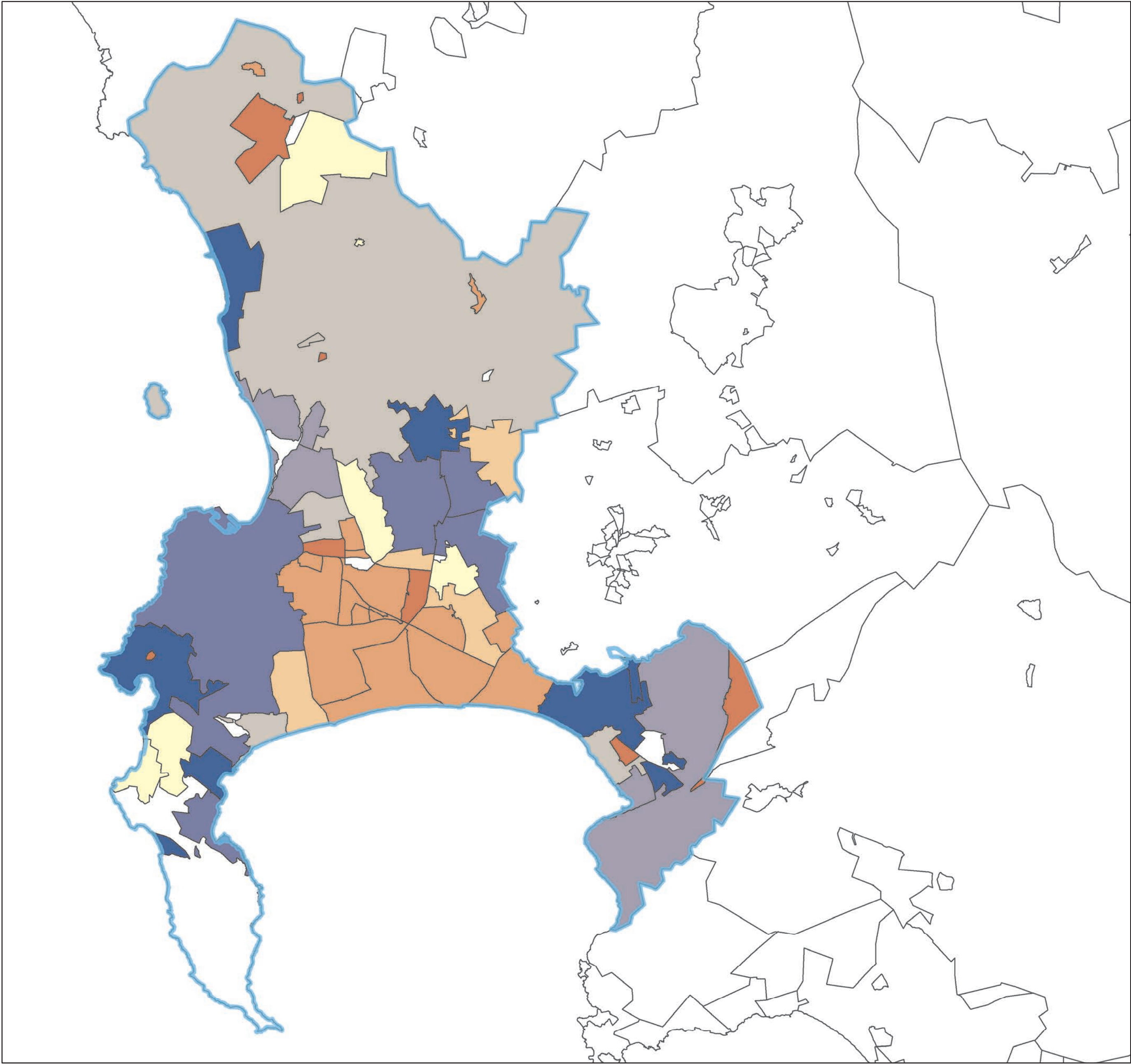
blue areas represent high resilience

Coordinate System: Hartebeesthoek 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: Hartebeesthoek 1994
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: 19.0000
Scale Factor: 1.0000
Latitude Of Origin: 0.0000
Units: Meter



Higher Education

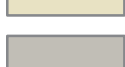
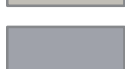
category: resilience time period: current conditions weighting 4



Legend

-  city_boundary
-  municipality boundaries

resilience

- Value
-  no data
 -  1 = low
 -  2
 -  3
 -  4
 -  5
 -  6
 -  7
 -  8
 -  9 = high



Percentage aged 20+ years-old with higher education (2011). Original raw data values used. The data were converted to raster and then reclassified to 1-9 using an equal interval method. Cells with no data were assigned a value of 0. Original resolution: Main Place. Credits: City of Cape Town

Coordinate System: Hartebeesthoek 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: Hartebeesthoek 1994
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False Northing: 0.0000
Central Meridian: 19.0000
Scale Factor: 1.0000
Latitude Of Origin: 0.0000
Units: Meter



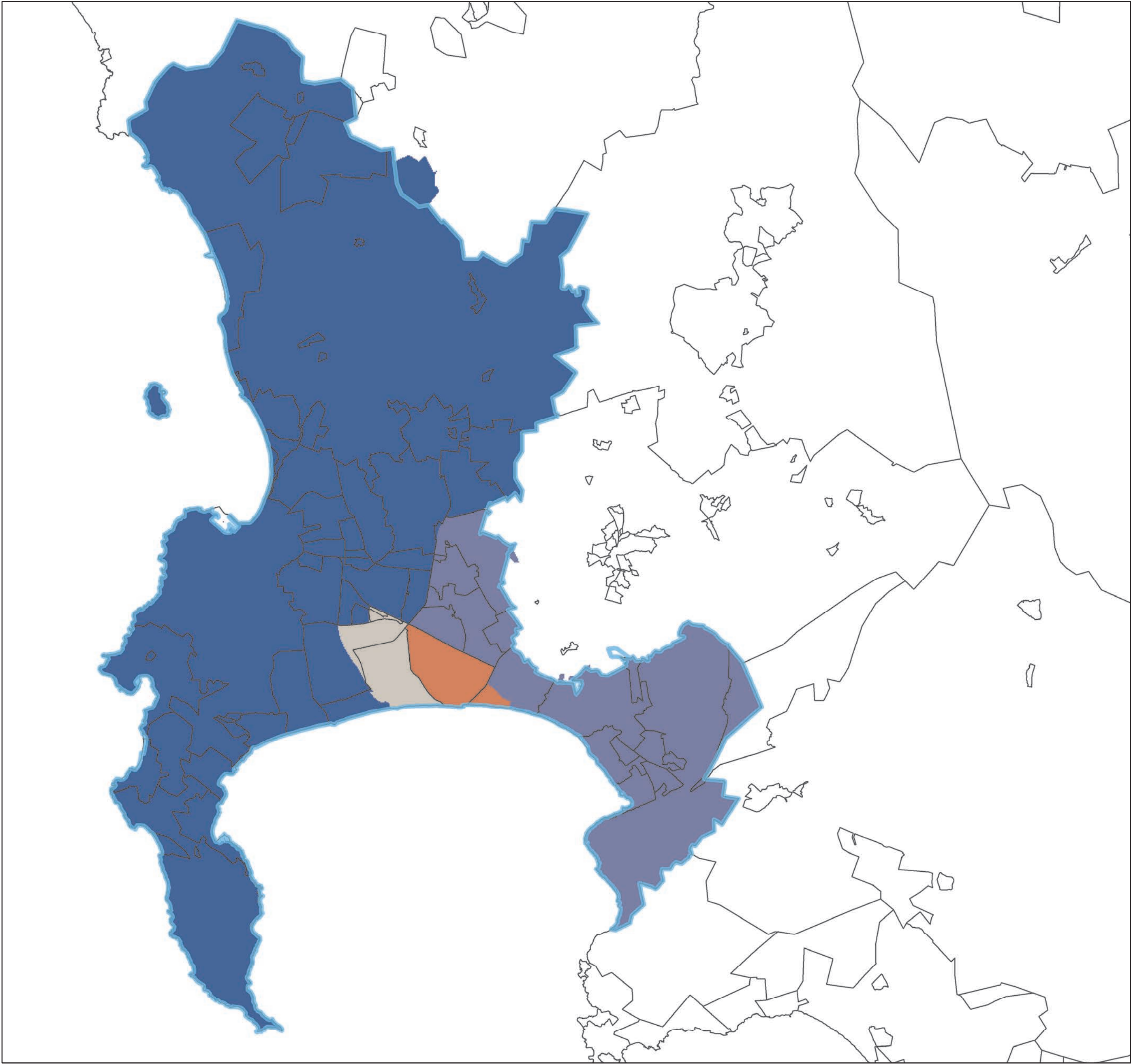
blue areas represent high resilience

HIV Rate

category: resilience

time period: current conditions

weighting3



city_boundary

municipality boundaries

051020

Kilometers

resilience

Value

no data

1 = low

2

3

4

5

6

7

8

9 = high

Estimated number of the uninsured population infected with HIV (2018). Original raw data values used. The data were reclassified to 1-9 using an equal intervals method. The reclassified values were inverted such that high values represented high Resilience. Cells with no data were assigned a value of 0. Original resolution: Health regions. Credits: City of Cape Town

Coordinate System: Hartebeesthoek 1994 Transverse Mercator

Projection: Transverse Mercator

Datum: Hartebeesthoek 1994

False Easting: 0.0000

False Northing: 0.0000

Central Meridian: 19.0000

Scale Factor: 1.0000

Latitude Of Origin: 0.0000

Units: Meter

suez

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habitat

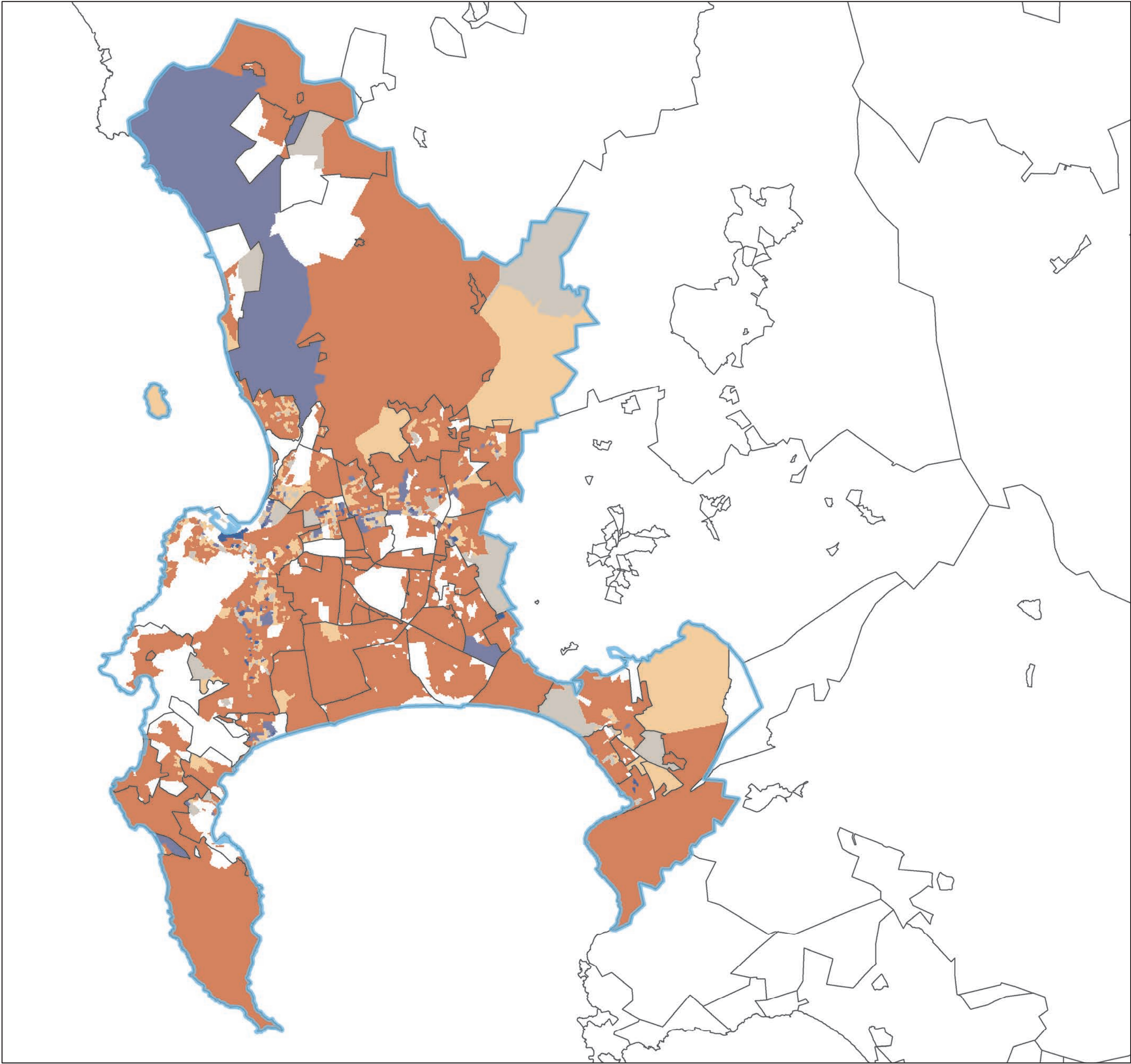
INFO

blue areas represent high resilience

map produced 29/04/2019

Social Integration

category: resilience time period: current conditions weighting 3



Legend

- city_boundary
- municipality boundaries



resilience

Value

- no data
- 1 = low
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9 = high

Integration Score (2011). CoCT data representing the % of three population groups (Black African, Coloured, White) in each SAL were used (Non-residential areas=0, <10% of each population group=1, >10% of each population group=2, >15% of each population group=3, >20% of each population group=4, >25% of each population group=5). The data were converted to raster and then reclassified to 1-9 using a manual method (0=0, 1=1, 2=3, 3=5, 4=7, 5=9). Cells with no data were assigned a value of 0. Original resolution: SAL. Credits: City of Cape Town

blue areas represent high resilience

Coordinate System: Hartebeesthoek 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: Hartebeesthoek 1994
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: 19.0000
Scale Factor: 1.0000
Latitude Of Origin: 0.0000
Units: Meter



