Strategy Development

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1. Introduction

The vulnerability assessment covered in this chapter is based especially in changes in temperatures, rainfall and extreme weather events as described in the Climate Change Model projections for the Free State Province report. The sectors assessed are agriculture, air quality, biodiversity, water, human health, the built environment and energy. An assessment of social vulnerability based on data from the Statistics South Africa is included, highlighting the vulnerability of the population in the Free State.

2. Sector Vulnerability

2.1 Agriculture

Agriculture is one of the strongest economic sectors in the Free State Province and it consists of animal production, crop farming and horticulture as well as dairy farming, game farming and aquaculture fruit production and agro-processing (Free State Business, 2012). An estimated 14.5% of the country‘s commercial farming is carried out in the Free State. Agriculture is critical to the well-being of the province, both as the provider of food and a major employer with the major crops such as maize, soy beans, wheat, sorghum, sunflowers, potatoes, groundnuts and wool being grown, In addition, 90% of cherry production in South Africa as well as 40% of the country’s potatoes are grown in the Free State. In terms of other agricultural produce, the province produces 100 000 tonnes of vegetables, mainly asparagus, and 40 000 tonnes of fruit as well as flowers (floriculture) mainly for the export market All this agricultural produce is attributed to the temperate climate of the Free State, especially the production of deciduous fruit like cherries, apples, berries, peaches, plums and apricots (Free State Province, 2012).

Agriculture dominates the Free State countryside, with agricultural land covering an estimated 3.2 million ha, which constitutes 90% of the province’s land area (see Figure 2.1). As mentioned above, agriculture is a major industry in the province, with an estimated 12% of the Free State’s working age sector being employed in the sector (Stats SA, 2011). Further, the Free State is thought of as the bread-basket of country, supplying substantial percentages of the country’s grains such as sorghum (53%), sunflowers (45%), wheat (37%), maize (34%), potatoes (40%), groundnuts (32%), dry beans (26%), wool (26%) over and above the produce previously mentioned. Agricultural as an economic sector contributes approximately 7% to the GDP of the Free State, with as much as 14% contributing to South Africa’s agricultural GDP. An estimated 14.5% of the country’s commercial farming is carried out in the Free State (Stats SA). The agricultural sector profits from the Vaal River north of the province and the Orange River to the south, with the Vaal-Harts irrigation system being recognised as one of the most productive in the country, covering around 44 000 ha with a variety of crops (Stats SA, 2011).

According to the land cover of the Free State (see figure 2.1) there are four different types of agriculture highlighted and these are cultivated subsistence, cultivated orchards, cultivated commercial pivots and cultivated commercial fields. The low shrub lands areas to the south of map are mainly reserved for sheep farming, while some of the grass land areas are reserved for cattle farming (Free State Province, 2012).

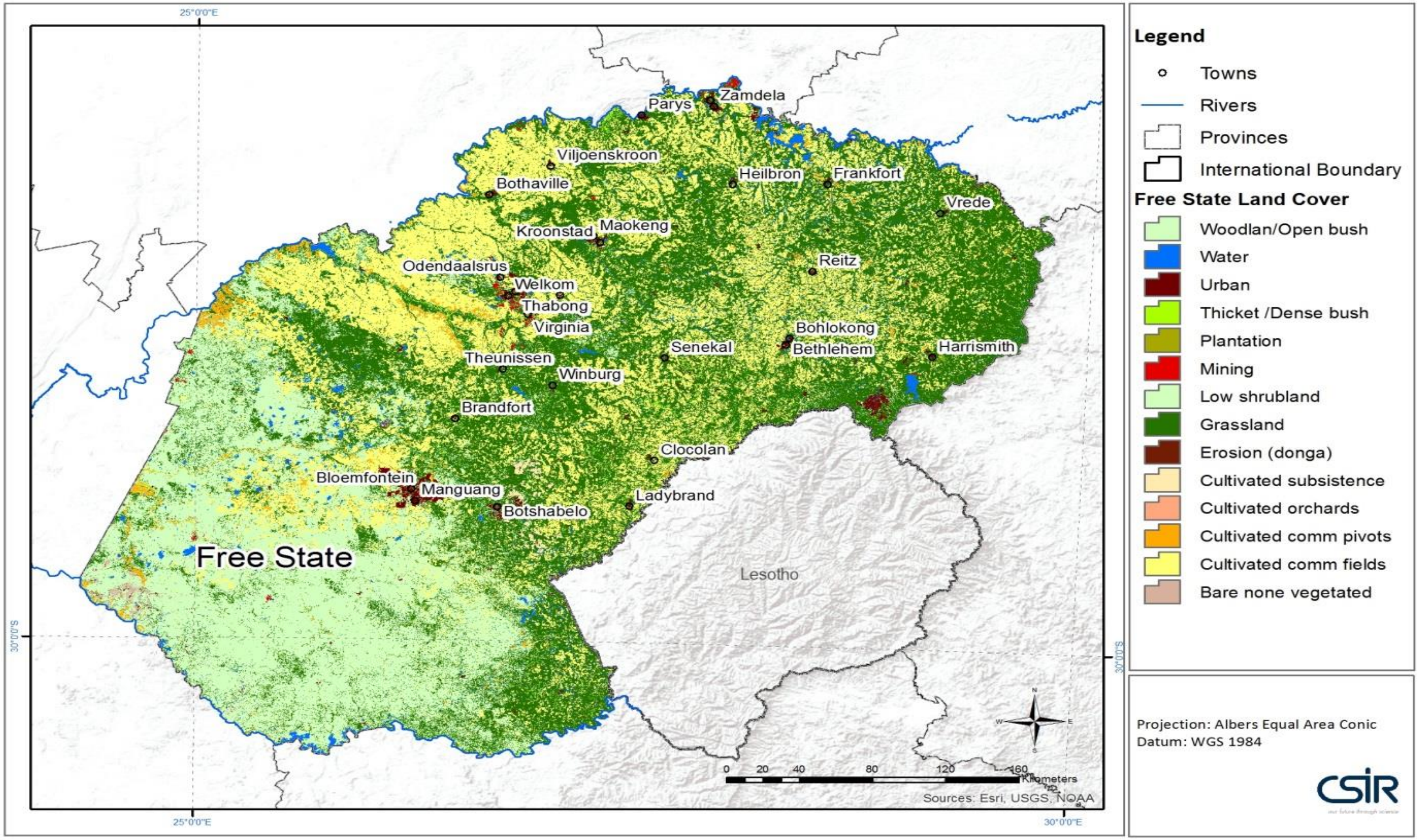

Figure 2.1: Land cover map of the Free State showing the different types of agricultural activities.

Below is a summary of where the agricultural activities are concentrated in the Free State (source Free State Province, 2012)

Table 2.1: Main Agricultural activities in the Free State Province (Free State Province, 2012)

Region	Main Agricultural Activities
Manguang	This region has grass plains and mountains to the east and commercial livestock farming, at Mantsopa and Naledi, is the main form of farming, while the eastern areas produce potatoes and sunflowers
Xhariep	The southern parts of the province are mostly dry areas where sheep farming is the most prominent. Irrigation schemes, such as the one at Jacobsdal, allow for the production of grapes, with Landzicht and Wilreza Cellars being two of the main wine producers. Potatoes and Walnuts are also farmed in this region.
Leiweleputswa	Maize is the main product in this region and also known as the mielie (maize) capital of South Africa. This region is known for its diversity in farming activities as wheat, sunflowers, nuts, vegetables and dairy are produced as well as commercial livestock farming.
Thabo Mofutsanyane	Approximately 90% of South Africa's cherries are produced in this region. Also to be found are two major asparagus factories where both white and green asparagus are produced. Soya, sorghum, sunflowers, potatoes, wheat and other important crops are also produced.
Fezile Dabi	This northern region is at the heart of wheat and maize production in the province as the Vaal Dam provides extensive water supply throughout the region. Furthermore, sunflower, tobacco, sorghum, peanut and cattle are also farmed.

2.1.1. Climatic factors affecting Agriculture

A myriad of factors both climatic and non-climatic affect agriculture in South Africa but this section will focus only on the climatic factors most of which will be affected by climate change. Rainfall is one of the most important climatic factors influencing agriculture, especially determining the suitability of crops and livestock across the country. Rainfall variability presents fundamental risk to climate change, in particular in the transitional areas of different seasonality and quantities of rainfall which are sensitive to and vulnerable to changes in climate. The dependence on water presents a threat for all agricultural activities, especially on irrigation which is the single largest water consumer using at least 60% for agriculture alone and 65% for related agricultural activities (DEA, 2013a).

Irrigated agriculture is the biggest water consumer in South Africa, and this dependence on water poses the biggest vulnerability for all agricultural activities. There is confirmation that that small holder or subsistence dry land farming is the most vulnerable to climate change in comparison to commercial farming activities but low scale irrigated agriculture will be least affected as long as there is sufficient rain (DEA, 2013a).

Evaporative losses, in South Africa are already high ranging between 1400 to 3000/mm per year and are caused by extremely high atmospheric demand. High evaporative losses when combined with unreliable rainfall often leads to semi-arid conditions. In some instances this is the case even where rainfall is adequate. Coupled with evaporation is evapotranspiration from crops which determines the amount of water a crop needs. An analysis to measure that sensitivity indicates that in the summer (January) a temperature increase of 2°C will increase the evapotranspiration from crops by 3.5% and in winter the percentage is higher than the summer increase. While the percentages of increase vary across the future, the consensus is that they will increase especially in the interior. In the near, intermediate and far future (DEA, 2013a),

Temperature is another critical factor for agriculture, affecting a wide range of agricultural processes as well as being used as an index of energy status of the environment. Temperature has been modelled with certainty and is expected to increase with global warming (DEA, 2013a).

Increases in temperatures bring about a myriad of additional issues for agriculture. The projected temperature increases range between 3.0 - 3.5°C and these are expected to increase up to 6°C by the turn of the century. Increases in temperatures are associated with heat waves which are defined as 3 or more consecutive days where temperatures are above 30°C and extreme heat waves above 35°C, Heat waves are expected to increase in the near and far future with the extreme heat wave day expected to double in the intermediate future, Areas already experiencing high temperatures will be the most affected (DEA, 2013a).

Other climatic factors important for agriculture are heat units and cold spells, which are essential for crop growth and has an influence on crop pest life cycles. These are expected to increase in future, with moderate increases in the summer for heat units and higher in ecological sensitive areas. On the other hand cold spells are defined as 3 or more days when temperature is less than minimum of <2.5°C for 3 or more consecutive days or extreme cold spell days where temperatures are expected to be <0°C for 3 consecutive days. It is projected that there will be a reduction of at least 70% in the cold spell and extreme cold spell days in the South African interior (DEA, 2013a).

Positive chill units are defined as a period of winter chilling that is essential for particular biennial plants to complete their dormant season in order to produce high quality fruit. The chill units are measured in positive chill units based on hourly temperatures over and below the essential thresholds. It is estimated that a 2°C increase in temperature will cause reductions of approximately 14-60% but with an average of 40%.

2.1.2. Climate Change and Agriculture in the Free State

The myriad of climatic factors and their impacts on agriculture has been discussed above. Of special interest are the impacts of increases in temperature and the various temperature related complication it brings which are detrimental to agriculture, given the different agricultural activities that the Free State Province is engaged in.

According to the climate modelling report, the temperature in the Free State is expected to increase by 1 to 2.5 °C by 2050 under low mitigation, and may rise by as much 2.5°C under high mitigation. It is expected that by the turn of the century, temperatures in the Free State will have risen by 7°C. These temperature increases as discussed above (2.1.1) will result in high evaporation with the threat of increasing aridity conditions while the increase in evapotranspiration rates, will increase the demand of water for the plants. The other impacts of temperature changes such as heat units, chill units all serve to affect crop (grains) and fruit production which are two of the most important agricultural crops in the Free State. The expected increases in the number of heat wave days and the very hot days (DEA 2013) a day, will affect livestock, especially in the west where most of the sheep farming is done as well affect crop yield and the possibly increase in veld and forest fires in the province.

The projected changes on rainfall are shrouded with a degree of uncertainty around them indicating that there will be decrease in precipitation under low mitigation with an increase in precipitation under high mitigation over the Free State. According to DEA (2013) the LTAS projections for rainfall presented on a river catchment scale indicate the same level of uncertainty under the different climate futures. The projected climate futures for the country from 2015–2035 (near future), 2040–2060 (medium future) and 2070–2090 (far future) indicate the following in terms of scenarios:-

- 1. Warmer (<3°C above 1961–2000) and wetter with greater frequency of extreme rainfall events.
- 2. Warmer (<3°C above 1961–2000) and drier, with an increase in the frequency of drought events and somewhat greater frequency of extreme rainfall events.
- 3. Hotter (>3°C above 1961–2000) and wetter with substantially greater frequency of extreme rainfall events.
- 4. Hotter (>3°C above 1961–2000) and drier, with a substantial increase in the frequency of drought events and greater frequency of extreme rainfall events.

These scenarios are elaborated regarding rainfall projections at sub-national level e.g. for South Africa's six hydrological zones (see Table 2.1) below.

Table 2.1 Rainfall projections over six of South Africa's hydrological zones (DEA, 2013)

Scenario	Limpopo/ Olifants/ Inkomati	Pongola-Umzimkulu	Vaal	Orange	Mzimvubu-Tsitsikamma	Breede-Gouritz/ Berg
1: warmer/ wetter	↑ spring and summer	↑ spring	↑ spring and summer	↑ in all seasons	↑ in all seasons	↓ autumn, ↑ winter and spring
2: warmer/drier	↓ summer, spring and autumn	↓ spring and strongly ↓ summer and autumn	↓ summer and spring and strongly ↓ autumn	↓ summer, autumn and spring	↓ in all seasons, strongly ↓ summer and autumn	↓ in all seasons, strongly ↓ in the west
3: hotter/wetter	Strongly ↑ spring and summer	Strongly ↑ spring	↑ spring and summer	↑ in all seasons	Strongly ↑ in all seasons	↓ autumn, ↑ winter and spring
4: hotter/ drier	Strongly ↓ summer, spring and autumn	↓ spring and strongly ↓ summer and autumn	↓ summer and spring and strongly ↓ autumn	↓ summer, autumn and spring	↓ all seasons, strongly ↓ in summer and autumn	↓ all seasons, strongly ↓ in the west

The hydrological zones of interest to the Free State, the Vaal and the Orange indicate the same trends under the different scenarios, with decreases expected in both the Orange and the Vaal during the summer, autumn and spring seasons which are most critical for agriculture under scenarios 1 and 3 but with increases under scenarios 2 and 4 (DEA, 2013).

The projected changes in temperature coupled with the uncertainly of rainfall will put strain on agriculture especially the increased demand in irrigation which is expected to increase under all scenarios, with the exception of the eastern part of the country (DEA, 2013). Irrigation demand over the Free State will remain unchanged in some areas (see Figure 2.2) (left) with minor increase of up to 1.0 – 1.10, while in the far future the demand will increase from 1.0 to 1.20 (right). This will have a detrimental impact on grain crops both summer such as maize and winter crops such as wheat and barley which are expected to increase in the near future but decrease in the far future including in areas in the Free State (DEA, 2013a), The increases and the decreases are however slight. In terms of sorghum which is a drought resistant crop, more suitable areas are expected to be gained in the Free State for the crop, resulting in a 30% increase in yield in the far future (DEA, 2013a). Soya bean production, another drop in the Free State, indicated that while there may be increases in the areas of suitability to grow, these areas may become more concentrated (DEA, 2013a).

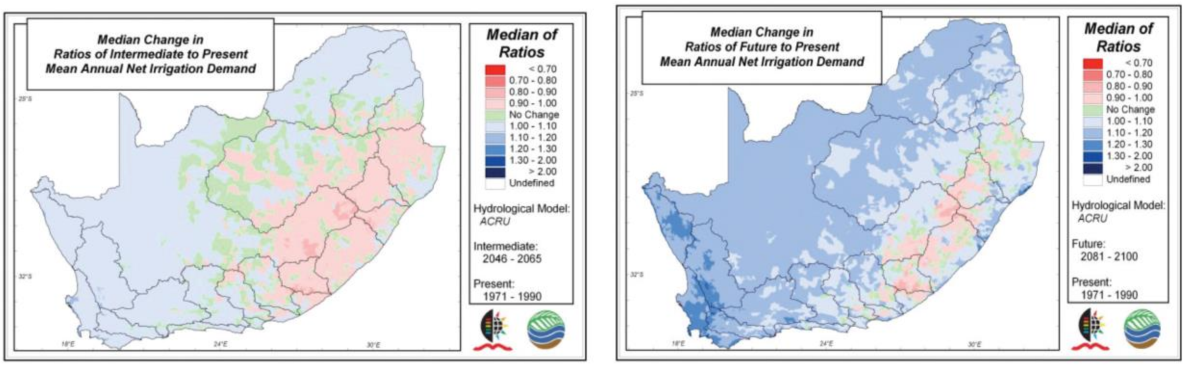

Figure 2.2: Modelled future of irrigation demand over South Africa from 2046 – 2065 (left) and 2081 – 2100 (DEA, 2013).

