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Managing Water Resources Under a Changing Climate

Climate Change Risk and Vulnerability Assessment of Water Resources in the Limpopo WMA

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Department of Water and Sanitation

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1 INTRODUCTION

1.1 Background

Climate Change is already altering the world's climate. Its impacts are felt in all sectors and regions of society, through changes in temperature and precipitation as well as through changes in the frequency and intensity of climate change extremes. Adverse impacts of climate change will negatively affect progress toward development in a number of key economic areas including agriculture and food security, water resources, climate related disaster risk management and natural resource management (NPC, 2012).

The average annual rainfall for South Africa is below the world average and the water availability is skewed in terms of distribution (Moseki, 2009). Evaporation rates far exceed precipitation (relatively higher in areas where it rains less) and water is not always fit for use, even under natural conditions due to the type of host rocks. All of the above mentioned issues translate to water scarcity even before taking climate change into account. Hence, climate change in South Africa will magnify the impact on the availability and use of water resources. Among the impacts observed and expected due to climate change include increased frequency of extreme climatic events.

Changes in South Africa's climate as indicated by DEA (2013) and MacKellar et al. (2014) are quite evidenced by current changes in rainfall patterns and intensity as well as temperature trends that though vary in time tend to have a clear increasing trend. Despite the uncertainties with regard to the level of confidence in climate scenario projections and in the extent (in quantitative terms), to which attribution to climate change can reliably be made, the climate footprint is quite evident.

Despite remaining uncertainties regarding the exact nature, magnitude and patterns of future rainfall changes in South Africa, already water resources are under pressure. With growing water demand in relation to a finite and limited supply, water resources will be under even greater pressure in the future as a result of climate change.

South Africa often experiences different degrees of water risks resulting from drought, floods, pollution and other impacts. Taking into consideration that the country's water availability is skewed and water quality in some areas is a problem, climate change is expected to further exacerbate this condition. The country has a spatial variation in climatic parameters such as precipitation and temperature (WRC 2012). Climate change is expected to further increase the variability of good water availability in terms of quality and quantity, adding more uncertainties and complication to the planning and management processes of the water resources (WRC 2012).

The understanding of risk and vulnerability of water resources, including the impact on water services is therefore important to ensure sustainable water management in the country. Undertaking a vulnerability assessment of water resources will identify vulnerable areas, highlight gaps in information and identify the factors that influence vulnerability. The assessment will provide decision makers with options to evaluate and modify existing policies and implement measures to improve water resource management.

The aim of the study is to provide an initial risk and vulnerability assessment to climate change impacts on water resources in the Limpopo WMA. The assessment identifies existing water related issues and then relate how risk and vulnerable the water resource would be due to climate change considerations based on downscaled model projections of the affected areas. This report specifically focuses on the Limpopo WMA a part of hydro-climatic zone 1. This report is based on the desktop study information through literature review, reconnaissance survey, interaction with DWS Regional office officials, and Forum meetings feedbacks.

1.2 Study Objective and Problem Statement

1.2.1 Study Objective

The project objective is to assess, identify and propose possible measures to deal with current and future risk and vulnerability of water resources due to climate change in the Limpopo WMA.

1.2.2 Problem Statement

The average annual rainfall for South Africa is below the world average and the water availability is skewed in terms of distribution. Evaporation rates far exceeds precipitation (relatively higher in areas where it rains less) and water is not always fit for use, even under natural conditions due to the type of host rocks. All this above mentioned issues translate to water scarcity even before taking climate change into account. Hence, climate change in South Africa will amplify the impact on the availability and use of water resources. Among the impacts observed and expected due to climate change include increased frequency of extreme climatic events.