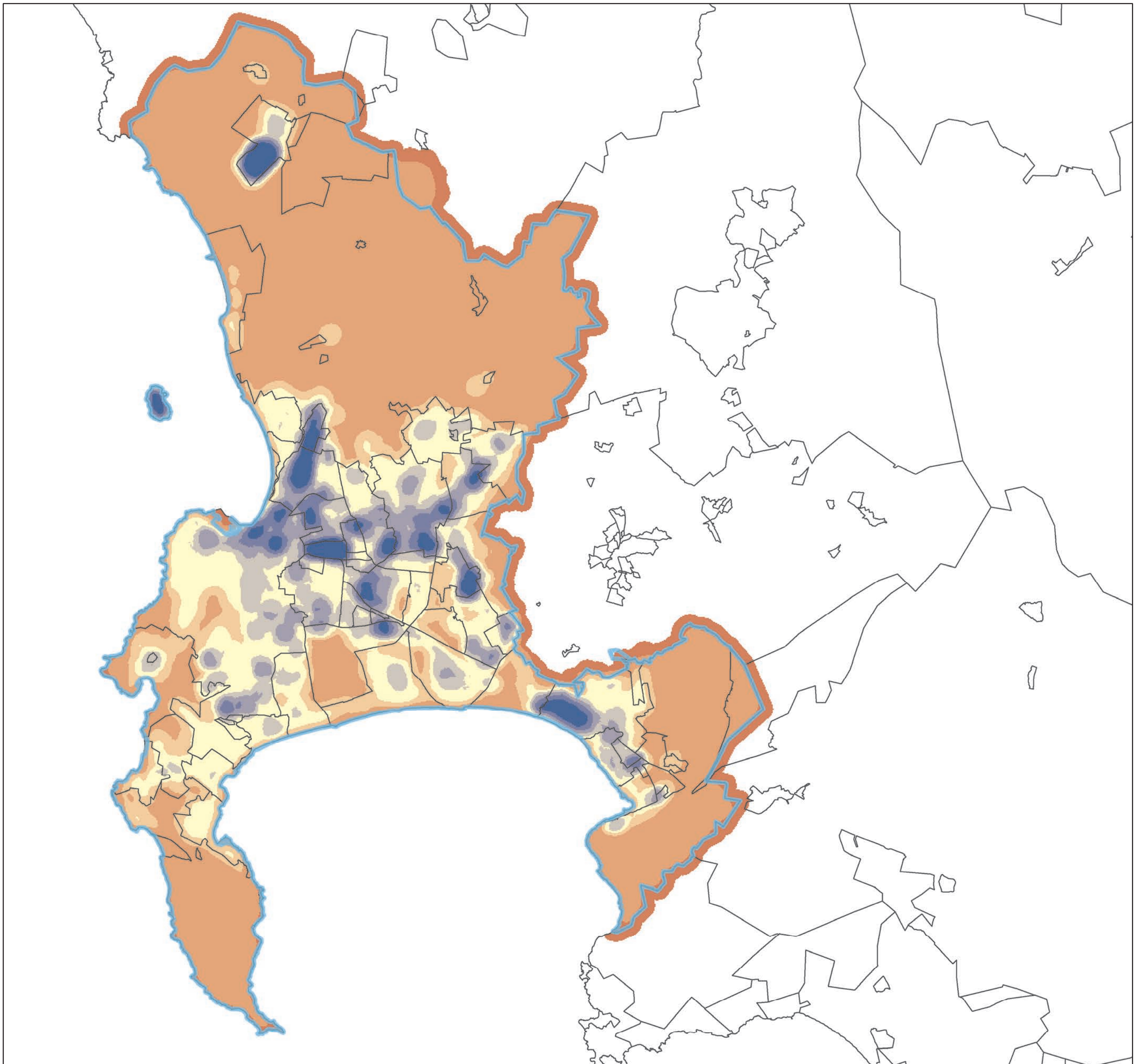
Employment opportunities within 1km

category: resilience

time period: current conditions

weighting

4

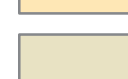
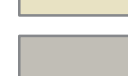


Legend

-  city_boundary
-  municipality boundaries

resilience

Value

-  no data
-  1 = low
-  2
-  3
-  4
-  5
-  6
-  7
-  8
-  9 = high

0 5 10 20
Kilometers

An indication of job opportunities within 1km was obtained through use of the integrated zoning layer which shows land use classes at high resolution. Each class was given a ranking score from 1 (poor job opportunities) to 9 (very good job opportunities). We ran a focal statistics to sum all of these scores within a 1km radius (raster resolution 100mx100m)

blue areas represent high resilience

Coordinate System: Hartebeesthoek 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: Hartebeesthoek 1994
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: 19.0000
Scale Factor: 1.0000
Latitude Of Origin: 0.0000
Units: Meter



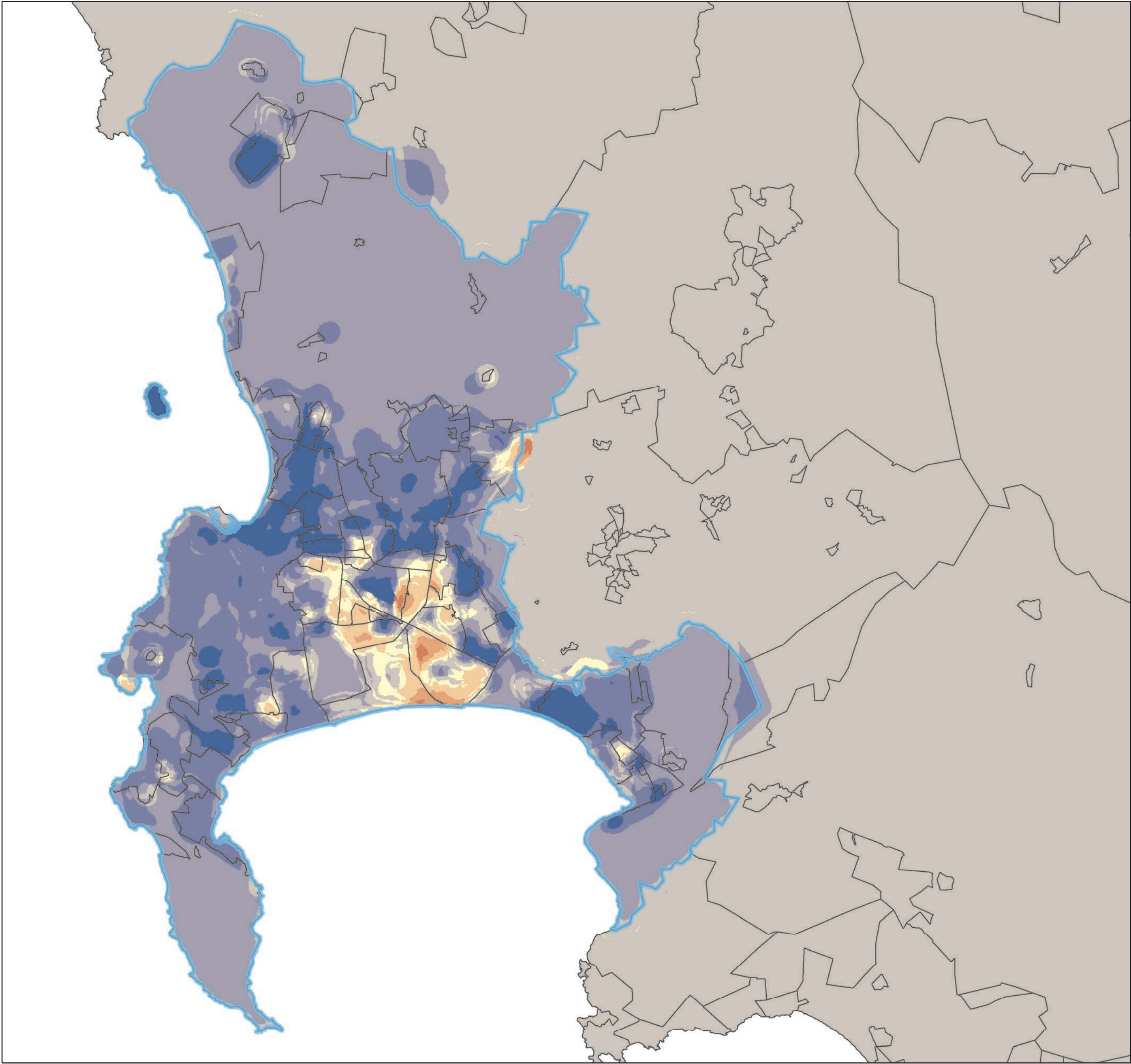
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ISIXEKO SASEKAPA
STAD KAAPSTAD

oneWORLD
We build resilient futures



Jobs : Population Balance

category: resilience time period: current conditions weighting 5



Legend

city_boundary

municipality boundaries

resilience

Value

no data

1 = low

2

3

4

5

6

7

8

9 = high

0

5

10

20

Kilometers

We used two inputs: indicator of population density within 1km radius and indicator of job opportunities within 1km. The latter was obtained by ranking each land use class from COCT integrated zoning layer. Both were scaled 1-9. To arrive at a comparison of where people live in relation to where the jobs are we simply subtracted the local population indicator from the local job indicator so high values in blue represent lots of jobs in the neighbourhood, not many people and low values in red represent not many jobs in the neighbourhood, lots of people competing for them. Reclassified scale from -9 to +8, to 1 to 9.

blue areas represent high resilience

Coordinate System: Hartebeesthoek 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: Hartebeesthoek 1994
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: 19.0000
Scale Factor: 1.0000
Latitude Of Origin: 0.0000
Units: Meter

suez

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DE DÉVELOPPEMENT

CITY OF CAPE TOWN
ISIXEKO SASEKAPA
STAD KAAPSTAD

oneWORLD
We build resilient futures

habitat
INFO

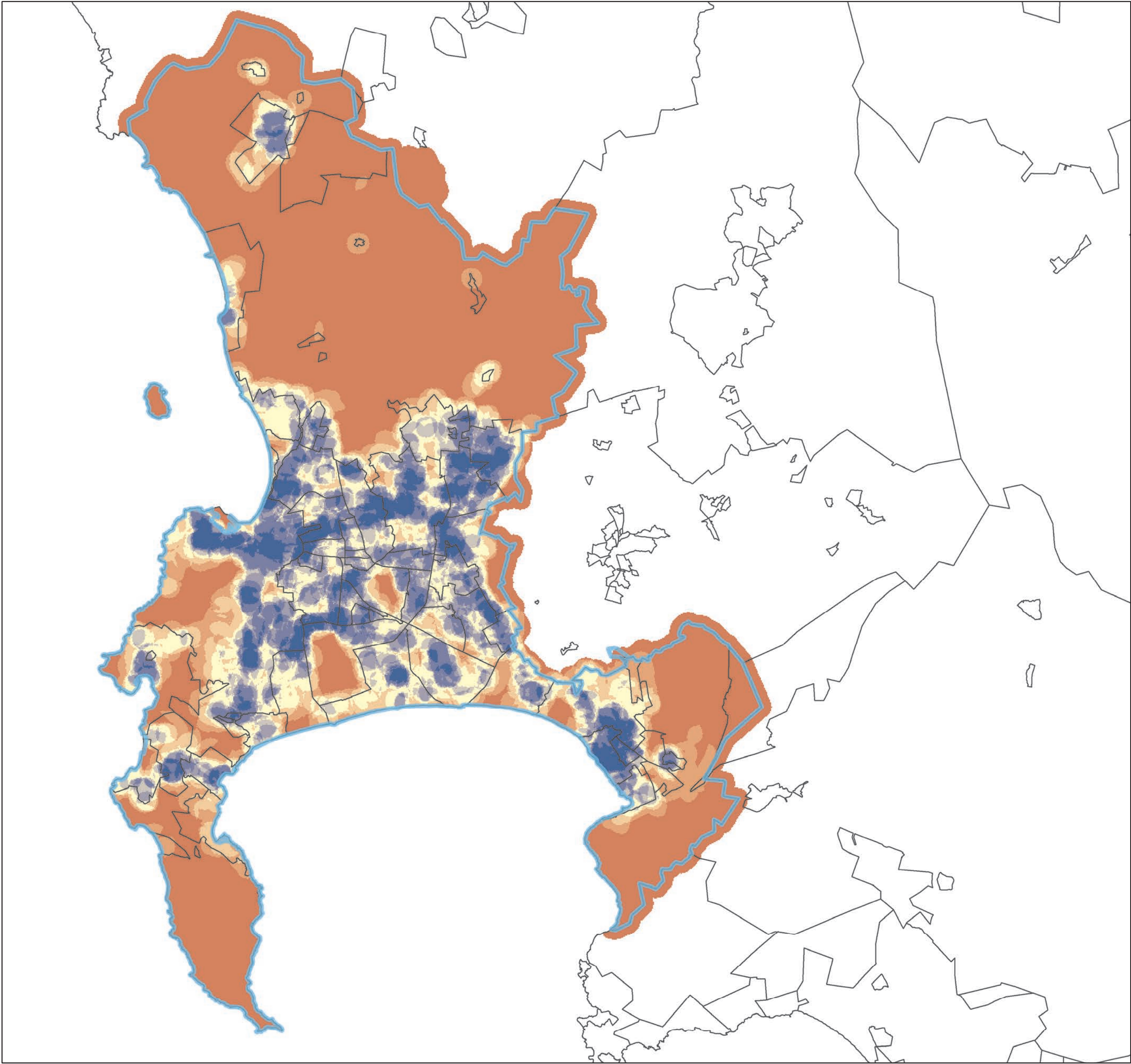
map produced 29/04/2019

Employment variety within 1km

category: resilience

time period: current conditions

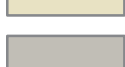
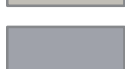
weighting3



Legend

-  city_boundary
-  municipality boundaries

resilience

- Value
-  no data
 -  1 = low
 -  2
 -  3
 -  4
 -  5
 -  6
 -  7
 -  8
 -  9 = high



An indication of job diversity within 1km was obtained through use of the integrated zoning layer which shows land use classes at high resolution. We ran a focal statistics to measure the variety of classes within a 1km radius (raster resolution 100mx100m)

blue areas represent high resilience

Coordinate System: Hartebeesthoek 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: Hartebeesthoek 1994
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: 19.0000
Scale Factor: 1.0000
Latitude Of Origin: 0.0000
Units: Meter

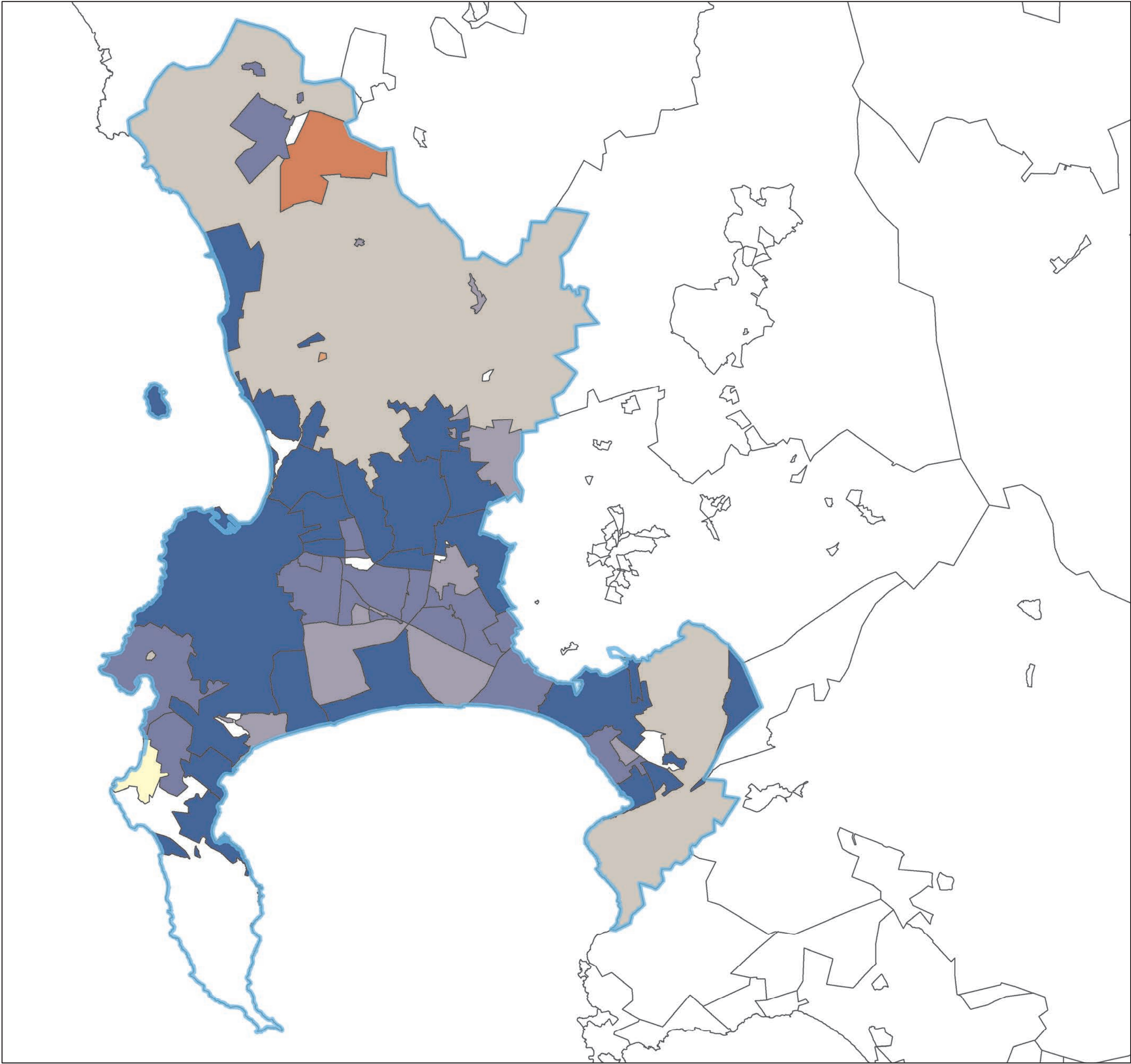


Education (no education)

category: resilience

time period: current conditions

weighting5



Legend

- city_boundary
- municipality boundaries

resilience

- Value
- no data
 - 1 = low
 - 2
 - 3
 - 4
 - 5
 - 6
 - 7
 - 8
 - 9 = high



Percentage aged 20+ years-old with no education (2011). Original raw data values used. The data were converted to raster and then reclassified to 1-9 using an equal interval method. The reclassified values were inverted such that high values represented high Resilience. Cells with no data were assigned a value of 0. Original resolution: Main Place. Credits: City of Cape Town