The second important crop in the Free State is its fruit. Apples and Pears while having very similar requirements for growing, they differ in the chill units needed, with apples needing strict chilling requirements due to high sensitivity to heat. Overall, apple production is expected to decrease while pear is expected to adapt to the changing climate conditions over time (DEA, 2013a). In terms of the other fruits grown in the Free State there has been no in-depth study of how they will react to temperature and rainfall change in South Africa. However, studies done globally indicated the *Prunus* genus is adapted to low winter temperatures and summer drought. The sensitivity of the peaches, apricots and cherries to temperature especially during the flowering season is most crucial. Disparities in flowering time transpire due to the variations in the chilling and heat requirement prior to the flowering (Dirlewanger et al., 2012), especially for apricots, peaches and sweet cherries which require more stringent chilling requirements compared to heat units. Further, those species with low chilling requirements bloom early in cold regions but are prone to frost damage while those with high chilling needs are prone to inadequate chilling in warm regions, damaging floral and leaf buds. All these result in poor fruit and is possibly challenging given the current global warming trend (Dirlewanger et al., 2012).

Given the projected changes in chilling unit and heat units attributed to increases in temperature (climate change model projections report) over the Free State, the production of these essential fruits for the province are under threat with reduced yield being the likely impact, especially for cherries, 90% of which are grown in the Free State.

The impacts of climate change oo agriculture, one of the most important industries in the Free State has highlighted the importance of temperature and rainfall both of which are affected by climate change, with possible losses and gains in both grains, fruits and livestock.

2.2. Air Quality

2.2.1. Description of Air Quality Rating Map for Free State

The air quality status of the Free State Province has not been extensively investigated. The province currently has its own air quality management by-law (Department of Cooperative Governance, Traditional Affairs and Human Settlement, 2011). Fezile Dabi District Municipality plans to formalise an air quality management by-law for the district (Mdluli, 2015). An air quality management plan for the province is still in draft form (Free State Province, 2009). Three municipalities in the province have been rated as having acceptable air quality, the Mangaung Metropolitan Municipality (MMM), Matjhabeng Local Municipality and Metsimaholo Local Municipality. The MMM presently has an air quality management plan and there are 3 air quality monitoring stations within the metropolitan municipality namely Bayswater Clinic; Pelonomi Hospital and Kagisanong Community Centre (Department of Environmental Affairs (DEA), 2012a). The pollutants measured by the stations according to DEA (2012b) and DEA (2014) include particles smaller than 10 µm (PM_{10}); particles smaller than 2.5 µm ($PM_{2.5}$); carbon monoxide (CO); sulphur dioxide (SO_2); oxides of nitrogen (NO_x), ozone (O_3) and lead (Pb). The Mangaung Metropolitan Municipality has plans to operationalise the air quality monitoring stations once more (Mdluli, 2015). A fourth air quality monitoring station in the province is located in Zamdela (Metsimaholo local municipality) and is a part of the Vaal Triangle Airshed Priority Area ambient air quality monitoring network (DEA, 2011). The Zamdela air quality monitoring station monitors PM_{10}, $PM_{2.5}$, SO_2, O_3, CO, NO_x.

The air quality management plan for the Free State Province includes an additional four air quality monitoring stations to those mentioned on the South African Air Quality Information System (SAAQIS). These air quality monitoring stations include Boiketlong, AJ_Jacobs, Hospital and Leitrum (Free State Province, 2009). At the Boiketlong air quality monitoring station, SO_2 and hydrogen sulphide (H_2S) are measured. At the AJ Jacobs air quality monitoring station, SO_2, H_2S, CO, PM_{10} and NO_2 pollutants are measured. At the Hospital air quality monitoring station, SO_2, CO, PM_{10} and nitrogen dioxide (NO_2) are measured. At the Leitrum air quality monitoring station, the pollutants measured include SO_2, CO, PM_{10}, NO_2, O_3, xylene, toluene and benzene. Air quality data from all monitoring stations were available until 2009, with 2008 the last year with a complete dataset for the whole year (Free State Province, 2009). The most number of exceedances of the PM_{10} national air quality standard

(DEA, 2009) for 24 hour averaged data occurred at the Leitrum air quality monitoring station (Table 2.2). A limited number of exceedances of the hourly NO_2 air quality standard (DEA, 2009) were counted at Leitrum and AJ Jacobs air quality monitoring stations (Table 2.3). In 2005, 164 exceedances of the hourly SO_2 air quality standard (DEA, 2009) were counted at the Boiketlong air quality monitoring station (Table 2.4). In the same year, 13 exceedances of the 24 hour SO_2 air quality standard (DEA, 2009) were counted at the Boiketlong air quality monitoring station (Table 2.5). Exceedances of the 8 hour running average national air quality standard for ozone (DEA, 2009) were counted at the Leitrum air quality monitoring station which totalled to 40 exceedances in 2005 (Table 2.6).

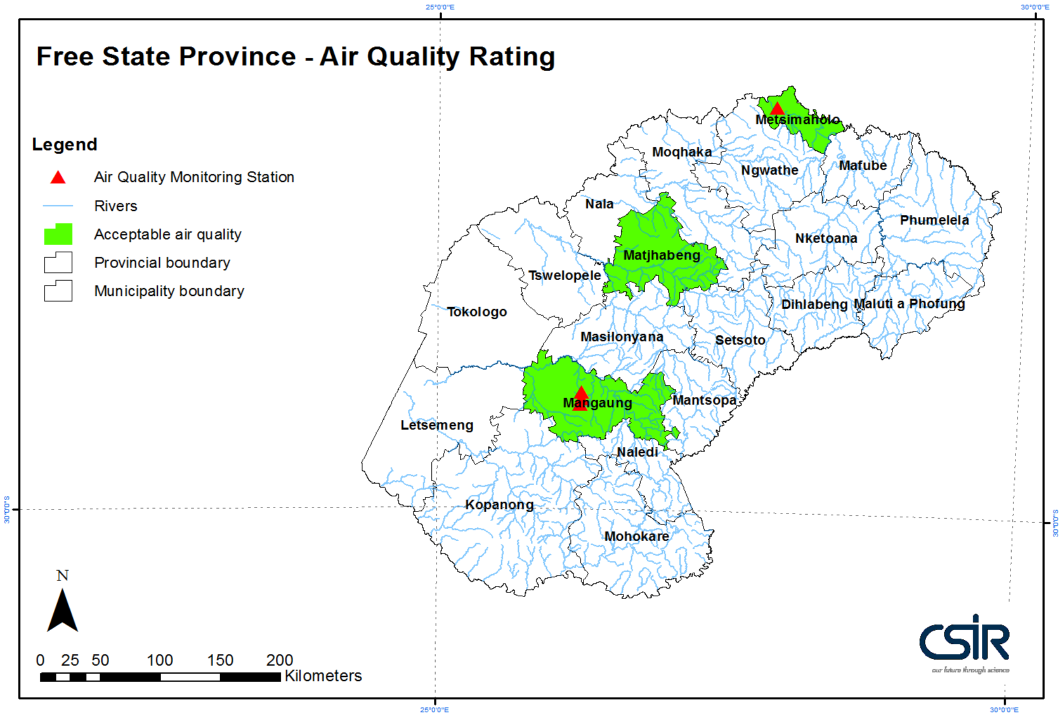

Figure 2.3: Air Quality Status of Municipalities in the Free State.

Table 2.2: Number of PM10 exceedances per station (Free State Province, 2009).

Station	Leitrum	AJ Jacobs	Hospital	Pelonomi
2004	84	No data	No data	**No data**
2005	42	No data	No data	**No data**
2006	50	No data	No data	**No data**
2007	98	56	43	**No data**
2008	118	33	46	**22**
2009 (until March)	3	0	0	**1**
Total	**395**	**89**	**89**	**23**

Table 2.3: Number of NO2 exceedances per station (hourly averages) (Free State Province, 2009).

Year	Leitrum	AJ Jacobs
2004	5	0
2005	1	0
2006	1	0
2007	0	0
2008	0	0
2009 (March)	0	0
Total	**7**	**0**

Table 2.4: Number of SO_2 exceedances (hourly averages) per station (Free State Province, 2009).

Year	Leitrum	AJ Jacobs	Hospital	Boiketlong
2004	5	51	26	48
2005	33	72	65	164
2006	11	54	17	88
2007	37	12	0	14
2008	15	39	17	

2009 (March)	5	24	24	
Total	**106**	**252**	**149**	**314**

Table 2.5: Number of SO2 exceedances (24 hour averages) per station (Free State Province, 2009).

Year	Leitrum	AJ Jacobs	Hospital	Boiketlong
2004	1	5	2	4
2005	2	12	4	13
2006	0	8	0	8
2007	3	2	0	2
2008	2	2	1	
2009	1	2	3	
Total	**9**	**31**	**10**	**27**

Table 2.6: Number of O3 exceedances (8-hour averages) per station (Free State Province, 2009).

Year	Leitrum
2004	19
2005	40
2006	27
2007	5
2008	3
2009 (March)	1
Total	**95**

2.3. Biodiversity

Healthy, functioning and biodiverse ecosystems are critical for human wellbeing, health and food security, by providing essential services such as formation of soil, provision of food and fresh water wood, fibre and fuel. Ecosystems also provide the regulation of climate, floods and protection from storm surges as well as disease (DEA, 2013b; Driver et al 2011). Ecosystems further serve as social, cultural and recreational role. A huge number or people and communities directly depend on ecosystems as a livelihood and safety net for food, energy, water and medicinal plants especially for rural populations (Murombedzi, 2008). South Africa has a wide range of habitats with 6% of the world's plant and mammals species, 5% of reptile species and 8% of birds all endemic to South Africa (Driver et al., 2011).

Mapping and classification of ecosystems into different ecosystem types is a first step in the assessment of the threat status and protection levels and classification system for South Africa, which includes vegetation types, river, wetlands marine, coastal and estuary ecosystems. This further allow for ecosystem monitoring, assessment and planning (Driver et al., 2011).

2.3.1. Ecosystems in the Free State Province

South Africa's biodiversity consists of nine biomes, four of which are found in the Free State Province, namely Grassland, Savanna, Nama-Karoo and Azonal vegetation (see figure 2.4).

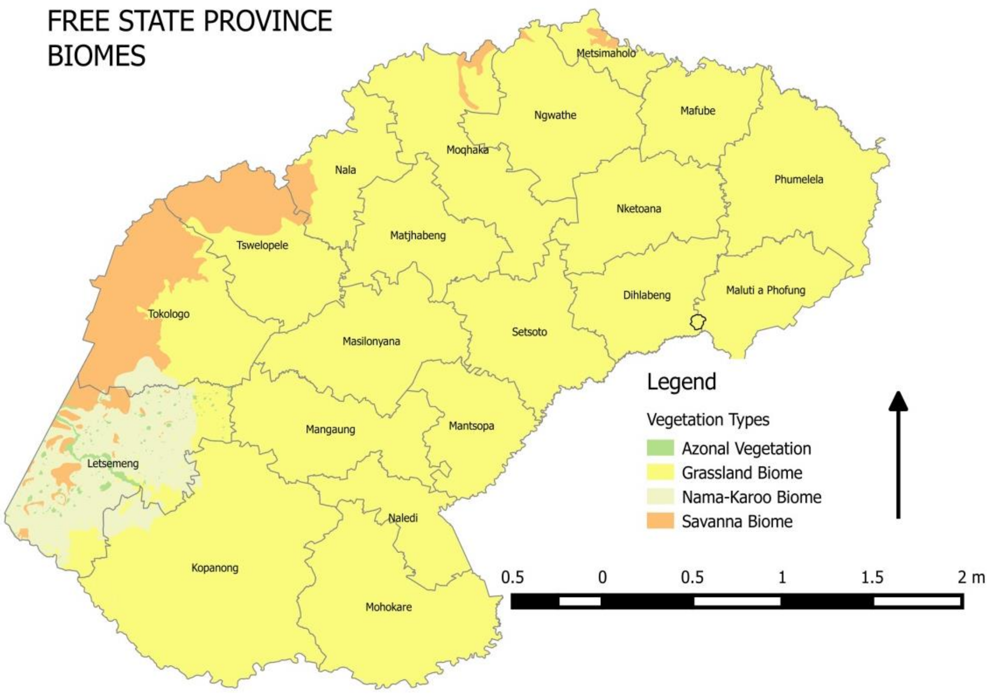

Figure 2.4: Biomes in the Free State Province (map compiled using data from BGIS – SANBI)

The grassland biomes covers most of the province and it is important that this is one of the most threatened biomes, with a sizable number of ecosystems types and threatened ecosystems, but with low protection rates (Driver et al., 2011). The grassland biome is a second priority in terms of threatened ecosystems but despite its threatened status, grasslands have an estimated value of over R8 000/km^2 per year for grazing and livestock (Driver et al. 2011). The grasslands also contains a sizable amount of plants used for medicinal purposes, a third of which are traded on the medicinal markets (Driver et al., 2011).

The second biome in the Free State is the savanna. The savanna biome supports millions of people especially in the rural population through the direct utilisation of the savanna goods. It is estimated that at least 9 to 12 million people use biomass for energy derived from savannas while a net worth of resources consumed from the savannah is estimated at R8 billion (Driver et al., 2011). Similarly to the grassland biome, savanna also house medicinal plants. The protection level of the savanna biomes vary based on the spatial location with those savannas located in national parks being more protected by those in the central regions with Free State as a case in point (Driver et al, 2011).

Other biomes found in the Free State is the Nama-Karoo, located mainly to the south west of the province and the Azonal vegetation.

2.3.2. Threatened Ecosystems in the Free State Province

Ecosystems are under immense pressure with threats of natural habitat due to land use and land cover change for example cultivation, mining and forestry as well as urban growth (Driver et al, 2011). Ecosystem threat status informs the extent to which ecosystems are still pristine or are otherwise losing vital aspects of their structure, function and composition, negatively impacting on their ability to provide ecosystem services.

Three ecosystems threat classifications, premised on the percentage of the ecosystem in good ecological condition are relative to a number of thresholds (see figure 2: 5). These are as follows:-

- Critically Endangered (CR)
- Vulnerable (VU)
- Least Threatened (LT)

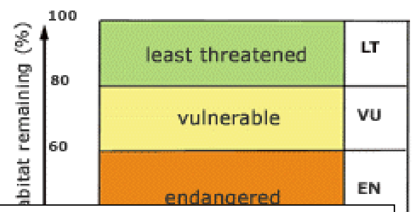

Figure 2.5:. Threatened Ecosystem Classification

*Biodiversity target

The threshold beyond which an ecosystem becomes critically endangered varies from 16% to 36%, and is dependent on the ecosystem, for example, ecosystems that are species-rich have a higher threshold, which is also known as the biodiversity target. In terms of classification, the **least threatened** ecosystems are still mostly intact while the **vulnerable ecosystems** are sensibly intact, but are on the verge of reaching thresholds beyond which they will begin to lose some ecosystem function. The endangered ecosystems have lost substantial quantities of their natural habitat, prejudicing their functionality and the **critically endangered** ecosystems have diminutive natural habitat remaining and not only has their functioning been severely compromised, but species associated with the ecosystem are also being lost (Driver et al., 2011). Threatened terrestrial ecosystems have a tendency to be concentrated in areas that are centres of economic production, with the remaining fragments of these ecosystems entrenched in production landscapes. The remaining natural habitat in critically endangered and endangered ecosystems makes up less than 3% of the country's area (Driver et al., 2011).

The Free State province has only two classes of threatened ecosystems, the endangered and the vulnerable ecosystems (see Figure 2.6) and these two classes are mainly located within the grassland biome which has already been highlighted as a second priority in terms of vulnerability and smaller area in the savanna biome. Approximately 30% of South Africa's grasslands have been permanently transformed and only 2% are formally conserved (Driver et al, 2012). The grasslands provide a critical ecosystem service in the regulation of water flow and economic development such as the provision of thatching grass and craft work materials as well as the provision of medicinal plants all which will be lost with the continual degradation and loss of the biome (DEA, 2013b). While the Nama-Karoo is not flagged as threatened, changes in this biome could impact ecosystem services of the seasonal provision of water due to the few non-perennial rivers, streams and shallow lakes found in the biome. The Nama-karoo further provides fodder for livestock grazing. This biome is not protected (Mucina et al, 2006b). The savanna biome is not threatened and it is anticipated that this biome will increase, replacing grasslands in some areas. This does not imply that changes in the biome will not affect the provision of a myriad of ecosystem services such as carbon sequestration, soil retention, and climate regulation in terms of woody savannas. Oher services provided include water, fodder for livestock grazing (Rutherford et al, 2006b) as well as significant wild fauna and diversity for recreation and subsistence livelihoods (DEA, 2013b)

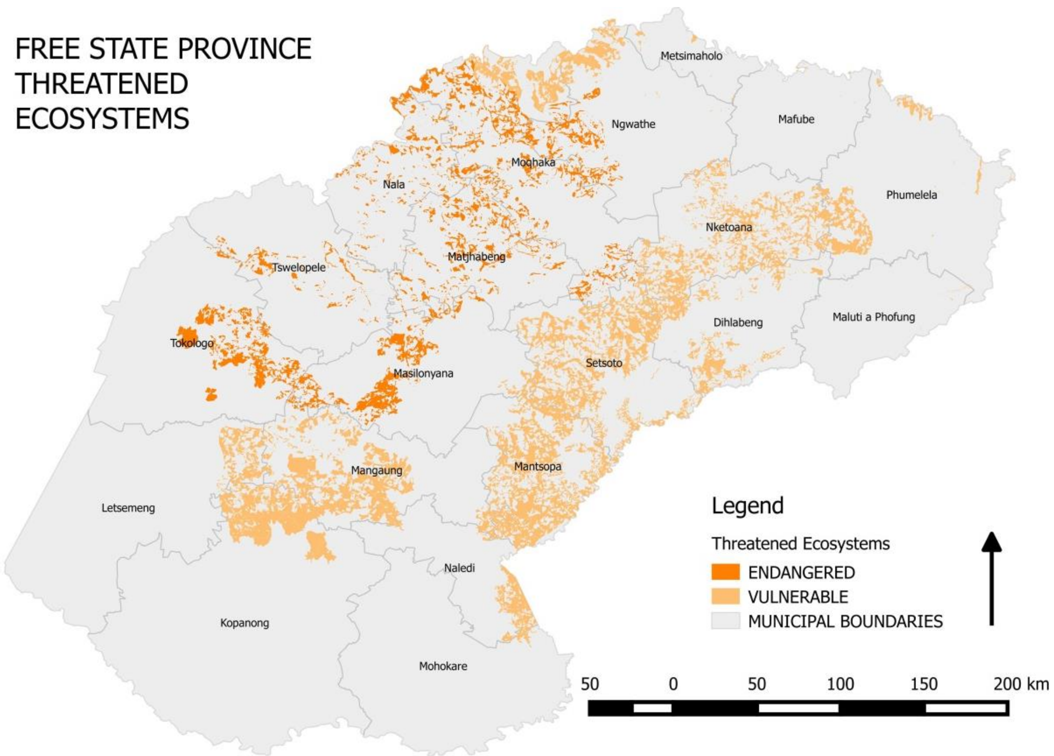

Figure 2.6 Threatened Ecosystems in the Free State (compiled from data provided by BGIS-SANBI)

2.3.3. Climate Change Impacts on Biodiversity (Biomes in Free State)

Bioclimatic envelopes are characteristic or a series of patterns of temperature, and rainfall within which each biome is found, which makes it a suitable habitat for certain species. The changes to the temperature and rainfall suitable for a particular biome might cause the changes to suit another biome, putting ecosystems and species in the biome under stress. Time is of essence when such changes occur given that if the change is long, occurring over thousands of years and where the biodiversity is in pristine condition, the ecosystem and the species are able to shift in response, However, when the changes in climate are rapid, and the ecosystems are degraded, over shorter periods of time such as decades the capacity of the ecosystem and the species to respond are not fully known. Nonetheless, the predictions of changes in climate based on the temperature and rainfall highlight three plausible climate futures premised on 15 global circulation models that were statistically downscaled for South Africa up to the year 2050 (Driver et al., 2011). These are

- Best case scenario: smallest predicted increases in temperature and changes in rainfall.
- Intermediate scenario: middle of the range (median) predicted increases in temperature increases and changes in rainfall.
- Worst case scenario: greatest predicted increases in temperature and changes in rainfall.