Water resources are key to continued socio-economic development and environmental sustainability for South Africans livelihood. Despite remaining uncertainties regarding the exact nature, magnitude and pattern of future rainfall changes in South Africa, it appears likely that water resources will be under pressure. This is a result of growing water demand in relation to a finite and limited supply, added to the expected climate change impacts. This is a result of three factors:

- the projected decrease in rainfall over much of the country,
- increased evaporation resulting from higher temperatures, and
- the amplifying effect that the hydrological cycle has on climate change.

Assessment for risk and vulnerability of climate change on water resources is therefore important to be done in order to identify issues so that proper planning is done to adress and to counteract the potential negative impacts associated with it.

2 THE STUDY AREA

2.1 Location

The Limpopo WMA forms part of the internationally shared Limpopo River Basin which also includes sections of Botswana, Zimbabwe and Mozambique. The Limpopo River forms the entire length of the northern international border between South Africa and Botswana and Zimbabwe before flowing into Mozambique and ultimately draining into the Indian Ocean. The Limpopo WMA is based in three provinces, Mainly Limpopo, parts of North West and Gauteng as can be seen in Figure 1 below. Limpopo WMA includes the former Crocodile (West) and Marico WMA as well as the Luvuvhu River catchment, previously part of the Luvuvhu/Letaba WMA shown in Figure 2 below. It is bordered by Zimbabwe and Mozambique on the north, Botswana on the west, Vaal WMA on the south and Olifants on the east.