Coordinate System: Hartebeesthoek 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: Hartebeesthoek 1994
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: 19.0000
Scale Factor: 1.0000
Latitude Of Origin: 0.0000
Units: Meter



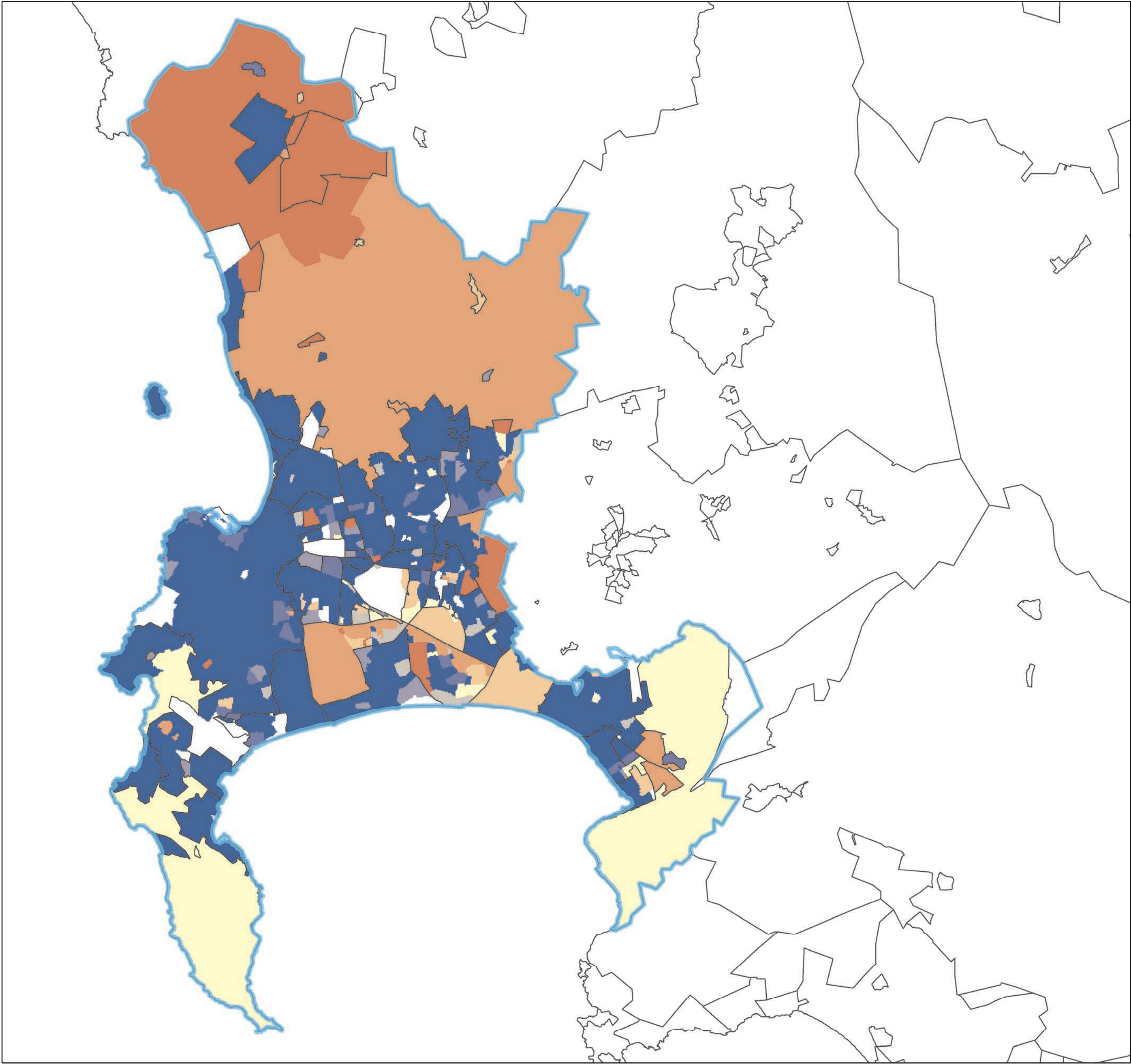
blue areas represent high resilience

Refuse Collection

category: resilience

time period: current conditions

weighting3



Legend

- city_boundary
- municipality boundaries

resilience

- Value

no data
- 1 = low
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9 = high



Percentage of households with no rubbish collections (2011). Original raw data values used. The data were converted to raster and then reclassified to 1-9 using a natural breaks method. The reclassified values were inverted such that high values represented high Resilience. Cells with no data were assigned a value of 0. Original resolution: SP. Credits: City of Cape Town

Coordinate System: Hartebeesthoek 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: Hartebeesthoek 1994
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: 19.0000
Scale Factor: 1.0000
Latitude Of Origin: 0.0000
Units: Meter



blue areas represent high resilience

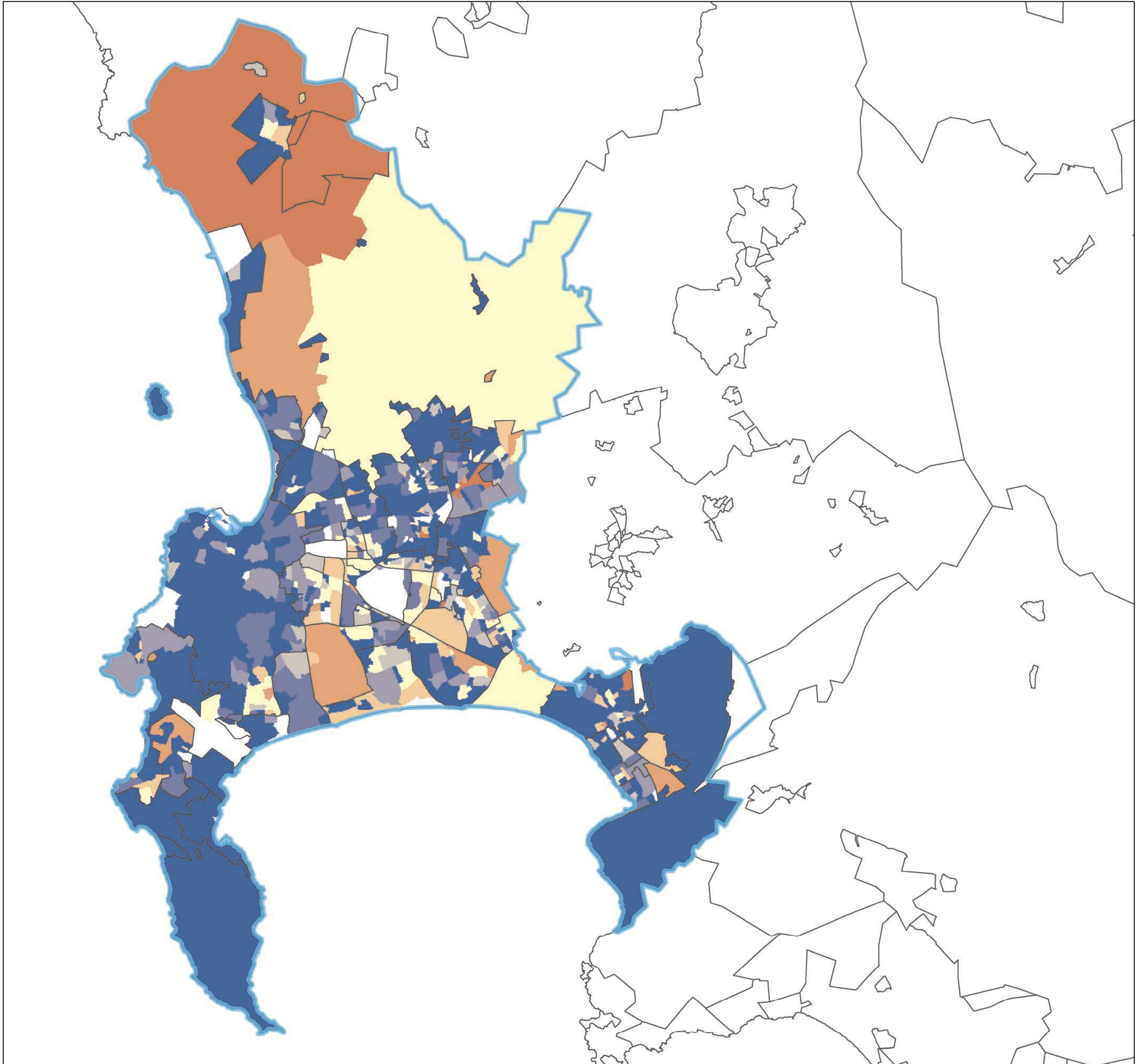
Tap Water

category: resilience

time period: current conditions

weighting

5

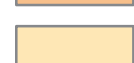
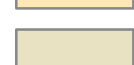
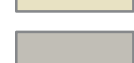


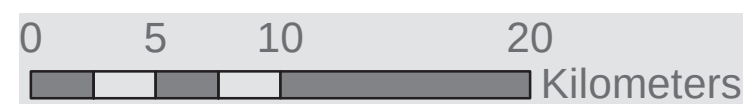
Legend

-  city_boundary
-  municipality boundaries

resilience

Value

-  no data
-  1 = low
-  2
-  3
-  4
-  5
-  6
-  7
-  8
-  9 = high



Percentage of households with no tap water (2011). Original raw data values used. The data were converted to raster and then reclassified to 1-9 using a natural breaks method. The reclassified values were inverted such that high values represented high Resilience. Cells with no data were assigned a value of 0. Original resolution: SP. Credits: City of Cape Town

Coordinate System: Hartebeesthoek 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: Hartebeesthoek 1994
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: 19.0000
Scale Factor: 1.0000
Latitude Of Origin: 0.0000
Units: Meter



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STAD KAAPSTAD

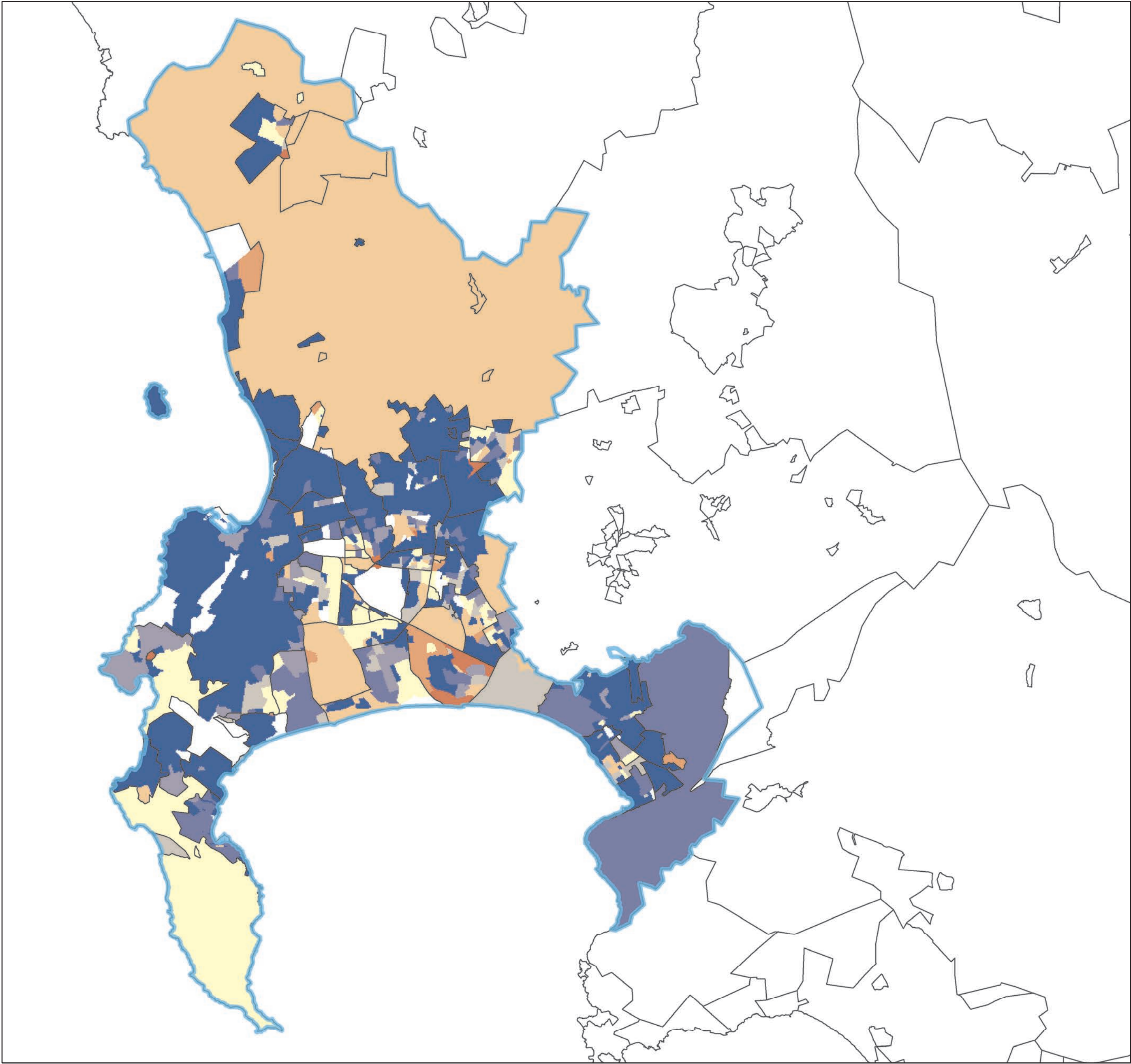
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blue areas represent high resilience

Toilet Facilities

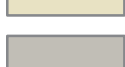
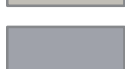
category: resilience time period: current conditions weighting 5



Legend

-  city_boundary
-  municipality boundaries

resilience

- Value
-  no data
 -  1 = low
 -  2
 -  3
 -  4
 -  5
 -  6
 -  7
 -  8
 -  9 = high



Percentage of households without any toilet (2011). Original raw data values used. The data were converted to raster and then reclassified to 1-9 using a natural breaks method. The reclassified values were inverted such that high values represented high Resilience. Cells with no data were assigned a value of 0. Original resolution: SP. Credits: City of Cape Town

Coordinate System: Hartebeesthoek 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: Hartebeesthoek 1994
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: 19.0000
Scale Factor: 1.0000
Latitude Of Origin: 0.0000
Units: Meter