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The results of the modelling based on the 15 different models are presented in Figure 2.7. Bearing in mind that the condition of the ecosystem is essential in its response to changes in climate, section above had highlighted that most ecosystems in South Africa no longer in pristine condition, most of them impacted by landuse change as well as the anticipated impacts of those changes on the biomes found in the Free State. This will hinder the capacity of the ecosystems to respond to bio climatic change.

The degradation of these essential ecosystems disturbs their capability to provide ecosystem services, which in turn directly negatively impact on human well-being and socio-economic conditions, especially for the poor populations. Climate change is plausible to cause stress to ecosystems through the alteration of their functioning ability thereby compromising individual species (IPCC, 2007c). Overall, climate change will exacerbate the challenges already faced by the ecosystems. Climate change presents both direct and indirect threats though the intensifying of the existing stresses. The direct threats on ecosystems include:-

- habitat degradation and changes in landscapes through the clearing of vegetation,
- introduction of pests and weeds,
- Highly modified and overcommitted water resources
- altered fire regimes
- widespread use of fertiliser and other chemicals,
- urbanisation, mining and, for some species, over-harvesting (DEA, 2013b).

An assessment of the spatial shifts of biome under the different climate scenarios (see Figure 2.7) below.

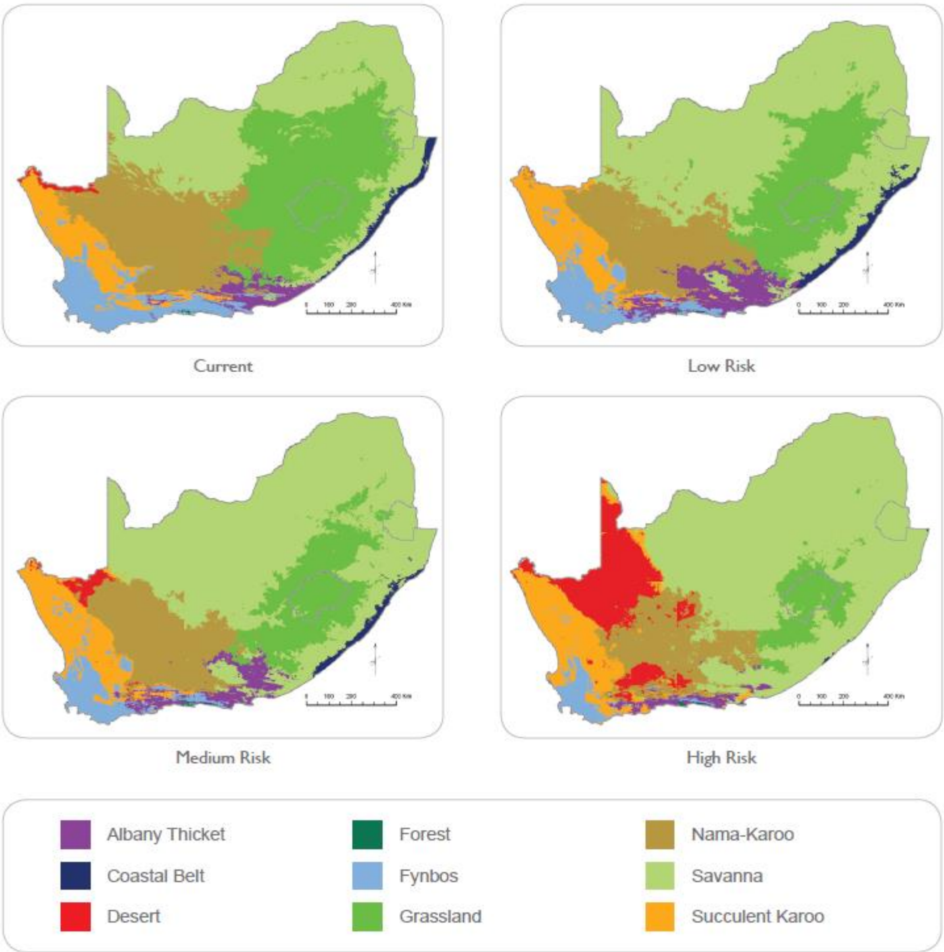

Figure 2.7: bioclimatic envelopes under statistically downscaled climate scenarios ahead to approximately 2050. Low Risk map simulates impacts of wet/cool future Projections of climate projections. High Risk simulates the impacts dry/hot projections. Medium Risk the median temperature and rainfall projections (DEA, 2013b)

An assessment of the spatial shift of the ideal climatic conditions for the biomes under low, intermediate (median) and high rick climate scenarios highlights that :-

- the grasslands biome seems to be one of the most threatened under all climate scenarios with significant changes anticipated in most grassland areas. The bioclimatic envelop for grasslands will be significantly reduced under all climate scenarios with the likelihood of grasslands being overtaken by savanna and in some areas, forest vegetation (Kiker, 2000).

- the Nama-Karoo is the second most threatened under all climate scenarios. The climatic envelope located in large spatial areas that are currently Nama-Karoo is likely to look like an arid savanna under the low-risk and intermediate scenarios, and a desert climate envelope under the high-risk scenario, presenting the threat of Nama-Karoo being replaced by savanna and desert in some areas (DEA, 2013b).

- the climate envelope ideal for the biome savanna will possibly expand significantly in the future, with particular savanna species benefiting. However, this does not necessarily benefit the current habitats and species groupings.

It is important to note that the assessment of bioclimatic envelops was conducted using two models both of which showed consistent results and while the assessment used was based on the statistically downscaling the trends for both the statistically and the dynamic downscaling in the climate change model projections report are also consistent. There are however some differences on the extent of change.

The same models have modelled the ecosystem location where the current climate envelops are expected to persevere, where the areas are expected to have stability in the ecosystem composition and structure (see Figure 2.8) (Driver et al., 2011).

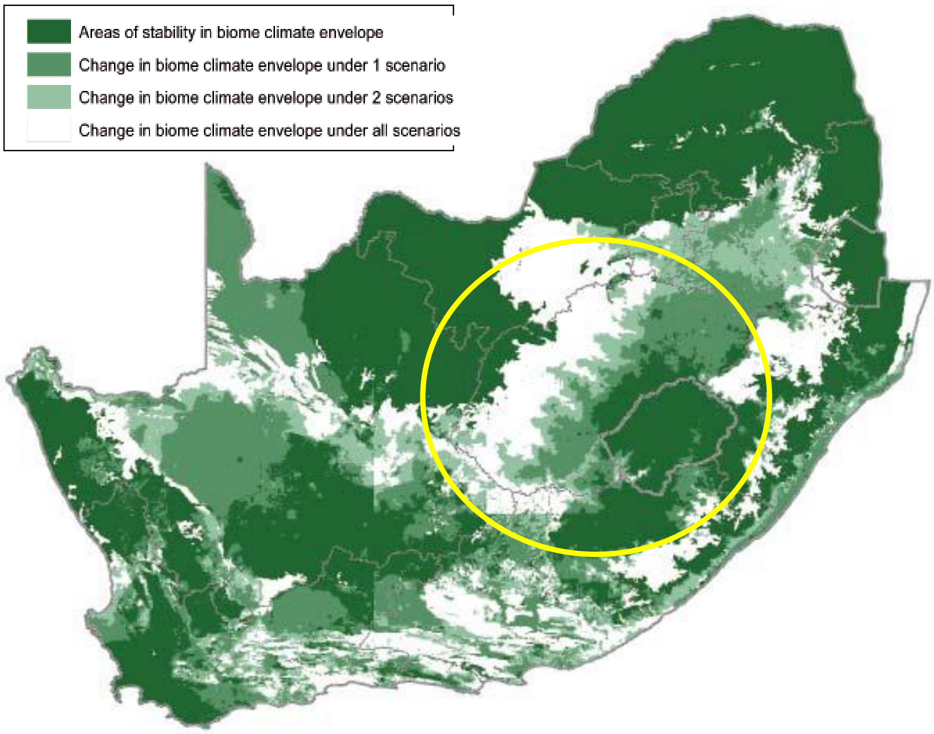

Figure 2.8.—Areas of biome stability in the face of climate change, under a range of climate scenarios, according to niche modelling results using statistically downscaled future climate scenarios only (DEA, 2013b).

According to the modelling, the darkest green areas are predicted to stay within their current climate envelopes under all three climate scenarios, and will thus most probably maintain a stable ecological composition and structure. The white areas however indicate areas where biomes are most at risk of change in composition and structure in the face of climate change (Driver et al., 2013). It is important to note that parts of the grasslands ecosystem in the Free State is highlighted in white indicating that it is at most risk of climate change under all scenarios, some areas under risk under scenarios 1 and 2 and a small area of the grassland showing stability including the savanna biome. Another observation is that the Nama-Karoo is also highlighted in white, showing risk under all scenarios.

The future implications for these losses are severe especially for the livelihood and economic sectors dependent on the ecosystem function and services such as agriculture including livestock will be severely affected by the increases in temperature, increased water insecurity in some areas of the Free State and overall human wellbeing. Adaptation responses to these changes need to take into account the multi stressors affecting biodiversity over and above climate change.

2.4. Water Sector Vulnerability

South Africa as an already water stressed country and faces numerous challenges with the management of its scarce water resources. The country, which is described as arid to semi-arid also, has to contend with climate change and variability which affect especially surface water availability. Currently, only 12% of the land areas provide up to 50% of the water resources. Further, decadal rainfall variability has resulted in dry and wet periods on the country, in a country where the water demand is very high and is expected to worsen with increases in population, urbanisation, changes in the standard of living and economic development (DEA, 2013c).

The projected changes in climate and climate variability will exacerbate the already strained water resources as well introduce new challenges as a result of variability and extreme weather events such as droughts and floods, changing rainfall seasons as well as the overall increase in temperatures which will lead to increased evaporation and surface water losses (DEA, 2013c). Water resources availability and management are key to the country's development, especially for the economic and agricultural sectors, infrastructure development as well as livelihoods. Water availability further affects human health and sanitation.

2.4.1. Surface Water Resources in the Free State

Water availability is a critical factor in the development of the Free State province given the extensive agricultural sector which is one of the major income and employment as well as the hydro power generation in the Upper Orange catchment and mining.

The main sources of surface water in the Free State province are the Orange and the Vaal River and their tributaries, which are managed under water management areas. A total of four main Water Management Areas are found in the Free State. Water Management Areas (WMAs) were designed to assist with the catchment level management of the extensive water resources and fall under the Water Resources Planning Framework.

The Orange River and its sub-catchments comprise of the Upper and Lower Orange catchment areas, the Upper, Middle and Lower Vaal river catchment management areas (see Figure 2.9). The surface water ecosystem for the Free State consists if a myriad of river catchment and sub catchment, dams as well as the extensive network of wetlands (Figure 2.11). Wetlands are an essential factor for ecosystem service for the provision of safe water.

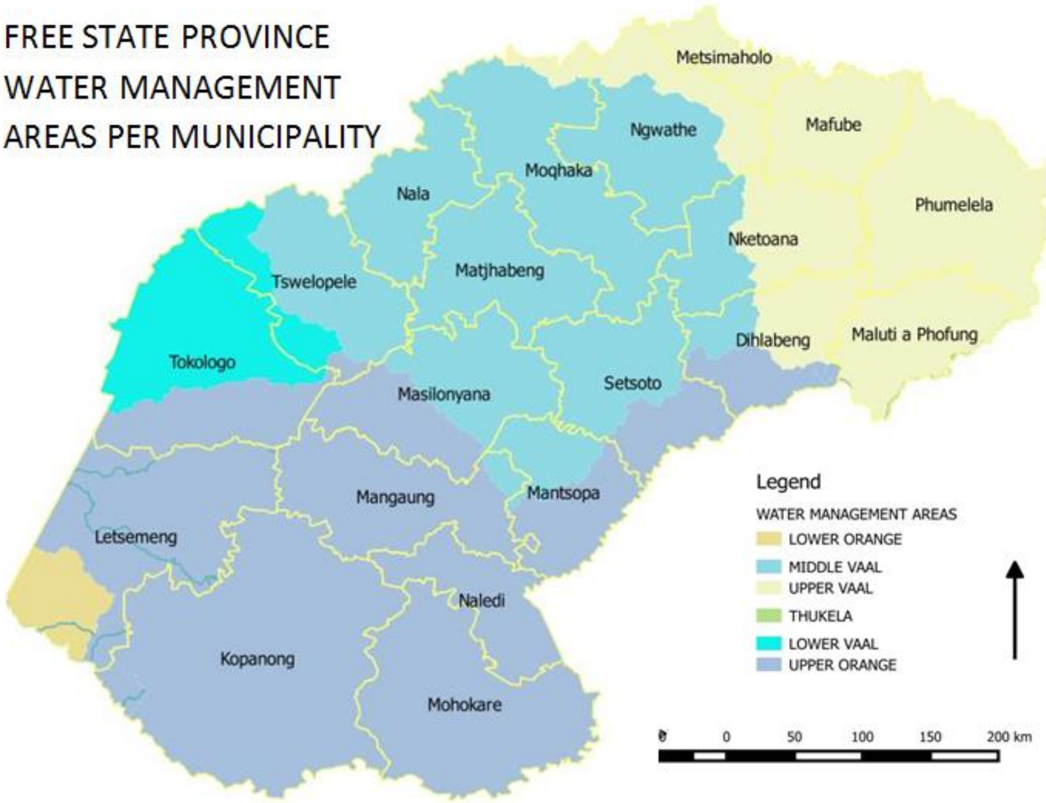

Figure 2.9: Water Management Areas for the Free State Province per municipality

2.4.1.1. Upper Vaal WMA

The Upper Vaal WMA consists of a number of rivers and includes eight dams with the main ones being the Vaal Dam and the Sterkfontein Dam. The water management areas is essential at both a national and provincial level, in particular the water transfers from this and other WMAs, due to its central location with water transfers to at least 10 other WMAs within and out of South Africa (PSDF, 2013).

2.4.1.2. Middle Vaal WMA

The Middle Vaal WMA is located downstream of the confluence of the Vaal and the Rietspruit Rivers and upstream of Bloemhof Dam. Eight dams are found in this WMA, with the main ones being Bloemhof, Allemanskraal and Erfenis dams. Parts of the areas towards the western areas of this WMA are drier, resulting in higher evaporation rates (PSDF, 2013). It is important to note that the Middle Vaal WMA, given its central position between the Upper and Lower Vaal, water availability is inextricably linked to the other two catchments as well as the water management of the Vaal river catchment. Furthermore, the middle Vaal is dependent on the Upper Vaal for meeting the water demand for its various uses including economic and domestic use. The middle Vaal is also a recipient of the pollution from the various industrial activities in the Upper Vaal, such as high salinity and nutrient content and impacts from mining activities. Apart from the surface water resources, the Middle Vaal also has ground water resources which are fully utilised, currently supplementing water resources in particular for irrigation and towns (PSDF, 2013).