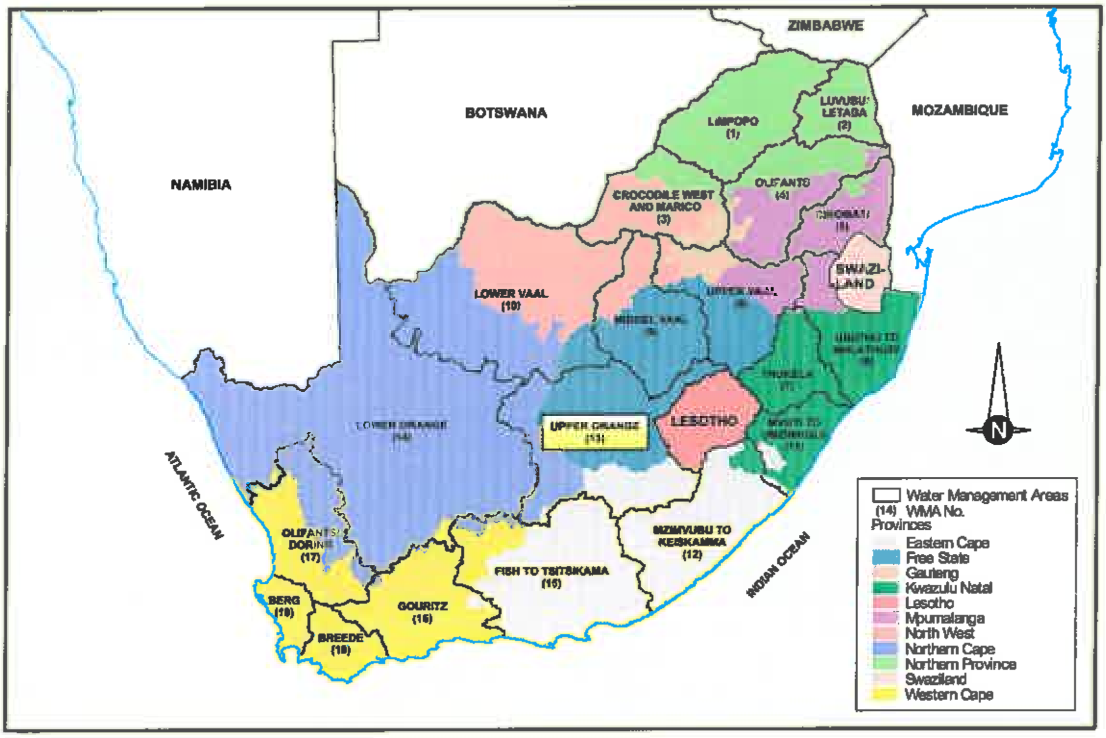


Figure 1: Old Water Management Areas in relation to provincial boundaries

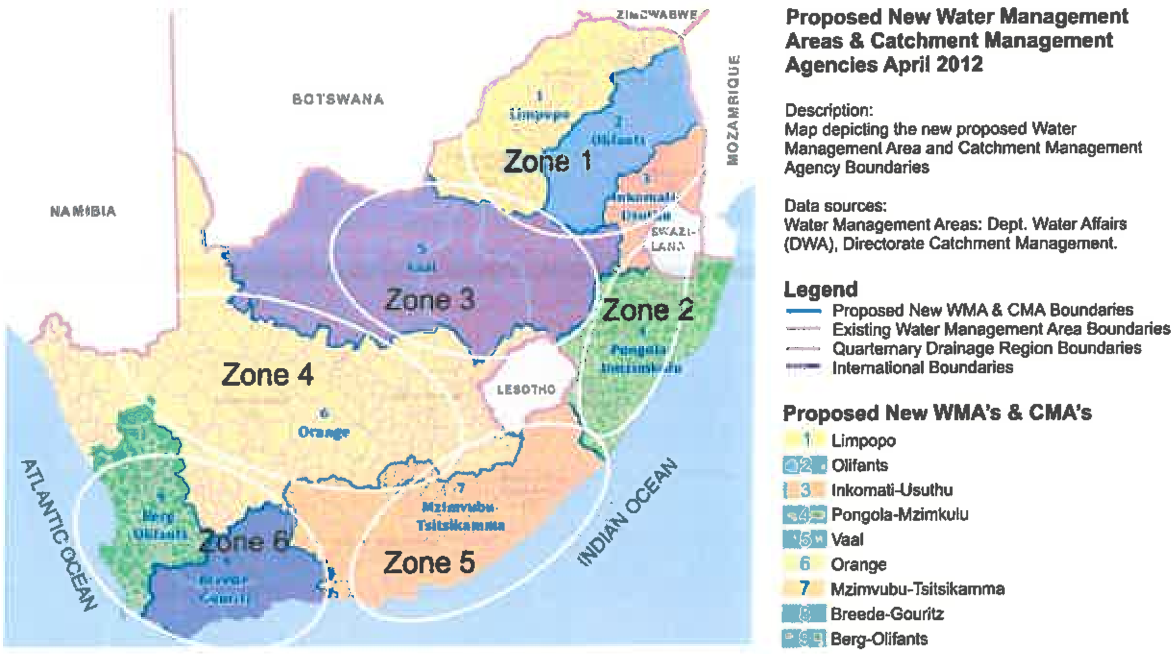


Figure 2. Location of the Water Management Areas (Limpopo in Zone 1)

Crocodile (West) and Marico WMA, has metros and District municipalities that falls in the North West, Gauteng and Limpopo Provinces as follows:

- **Metros**; City of Johannesburg, City of Tshwane and Ekurhuleni.
- **Waterberg DM**: Bela-Bela, Thabazimbi
- **Bojanala Platinum DM**: Kgetlengrivier, Madibeng, Moretele, Moses Kotane, Rustenburg
- **West Rand DM**; Mogale City and Randfontein

The other large part of the Limpopo WMA referred to as the Limpopo WMA north, is largely the area on the left side of the N1 road from Bela-Bela to Musina. Figure 3 below shows the location of catchments, District municipalities, and towns mainly in the old Limpopo Water management area (referred to as Limpopo WMA north).

Figure 3: Location of District Municipality and towns within the WMA (DWS, 2017).