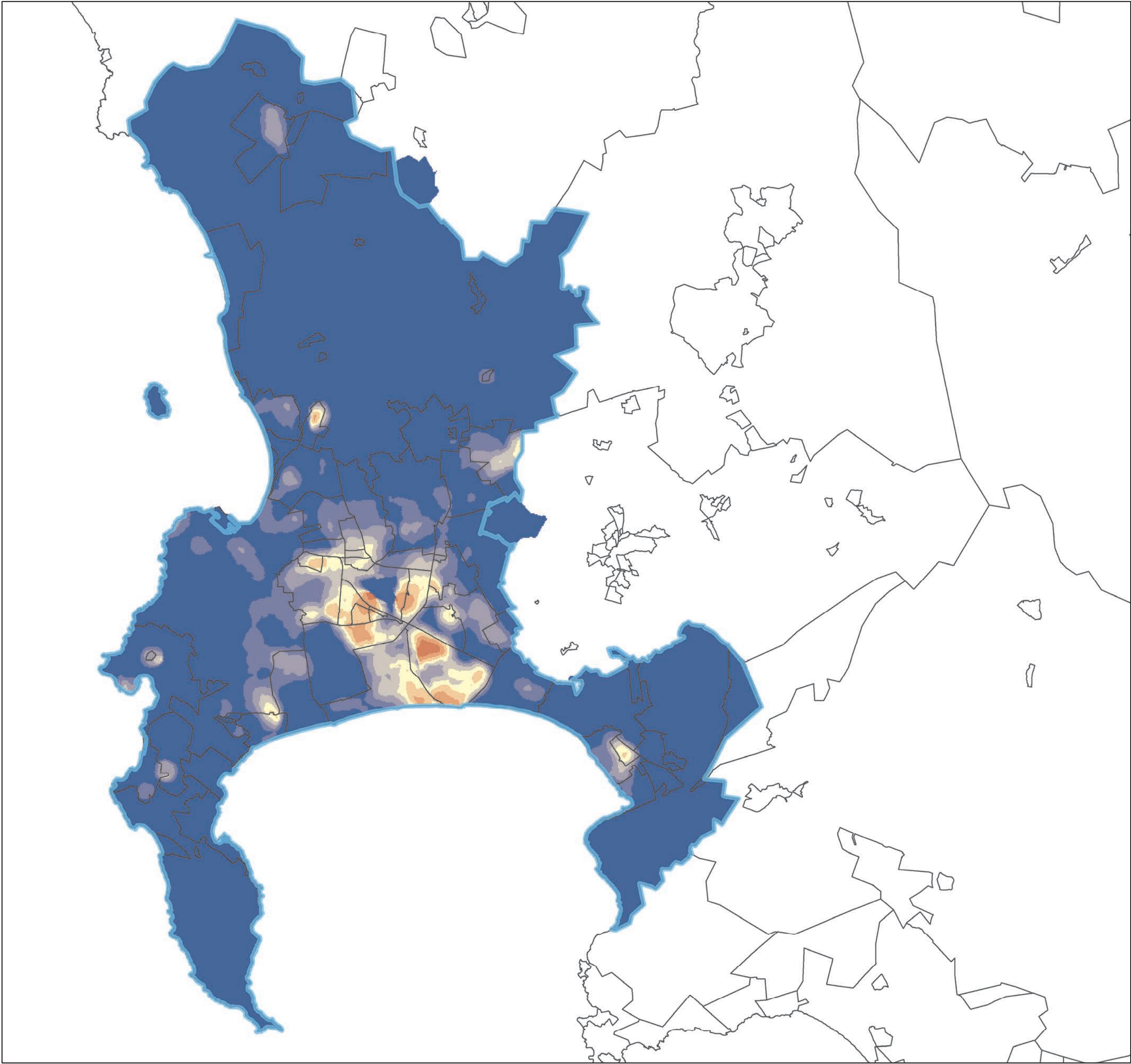
blue areas represent high resilience

Population Density

category: resilience

time period: current conditions

weighting5



Legend

- city_boundary
- municipality boundaries

resilience

- Value
- no data
 - 1 = low
 - 2
 - 3
 - 4
 - 5
 - 6
 - 7
 - 8
 - 9 = high

Data on population density (people per km2) were obtained from the 2011 Census at ward district resolution. We converted polygon values to a raster of 100m resolution, inverted and reclassified values on a scale 1 to 9 such that high values of resilience corresponded to low values of population density. Credits: City of Cape Town.

blue areas represent high resilience

Coordinate System: Hartebeesthoek 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: Hartebeesthoek 1994
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: 19.0000
Scale Factor: 1.0000
Latitude Of Origin: 0.0000
Units: Meter

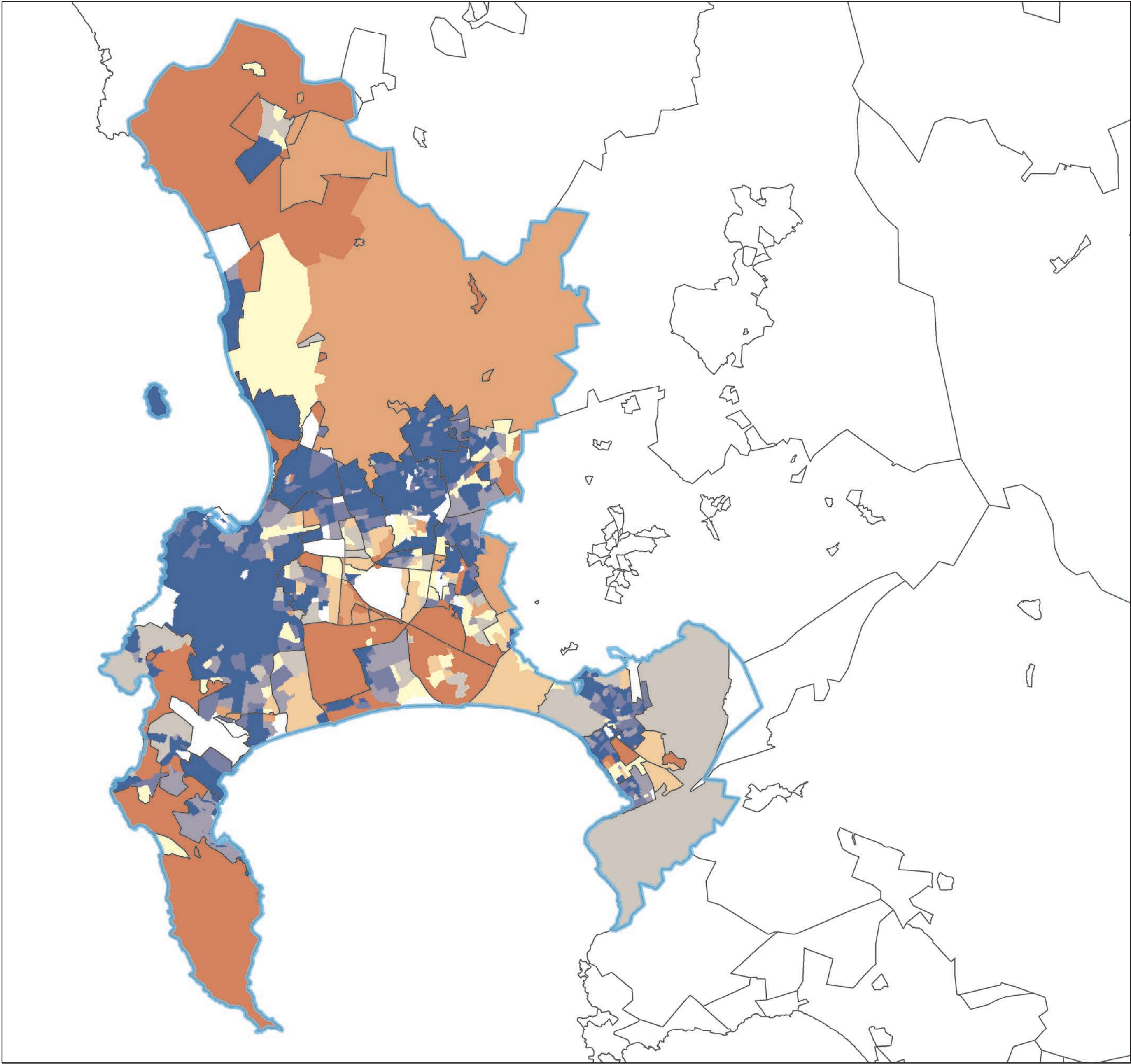


Tap Water Inside Houses

category: resilience

time period: current conditions

weighting 4

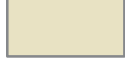


Legend

-  city_boundary
-  municipality boundaries

resilience

Value

-  no data
-  1 = low
-  2
-  3
-  4
-  5
-  6
-  7
-  8
-  9 = high



Percentage of households with tap water inside (2011). Original raw data values used. The data were converted to raster and then reclassified to 1-9 using a natural breaks method. Cells with no data were assigned a value of 0. Original resolution: SP. Credits: City of Cape Town

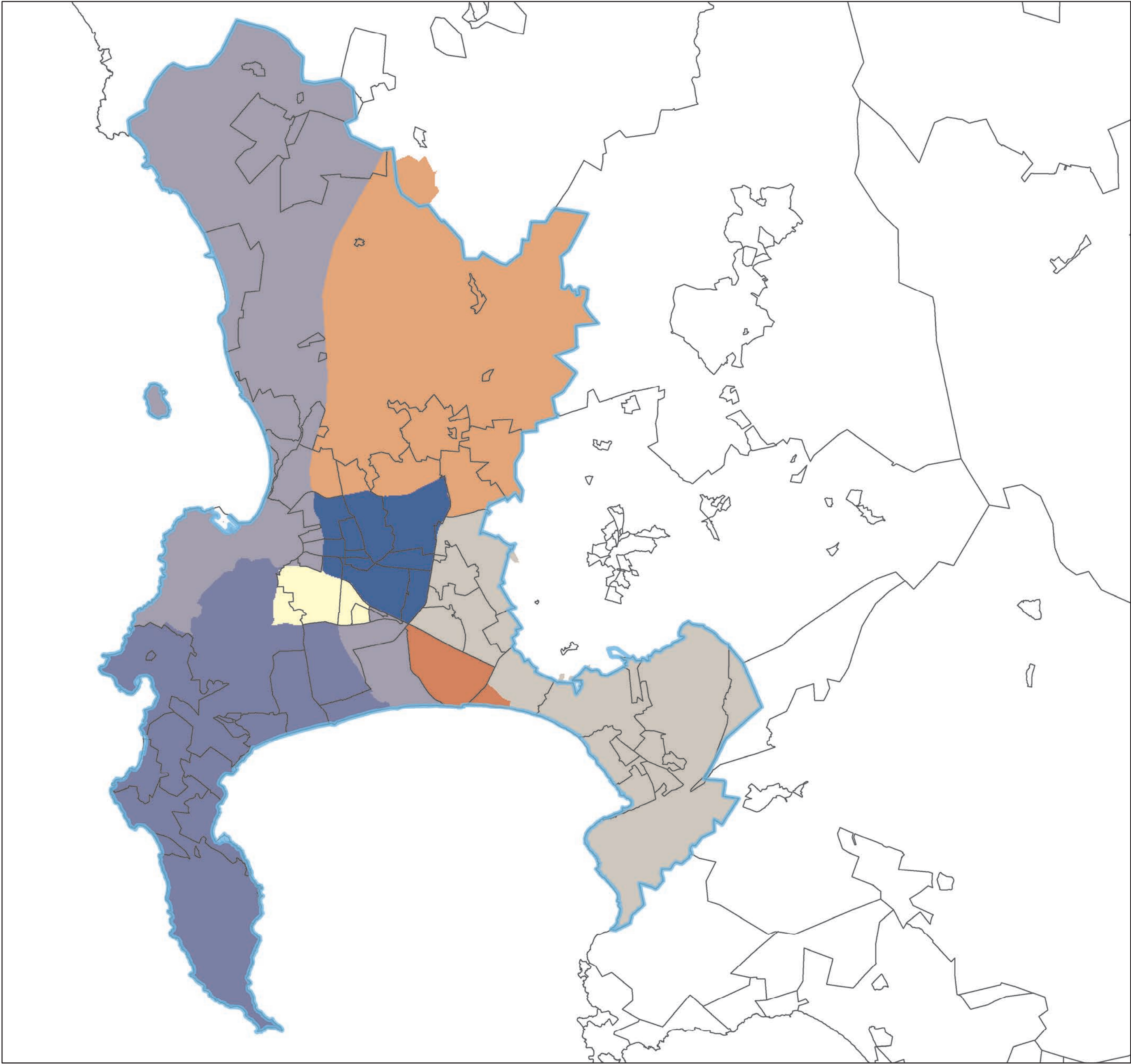
Coordinate System: Hartebeesthoek 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: Hartebeesthoek 1994
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: 19.0000
Scale Factor: 1.0000
Latitude Of Origin: 0.0000
Units: Meter



blue areas represent high resilience

TB Rate

category: resilience time period: current conditions weighting 2



Legend

- city_boundary
- municipality boundaries

resilience

- Value
- no data
 - 1 = low
 - 2
 - 3
 - 4
 - 5
 - 6
 - 7
 - 8
 - 9 = high



% of people tested for TB who are infected (unknown year). Calculated as the proportion of the people who have been tested who are infected. The data were converted to raster and then reclassified to 1-9 using a natural breaks method with some manual input. The reclassified values were inverted such that high values represented high Resilience. Cells with no data were assigned a value of 0. Original resolution: Health regions. Credits: City of Cape Town

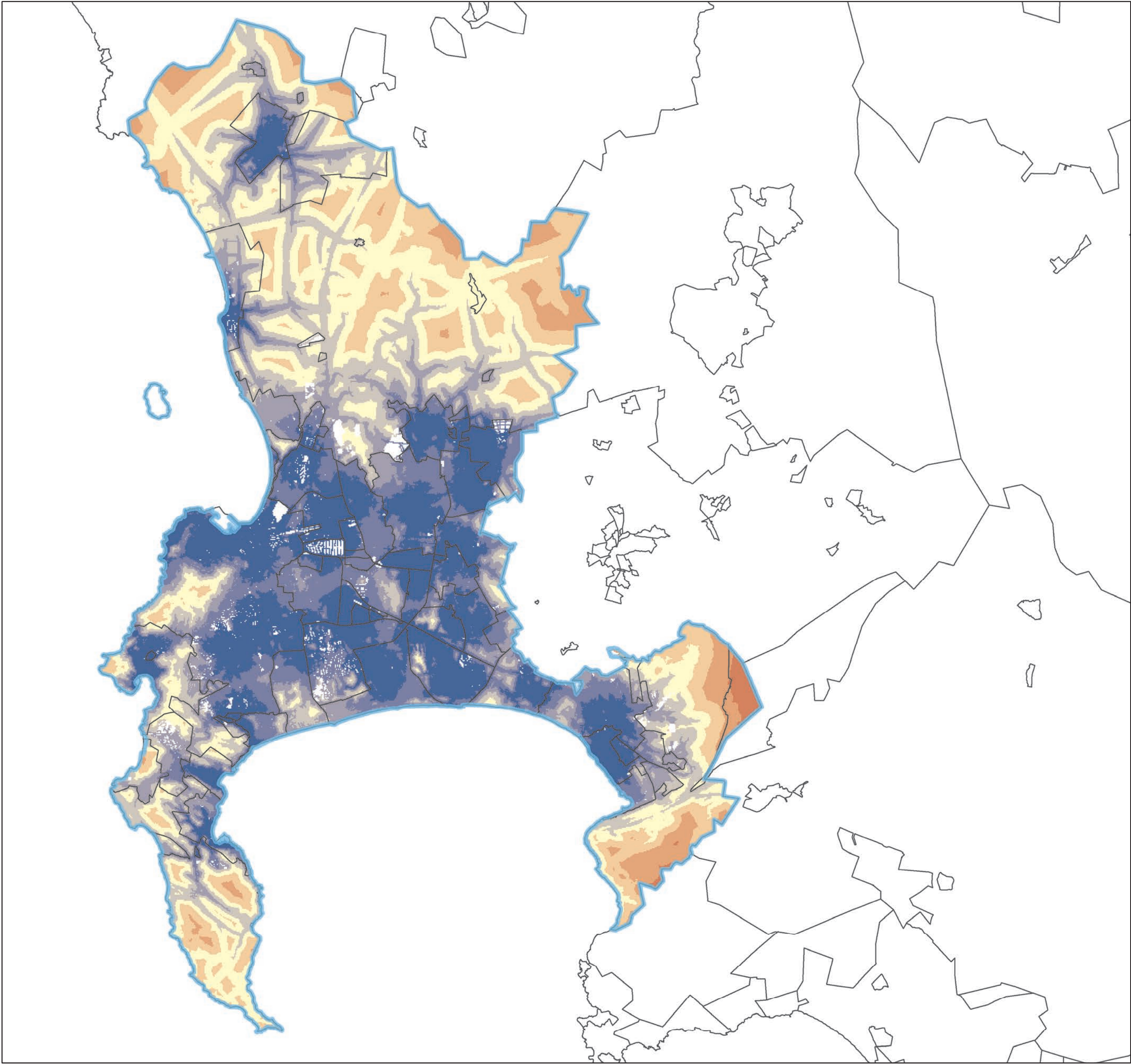
Coordinate System: Hartebeesthoek 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: Hartebeesthoek 1994
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: 19.0000
Scale Factor: 1.0000
Latitude Of Origin: 0.0000
Units: Meter



blue areas represent high resilience

Access to Fire Stations

category: resilience time period: current conditions weighting 4



Legend

 city_boundary

 municipality boundaries

resilience

Value

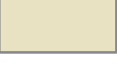
 no data

 1 = low

 2

 3

 4

 5

 6

 7

 8

 9 = high

0 5 10 20 Kilometers

Travel time within the city to fire stations via road and foot (2019). OpenStreetMap (OSM) landuse and roads categories were accessed and speeds attributed to each sub-category of these. These were combined into a friction layer from which travel time was calculated from each cell for. Fire station locations provided by CoCT. The data were reclassified to 1-9 using a geometrical intervals method. The reclassified values were inverted such that high values represented high Resilience. Original resolution: n/a. Credits: habitat INFO, OSM, CoCT