2.4.1.3. Lower Vaal WMA

The Lower Vaal WMA is located downstream of Bloemhof Dam and upstream of the Douglas Weir. Annual rainfall ranges in the WMA from approximately 500 mm in the east to as low as 100 mm in the west. However, the potential evaporation can be as high as 2 800 mm per annum, significantly exceeding the rainfall. Vegetation over the WMA is sparse, consisting mainly of grassland and scattered thorn trees and alluvial diamonds are found in the vicinity of Bloemhof. Issues of concern in this WMA include the high rates of water use for both the surface and ground water. Furthermore, the impact of activities in the other WMAs impact on the lower Vaal and these include pollution which affects water quality as well as the over exploitation of ground water resources (PSDF, 2013).

2.4.1.4. Upper Orange WMA

The Upper Orange lies predominantly within the Free State, with the Caledon River as the largest tributary to the Orange River within the Upper Orange WMA. There are twenty dams located in this WMA, with the main ones being the Gariep, Vanderkloof, Kalkfontein, Krugersdrift, Rustfontein and Knellpoort dams. This WMAs is subjected to summer thunder showers of rainfall and most of the water in this catchment comes from Lesotho (Basson and Rossouw, 2003). The Upper Orange water management area has the highest yield in the country and has potential for increased water development.

The yield from the Upper Orange WMA is the largest of all WMAs in the country, with a significant potential for further water resource development. Some key developments in the Upper Orange include the Lesotho Water Highlands Project, and the Mohale Dam construction as well as the 12 000 hactares of a new irrigation system after which there will be limited water supply in the Orange River (PSDF, 2013). This WMA is essential for the transfer of water to other WMAs in the country such as the Tsitsikama WMA. Other issues include the flood management at the Gariep and Vanderkloof Dams and flood management along the Vaal river, which is essential for the river bank development along the Lower Orange river.

Hydropower for peaking purposes is generated at the Gariep and Vanderkloof dams, and is an important factor of Eskom's peak generation capability, thus changes in the water availability in the catchment will also affect hydro power generation.

2.4.2. River and Wetlands Ecosystems in the Free State

2.4.2.1. River Ecosystem

In a country where water is a scare resource, river ecosystems play a key role in the supply of fresh water through the storage and transportation of water and when integrated with constructed water storage, supply urban and rural areas as well as agriculture through irrigation. Rivers are also essential for the removal of waste and the provision of recreation. In addition, healthy tributaries assist in the maintenance of natural flow pulses and the removal of pollutants from larger rivers, thereby contributing to water quality and quantity (Drive et al, 2011).

River ecosystems are under immense pressure from abstraction of water and other modifications to the timing and flow due to the dams being built between catchments as is the case on the Orange river in the Free State. Issues of pollution are also becoming a major issue impacting on the river ecosystems exacerbated by the removal of riverine vegetation causing irreparable damage to river and hindering their provision of ecosystem services (Driver et al., 2011).

In South Africa, at least 57% of the river ecosystems are threatened, with 25% critically endangered and 13% being vulnerable. Of the river ecosystems, tributaries are less threatened with the proportion of threatened river ecosystems higher in the lowlands and the lower foot hills and mountain streams highlighting that agricultural and urban areas are contributing to the degradation of the river ecosystems (Driver et al., 2011). The Free State due to its agricultural development is a case in point.

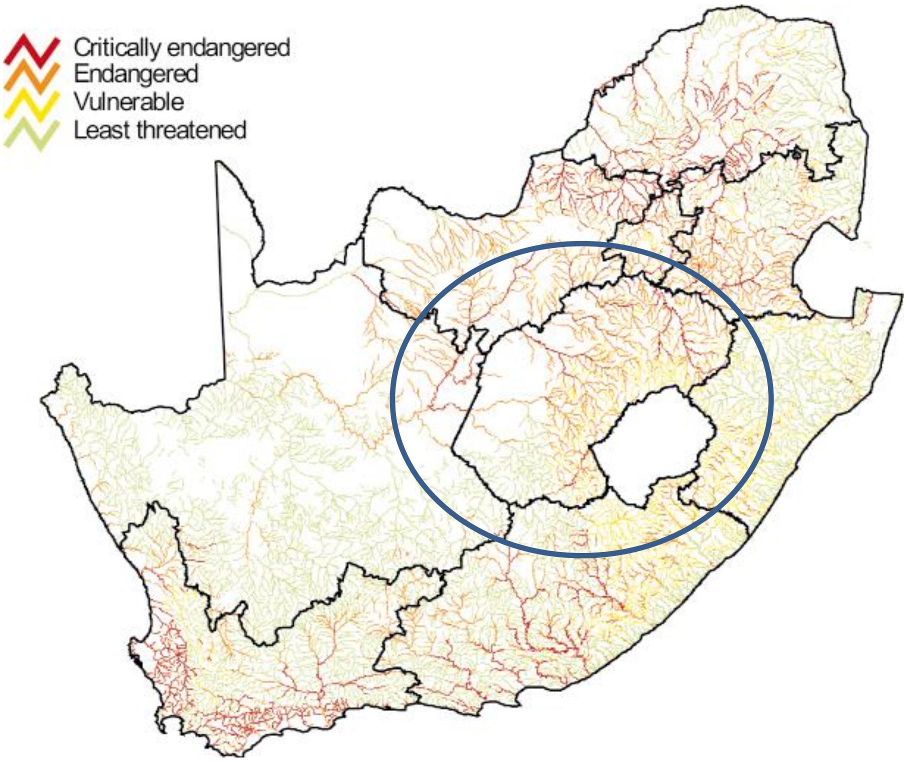

Figure 2.10: Critically endangered and endangered ecosystem types are concentrated around major cities and in production landscapes, where pressures on water resources are highest and catchments have lost much of their natural habitat

The river ecosystem in the Free State ranges from critically endangered, endangered and vulnerable, especially the river in the grasslands areas (Figure 2.10). The rivers within the Nama-Karoo are classified as least threatened.

2.4.2.2. Wetland Ecosystems

While wetlands would be ideally discussed under biodiversity, they are discussed under water given the contribution of wetlands to water security as well as the extent of wetlands in the Free State Province. Wetland ecosystems are recorded as the most threatened with at least 48% of all wetlands classified as critically endangered. Despite occupying only 2% surface areas, wetlands provide critical ecosystem services such as water purification and flood control, contributing towards water security (Driver et al., 2011).

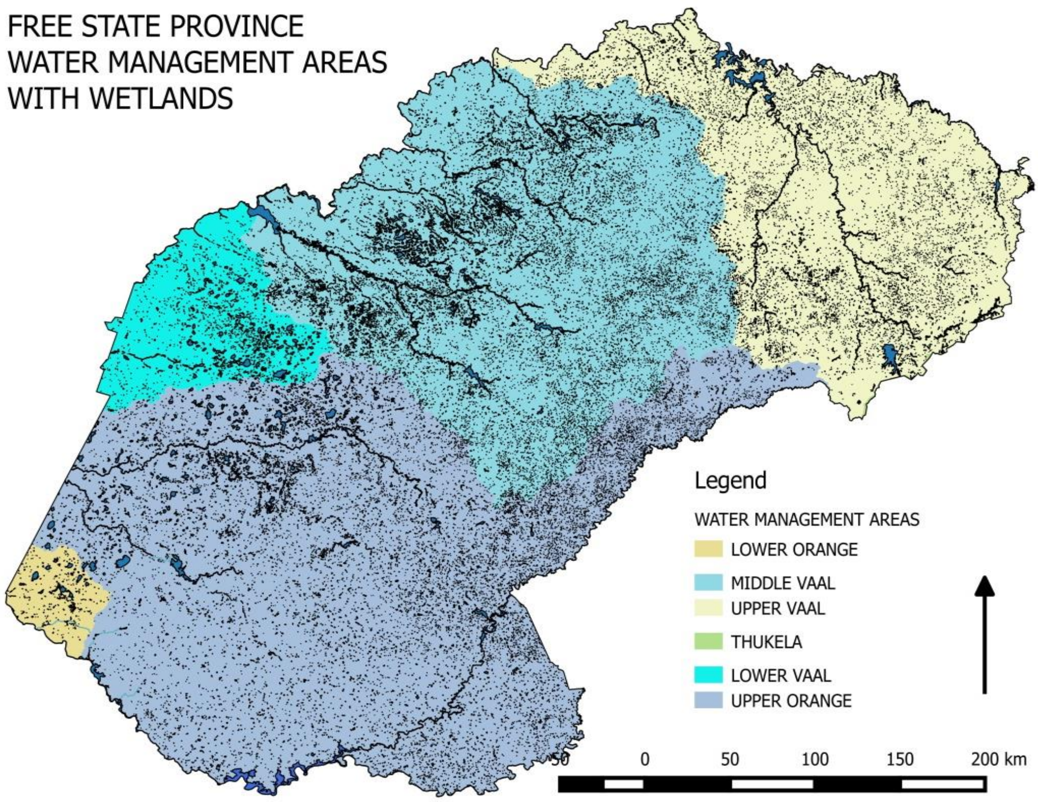

Figure 2.11: Water Management areas with wetlands overlay.

2.4.2.3. Wetland Ecosystems Status

According to Figure 2.11 above, Free State has a sizable number of wetlands that are already under the critically endangered and endangered and vulnerable classes. Similarly to the river ecosystems, the wetlands showing the high threat status are those associated with production and urban areas. The spatial patterns of wetlands and of river ecosystems are consistent across all three classes, critically endangered, endangered and vulnerable and these are located in the grassland biome (Driver et al., 2011). Wetlands under the savanna biome are classifies as least threatened while the extent of the wetlands in the Nama-Karoo that are under threat is less than in the grassland biome.

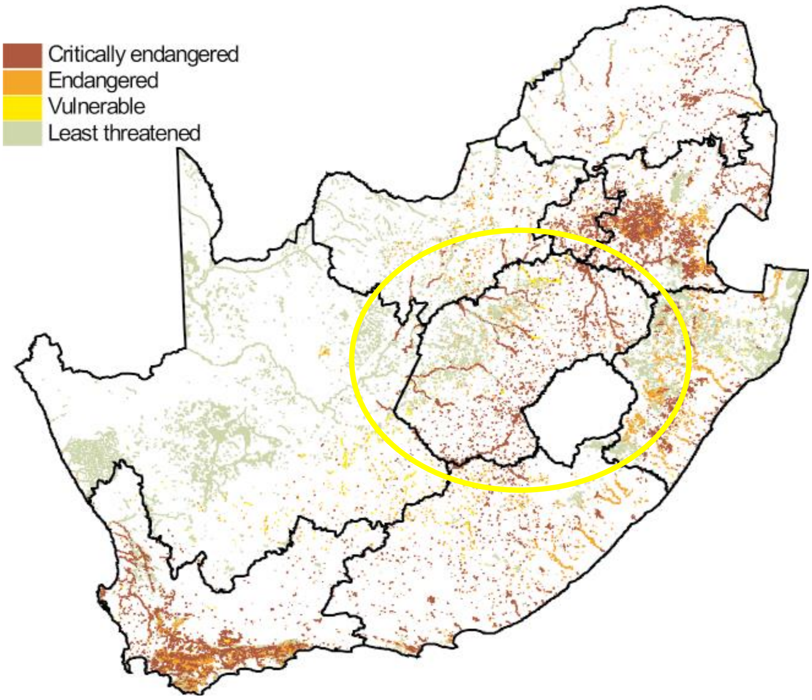

Figure 2.12: Ecosystem threat status for wetland ecosystem types. Consistent with the picture for rivers, high numbers of critically endangered and endangered wetland ecosystem types are associated with production landscapes and urban centres (Source Driver et al., 2011).

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2.4.3. Climate Change impacts on Water Resources in the Free State

The impacts of climate change on the water sector are discussed based on a catchment scale and are mainly extracted from the Long Term Adaptation Strategies flagship programme, in particular the water sector report. As highlighted above four catchments provide water to the province and this catchment will be affected differently by climate change.

2.4.3.1. Climate change and River Ecosystems

The Lower Orange, which covers the smallest area of the province, will be extremely vulnerable to temperature and the projections indicate that temperatures in this catchment will increase at twice the national rate with detrimental impacts for especially the agricultural sector. Increasing temperature will cause dry areas to lose more water in an area where the demand for irrigation is expected to increase (DEA, 2013c). Water availability and quality is further compromised by the accumulation of salts leading to higher salinity as well as effects from the mining and irrigation upstream. It is anticipated that the increased temperatures will consequently lead to increased water losses from the catchment, impacting on mining and agriculture (DEA, 2013c).

The Vaal covers a substantial area in the Free State with the catchment being divided into the lower, middle and upper Vaal water management areas. Climate projections for the Vaal indicate that rainfall will either remain unchanged or will increase, while the mean annual temperatures are expected to increase but not radically. Climate variability will immensely impact on the rainfall and runoff in the catchment and thus there is a need to understand this more, especially at a sub-catchment scale of the rivers that feed into the catchment such as the Inkomati. Extreme rainfall events such as flooding will be experienced in some parts of the catchment (DEA, 2013c).

The Agricultural sector will be the most affected by issues of climate change in this catchment, given the threats posed by the increases in temperature, making the future of agriculture uncertain especially the dependency on irrigation. The continual increases in the cost of water will impact on water use. The potential water insecurity in the catchment will further impact the selection of crops with a need for diversification in the location and type of crops grown as an adaptation measure (DEA, 2013c). The other sector to be affected is mining, which forms part of the mining belt. Mining will be affected by Acid Mine Drainage (AMD) and this may be exacerbated by the potential increases in rainfall. The last sector is urban or the built up areas, especially the economic growth and increase in demand for a growing population and quality of living (DEA, 2013c).

The upper Orange River covers the most of the province. However, no extensive climate change studies have been conducted on the Upper Orange catchment but according to the LTAS phase 1 report (DEA, 2013c), there does not seem to be any major vulnerabilities in the catchment and for the risks that do exist, these are not related to climate change (DEA, 2013c).

All river ecosystems are also susceptible to alien invasive species which consume an estimated 7% of all runoff in the country. Change in rainfall and temperature will have an impact in the growth and extent of alien invasive species, while temperature and rainfall will further impact on the river flows (Driver et al., 2011).

Apart from the myriad of ecosystem services provided by wetlands which contribute to water quality and supply, they are also key as a response to climate change. Given that climate change will bring with it climate variability and intense rainfall events among other impacts, wetlands mitigate extreme floods or rainfall events and droughts, by attenuating floods and combating desertification as well as the reduction of vulnerability to droughts. The wetlands also support rich biodiversity which is of both intrinsic and economic value. Similarly to the grassland biome, wetlands also provide medicinal plants (Driver et al., 2011).

2.4.4. Free State Province Ground Water Resources

Ground water is an essential resource and performs a key function, especially for settlements located far from major rivers and water sources. Currently, groundwater is used for rural domestic supplies, livestock as well as supplying towns where surface water supply is insufficient or bulk water supply is not monetarily feasible. The total availability of groundwater in the four WMAs is estimated as follows (DETEA, 2009):

- Upper Vaal WMA: 32 million m3 per annum.
- Middle Vaal WMA: 54 million m3 per annum.
- Lower Vaal WMA: 126 million m3 per annum.
- Upper Orange WMA: 65 million m3 per annum.

According to the Water Master Plan for the Free State Province (DWA, 2012) ground water consumption breakdown in the WMAs in the province is as described below.

2.4.4.1. Middle Vaal WMA:

The middle Vaal WMA is generally underlain by fractured aquifers (Figure 2.13), which are well utilised for rural supplies, with little un-use volumes happening. The quality of groundwater is generally very good and an estimated 11 million m^3 of groundwater, which is mined yearly to dewater mines in the Welkom-Virginia area. The water is allowed to evaporate from pans (DWA, 2012).

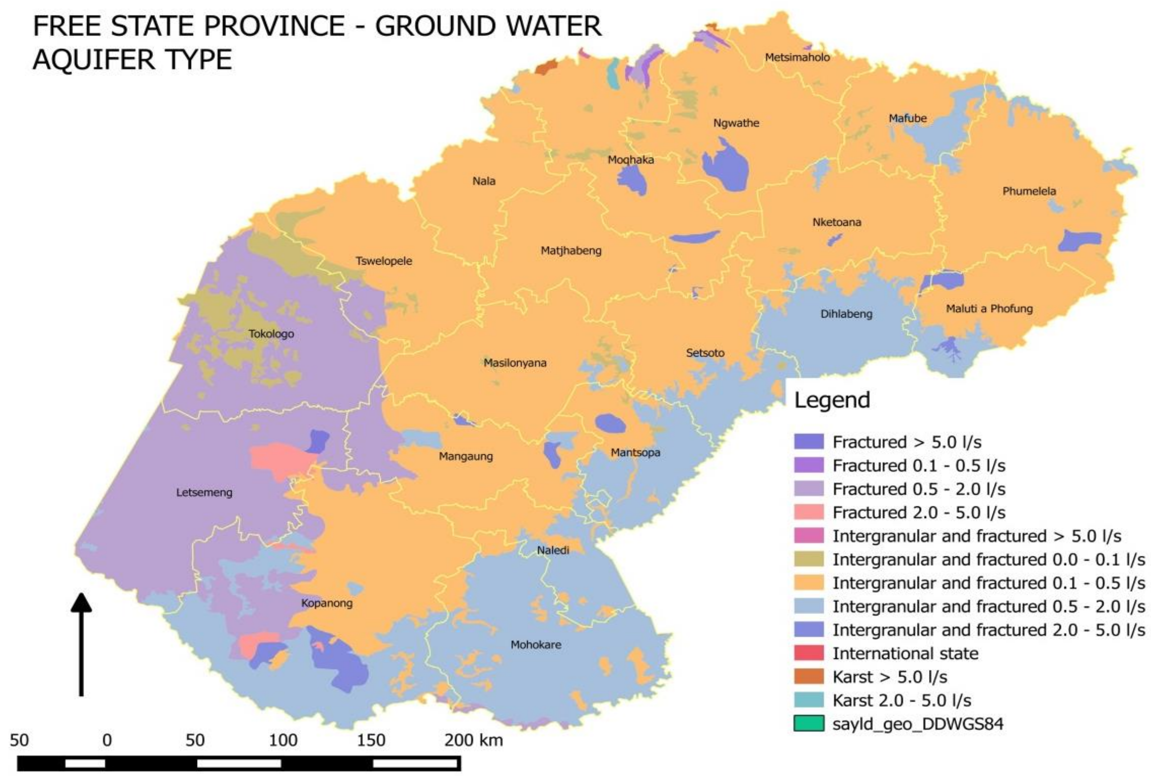

Figure 2.13: Ground Water Resources (Aquifer types) complied by data from BGIS-SANBI)

2.4.4.2. Upper Vaal WMA:

The large dolomite aquifers range across the north-western parts of the Upper Vaal WMA and large quantities of groundwater are abstracted for urban use consumption as well as irrigation. Given the direct link between the dolomite aquifers and surface Water, an increase in groundwater abstraction leads to a decrease in surface flow. Further, the lowering of spring flow may similarly lead to the formation of sinkholes (DWA, 2012). Further, intensive de-watering of the dolomite partitions for mining purposes in the northwest, where the dolomite formations are underlined by gold ore, has resulted in provisional increases in surface flow as well as the lowering of water levels. What's left of WMA lies beneath mainly fractured aquifers, (see Figure 4.*) which are well exploited for rural domestic water use and livestock and only 3% of the total water needs in the WMA are supplied by groundwater. Overall, the quality of ground water in this WMA is good (DWA, 2012).