2.2 Land Uses within the Limpopo WMA

The Limpopo WMA has mixture of urban and rural settlement, commercial and small scale farming, forestry, mining and nature conservation types of land use. The main urban areas within the WMA include Pretoria, Midrand, Centurion, Rustenburg, Mokopane, Polokwane, Mookgophong, Modimolle, Lephalale, Louis Trichardt and Musina. The WMA has a large number of populations due to concentration of people in town for job opportunities. About 800 rural communities are scattered throughout the WMA, mostly concentrated in the central region. The main economic activities are industries, mining, irrigation and livestock farming. The water resources, especially surface water resources, are heavily stressed due to the present levels of development. Hence, the land use type and its management strategies, with climate change impacts and effects, may pose threat to water resources.

2.2.1 Mining

There is expanding mining operations due to the vast untapped mineral resources in the area for coal and platinum. Though mining is not using much water, the process of mining does impact the quality of water and runoff. Mining do disturb soil profile, leading to water runoff direction change, erosion, pollution from flooding such as from coal stockpile spillage and acid mine drainage. Main minerals mined are coal and platinum. Coal is largely mined in the Lephalale area, whereas platinum is mined in Rustenburg and Thabazimbi.

2.2.3 Livestock watering

Livestock watering is primarily supplied from surface water resources. The tendency to convert land-use from irrigation to livestock farming, particularly game farming in the Mokolo, Lephalala and Sand catchments, has increased the stock watering requirements. Table 1 provides a summary of the livestock watering requirements within the Limpopo WMA north catchment. With climate change, animals are expected to increase water intake as cool their body. Also, with increasing population and demand for protein, livestock is expected to increase. Hence, increase in water demand

Table 1: Livestock water requirements in the Limpopo WMA North at the 2010-development level (NB –Crocodile West and Marico catchment not included

Catchment	Livestock water requirement (million m3/a)
Matlabas	2.28
Mokolo	2.11
Lephalala	2.39
Mogalakwena	11.49
Sand	4.39
Nzhelele	0.75
TOTAL	25.16

2.2.3 Invasive Alien Plants (IAP)

IAPs tend to utilise more water compared to indigenous plant species and subsequently reduce the available runoff in a catchment. IAPs in the riparian zone have the largest impact on the reduction of runoff due to the greater water availability from rivers. It should be noted that afforestation and IAPs are not considered as water users but rather stream flow reducers.

Considering the Limpopo WMA north, with the exception of the Matlabas River catchment, IAPs are widespread throughout most of the catchments area. The highest density of IAP occurs in the Sand catchment with a total IAP condensed area of 134 km^2 (2% of catchment area). Table 2 summarises the IAP distribution and the estimated 2010-development level runoff reduction used as input to the WRSM2000.

Table 2: Summary of IAP estimated runoff reduction for 2010-development levels in the Limpopo WMA North

Catchment	**Condensed area (km2)**	**Runoff reduction (million m3/a)**
Matlabas	0.0	0.0
Mokolo	26.2	0.0
Lephalala	12.6	1.2
Mogalakwena	83.5	2.6
Sand	134.3	1.0
Nzhelele	59.0	2.1
TOTAL	315.5	6.9

Afforestation

Afforestation is confined to the high rainfall regions (> 800 mm/a) on the slopes of the Soutpansberg mountains, in the upper reaches of the Nzhelele catchment and quaternary catchments A71C and A71H of the Sand catchment. The impact of afforestation on the water resources in the study area is considered negligible, reducing the runoff in the Nzhelele River catchment by approximately 2 million m^3/a, and 0.2 million m^3/a in the Sand River catchment.

3 WATER RESOURCES AND WATER QUALITY SITUATION ON THE LIMPOPO WMA

3.1 Water Resources

The water situation discussed below is based on the Limpopo WMA Reconciliation Strategy (DWS, 2017). The most western area of the Limpopo WMA, the Matlabas catchment, is a dry catchment with no significant dams and with a low growth potential for land use development. The large Mokolo Dam, in the Mokolo catchment, supplies water to the Matimba Power Station, Medupi Power Station, Grootgeluk Coal Mine, the Lephalale Local Municipality as well as a number of downstream irrigators. The dam is able to meet the bulk of the current requirements but will in future rely on transfers from other WMAs to meet the water requirements at a sufficiently high assurance of supply (DWS, 2017).