Coordinate System: Hartebeesthoek 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: Hartebeesthoek 1994
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: 19.0000
Scale Factor: 1.0000
Latitude Of Origin: 0.0000
Units: Meter







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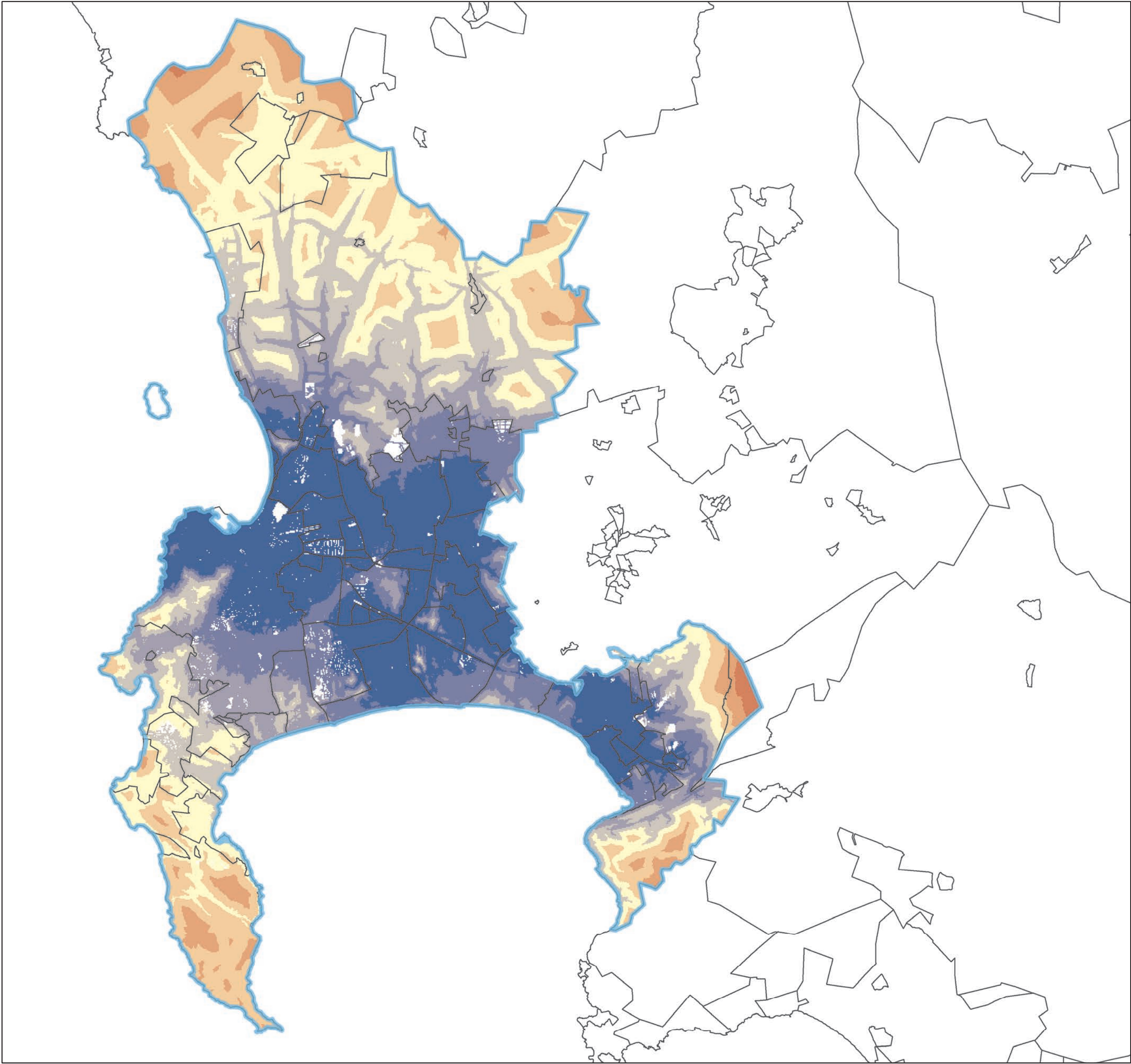
map produced 29/04/2019

Access to Hospitals

category: resilience

time period: current conditions

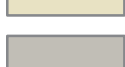
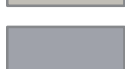
weighting 4



Legend

-  city_boundary
-  municipality boundaries

resilience

- Value
-  no data
 -  1 = low
 -  2
 -  3
 -  4
 -  5
 -  6
 -  7
 -  8
 -  9 = high



Travel time within the city to hospitals via road, rail and foot (2019). OpenStreetMap (OSM) landuse, roads and railways categories were accessed and speeds attributed to each sub-category of these. These were combined into a friction layer from which travel time was calculated from each cell for. This travel time analysis includes railways, but does not account for ability to only access railways at defined points (i.e. stations). Hospital locations sourced from OSM buildings category. The data were reclassified to 1-9 using a geometrical intervals method. The reclassified values were inverted such that high values represented high Resilience. Original resolution: n/a. Credits: habitat INFO, OSM, CoCT

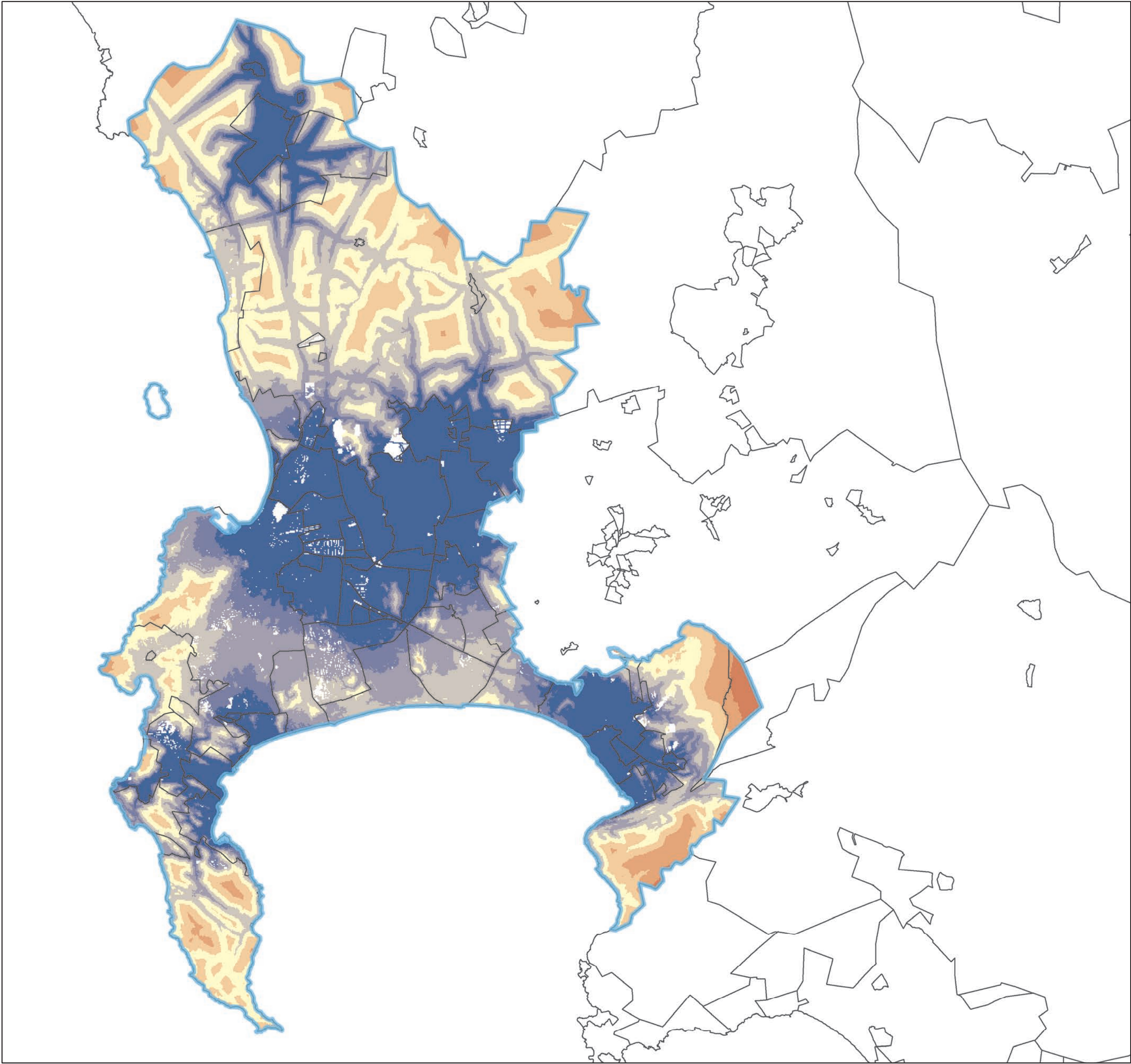
Coordinate System: Hartebeesthoek 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: Hartebeesthoek 1994
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: 19.0000
Scale Factor: 1.0000
Latitude Of Origin: 0.0000
Units: Meter



blue areas represent high resilience

Access to all CBDs

category: resilience time period: current conditions weighting 3



Legend

city_boundary

municipality boundaries

resilience

Value

no data

1 = low

2

3

4

5

6

7

8

9 = high

0 5 10 20

Kilometers

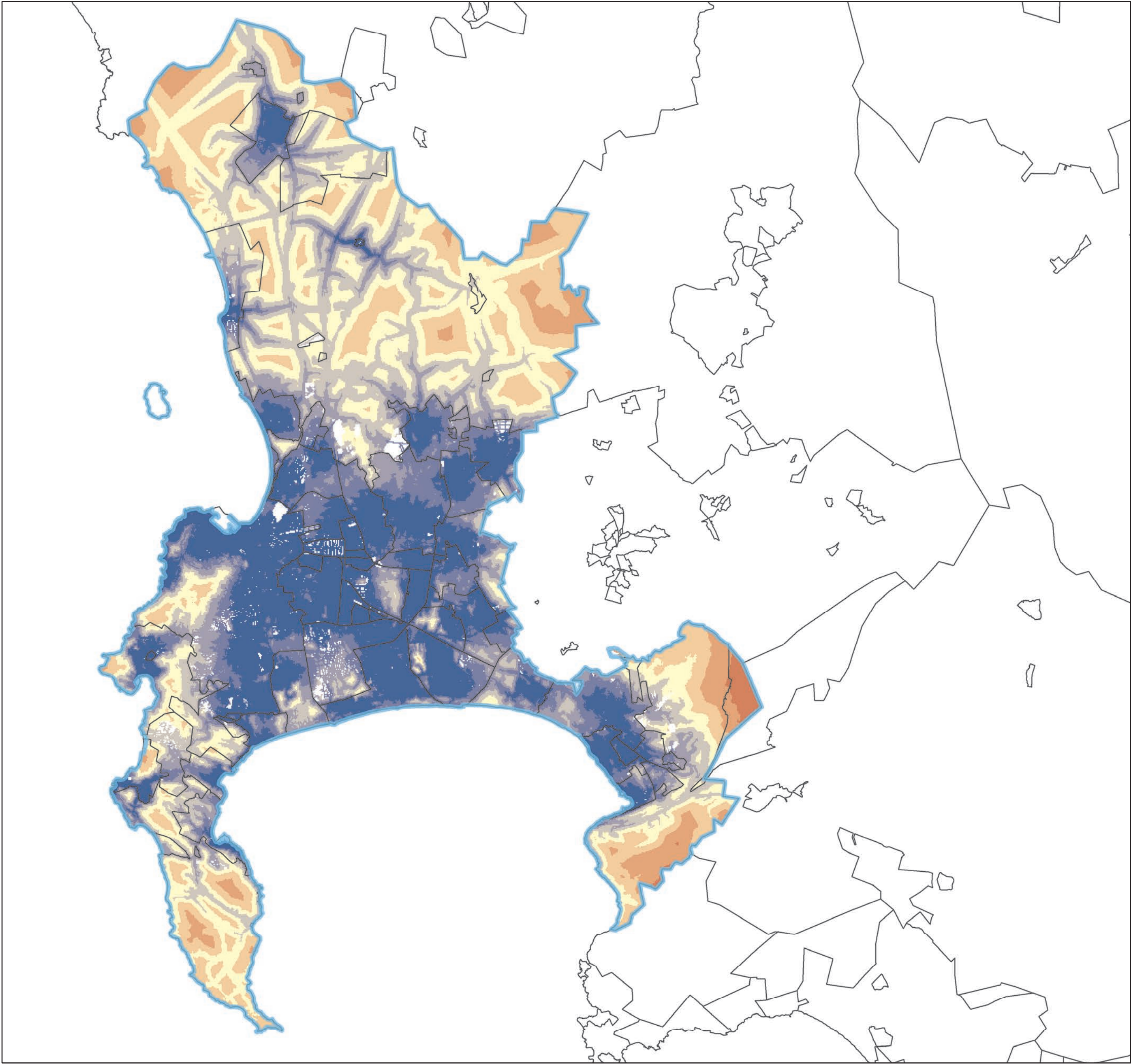
Travel time within the city to other CBDs via road, rail and foot (2019). OpenStreetMap (OSM) landuse, roads and railways categories were accessed and speeds attributed to each sub-category of these. These were combined into a friction layer from which travel time was calculated from each cell for. This travel time analysis includes railways, but does not account for ability to only access railways at defined points (i.e. stations). CBD locations identified from the CoCT integrated zoning data. The data were reclassified to 1-9 using a geometrical intervals method. The reclassified values were inverted such that high values represented high Resilience. Original resolution: n/a. Credits: habitat INFO, OSM, CoCT

Coordinate System: Hartebeesthoek 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: Hartebeesthoek 1994
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: 19.0000
Scale Factor: 1.0000
Latitude Of Origin: 0.0000
Units: Meter

blue areas represent high resilience

Access to Police Stations

category: resilience time period: current conditions weighting 3



Legend

city_boundary

municipality boundaries

resilience

Value

no data

1 = low

2

0 5 10 20

Kilometers

Travel time within the city to police stations via road, rail and foot (2019). OpenStreetMap (OSM) landuse, roads and railways categories were accessed and speeds attributed to each sub-category of these. These were combined into a friction layer from which travel time was calculated from each cell for. This travel time analysis includes railways, but does not account for ability to only access railways at defined points (i.e. stations). Police station locations provided by CoCT. The data were reclassified to 1-9 using a geometrical intervals method. The reclassified values were inverted such that high values represented high Resilience. Original resolution: n/a. Credits: habitat INFO, OSM, CoCT

Coordinate System: Hartebeesthoek 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: Hartebeesthoek 1994
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: 19.0000
Scale Factor: 1.0000
Latitude Of Origin: 0.0000
Units: Meter