2.4.4.3. Lower Vaal WMA:

Groundwater resources are the only source of water over much of the WMA. It is mainly used for supply of water to several towns, rural domestic supplies and stock watering. (DWA, 2012).

2.4.4.4. Upper Orange WMA:

Relatively large quantities of ground water can be abstracted from fracture zones along dolorite intrusions (Figure 2.14). The recharge rates and consequently the sustainable yields are low. The higher recharge occurs in localised areas especially in areas where lime bogs are located. In drier areas on the Upper Orange, ground water. Where the drier parts, are located, groundwater constitutes the main and frequently the only source of water for rural domestic supplies and stock watering. Further groundwater is severely overexploited. In particular, semi-urban areas, such as smallholdings near Bloemfontein, and at Petrusburg, where ground water is used for irrigation. In terms of water quality, groundwater is naturally good in the eastern high rainfall parts but becomes more mineralised and brackish in the drier areas that are located in the vicinity of salt pans. However, ground water quality in the Riet/Modder catchment is polluted due to the use of pit toilets and as a result some boreholes in the Thaba Nchu have recorded high nutrient and microbial pollutants and thus, not safe for human consumption (DETEA, 2009).

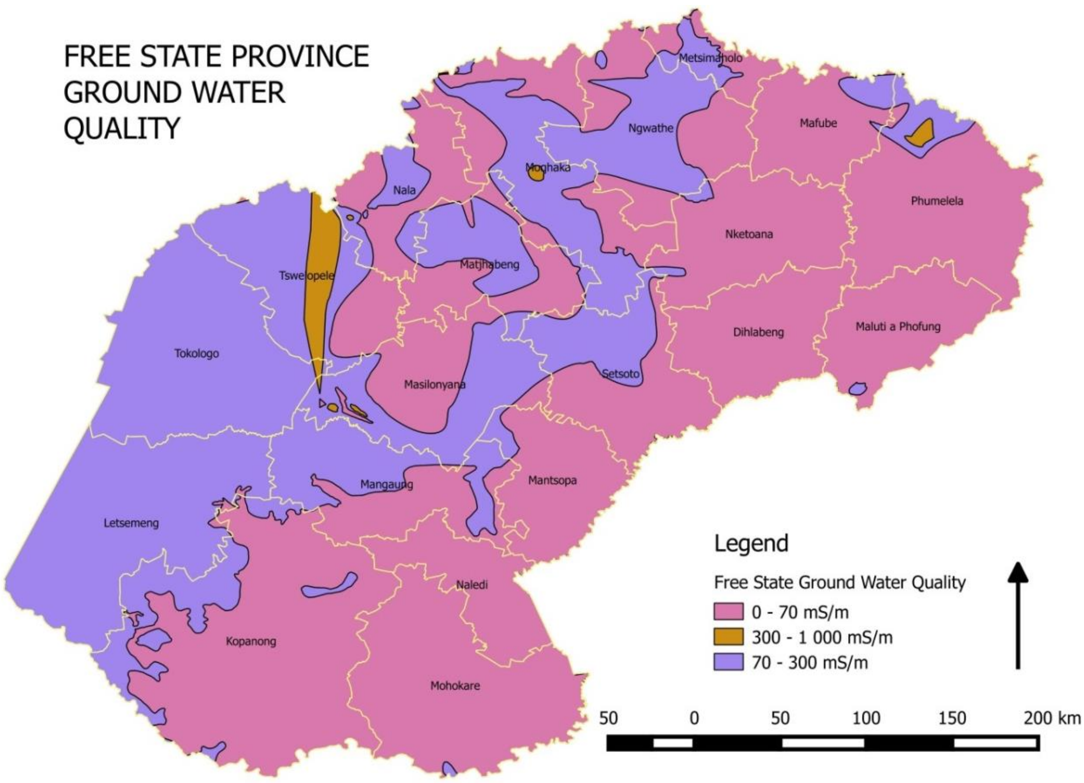

Figure 2.14: Ground water quality in the Free State (compiled from data provided by BGIS-SANBI)

2.4.5. Climate Change Impacts on Ground water

Precipitation is the main source for ground water and therefore climate variability and change affect rainfall, and the supply to ground water is affected. Some of the impacts of climate change are discussed below.

2.4.5.1. Recharge

Groundwater recharge happens locally from surface water bodies or through diffusion from precipitation through the unsaturated soil zone. Rainfall is the principal climatic driver for groundwater recharge, with temperature and CO_2 concentrations influencing the evapotranspiration rates as well as the amount of rainfall draining through the soil profile to aquifers. Changes in the extent of groundwater recharge will not always follow the same trend as precipitation changes given that recharge is not only influenced by the extent of precipitation, but also by its intensity, seasonality, regularity, and nature. The non-climatic factors, such as changes in soil properties or vegetation type and water use can also affect recharge rates as well as land cover and aquifer type, Furthermore, groundwater recharge rates are highly dependent on the geological setting of the area (Clifton et al., 2010).

2.4.5.2. Discharge

The impacts of climate change on groundwater discharge are not yet fully recognised and less well understood. This has been attributed to the focus being more on the quantity of water getting into the aquifers and its quality, but also reflects the difficulty of measuring ground water discharge with even less attention given ground water support such as ground flow springs, streams, wetlands, oceans and terrestrial vegetation (Clifton et al., 2010).

The direct impacts of climate change for evapotranspiration are discussed below and listed as _

- changes in groundwater use by vegetation as a result of increased temperature and CO_2 concentrations,
- changes in the availability of water to be evaporated or transpired mainly as a result of changes in the rainfall system.
- Exploratory evidence on heightened levels of atmospheric CO_2 may cause a reduction of stomata in plants, resulting in lower transpiration rates. Furthermore, the effects of CO_2 are comparable but opposite to the magnitude of predicted temperature induced increases in evapotranspiration.
- It is important to note that the influence of CO_2 in water balance is not yet fully understood (Clifton et al., 2010).
- Augmented duration and occurrence of droughts, as a result of increased temperatures and increased variability in rainfall will probably cause greater soil moisture insufficiencies leading to heavy reliance by vegetation on ground water in cases where the ground water is within the root zone. This could lead to increased evapotranspiration from ground water during the dry periods.
- Non-climatic factors related to land use change could also affect evapotranspiration (Dragoni and Sukhija, 2008).

2.4.5.3. Ground Water Storage

Groundwater storage is the variance between recharge and discharge over the time scales that these processes occur, from days to thousands of years. Ground water storage is subjective by particular aquifer type, size and properties due to the deeper aquifers having a delayed reaction to large-scale climate change but not to short-term climate variability. On the other hand, shallow groundwater systems (especially unconsolidated sediment or fractured bedrock aquifers) are more receptive to smaller scale climate variability (Kundzewicz and Doll, 2008). Further, the impacts of climate change on storage are dependent on whether or not groundwater is renewable (contemporary recharge) or comprises of a fossil resource (Clifton et al., 2010).

2.4.5.4. Water quality

The maintaining of ground water quality in the aquifers is a critical water supply for communities and agricultural activities. The properties of ground water, both thermal and chemical may be affected by climate change, especially for shallow aquifers where ground water temperatures may increase due to increased temperatures. In semi-arid and arid areas, increased evapotranspiration may lead to ground water salinization. Further, variations in recharge and discharge will probably increase the vulnerability of aquifers to diffuse pollution (van Vliet, 2007). In terms of increases of rainfall intensity, pollutants such as organic matter, pesticides and heavy metals will pollute ground water sources, especially where recharge aquifers are present (IPCC, 2007). In cases where recharge is expected to lessen, water quality may reduce due to intrusion of poor water quality from adjoining aquifers (van Vliet, 2007.

Issues of water availability, from both surface water and ground water are critical especially in the face of climate change and the implications of these changes will be detrimental to agriculture which is one of the critical economic sector for Free State Province, both for the development as well as the food security of the subsistence farmers who are dependent on rainfall as the livelihood. Water security is also a critical resource for human health and sanitation. Climate change adaptation option need to seriously consider the impacts of water insecurity and the future of the development of the province.

2.5. Human Health

The impacts of climate change on human health resulting from expected increases in the frequency, intensity and duration of extreme weather events are likely to have a major effect on public health (DEA, 2013). Human exposure to climate change may be direct and/or indirect, and will be determined by the character, magnitude and rate of climate variability (WHO, 2003 in DEA, 2013).

2.5.1. Human Health Vulnerability

A key consideration for climate change and human health is the vulnerability of the population to the impacts and the ability to cope and or respond. In this instance vulnerability is defined as the extent to which the population/health target group is prone to the effects of climate change, exposure being the contact between public health system with climate change and the extreme weather events and lastly sensitivity will be defined by the characteristics that inform the response of the system to the effects of climate change and adverse weather events (DEA, 2013h). Adaptive capacity depends on the capacity of the health system to respond to climate change and extreme weather. The social and bio-physical factors of a population may alter the outcome of the relationship between climate change and human health; these factors include poverty, urbanisation and its associated problems (DEA, 2013h). These are covered in detail in section 3 below (Social Vulnerability).

The impacts of climate change maybe direct or indirect with the impacts projected to affect agricultural production, leading to food insecurity and malnutrition. The Free State province has the second highest percentage of malnutrition in South Africa, which will only be exacerbated by climate change. This will be credited to the accelerated frequency and intensity of dry spells and flooding events that will concede food availability, food access and utilisation (DEA, 2013h). This will be further worsened by the loss of ecosystem services for the ecosystems that support agriculture and livelihoods, worsening the situation (DEA, 2013h).

Climate change will further affect communicable diseases as well as assist in the transmission of non-communicable diseases mainly influenced by temperature, rainfall and wind (DEA, 2013h), for example cholera is a well-recognised communicable disease, diahorreal and water disease in the country (DEA, 2013h).

2.5.2. Climate change and vector-borne diseases

According to the LTAS Human health report (DEA, 2013b), little is known about disease vectors in South Africa. Vectors of concern include mosquitoes (malaria, dengue fever and yellow fever) and ticks (Lyme disease). According to Clifton et al., 2010, the risk from these diseases is expected to rise because of climate change due to the increased extent of areas with conditions conducive to vectors and pathogens (Clifton et al., 2010, 2013 in UNEP, 2014; WHO, 2014). There was however, a significant decrease in the cases and deaths of malaria recorded in South Africa between 2000 and 2011 (DOH, 2012 in DEA, 2013b).

Changes in temperature and precipitation directly affect vector borne diseases (VBD) and zoonotic diseases (ZD) through pathogen-host interaction (e.g. VBDs are transmitted by the bites of infected mosquitoes and other insects (vectors), and indirectly through ecosystem changes and species composition. Where mosquitoes are the vectors, temperature plays an important role. The optimum temperature for transmission is an annual average of 22 °C (DEA, 2013b, p25), with the parasite not developing at temperatures below 16 °C and the mosquitoes not surviving temperatures above 40°C). There is an association between availability of water (for breeding) and rainfall and an increase in mosquito population, thus more droughts will have the opposite effect (DEA, 2013). However, heavy rainfall may wash breeding sites away, while a little pool of stagnant water after normal rainfall could become a breeding site, thus the association is not linear (Thomson et al., 2005 in DEA, 2013b). The life cycle of pathogens inside vectors is shortened under warmer conditions. (**Error! Reference source not found.** from Friel et al., 2011), indicates the direct and indirect pathways from climate change to non-communicable diseases (NCDs).

2.5.3. Human Health and Extreme Weather Events

Direct climate change exposures include atypical temperature and precipitation, storms, and natural disasters (Samet, 2009; WHO, 2009a in LTAS, 2013). Indirect exposures may include increased air pollution, pollen production, constraints in the agriculture sector leading to food shortages and malnutrition, an optimised environment for the production and distribution of disease vectors, and ecosystem changes leading to loss of ecosystem goods and services (Samet, 2009; WHO, 2009; Abson et al., 2012 in DEA, 2013). Climate change may thus also affect social and environmental determinants of health such as clean air, safe drinking water, and sufficient food and secure shelter (WHO, 2013). Given these wide range of exposures, it is important that both direct and indirect climate exposures are addressed when dealing with vulnerability to climate change (DEA, 2013, p 24).

2.5.3.1. Heat

Extreme high air temperatures as predicted will contribute directly to deaths from cardiovascular and respiratory disease, affecting elderly people in particular (WHO, 2013). High temperatures also result in increased levels of pollutants in the air such as ozone (see also section 3 below) that exacerbates cardiovascular and respiratory disease (WHO, 2013). Pollen and other aeroallergen levels are also elevated in extreme heat, which can trigger asthma (WHO, 2013). Local studies on heat stress are however limited. There are projections from the present to 2100 on the potential impact of climate change on increasing the number of "hot days". The study indicates that heat-related impacts (heat stress symptoms) are likely to increase in the future, and that these impacts are likely to be exacerbated by socio-economic vulnerability of the population. However, the relevance of this temperature-health impact relationship and the vulnerability factors applicable to the South African population are not well documented.

2.5.3.2. Droughts

Rainfall patterns are likely to be increasingly variable, thus affecting the supply of clean, fresh water. This in turn can compromise hygiene and increase the risk of diarrhoeal disease (WHO, 2013). In extreme cases, water scarcity results in drought and famine. It has been predicted that, by the 2090s, climate change is likely to widen the area affected by drought, double the frequency of extreme droughts and increase their average duration six-fold (Arnell, 2004 in WHO, 2013).

2.5.3.3. Floods

Floods have also been increasing in frequency and intensity, contributing to contaminated freshwater supplies, a heightened risk of water-borne diseases and breeding grounds for disease-carrying insects such as mosquitoes. Physical hazards from floods include drowning and physical injuries, damage to homes and disruption in the supply of medical and health services (WHO, 2013). The combination of increased temperatures and variable precipitation contribute to a decrease in the production of staple foods which will increase the prevalence of malnutrition and under-nutrition (WHO, 2013).

Table 2:8. The direct and indirect impacts of climate change on NCDs (from Friel et al., 2011)

Climate change impacts	Pathway for climate change to NCDs	NCD outcome	Direction of health risk
Direct			
More frequent and increased intensity of heat extremes	Heat stress	Cardio-vascular diseases (CVD)	Increased risk
Increased temperatures and less rain	Higher ground-level O_3 and other air pollutants	CVD; Respiratory disease	Increased risk

Climate change impacts	**Pathway for climate change to NCDs**	**NCD outcome**	**Direction of health risk**
	Increases in airborne pollens and spores		
Changes in stratospheric O_3, precipitation and cloud cover	Decreased exposure to solar UVR	Autoimmune diseases Skin cancer	Reduced risk
High winter temperatures		CVD; Respiratory disease	Reduced risk
Extreme weather events (fires, floods, storms)	Structural damage	Injuries	Increased risk
Indirect			
Drought, flooding	Impaired agriculture, reduced flood yields, nutrition insecurity	Poor general health	Increased risk
Extreme weather events (fires, floods, storms)	Trauma	Mental health (post-traumatic stress disorder)	Increased risk
Extreme weather events (fires, floods, storms)	Impaired livelihoods, impoverishment	Mental health (anxiety/depression)	Increased risk

2.5.4. Climate Change, Human Health and Air Quality

Climate change may have an effect on air quality in the country through effects on the weather thus influencing particulate matter (PM), sulphur dioxide, ozone, carbon station in the province. The health impacts of these gases and elements leads to acute respiratory infection, eye irritation, chronic respiratory disease and TB which sometimes leads to death (see table 2.9) for more details on the health impacts of air quality (DEA, 2013h) monoxide, benzene, lead and nitrogen oxide. All these gases are monitored in the various stations across the province. Presently, the air quality of the Free State is acceptable in three municipalities.