The middle reaches of the Lephalale catchment have a high conservation value with irrigation activities dominant in the remainder of the catchment. Irrigation in this area is supplied by surface water and alluvial aquifer abstraction.

The bulk of the water resources in the Mogalakwena catchment have been fully developed. The Doorndraai Dam is over allocated. Additional water to support the rapid expanding mining activities in the vicinity of Mokopane needs to be augmented by transfers from the Flag Boshielo Dam in the adjacent Olifants River catchment. Glen Alpine Dam currently supplies water to emerging farmers, who has not yet taken up their full allocated quota, and is expected to supply the growing domestic requirements in future.

Groundwater resources in the Mogalakwena and the Sand catchment have been extensively utilized, and possibly over-exploited by the dominating irrigation sector. The expanding urban and industrial requirements of the Polokwane and Mkhado Local Municipality rely heavily on water transfers from the adjacent Luvuvhu/Letaba and Olifants WMA additional to groundwater. This includes transfers from the Ebenezer, Dap Naude, Flag Boshielo and Albansini dams, as well as the Olifantspoort Weir supported by releases from Flag Boshielo Dam, currently supply the demand of the Polokwane LM in the Sand catchment. Louis Trichadt (Makhado LM) is currently supplied by the Albasini Dam. The Nandoni Dam is proposed to augment the water supply to the Makhado LM, as well as the Matoks region located between Louis Trichadt and Polokwwane in the Sand catchment. As part of the Olifants River Water Resource Development Project, water from Flag Boshielo Dam (indirectly supported from De Hoop Dam) will be transferred to Mokopane (Mogalakwena LM) and rural ares in the Aganang LM, located in the Mogalakwena River catchment.

Domestic and irrigation water in the small but highly developed Nzhelele catchment is supplied through the Mutshedzi Dam Regional Water Scheme and the Nzhelele Dam River Water Scheme, as well as extensively from groundwater resources. The flows to the Mutshedzi and Nzhelele dams have been reduced as a result of afforestration upstream of these dams. The area is in deficit due to the over allocation and over development of irrigation. The Sand and Nzhelele catchments have high coal mining potential but the availability of local water resources is indicated that it may limit future mining development. Below are the water resources issues per catchment:

a. Matlabas catchment (A41)

The Matlabas catchment is a dry catchment with non-perennial flow and hence no sustainable yield from surface water. The limited water use in this catchment is mostly from groundwater, which is under-exploited. The majority of the water required in this catchment is for irrigation purposes with the very small local population abstracting water from boreholes for personal use.

b. Mokolo catchment (A42)

The Mokolo catchment is located in the higher rainfall portion of this WMA and is also the most developed catchment from a water resources point of view. The Mokolo Dam is the largest dam in the WMA and provides water for a multitude of uses, the most important being the supply to the Matimba Power Station and Grootegeluk coal mine. There is also a significant amount of irrigation from groundwater.

Groundwater is under-utilised and could be used to support increased domestic requirements, provided the water quality is acceptable. High future water requirements are expected as a large amount of mining potential has been identified within the Waterberg Coal Field which falls within this catchment.

c. Lephalala catchment (A50)

The Lephalala catchment has limited water resources. Irrigation takes place mainly in the higher rainfall upper reaches where there are a large number of farm dams, while lower in the catchment irrigators make use of water from alluvial aquifers. Nevertheless, the catchment appears to be stressed and no new allocations are expected to be made for irrigation purposes. Additional water for domestic purposes should be sourced from groundwater. The middle reaches of the Lephalala catchment have a high conservation value.

d. Mogalakwena River (A61 to A63)