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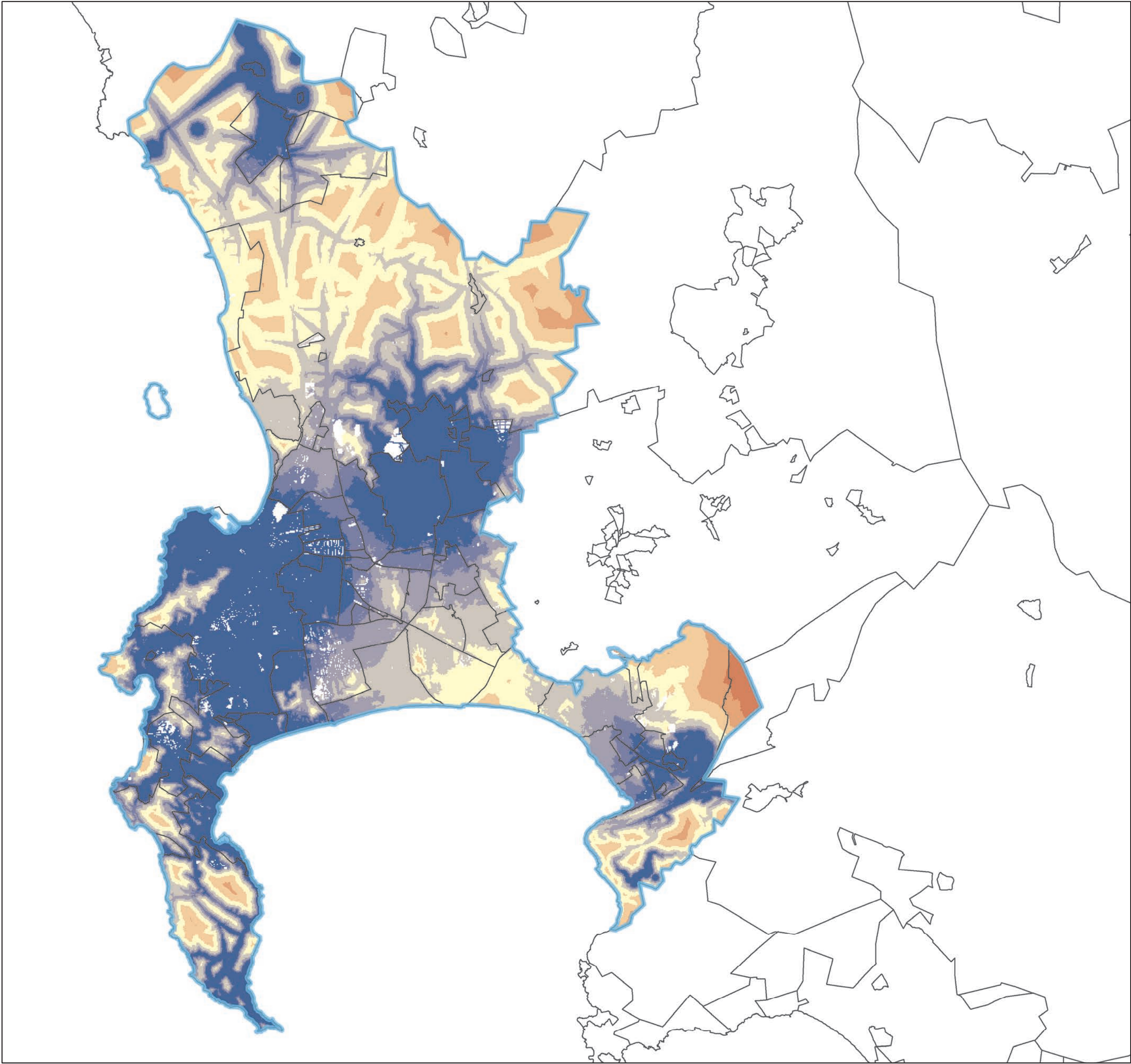
habitat
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Access to Freshwater Springs

category: resilience

time period: current conditions

weighting1



city_boundary

municipality boundaries

051020

Kilometers

resilience

Value

no data

1 = low

2

3

4

5

6

7

8

9 = high

Travel time within the city to springs via road, rail and foot (2019). OpenStreetMap (OSM) landuse, roads and railways categories were accessed and speeds attributed to each sub-category of these. These were combined into a friction layer from which travel time was calculated from each cell for. This travel time analysis includes railways, but does not account for ability to only access railways at defined points (i.e. stations). Spring locations provided by CoCT. The data were reclassified to 1-9 using a geometrical intervals method. The reclassified values were inverted such that high values represented high Resilience. Original resolution: n/a. Credits: habitat INFO, OSM, CoCT

blue areas represent high resilience

Coordinate System: Hartebeesthoek 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: Hartebeesthoek 1994
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: 19.0000
Scale Factor: 1.0000
Latitude Of Origin: 0.0000
Units: Meter

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habitat
INFO

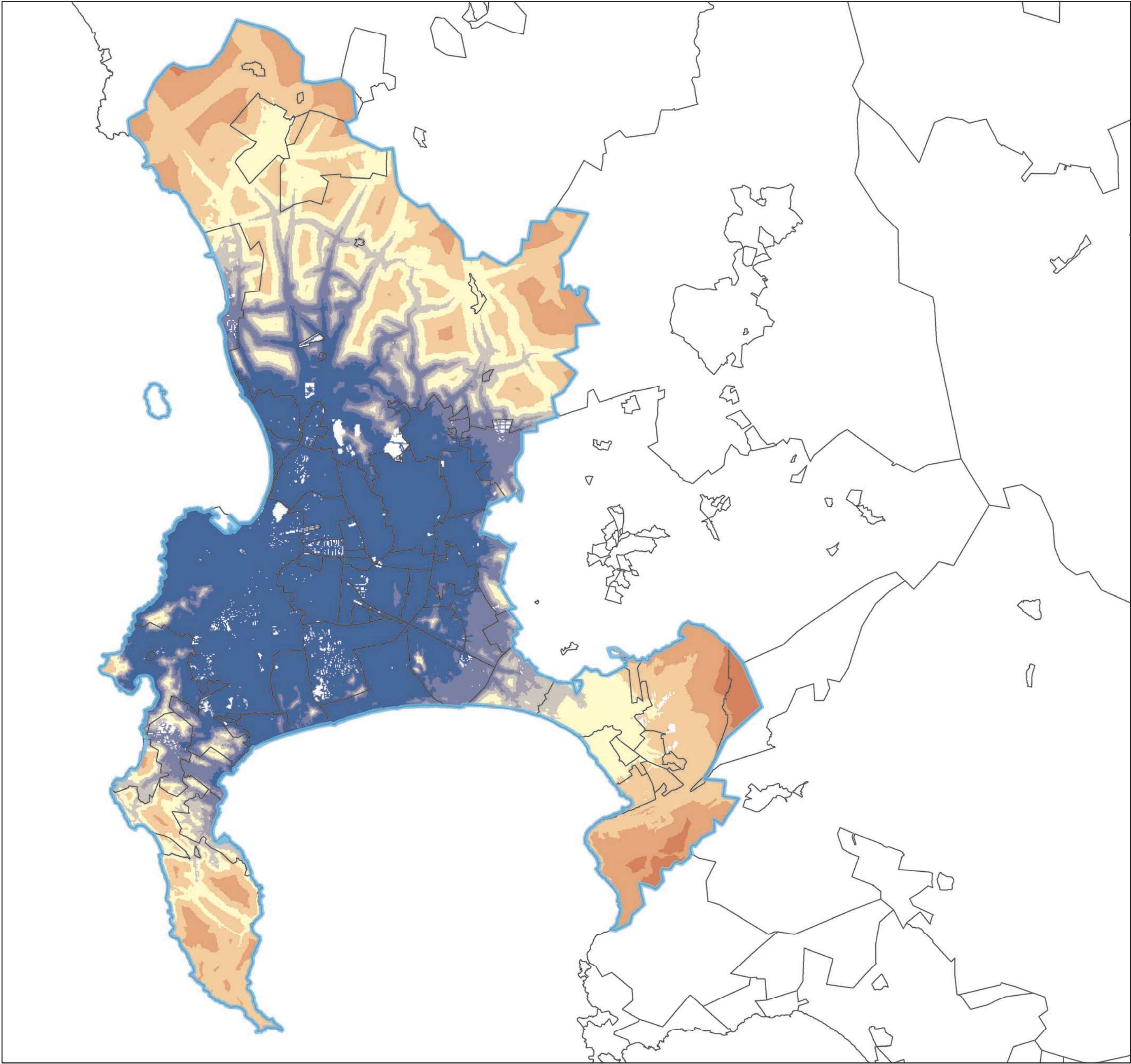
map produced 29/04/2019

Access to Cape Town CBD

category: resilience

time period: current conditions

weighting 4



city_boundary

municipality boundaries

051020

Kilometers

resilience

Value

no data

1 = low

2

3

4

5

6

7

8

9 = high

Travel time within the city to the CBD via road, rail and foot (2019). OpenStreetMap (OSM) landuse, roads and railways categories were accessed and speeds attributed to each sub-category of these. These were combined into a friction layer from which travel time was calculated from each cell for. This travel time analysis includes railways, but does not account for ability to only access railways at defined points (i.e. stations). CBD location provided by CoCT. The data were reclassified to 1-9 using a geometrical intervals method. The reclassified values were inverted such that high values represented high Resilience. Original resolution: n/a. Credits: habitat INFO, OSM, CoCT

blue areas represent high resilience

Coordinate System: Hartebeesthoek 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: Hartebeesthoek 1994
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: 19.0000
Scale Factor: 1.0000
Latitude Of Origin: 0.0000
Units: Meter

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INFO

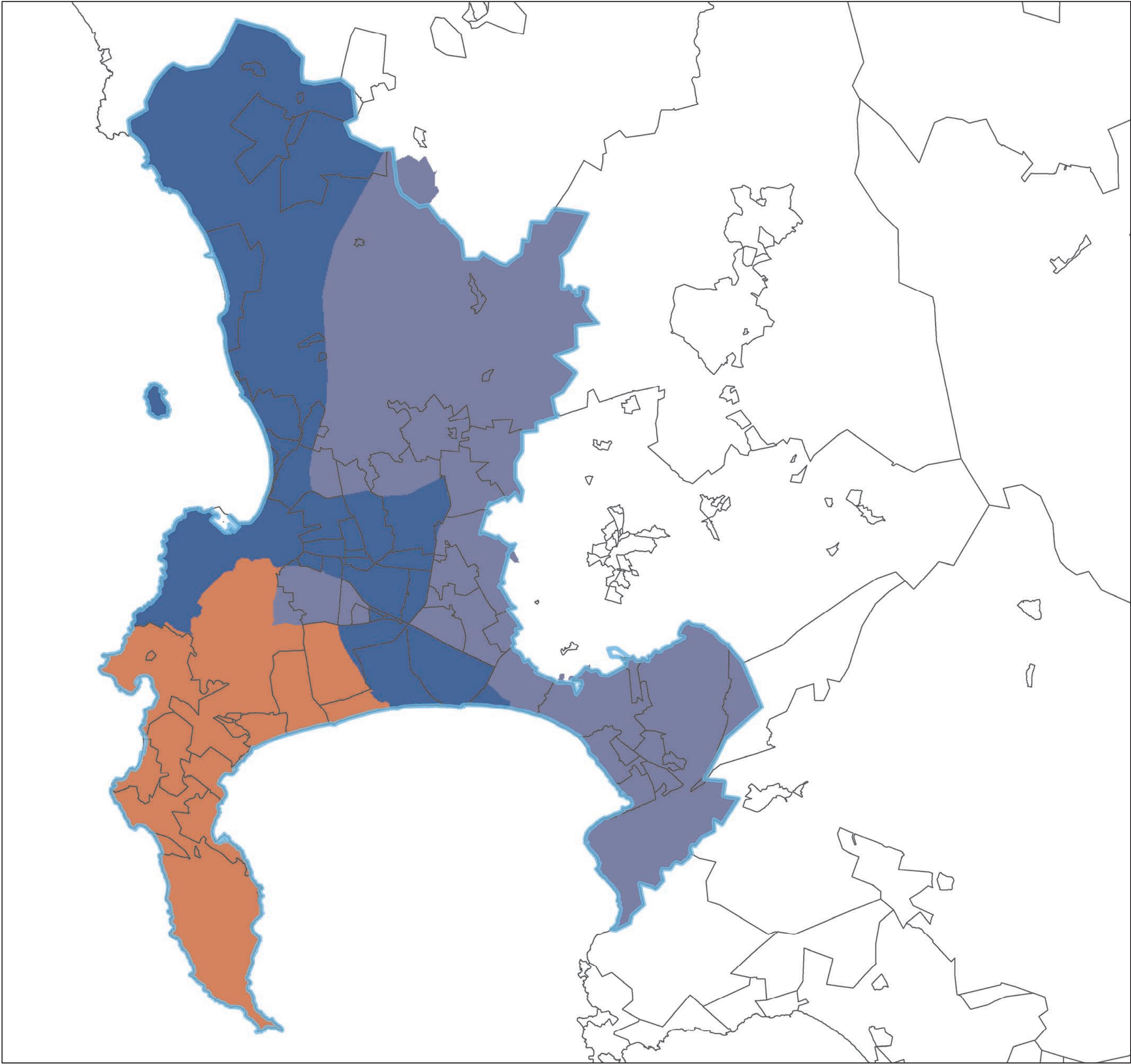
map produced 29/04/2019

Typhoid Rate

category: resilience

time period: current conditions

weighting2



Legend

- city_boundary
- municipality boundaries

resilience

- Value
- no data
- 1 = low
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9 = high

Number of people infected with Typhoid (2017). Original raw data values used. The data were converted to raster and then reclassified to 1-9 using an equal intervals method. The reclassified values were inverted such that high values represented high Resilience. Cells with no data were assigned a value of 0. Original resolution: Health regions. Credits: City of Cape Town

blue areas represent high resilience

Coordinate System: Hartebeesthoek 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: Hartebeesthoek 1994
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: 19.0000
Scale Factor: 1.0000
Latitude Of Origin: 0.0000
Units: Meter