Table 2.9. Air Quality impacts on Human health (DEA, 2013h)

Criteria pollutant	Health impact	References
PM	• Respiratory diseases (including lung disease) • Premature death	• Atkinson et al., 2011 • Dominici et al., 2006 • Schwartz, 1994 • Balakrishnan et al., 2011 • Schwartz et al., 1994 • WHO, 2003
SO_2	• Respiratory problems • Eye irritations • Cardiac disease • Premature death	• Fenger, 2002 • WHO, 2011b
O_3	• Increase in morbidity rates • Increase in mortality rates • Asthma • Damage to lung tissue • Bronchitis	• Jacob et al., 1996 • Seinfeld and Pandis, 1998 • Jacob et al., 1996
CO	• Cardiovascular disease • Cerebrovascular impacts • Behavioural impacts	• Australian Government, 2009
C_6H_6	• Skin irritations • Hematologic impacts • Reproductive and development effects • Cancer risk	• US EPA, 2012
Pb	• Neurologic impacts • Hematologic impacts • Gastrointestinal impacts • Cardiovascular impacts • Renal impacts	• WHO, 2013e
NO_2	• Wheezing • Coughing • Colds • Flu • Bronchitis	• WHO, 2013d

2.5.5. Vulnerable populations in the context of climate change

Population in general play a key role in the vulnerability of a population to climate change, especially where social vulnerability factors are at play. As indicted in the table below, the response of the Free State to climate change risks and extreme events differed greatly when population was considered. The impacts of the risks on the province were consistent between all the municipalities making highly vulnerable to gradual, long term increase in temperature and decrease in rainfall with variation for extreme hot days. After the population size was considered, (Table 2.10) the high vulnerability status for most municipalities changed from high to low, with the exception of Matjhabeng, Maluti a Phofung and Mangaung.

Table 2.10. Ranking of regional vulnerability of Free State Municipalities to climate change, before and after adjusting for population size.

	Vulnerability before popuplation size considered			Vulnerability after popuplation size considered		
Free State Municipalities	Gradual/longer-term incr in temp, decr in rainfall	Extreme precipitation, incl hail, wind storm, flooding	Extreme hot days (heat waves)	Gradual/longer-term incr in temp, decr in rainfall	Extreme precipitation, incl hail, wind storm, flooding	extreme hot days (heat waves)
Letsemeng	Red	Red	Red	Green	Green	Green
Kopanong	Red	Red	Yellow	Green	Green	Green
Mohokare	Red	Red	Red	Green	Green	Green
Naledi	Red	Red	Yellow	Green	Green	Green
Masilonyana	Red	Red	Red	Green	Green	Green
Tokologo	Red	Red	Red	Green	Green	Green
Tswelopele	Red	Red	Red	Green	Green	Green
Matjhabeng	Red	Red	Yellow	Red	Red	Red
Nala	Red	Red	Red	Green	Green	Green
Setsoto	Red	Red	Red	Green	Green	Yellow
Dihlabeng	Red	Red	Yellow	Green	Green	Green
Nketoana	Red	Red	Red	Green	Green	Green
Maluti a Phofung	Red	Red	Yellow	Red	Red	Red
Phumelela	Red	Red	Red	Green	Green	Green
Mantsopa	Red	Red	Red	Green	Green	Green
Moqhaka	Red	Red	Yellow	Yellow	Yellow	Yellow
Ngwathe	Red	Red	Red	Green	Green	Yellow
Metsimaholo	Red	Red	Yellow	Yellow	Yellow	Yellow
Mafube	Red	Red	Red	Green	Green	Green
Mangaung	Red	Red	Yellow	Red	Red	Red

This highlights the importance population size when considering vulnerability especially where population is high with key issues associated with population being poverty level, education, employment status as well as disability. While all populations will be affected by climate change, some are more vulnerable than others , such as the elderly and children (due to their physiological development), people with pre-existing medical conditions and those considered 'special needs populations' such as the physically or mentally challenged (WHO, 2013). Vulnerable population groups have decreased ability to cope with climate change and the socio-economic status of communities is as important as their susceptibility/sensitivity in terms of their coping capacity (WHO, 2013).

2.6. Built Environment and Human Settlements

The built environment is classified as the structures and infrastructure that is found prevalently in cities, towns and other built up areas. The built environment can also include man-made outdoor environments and provides the basic necessities for human well-being and is closely linked to delivery of basic services, especially in South African cities and urban areas. Some of the examples of infrastructure include water and sewer lines, electric lines and other utilities, roads, bridges and even pavements. The built environment has an impact on human health and well-being, especially for the unemployed and low income earners, given the areas and spaces these population groups occupy within the built environment. Issues of climate change impacts will only serve to exacerbate these already vulnerable populations groups unless planned for at a local level. Climate change, especially the extreme climate related events such as floods, will also result in extensive damage to infrastructure costing governments immense financial resources to repair, maintain and upgrade such infrastructure especially where the demand on infrastructure are exacerbated by increases in population as is the case in some of the municipalities in the Free State.

Cities, towns and settlements are key in the development of South Africa and according to the updated settlement and town typology conducted by the CSIR, Built Environment (BE) (2011) these settlements or functional urban areas house more than 70% of the SA population and more than 90% of all economic activity, and thus, the need to understand settlement dynamics within the context of risk and vulnerability for municipalities is clearly essential. The settlement typologies found in South Africa include City regions; Cities; Regional service centres (large and medium sized towns); Service towns; as well as Local & niche nodes (CSIR BE, 2011). Typologies also encompass urban formal, urban informal and former homeland areas.

2.6.1. Built Environment in Free State

The Free State province is made up of ninety urban settlements that differ in size. As a result of apartheid planning, some areas have extremely low population densities, low levels of efficiency and long distances between places of residence and those of employment, especially in urban areas. The approximate population of Free State population living in urban areas was 40%, an increase in urbanisation from 70.5% in 1996 to 80% in 2006 (SOER, 2009).

There are five typologies of settlements in the Free State and are as follows:-

- Large urban settlements: Bloemfontein, Thaba Nchu, Botshabelo, Welkom, Virginia, Odendaalsrus, Allanridge, Henneman and Sasolburg.
- Regional towns: Kroonstad and Bethlehem.
- Middle Order towns: Ladybrand, Ficksburg, Puthaditjhaba, Heilbron, Frankfort, Senekal, Parys, Bothaville, Viljoenskroon, Harrismith and Reitz.
- Small towns: Rural and small-farming communities.
- Communal: Rural areas of Thaba Nchu and Maluti a Phofung.

Presently, there are indications of increasing pressure in the urban areas of Free State as the trend towards urbanisation continues resulting in the depopulation of the rural areas within the province as well as a large ecological footprint and detrimental repercussions on the environment (FSGDS, 2012). In terms of poverty within the province, there are two municipalities within the province, Mangaung and Maluti a Phofung recorded to have high poverty rates. In addition, these two municipalities are former homelands settlements. The above average poverty rates are found in Nala, Moghaka, Sesotso and Dihlabeng (FSDGS, 2012).

2.6.2. Human Settlements

Housing is one of the basic human needs that have a profound impact on the health, welfare, social attitudes and economic productivity of people. It is used as an indicator of a person's standard of living and place in society and is one of the Millennium Development

Goals (Free State Province (2013) and the provision of proper housing by the government is part of the National Development Plan. In order to achieve this goal, the government plans to eliminate all informal dwellings, bucket type toilets, and ensure that all citizens have access to electricity for lighting, and access to clean, safe water within a reasonable distance (Stats SA, 2007).

According to the 2011 Census, the Free State has 823 316 households and in 2009 the province had a housing backlog of 160 000 dwelling units (Stats SA, 2009).the below (Table 2.11) shows the growth in the number of households in the districts of the Free State for the 2001 and 2011 Census.

Table 2.11: Number of households in the districts of the Free State for the 2001 and 2011 Census (Source: Stats SA, 2011).

REGION	CENSUS 2001	CENSUS 2011
South Africa	11 205 706	14 450 162
Free State	733 302	823 316
Mangaung Metro	185 013	231 921
Xhariep	46 454	453 68
Lejweleputswa	184469	183 163
Thabo Mofutsanyane	197 018	217 884
Fezile Dabi	120 347	144 980

The settlement typology for the province in relation to its people indicated that by 2011, at least 81.1. % of the households lived in formal housing, 15.7 % if informal housing and 2.4 % in traditional (see Table 2.12) below and by 2011there was an estimated 129 260 informal housing units and 29 639 traditional dwellings and backyard houses in the province.

Table 2.12: Percentage distribution of households by type of main dwelling in the Free State according to the 2001 and 2011 Census (Stats SA, 2011).

Variable – Type of main dwelling.	Free State Province - 2001	Free State Province - 2011
Formal	66.5	81.1
Informal	26.1	15.7
Traditional	7.2	2.4
Other	0.3	0.9

2.6.2.1. Informal Settlements

Informal settlements are unplanned settlements that develop and change as people settle in areas closer to employment opportunities. While the location of these unplanned settlements may differ, these are usually located within planned townships, open land within the urban and peri-urban areas which develop on farm or small holdings on the out skirts of urban areas (Department of Human Settlements, 2005). The locations are often unsuitable for human settlement, characterised by unstable soils, wetlands and some are located in the flood lines, which are prone to flood risk. This results in annual flooding of these settlements. These types of settlements consist of a range of housing, such as backyard shacks and free-standing structures, normally without services, with some being illegal, while others are on communal land, or on land on which tenure has been secured following settlement

(Department of Human Settlement, 2005). The substantial backlog of the delivery of basic services in the country is associated with informal settlements which are often characterised by high poor population, who are socially vulnerable to climate and its impacts (DEA, 2013).

Mixed settlements comprise of a mix of urban and rural settlements and not as densely populated, with most of them support peri-urban intense agriculture. The housing typology can include formal, informal and back yard shacks and are sometimes associated with former homeland areas which were not properly planned (DEA, 2013 hs). Rural settlements are predominantly dependent on agriculture, herding and tourism, and are affected by the drives of social vulnerability that affect informal and mixed settlements. The dependence of poor rural populations to subsistence agriculture makes them highly vulnerable to climate change, given the reduced and degraded of ecosystem upon when they rely. Other rural communities are also isolated due to poor transport network, increasing their vulnerability in the cases of extreme events such as flooding (DEA, 2013 hs).

2.6.3. Climate change and Human Settlements

Human settlement are vulnerable to climate change based on their exposure to the climate risks and the degree to which the communities can adapt and respond, (discussed in section 3 below) is strongly influenced by social vulnerability. The impact of climate change on human settlements is location based being affected by climate, topology, and the settlement patterns. Some of the impacts include and are not limited to:-

- **Increased temperatures** – heat stress impacts on human health exacerbated by urban heat, islands; loss of productivity; declining air quality in cities; and increased demand for cooling;
- **Extreme weather:** heat waves and droughts – increased water demand, water quality problems, heat-related deaths and reduced quality of life, food insecurity;
- **Extreme weather**: heavy rainfall and violent storms – water quality problems; deaths and injuries, infections and water-borne disease; damage to infrastructure and economy, loss of property.

The social drivers of settlement vulnerability include but are not limited to:-

- **Access to basic services**: households without access to electricity, water, and sanitation and waste management services are more impacted by climate extremes.
- **Type of dwelling**: Houses that are poorly built, are poorly located, or lack of flood and lightning protection, efficient water systems, cool spaces, heat-reflective surfaces or damp-proofing are a source of climate vulnerability. Informal housing (shacks) are particularly vulnerable.
- **Health**: climate resilience is dependent on baseline health, including age. Children and the elderly are more susceptible to illness, heat stress, food insecurity and malnutrition, all of which are projected climate hazards.
- **Economic factors** such as poverty and unemployment link to many of the abovementioned factors and reduce the ability of households to recover from climate

shocks. Land tenure status is another important factor: households with insecure tenure such as squatters are less likely or able to invest in adaptation.

- **Demographic factors** including **age** and **gender**. In addition to age-related vulnerabilities to health impacts, asymmetrical power relations may increase the vulnerability of women. Communities with a smaller than average proportion of working-age adults, are particularly vulnerable (DEA, 2013hs).

The urban settlement environment will face more complicated challenge due to rapid urbanisation which is currently adding undue pressure on infrastructure. Urban growth is being exacerbated by migration trends to urban areas. As a legacy of apartheid, spatial planning in some urban areas is not up to standard, placing, historically disadvantaged households on the urban periphery, far from economic opportunities. This forced the poor household to spend a substantial amount of their earnings on transport, which was neither safe nor affordable (DEA, 2013hs).

The expected impacts of climate change on urban economies are multifaceted and varied, and are direct and indirect. They include but are not limited to:-

- Direct impacts of weather on construction and other industries in terms of loss of production
- Increases in the costs of water, liquid fuels and electricity as industrial inputs
- Increased costs of labour linked to food, energy, water and transport costs
- Potential impacts arising from regulation of carbon emissions
- Disruptions to water and electricity supply reducing productivity

Extreme weather events will add to the woes of urban settlement in terms vulnerability to climate change and will cause extensive damage to infrastructure such as roads, rails, bridges, airports, tunnels. Other damage will be residential infrastructure such as houses and buildings and other infrastructure that supports settlement such as water, energy and telecommunications.

Extreme weather events such as floods are expected to increase in the future as a result of climate change, especially in the Free State (see Figure 2.15.) and more details are in Table 2.13) below.

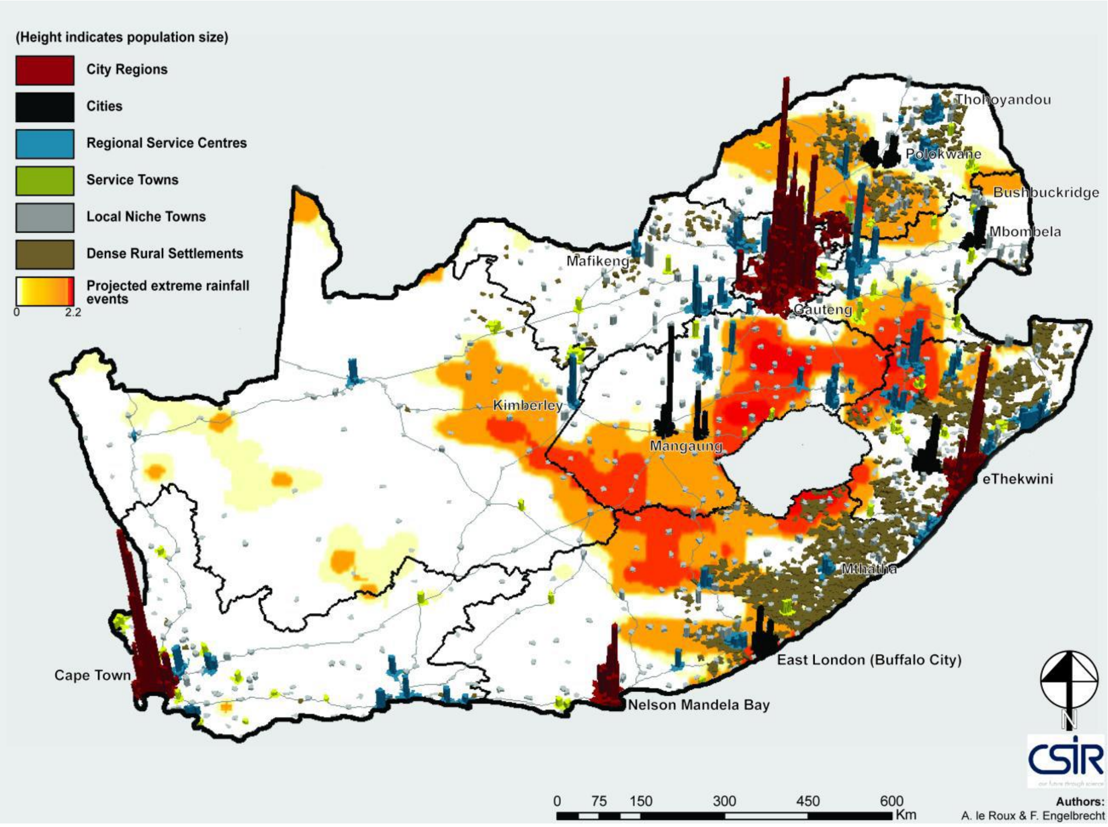

Figure 2.15: Population density and risk of extreme rainfall events (SARVA)

2.6.2.2. Basic Service Delivery

The provision of basic services such as water and sanitation, as well as electricity are critical for human wellbeing, especially for sanitation which extends beyond just the provision of a toilet and sewerage infrastructure but has to do with human dignity while providing a healthy living environment. Sanitation overlaps a number of sectors which include housing and settlement development, water and environment resource management, while poor sanitation leads to the spread of cholera and other diarrhoeal diseases, worms and parasites which are detrimental to children's growth (Free State Province, 2013). By 2011, 89% of the Free State province had appropriate sanitation, with only 3.2% having no sanitation facilities and still using the bucket system. At least 97.3% of the Free State has access to piped water (Free State Province, 2013). There has been an increase in the number provision of telecommunication as well as electricity in the province, with the electricity being used for lighting (86.6%), cooking (75.2%) and heating (54.6%) in 2007.

2.6.4. Infrastructure

The infrastructure in the Free State includes, water and sanitation as well as telecommunications and energy which has been briefly discussed above. Extreme weather events will further cause damage to all infrastructure most of which is in dire need of upgrading. For example higher temperature will increase heat stress on the construction material.