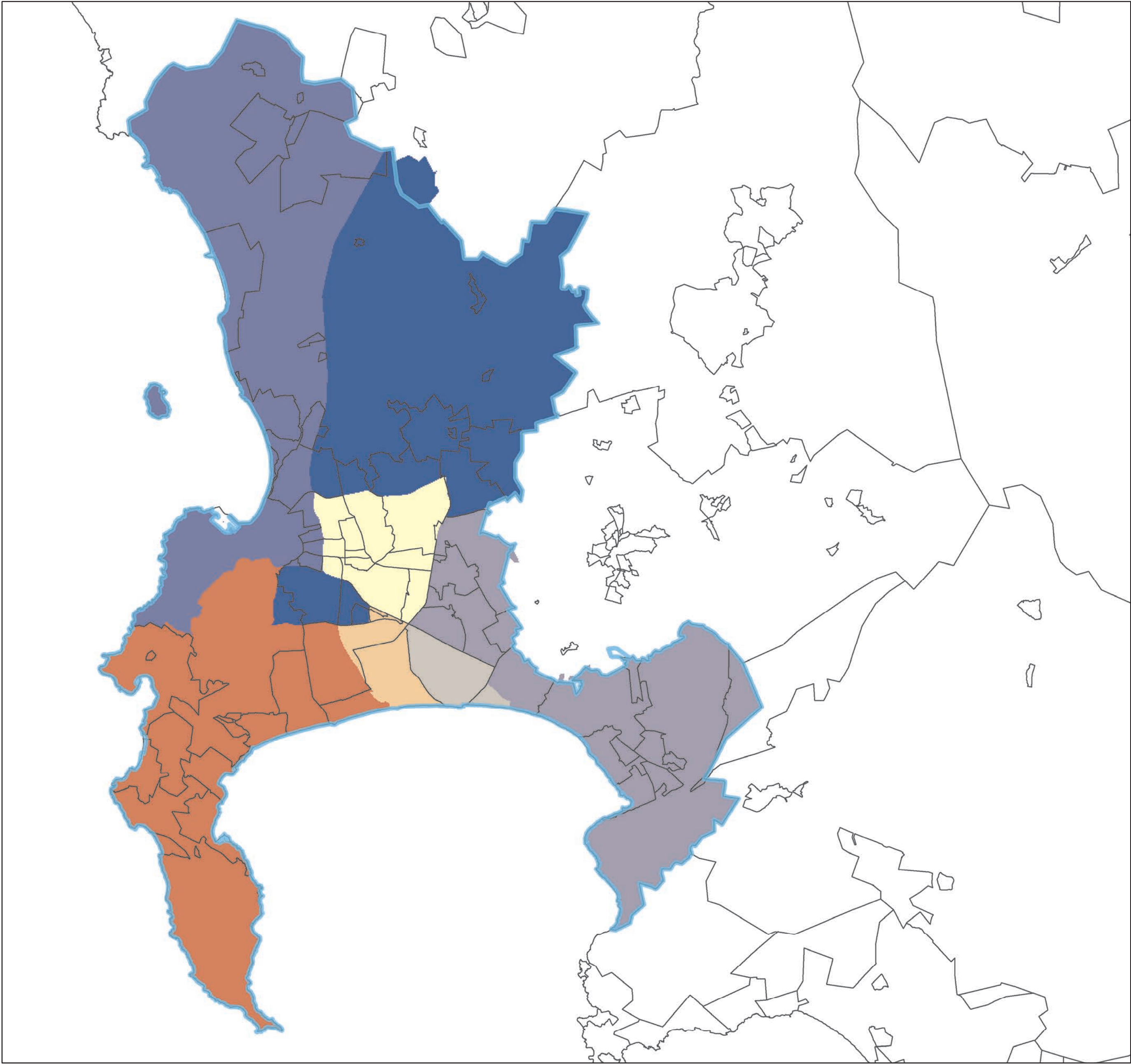


Malnourishment Rate (Children under 5y)

category: resilience

time period: current conditions

weighting3



city_boundary

municipality boundaries

051020

Kilometers

resilience

Value

no data

1 = low

2

3

4

5

6

7

8

9 = high

Number of malnourished children aged under 5 years-old (unknown year). Original raw data values used. The data were converted to raster and then reclassified to 1-9 using a natural breaks method with some manual input. The reclassified values were inverted such that high values represented high Resilience. Cells with no data were assigned a value of 0. Original resolution: Health regions. Credits: City of Cape Town

Coordinate System: Hartebeesthoek 1994 Transverse Mercator

Projection: Transverse Mercator

Datum: Hartebeesthoek 1994

False Easting: 0.0000

False Northing: 0.0000

Central Meridian: 19.0000

Scale Factor: 1.0000

Latitude Of Origin: 0.0000

Units: Meter

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INFO

blue areas represent high resilience

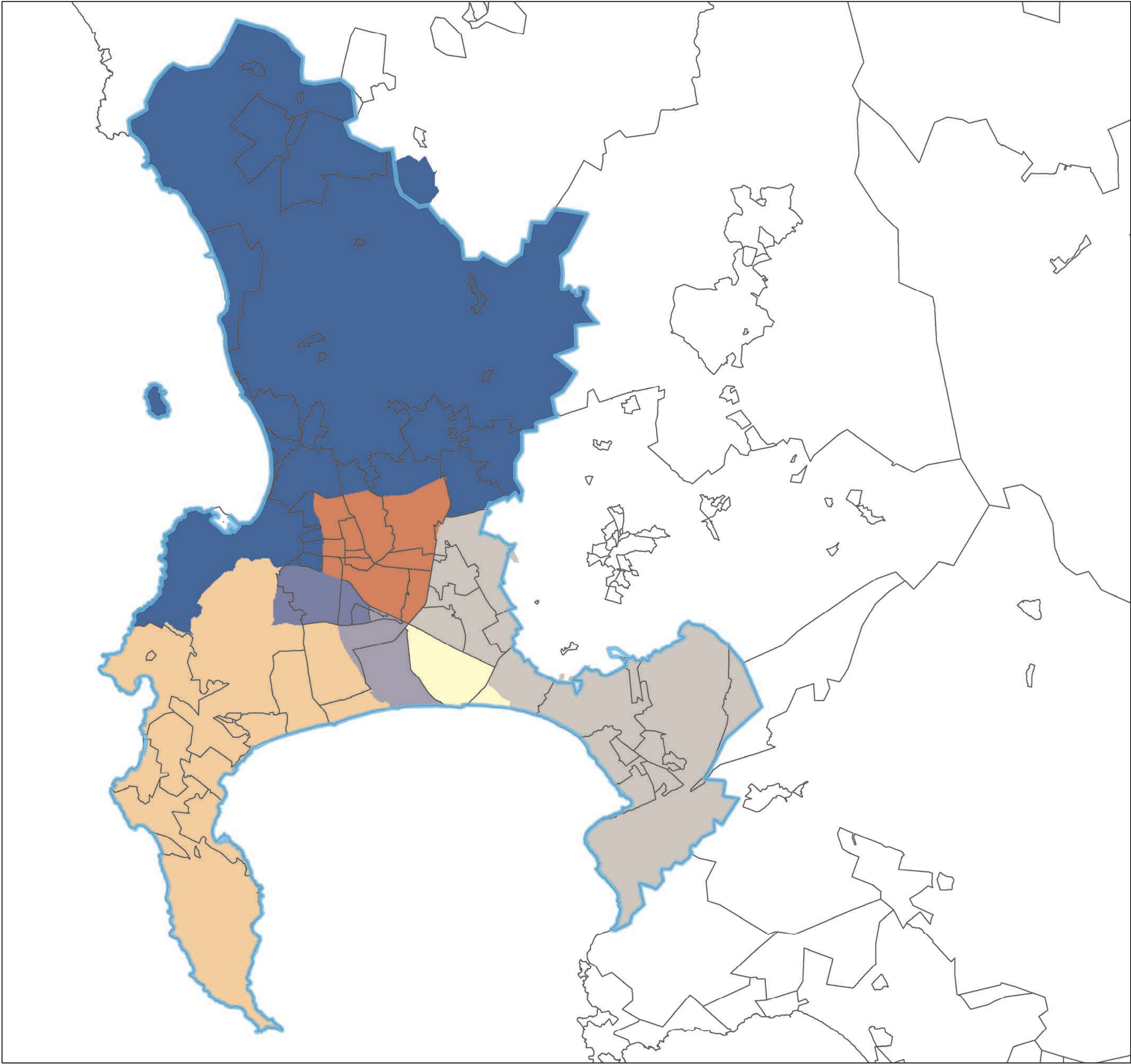
map produced 29/04/2019

Pneumonia Rate (Children under 5y)

category: resilience

time period: current conditions

weighting2



city_boundary

municipality boundaries

051020

Kilometers

resilience

Value

no data

1 = low

2

3

4

5

6

7

8

9 = high

Number of children aged under 5 years-old with Pneumonia (unknown year). Original raw data values used. The data were converted to raster and then reclassified to 1-9 using a natural breaks method with some manual input. The reclassified values were inverted such that high values represented high Resilience. Cells with no data were assigned a value of 0. Original resolution: Health regions. Credits: City of Cape Town

Coordinate System: Hartebeesthoek 1994 Transverse Mercator

Projection: Transverse Mercator

Datum: Hartebeesthoek 1994

False Easting: 0.0000

False Northing: 0.0000

Central Meridian: 19.0000

Scale Factor: 1.0000

Latitude Of Origin: 0.0000

Units: Meter

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blue areas represent high resilience

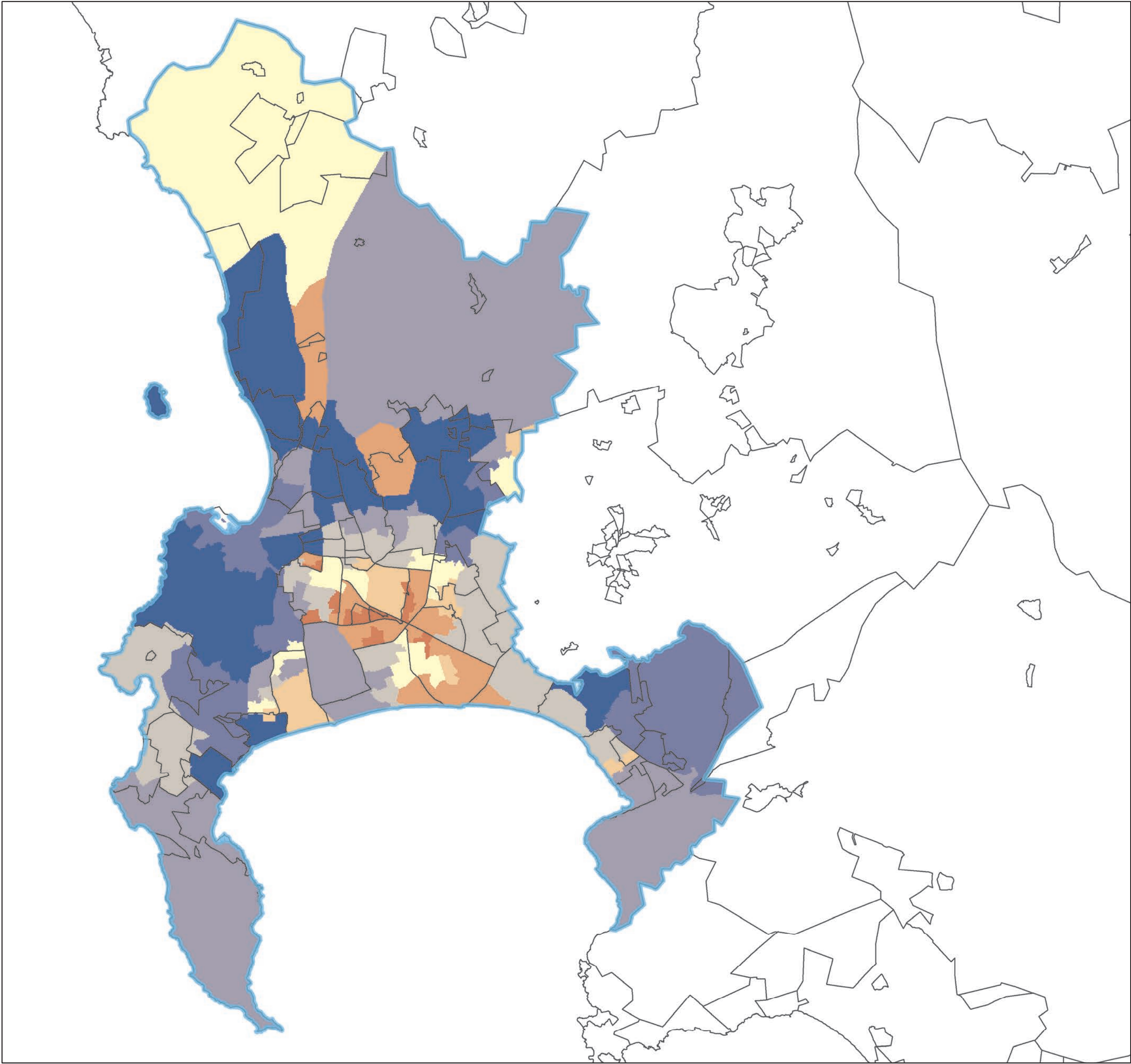
map produced 29/04/2019

Employment Rate

category: resilience

time period: current conditions

weighting 4

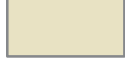


Legend

-  city_boundary
-  municipality boundaries

resilience

Value

-  no data
-  1 = low
-  2
-  3
-  4
-  5
-  6
-  7
-  8
-  9 = high

Percentage of the labour force unemployed (2011). Calculated as the proportion of the total labour force who are unemployed. The data were converted to raster and then reclassified to 1-9 using a natural breaks method. The reclassified values were inverted such that high values represented high Resilience. Cells with no data were assigned a value of 0. Original resolution: Ward. Credits: City of Cape Town

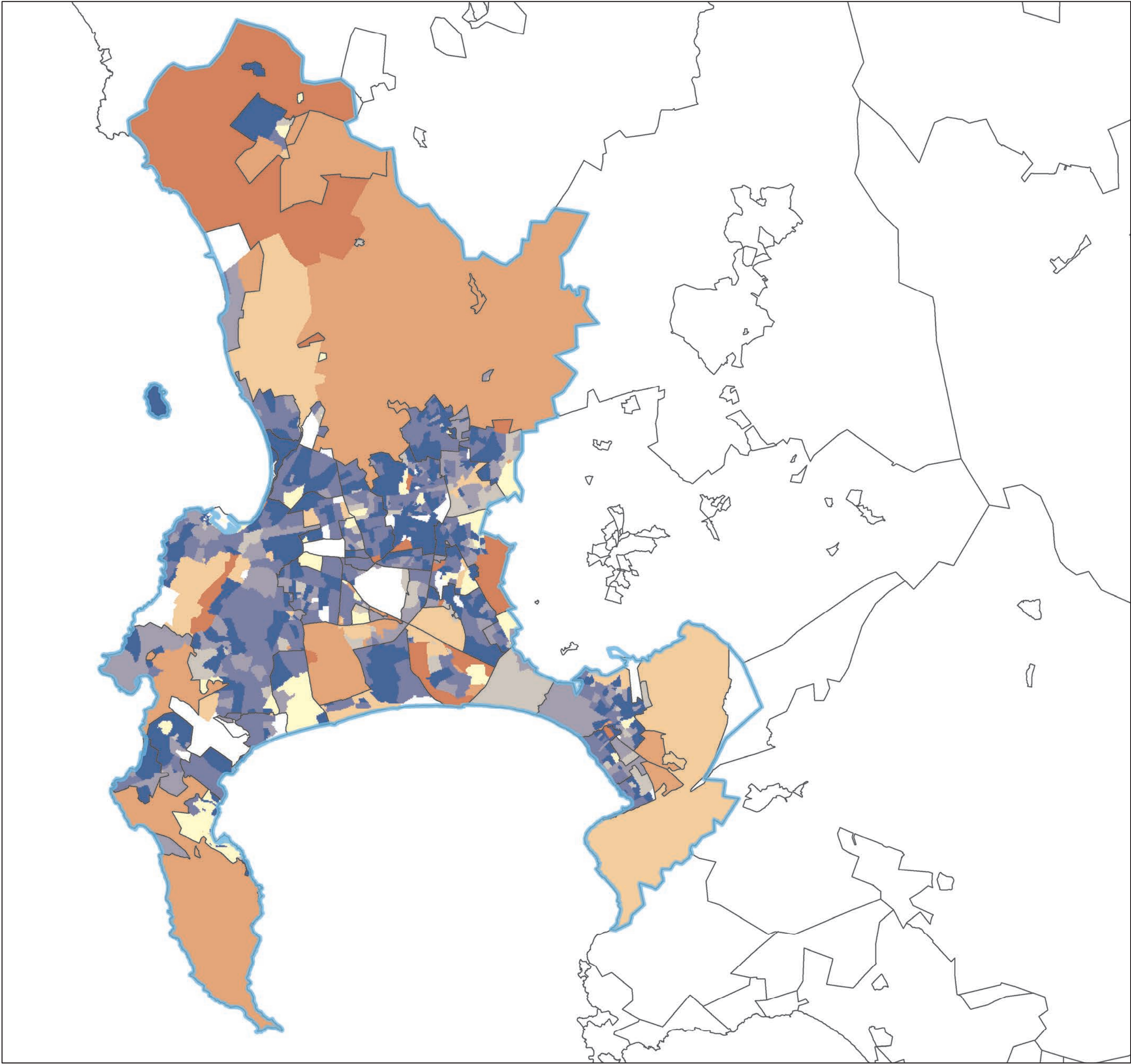
blue areas represent high resilience

Coordinate System: Hartebeesthoek 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: Hartebeesthoek 1994
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: 19.0000
Scale Factor: 1.0000
Latitude Of Origin: 0.0000
Units: Meter



Weekly Rubbish Collection

category: resilience time period: current conditions weighting 3



Legend

city_boundary

municipality boundaries

resilience

Value

no data

1 = low

2

3

4

5

6

7

8

9 = high

blue areas represent high resilience

051020

Kilometers

Percentage of households with weekly rubbish collections (2011). Original raw data values used. The data were converted to raster and then reclassified to 1-9 using a natural breaks method. Cells with no data were assigned a value of 0. Original resolution: SP. Credits: City of Cape Town

Coordinate System: Hartebeesthoek 1994 Transverse Mercator

Projection: Transverse Mercator

Datum: Hartebeesthoek 1994

False Easting: 0.0000

False Northing: 0.0000

Central Meridian: 19.0000

Scale Factor: 1.0000

Latitude Of Origin: 0.0000

Units: Meter

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INFO

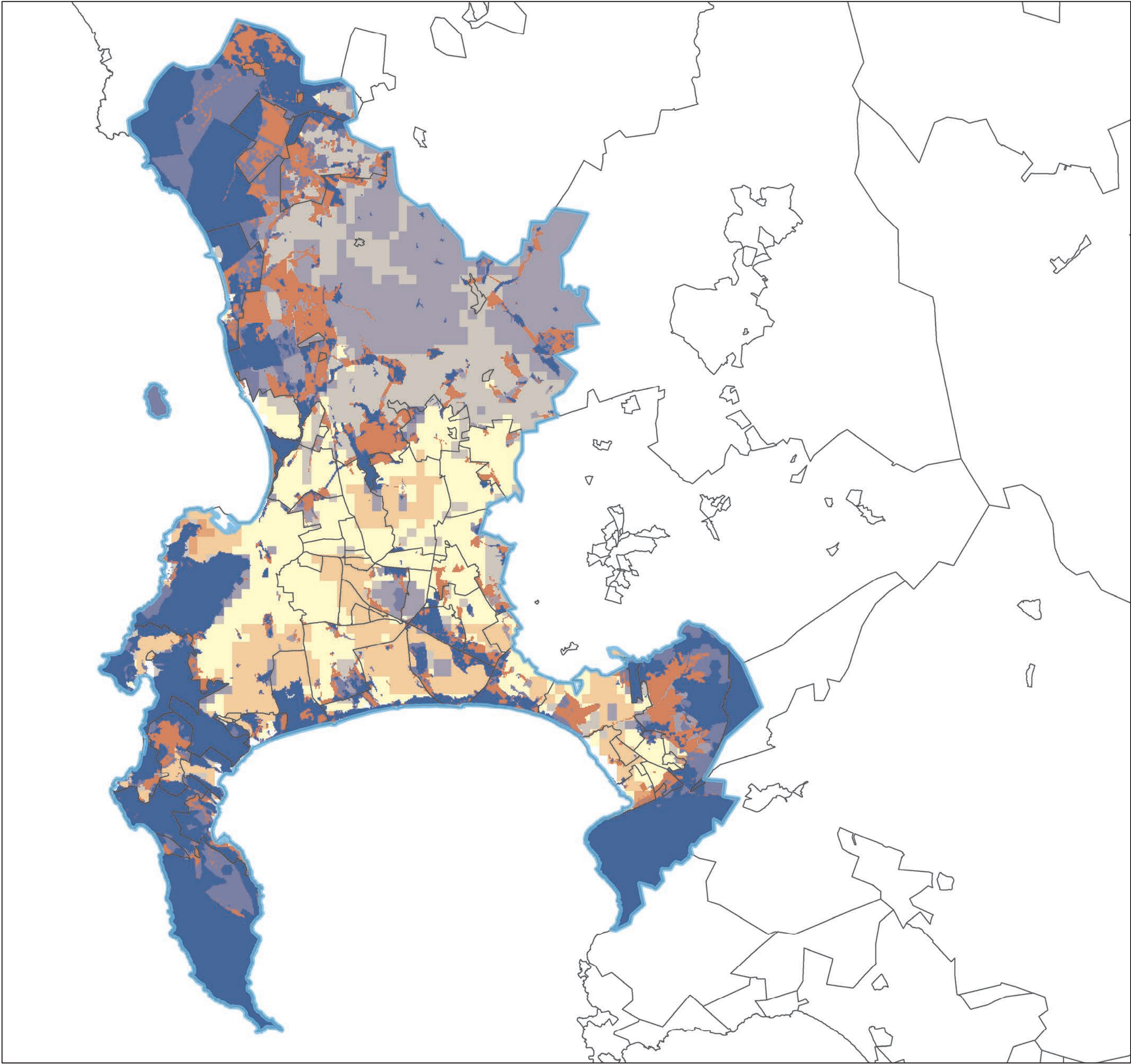
map produced 29/04/2019

Biodiversity Services

category: resilience

time period: current conditions

weighting 4

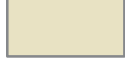


Legend

-  city_boundary
-  municipality boundaries

resilience

Value

-  no data
-  1 = low
-  2
-  3
-  4
-  5
-  6
-  7
-  8
-  9 = high



For a measure of the degree to which biodiversity services are intact and fully functional we used the COCT Bionet dataset: Critical Biodiversity Areas (which takes account of protected species and habitats, climate refugia and protected area management and status). We reclassified the CBA categories following: 1,3 to 9; 4,5,6 to 8; 7,8,10,12 to 7; 9 to 6; 11,13 to 1; 0 to 0. This dataset leaves large parts of the city area with no recorded biodiversity value (where habitats are considered irreversibly modified). Yet variation of biodiversity services should exist here with more biodiversity present in less densely populated areas further from roads with some levels of protection. So we used a prior dataset for biodiversity value measured in these terms at 1km2 resolution for the whole of Africa to fill in the gaps between the CBA patches.

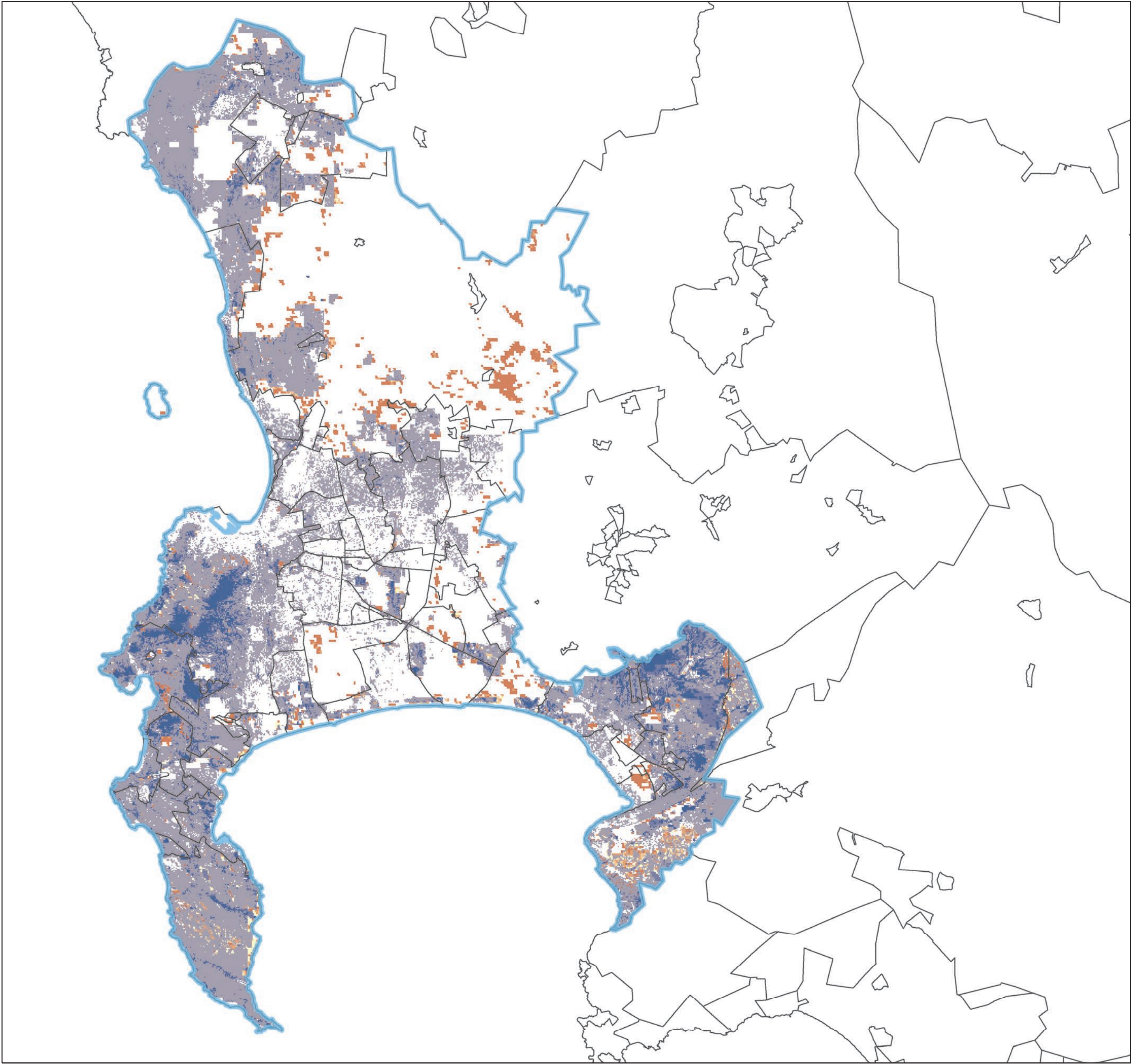
blue areas represent high resilience

Coordinate System: Hartebeesthoek 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: Hartebeesthoek 1994
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: 19.0000
Scale Factor: 1.0000
Latitude Of Origin: 0.0000
Units: Meter



Forest and Upper-storey Services

category: resilience time period: current conditions weighting 3



Legend

- city_boundary
- municipality boundaries

resilience

- Value
- no data
 - 1 = low
 - 2
 - 3
 - 4
 - 5
 - 6
 - 7
 - 8
 - 9 = high

We combined two data layers to obtain a measure of the beneficial ecosystem services provided by forests, trees and upper-storey vegetation (e.g. forestry and timber, provision of shade and microclimate, production of oxygen, consumption of CO2). Layer one is the FAO Global Forest Resources Assessment (FRA 2010 v1.2) at 250m resolution. Percent forest cover was reclassified on the scale 0 – 9. Layer 2 is the same upper-storey fuel load assessment as used for determining high fire risk areas. We used the African Soil Information Albedo dataset to exclude areas with a high bare substrate reflectance (values >225). In areas where vegetation cover (mostly) produces lower reflectance we take the values from another global treecover dataset 2010 <http://glcf.umiacs.umd.edu/data/vcf/> which scale from 0 - 100 representing % cover as an indicator of potential fuel load for combustion. These values were also reclassified on the scale 0-9. The two layers were then combined by taking the maximum value for any grid cell.

blue areas represent high resilience

Coordinate System: Hartebeesthoek 1994 Transverse Mercator
Projection: Transverse Mercator
Datum: Hartebeesthoek 1994
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: 19.0000
Scale Factor: 1.0000
Latitude Of Origin: 0.0000
Units: Meter

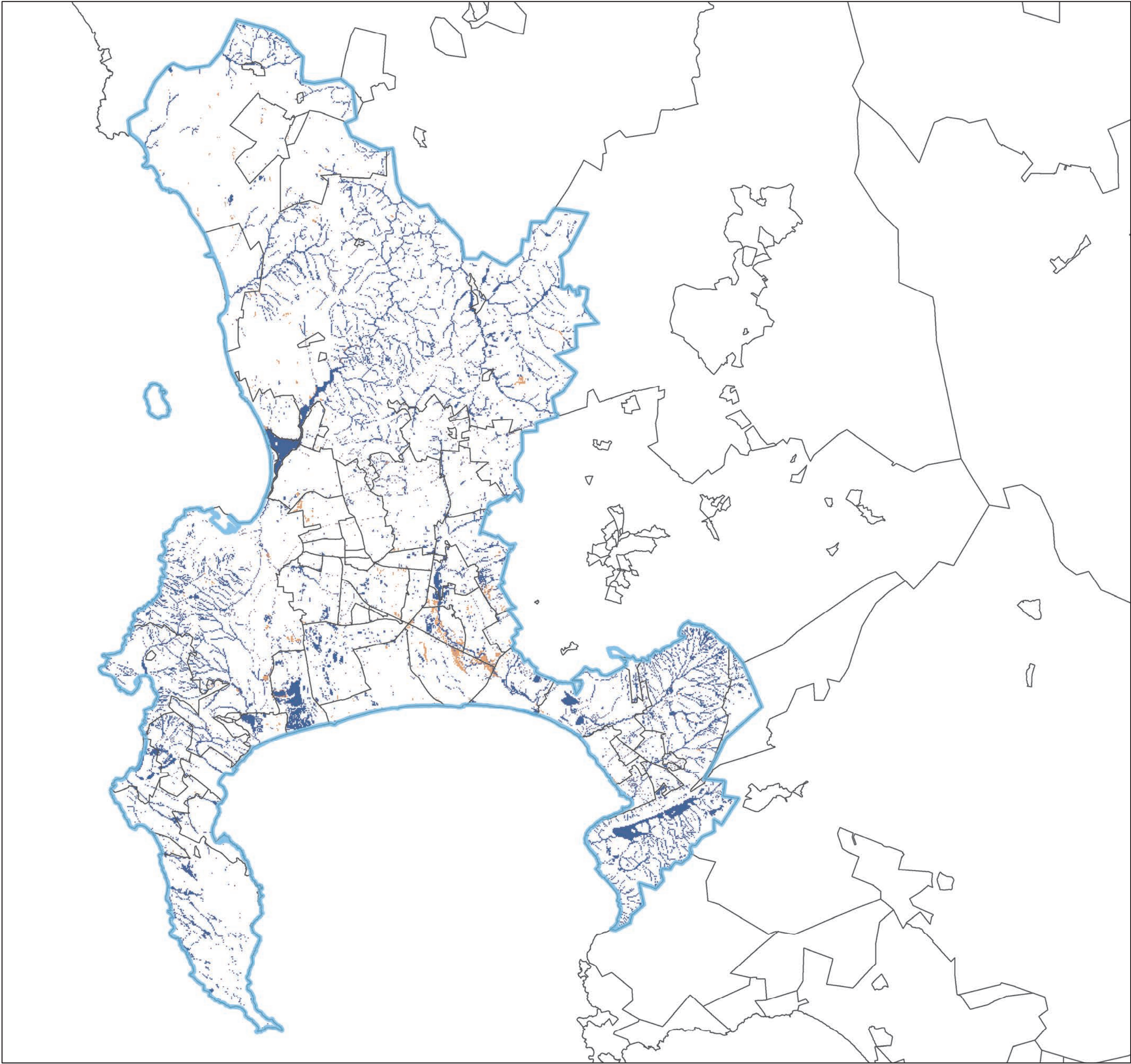


Wetland and Watercourse Services

category: resilience

time period: current conditions

weighting4



Legend

- city_boundary
- municipality boundaries

resilience

Value

- no data
- 1 = low
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9 = high

For a measure of the ecosystem benefits provided by wetlands (e.g. filtration and retention) and watercourses (e.g. microclimates) we developed these two layers separately and then combined them into a single layer. For wetlands we were able to reclassify using the same lookup table on critical biodiversity area category from the bionet dataset because the latter includes wetlands. The only code value we found in this that did not match was the value 80 to which we reclassified as 5. For watercourses we obtained the Open Watercourse dataset from COCT. This dataset contains 164 different water course types all represented as lines. For each type we ascribed a buffer distance based on an estimate of the extent of influence of each microclimate on a scale 20m for drainage channels to 50m for natural rivers; and we ascribed a score for each watercourse type on a scale 0-9 based on the expected ecosystem benefits (e.g. ranging from 6 for a culvert to 9 for a natural river). We then buffered each line outward in both directions by the set buffer distance for that type and we converted these polygons to a raster grid which retained the score values. To combine wetlands with watercourse we overlaid these two datasets and obtained the maximum value using Cell Statistics.

blue areas represent high resilience

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