2.7.4.1. Transport

Transport is one of the critical infrastructures in the Free State, given its central location in the country as well as its major agricultural industry and manufacturing all of which are heavily dependent on good roads networks. Presently, there are four main transport routes which include the N3 between Durban and Gauteng which is a key freight route, the N1, linking Gauteng to the Western Cape, which is also a key freight route for local produce such as processed foods, coal and chemicals, fruit and beverages (Free State Province, 2013). The third major route links the Western Cape and Gauteng via Port Elizabeth and the last one being the Gauteng link to Western Cape through East London (see Table 2.13). A number of goods are transported on these roads including meat, maize and motor vehicles. Rail is also a key contributor to the transport network in the Free State. There is an anticipated growth in the freight business in the Free State in future, for local and international markets (Free State Province, 2013).

Table 2.13: Primary road in the Free State

ROUTE	DESCRIPTION
N1	Main route between Gauteng and the Western Cape via Bloemfontein.
N3	Main route between Gauteng and KZN across the Free State.
N5	Main route between KZN, Gauteng and the Free State.
N6	Main route between Gauteng and the Eastern Cape via Bloemfontein.
N8	Linking the Free State with the Northern Cape and Lesotho.

The Free State has an additional 3305 kms of roads, not including the major highways listed above. While most are in fair, good and very good condition, the province is struggling to maintain the transport infrastructure which is estimated to cost R4.127 billion, with an overall budget requirement of R R11.403 billion for upgrading and maintenance costs for all roads in the province, including the gravel roads. Most affected in terms of maintenance is the resealing of roads which should ideally happen every12 years. Other transport infrastructure in the Free State includes an airport, (the third largest in the country) some air fields and a railway network (Free State Province, 2013).

2.6.4.1. Water Distribution Network

Water service delivery in the Free State is the mandate of twenty water services authorities with Bloem water and Sedibeng water being the main water providers responsible for abstracting, treating and supplying drinking water to municipal networks through bulk water schemes (FSGDS, 2012). Given the fact that the abstraction happens in the four water management areas in the Free State, the need for water infrastructure is great and it needs to be in place to make the water schemes efficient. The uses of water in the Free State are highlighted in table 2.14 below (Free State Province, 2013).

Table 2.14: Total volume (expressed in millions) of water use by different sectors within each Water Management Area (DWAF, Annual Report, 2007/2008).

REGISTERED VOLUME BILLING PERIOD APRIL 2007 – MARCH 2008						
WMAS		GENERIC WATER USE SECTOR				
No.	Name	Agriculture: Irrigation/ Livestock Watering	Domestic/ Industrial	Forestry	Unbillable	Grand Total
8	Upper Vaal	446 695 274.47	1 922,638 120.03	10 797.00	703 900.65	2 370 048 092.16
9	Middle Vaal	282 241 189.58	313 584 862.13	-	3 650	595 829 701.72
10	Lower Vaal	604 936 692.28	158 159 661.73	-	216 401	763 312 755.01
13	Upper Orange	784 329 454.62	99 862 552.99	-	-	884 192 007.61
	Grand Total	2 118 202 610.95	2 494 245 196.88	10 797.00	923 951.65	4 613 382 556.50

The current water supply network and systems are highlight in the Table 2.15, below. Given the extent of water use for agricultural, livestock, domestic and industrial use in the province, the investment in the infrastructure to meet this water demand is critical, in the face of climate and already ageing infrastructure that is in need of upgrading and repair.

Table 2.15: Water distribution by each Water Management Area in the Free State (Draft 2012 Free State Water Master Plan, DWA

WATER DISTRIBUTION NETWORK	
WATER MANAGEMENT AREAS:	CURRENT SUPPLY SITUATION
Upper Vaal WMA	Large quantities of water are subtracted out of this WMA, not only for local use, but also transferred to surrounding WMAs. The highest percentage of water requirements in the Upper Vaal WMA is in the Sub-Areas downstream of the Vaal Dam. Approximately 60% of local requirements are for urban use (17% for industrial and mining) and most irrigation also takes place in this Sub-Area (downstream of Vaal Dam).
Middle Vaal WMA	The majority of water requirements in the Middle Vaal WMA are transferred from the Upper Vaal WMA to the Lower Vaal WMA via the Vaal river. Approximately 40% of local water requirements are used for irrigation mainly in the Sand-Vet Sub-Area (supplied by Allemanskraal and Erfenis dams) and 25% of water is needed for urban and mining/industrial use respectively.
Lower Vaal WMA	Water usage in the Lower Vaal Management Area is dominated by irrigation, mainly the Vaalharts Irrigation Scheme, which represents 80% of local requirements for water. Approximately 12% is for urban and industrial use, 7% for rural domestic supplies and stock watering. A substantial proportion of water used in the urban and industrial sectors is used non-consumptively and becomes available as effluent.
Upper Orange WMA	Water requirements within Upper Orange WMA are dominated by irrigational use (80% of local requirements). Most of the urban and industrial requirements are in the Riet/Modder sub-area, where Bloemfontein and Thaba Nchu are located. Large quantities of water used for power generation at Gariep and Vanderkloof Dams are released for downstream users.

Table 2.16 below, while it highlights the impacts of climate change on human settlement it also covers to a small extent of the impacts of climate on road, water and transport infrastructure within the built environment as well as some healthy impacts on population.

Table 2.16: Possible impacts of climate change phenomena on human settlements

Change Phenomenon	Consequences for human settlements
General warming – less intensely and fewer cold days and nights, more frequent and intense hot days and nights	• Intensified heat island effect • Increased energy demand for cooling • Declining air quality in cities • Reduced energy demand for heating • Reduced disruption to transport due to snow, ice
Extreme weather – heat waves and drought	• Increased water demand • Water quality problems • Increased risk of heat-related mortality, especially for the elderly, chronically sick, very young and poor. • Reduction in quality of life for people without appropriate housing
Extreme weather – heavy precipitation events and violent storms	• Adverse effects on quality of surface and groundwater, contamination of water supply • Increased risk of deaths, injuries, infectious, respiratory and skin diseases water and food-borne diseases; and post-traumatic stress disorders • Disruption to commerce • Large displacement of people and distress migration to urban areas • Pressures on urban and rural infrastructure, including power outages, disruption of public water supplies and transport • Loss of property and withdrawal of risk coverage in vulnerable areas by private insurers
Sea level rise and storm surges	• decreased freshwater availability due to salt-water intrusion • increased risk of deaths and injuries by drowning in floods and migration-related health effects • loss of property and livelihoods, loss of property and withdrawal of risk coverage in vulnerable areas by private insurers • permanent erosion and submersion of land • Costs of coastal protection versus costs of land-use relocation and damage to natural infrastructure - potential requirement for movement of populations and infrastructure

2.6.5. Energy

The energy sector is one of the key economic industries in the province, especially energy generation. Given the increase in demand for energy in the country, The Free State plays its part in the supply of energy, generating power from natural gas, methane, solar and hydro power in the more recent power station while existing power station such as Lethabo, which is owned by Eskom still uses coal. Eskom, the country's energy provider is involved in major energy projects in the Free State and has been active in rolling out energy efficient equipment including solar geysers. Some of the energy projects include:-

- Sasol is building a gas-fired plant in Sasolburg. The 140 MW facility is to be built by Finnish company, Wärtsiä and Sasol New Energy division employees will receive training in how to run the plant (Free State Business, 2013).
- Another company Omnia, a chemical manufacturer will be generating some of its own power requirements. Its new nitric acid plant, built at a cost of R1.4 billion, will produce half the power the company needs, using excess steam given off by the manufacturing process.
- Mining company, Gold Fields, is investigating the conversion of the methane gas produced in its mining processes to produce electricity. The company would not only be able to generate electricity, which would help reduce its input costs, but also earn an income from selling carbon credits on the international market.
- Centlec is the electrical utility responsible for supplying services to several municipalities in central and Southern Free State. It is entirely owned by Mangaung Metropolitan Municipality and distributes electricity to 178 000 customers. Centlec owns a thermal power station but it is currently not operational and the utility is looking for a private company as a possible operator (Free State Province, 2013).

2.6.5.1. Renewable Energy

The South African government by signing agreements with independent power producers has opened the energy sector with a focus on renewable energy, with an investment of R47 billion expected. The likely new sources of renewable energy will include solar and wind renewable projects across some of South Africa's most rural and least developed provinces, including the Free State.

South Africa averages more than 2500 hours of sunshine per annum with solar radiation levels between 4.5 and 6.5 kWh per m^2 per day and a global average of 220 w per m^2, making South Africa's local solar resource one of the highest in the world (National Department of Energy 34). The Free State province has immense solar harvesting potential in addition to other projects including the possibility of manufacturing of solar products such as geysers and panels (Free State Business report, 2012). The conceptualised plans such as the solar water geyser manufacturing in Botshabelo, to produce 300 000 units per annum and the manufacture of solar modules and solar panels assembly facility have been done. Within the Free State, the Xhariep region has the second-best solar radiation index (see Figure 2.16) making it opportune to harness the solar power and generate electricity through photovoltaic solar power generation (Free State Business, 2013). Presently, there is a solar park under development in the Xhariep district for a 250MW capacity by the Free State Development Cooperation as well as manufacture of solar products.

Other solar projects in the Free State include the R2.5 billion-Letsatsi solar park located north of Bloemfontein, occupying an area of 150 ha. It is envisaged the Letsatsi will produce 64MW, create at least 50 permanent jobs as well as 300 construction jobs. This project has various national and international partners. In addition, the Free State is quickly becoming a sought our region for solar park projects (Free State Province, 2013).

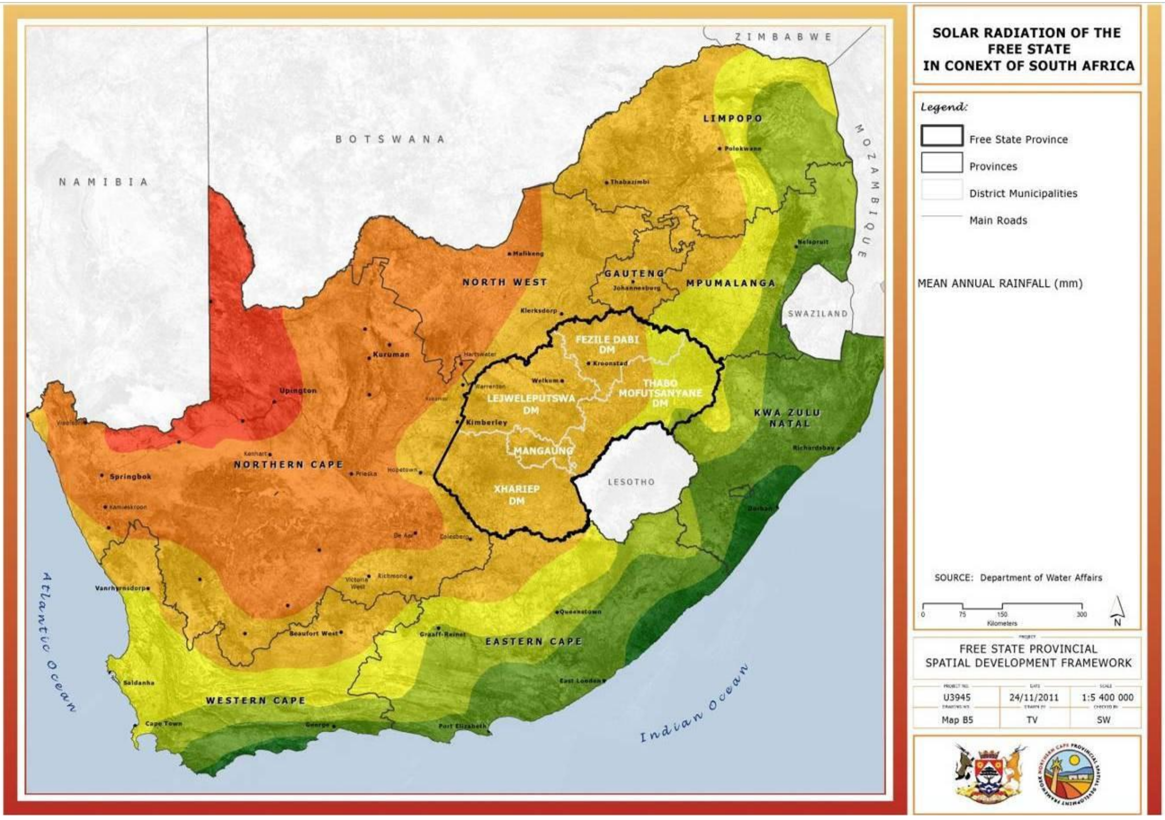

Figure 2.16: Levels of solar radiation in South Africa

The other renewable energy interest for the Free State is in hydro power, which is generated at the Gariep and Venderkloof dams power stations with a generation capacity of 360 MW and 240 MW respectively. This power is used as a backup during peak demand periods. There are other hydro power projects in the Free State and these are:-

- The Ingula pumped-storage scheme which is complete (whereby water is pumped to reservoirs and then released), with another 1 368 MW unit that will become available in the near future. This is an Eskom project on the provincial border with KwaZulu-Natal, and will cost approximately R16 billion. The first phase was due to come on stream in 2014.
- A new private project at the Sol Plaatje Dam started delivering hydro power in late 2009, with NuPlanet[1] supplying electricity to the Dihlabeng Local Municipality. The project's first 3 MW plant (i.e. Sol Plaatje Power Station) is near Bethlehem while the second, 4 MW plant (i.e. Merino Power Station), is being built between that town and Clarens. The carbon credits derived from this project, with an estimated 33 000 tonnes per year of carbon dioxide being curbed, would be sold to Norwegian State-owned electricity company, Stalkraft AS.
- Furthermore, NuPlanet has identified several sites along the Liebenbergsvlei Rivers for possible future sites – these sites utilise the outflow of the Lesotho Highlands Water (Free State Business, 2012 and 2013).

[1] A leading producer and developer of hydro power in South Africa

The option for renewable energy available for the Free State are both dependent on climate change and its impacts, which will also be affected by the availability of both rain for hydro power and solar radiation for solar energy. While the anticipated increases in temperature will continue to boost solar radiation and solar power, there is uncertainty around hydro power, given the uncertainty over projected rainfall in the country and in the Free State.

2.7. Extreme Weather Events

The Free State Province is susceptible to a myriad of extreme climate events and its location on the Highveld makes it vulnerable to particular types of risk which heightens its exposure, and the exposure of its poorer populations. While the determined extreme events are related, i.e. variation in temperature, variation in rainfall and extreme events, the Free State faces other disasters that are not naturally based. A detailed study on disasters in the metropolitan municipality highlights the types of extreme events associated with hydro-meteorological factors. Among the critical extreme weather events are floods and droughts.

Hydro-meteorological hazards such as floods including flash floods, droughts, thunderstorms, hailstorms, tornados, heat waves and cold spells have a myriad of socio-economic impacts including extensive damage to property, loss of life, injury or other health impacts, loss of livelihoods, social and economic disruption, or environmental damage (MMM, 2013/14). While hydro-meteorological events are the most common, other events caused by extreme temperatures changes do occur such as veldt fires due to high temperatures.

2.7.1. Flooding

Flooding, including flash floods is one of the most common hazard, affecting most of the province, especially those areas with the flood lines of the perennial rivers. The impacts of the flood would be more severe in areas with informal settlements and in areas with high densities of population. These would be areas characterised by high social vulnerability as well given that adaptation capacity is dependent on social vulnerability status. A few serious flooding events have happened in the province.

2.7.2. Droughts

Drought incidents have been known to affect The Free State province in the past and are a serious issue given the dependence on the province on irrigation for agriculture, as well as hydroelectricity. Drought also affects the availability of water for domestic and industrial use, this is exacerbated by ageing infrastructure.

2.7.3. Other Hazards

The Free State experiences a myriad of hazards over and above the ones mentioned above and these include:-

- Strong Winds
- Severe thunder storms and lightening
- Veld Fires (see Figure 2.17).

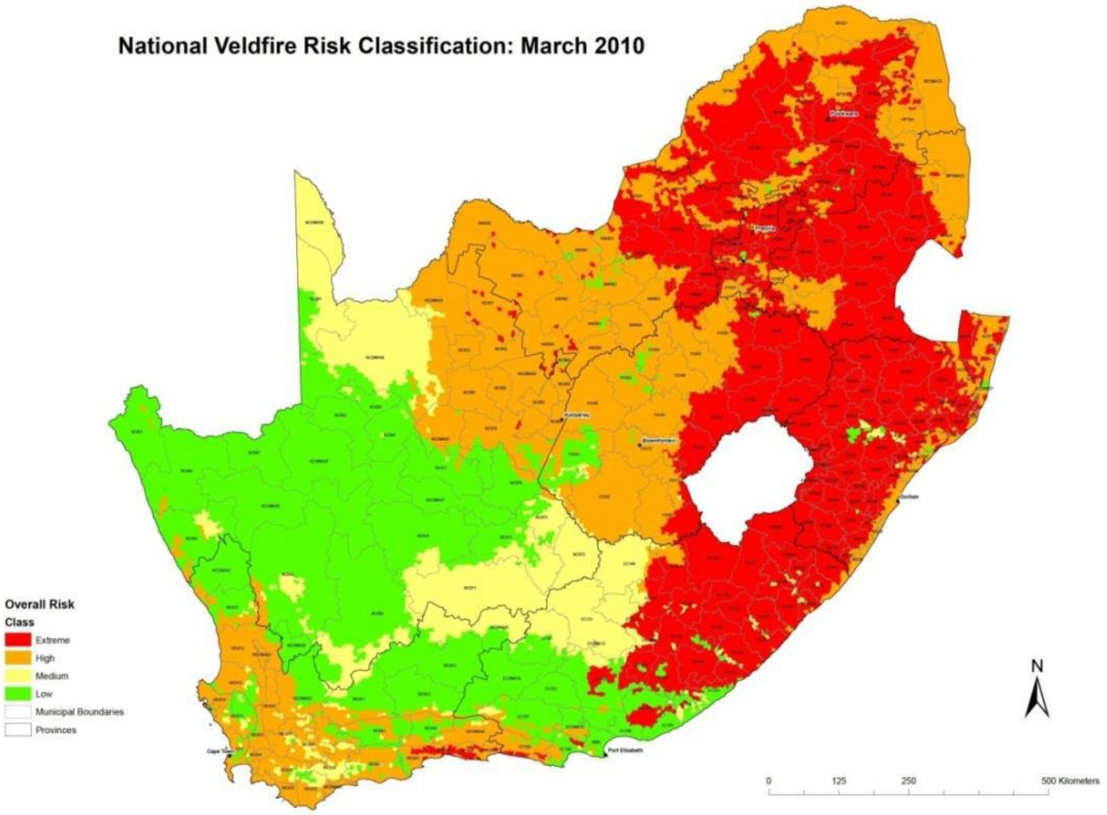

Figure 2.17: National map of Veld Risk

The Free State province is classified as having extreme to high probability of veld fires, with all the other extreme events reviewed having an impact on agriculture, biodiversity and human wellbeing.

3. Social Vulnerability

The definition of social vulnerability is "the state of individuals, groups, or communities defined in terms of their ability to cope with and adapt to any external stress placed on their livelihoods and well-being". Social vulnerability is regarded as one aspect of vulnerability in the broader disaster risk assessment field (Taspell et al., 2010). Profiling of social vulnerability of people and communities is essential in order to identify and understand vulnerability, in particular the ability of the identified population and places to cope with and respond to the various impacts of climate change (van Huysteen, 2013). Therefore the first step in starting to plan for resilient communities would be to profile spatial and social vulnerability, in order to better understand the risks to communities and to permit planners and decision makers to effectively develop local based climate change responses and adaptation (Tapsell et al. 2010; Cutter and Finch 2007). Determining socially vulnerable communities assists decision makers with appropriate information to effectively measure inequalities, identifying priority intervention areas and a better understanding of the drivers contributing to making communities more or less vulnerable (le Roux et al., 2015). Social factors, while being non-climatic, have a key role to play in enhancing vulnerability to climate related events. It is important to note that different social clusters and population groups have different strengths and needs. Social factors such as social cohesion play a pertinent role in community coping capacity – resilience vs vulnerability

3.1. Approach

Two methodologies were used to illustrate the vulnerability of communities within the different municipalities of the Free State.

- A Social Vulnerability Index (SVI), which was developed by Le Roux et al. in support of national decision-making in South Africa. This index provides a comparison of vulnerability of municipalities in Free State to those in the whole of South Africa (classifying them from the least to the most vulnerable). This index was built for the purpose of developing an appropriate index to measure social vulnerability across South Africa by performing principal component analysis of 14 unique (South African-specific) variables. This index was required by the South African National Disaster Management Centre in terms of the National Disaster Management Framework of 2005 (Le Roux et al., 2015).
- In order to show the drivers of social vulnerability within the Free State, a provincial composite index was derived using the same type of indicators as used by Le Roux et al. The indicators also used the 2001 Census data. Each indicator was looked at on an individual bases .The dependency indicator were derived by considering the dependency ratio ((<15, >65)/15-65)), with all other indicators using a proportion of the total population in the ward. Indicators were summed and the total used to rank the municipalities.

A myriad of social and economic factors play a crucial roles in the vulnerability as well as the coping capacity and adaption of the different population groups to the various impacts of climate change. Factors such as demographics, economic status, education and employment status as well as types of residences or dwelling all contribute to this profile. In particular, the types of housing may either increase or decrease vulnerability, with informal settlements as a case in point. The social factors in Table 3.1 below were considered for social vulnerability.

Table 3.1 Social attributes used for the different climate scenarios

Attribute	Gradual/longer-term increase in temp, decrease in rainfall	Extreme precipitation, including hail, wind storm, flooding	Extreme hot days (heat waves)
Type of housing (shacks)	y	y	y
Education (older than 25 years, no education)	y	y	y
Employment: unemployed	y	y	y

Attribute	Gradual/longer-term increase in temp, decrease in rainfall	Extreme precipitation, including hail, wind storm, flooding	Extreme hot days (heat waves)
Household density (> 4 people/room)	y		y
Poverty line (hh earning < R400/month)	y		
Economic dependency (young and old compared to economic active population)	y		
Physiological vulnerability (young and old)		y	y
Air pollution (fuel use other than electricity)			
Access to water (no piped water)	y	y	y
Single parents (female-headed households)	y		
Child-headed households	y	y	y
Access to transport (no car)		y	
Access to information (neither radio or cell phone)	y	Y	y
In need of assistance (determined by problems with hearing, mobility, seeing, self-care, speaking)	y	Y	y
Social cohesion (non-South Africans in informal areas for < 2 years).		y	y

3.2 Free State

The main drivers of social vulnerability in the different municipalities are access to transport and economic dependency. Vulnerability to a particular climate scenario was determined by summing the proportions of the individual risk factors and determining the percentile of each municipal score as compared to the maximum score for that scenario. Vulnerability was therefore relative to the municipality with the highest vulnerability. This was done before and after adjusting for population size. Before considering population size, the relative vulnerability for the three climate scenarios was classified as high at all municipalities for the first two scenarios, and at 12 of the 20 for extreme hot days. The population-adjusted vulnerability at Matjhabeng, Maluti a Phofung and Mangaung was the highest for all three scenarios.

The following six high social vulnerability municipalities (Figure 3.2) are highlighted as Mangaung, Dihlabeng, Matjhabeng, Maluti a Phofung, Moqhaka, and Metsimaholo in orange shade on the map above. Seven municipalities are classified as having medium vulnerability while the rest of the municipalities (eight) located in the mainly commercial agricultural areas are considered to have low social vulnerability. This is attributed to low population in these areas. The main influencing factors for Mangaung include poverty, economic dependency and lack of access to transport. In term of Metsimaholo and Matjhabeng, unemployment proved to be the biggest social issue. In Maluti a Phofung, the issue of household is highlighted with single headed and chid headed household showing high scores of vulnerability. For a detailed analysis of social vulnerability please refer to Table 3.2 below.

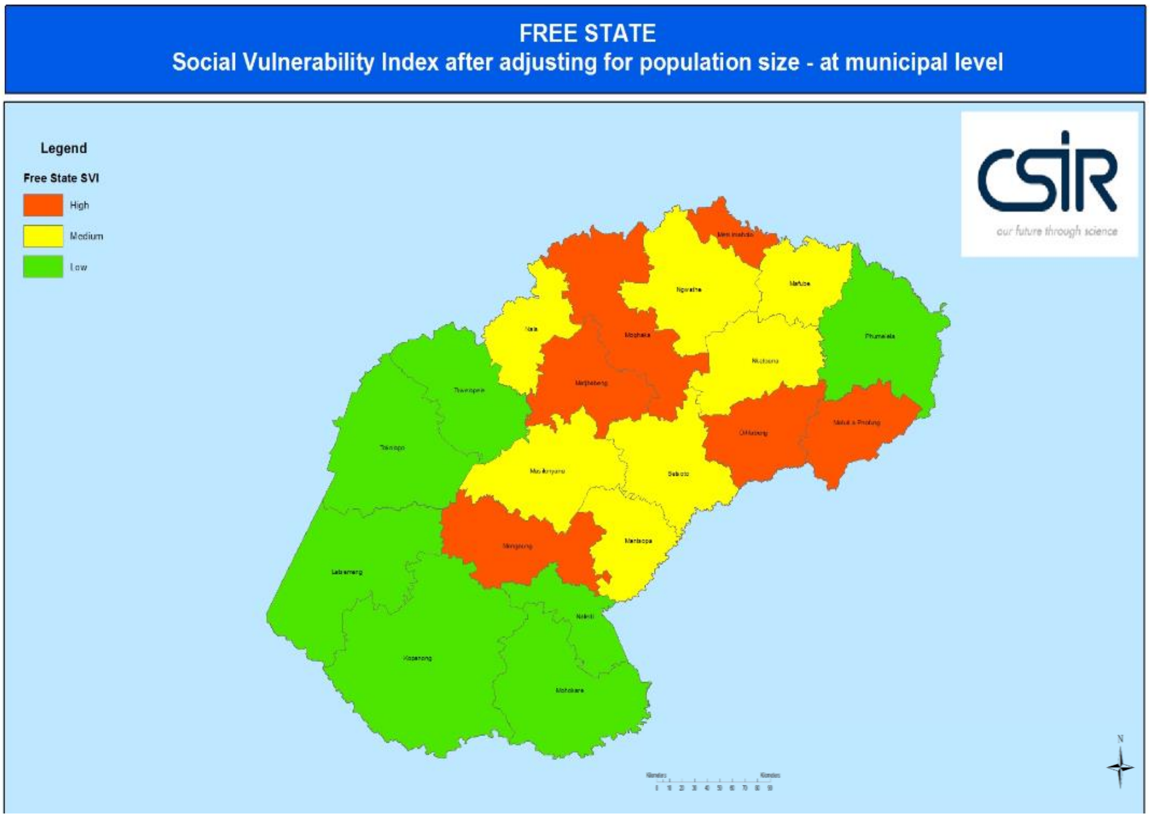

Figure 3.2 Social Vulnerability of the Free State Provinces

The issue of population is further corroborated by the population statistics of the province (see Figure 3.3) which highlights the six municipalities with the high social vulnerability classification as the same municipalities that have high population densities, indicated in Figure 3.3 with red and orange shades.

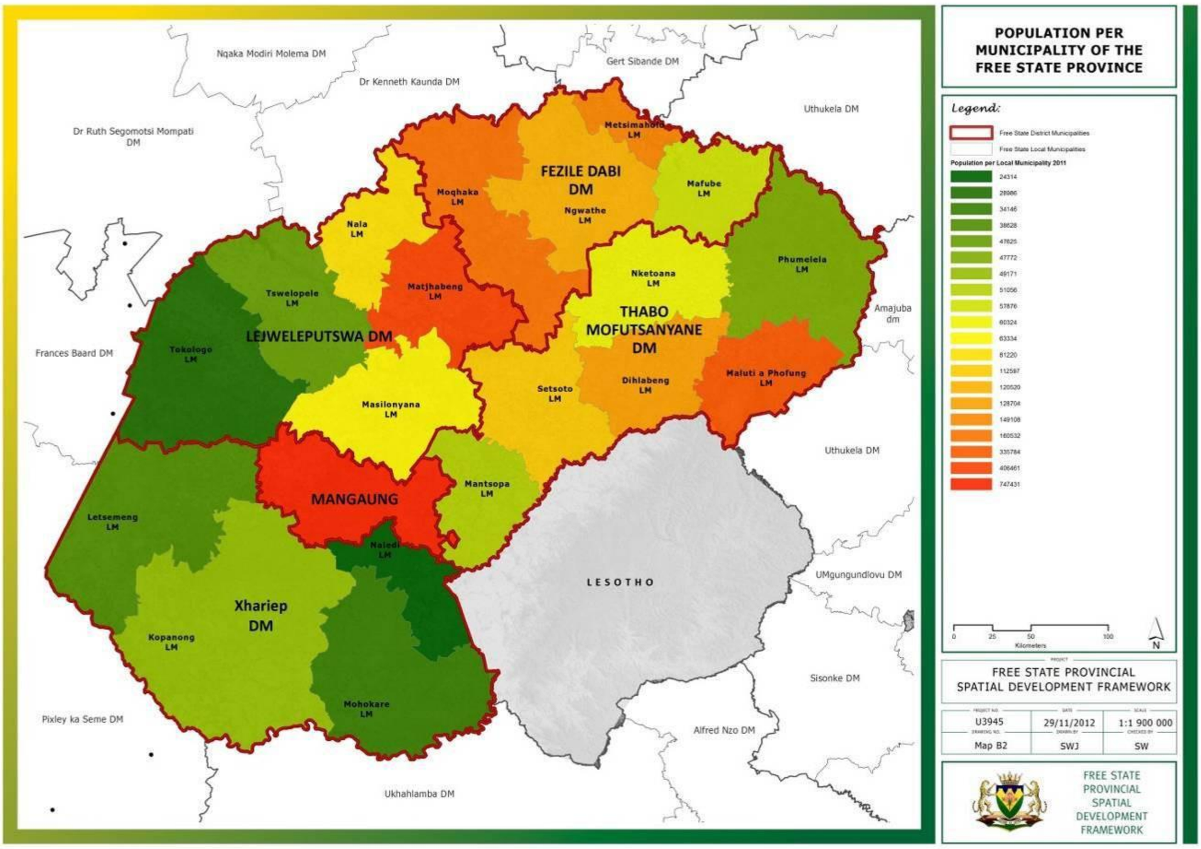

Figure 3.3 Population per local municipality in 2001 census (Free State Province, 2012).

Issues of social vulnerability, especially population dynamics are key factors in the response of the affected population to climate change and thus should be regarded as such in an attempt to make or improve the resilience of a population to climate change.

Attribute	Letsemeng	Kopanong	Mohokare	Naledi	Masilonyana	Tokologo	Tswelopele	Matjhabeng	Nala	Setsoto	Dihlabeng	Nketoana	Maluti a Phofung	Phumelela	Mantsopa	Moqhaka	Ngwathe	Metsimaholo	Mafube	Mangaung
Type of housing (shacks)	0.161	0.078	0.122	0.143	0.159	0.148	0.187	0.197	0.214	0.266	0.179	0.224	0.091	0.166	0.147	0.103	0.175	0.143	0.274	0.141
Education (older than 25 years, no education)	0.116	0.090	0.070	0.042	0.057	0.137	0.084	0.031	0.051	0.056	0.060	0.082	0.055	0.073	0.037	0.037	0.056	0.039	0.091	0.030
Employment: unemployed	0.105	0.134	0.168	0.115	0.177	0.137	0.179	0.212	0.177	0.171	0.163	0.157	0.182	0.122	0.152	0.183	0.185	0.203	0.165	0.160
Household density (> 4 people/room)	0.004	0.007	0.015	0.012	0.017	0.012	0.013	0.009	0.002	0.012	0.017	0.019	0.003	0.003	0.014	0.003	0.003	0.002	0.002	0.009
Poverty line (hh earning < R400/month)	0.609	0.596	0.651	0.653	0.672	0.628	0.689	0.647	0.687	0.687	0.593	0.651	0.722	0.652	0.634	0.609	0.643	0.607	0.669	0.586
Economic dependency (young and old compared to	0.691	0.718	0.794	0.836	0.701	0.749	0.812	0.595	0.785	0.791	0.670	0.789	0.815	0.774	0.758	0.635	0.752	0.551	0.787	0.600
Physiological vulnerability (young and old)	0.348	0.359	0.381	0.389	0.351	0.366	0.388	0.316	0.380	0.375	0.344	0.377	0.376	0.373	0.368	0.330	0.370	0.303	0.374	0.317
Air pollution (fuel use other than electricity)	0.102	0.117	0.221	0.158	0.105	0.191	0.105	0.112	0.130	0.169	0.233	0.242	0.176	0.414	0.187	0.096	0.104	0.155	0.232	0.106
Access to water (no piped water)	0.022	0.013	0.012	0.021	0.024	0.023	0.028	0.020	0.012	0.019	0.022	0.055	0.039	0.040	0.012	0.010	0.010	0.009	0.024	0.021
Single parents (female-headed households)	0.094	0.117	0.127	0.147	0.116	0.096	0.101	0.118	0.106	0.134	0.120	0.114	0.145	0.104	0.124	0.112	0.124	0.097	0.118	0.123
Child-headed households	0.004	0.005	0.007	0.007	0.005	0.005	0.005	0.004	0.005	0.008	0.004	0.006	0.008	0.009	0.006	0.003	0.005	0.003	0.007	0.003
Access to transport (no car)	0.758	0.774	0.816	0.825	0.819	0.787	0.776	0.715	0.795	0.809	0.734	0.776	0.823	0.744	0.801	0.743	0.753	0.661	0.756	0.698
Access to information (neither radio or cell phone)	0.135	0.092	0.071	0.054	0.073	0.126	0.063	0.047	0.082	0.071	0.047	0.053	0.043	0.054	0.064	0.049	0.051	0.031	0.058	0.041
In need of assistance (determined by problems with hearing, mobility, seeing, self-care, speaking)	0.244	0.134	0.432	0.168	0.240	0.124	0.319	0.123	0.169	0.197	0.135	0.163	0.177	0.191	0.347	0.100	0.203	0.198	0.517	0.129
Social cohesion (non-South Africans in informal areas for < 2 years).	0.216	0.219	0.229	0.153	0.124	0.183	0.173	0.135	0.146	0.161	0.124	0.166	0.134	0.240	0.137	0.197	0.187	0.115	0.213	0.147

Table 3.2. Social Vulnerability indicators for the Free State Municipalities, indicating their relative vulnerability (green: lowest → red: highest)

4. Conclusion

This report has reviewed the vulnerability of the different sectors in the Free State province, both environmental, economic and social that will be affected by climate change and extreme events. These identified vulnerabilities are the starting point to devising appropriate response plans and adaptation strategies to combat climate change impacts in the province while building communities resilient to climate change, by knowing where they are located and the nature of their vulnerability. The key issues for vulnerability, affecting the economic development of the province include the loss of the grassland biome, availability of water as well temperature changes all of which will have a detrimental impacts of agriculture, the energy sector and human wellbeing and should be key consideration in the development of adaptation responses, options and strategies.