The Mogalakwena catchment has limited surface water resources but large groundwater resources, which have already been extensively exploited by the irrigation sector. There is a rapid expansion of mines in the area and the water supply to these mines must be secured as a matter of priority. Additional water resources are groundwater and transfers from the Olifants River catchment.

e. Sand catchment (A71)

The Sand catchment is a dry catchment with very limited surface water resources. However, it has exceptional groundwater reserves which have been fully and possibly over-exploited, mostly by irrigation. The water requirements are large compared to the rest of the WMA, but again irrigation is the largest water user. Although the urban requirements are high, a large amount of water is supplied through transfers from other WMAs.

f. Nzhelele catchment (A80A to A80J)

The Nzhelele catchment (A80A to A80G) is small and is dominated by irrigation, with a small area of afforestation and domestic use by the rural sector. Nzhelele Dam is the second largest dam in the Limpopo North WMA and provides most of the water requirements in this catchment while groundwater is also extensively used.

g. Nwanedzi catchment (A80H to A80J)

The Nwanedzi catchment (A80H to A80J) is a small catchment in the north-eastern corner of the WMA characterised by over-allocated and over-developed large areas under irrigation and included as part of the Nzhelele catchment.

h. Marico catchment (A31 and A32)

The Marico catchment which is in the North West province is characterised by rural areas, agricultural farming and wild life farming. The area is a low rainfall as compared to the adjoining crocodile, though temperatures are high. It has been indicated that groundwater levels have dropped down due to overexploitation for irrigation.

i. Crocodile catchment (A21 – A24)

Crocodile catchment is normally has fairly good rains. However, land use that includes, dense population settlement, AMD from the Witwatersrand gold mines, irrigation and industries, result in poor water quality. Two main dams in the catchment, Hartbeespoort and Roodeplaat dam, are polluted and have algal bloom and hyacinth growth.

3.1.1 Dams

There are several numbers of dams within the Limpopo WMA developed mainly for irrigation and domestic water supply. Among the known large dams includes, Hartbeespoort, Groot Marico, Vaalkop, Boospoort, Koster, Ngotoane, Albasini, Nandoni, Ebenezer, and Dap Naude dams.

3.1.2 Rivers

The main rivers in the Limpopo WMA are the crocodile, Marico, Matlabas, Mokolo, Lephalala, Mogalakwena, Sand, and Nzhelele Rivers. These rivers, together with other smaller tributaries, flow northwards and ultimately discharge into the Limpopo River.

3.1.3 Groundwater

The groundwater is used to augment surface water for domestic water supply and for irrigation and stock watering. DWS (2017) indicate that groundwater contributes approximately 40% towards the water supply from local resources and is the only dependable water source for the majority of rural domestic users in the study area. Since surface water resources are fully developed, groundwater might be the only possible local water source to augment supply in some areas. However, groundwater resources in the Mogalakwena and Sand catchments have been extensively utilised, and possibly over-exploited by the dominating irrigation sector.

3.1.4 Inter-catchment transfers

The Limpopo WMA, as indicated (DWS, 2017) forms part of the internationally shared Limpopo River Basin which also includes sections of Botswana, Zimbabwe and Mozambique. Hence, water flows across within these countries. The main water transfer within the WMA is from the Vaal WMA. This transfer is largely for the development and operation of coal power station in Lephalale.

3.1.5 Rainfall, Evaporation and Runoff

The precipitation of the Limpopo WMA like in most part of the country's WMA is indicated to be lower that evaporation rate. Table 3 below, shows the rainfall, evaporation and Mean Annual Runoff for various Water Management Areas within the Limpopo WMA.

Table 3: Rainfall, evaporation and run-off for Limpopo WMA

Sub-Catchment		**Rainfall**		**S-pan evaporation**	**NATURALISED FLOW MARs**			
		MAP (mm)		**MAE (mm)**	**1920 - 1989**	**1920 - 2004**	**1920 - 2009**	
catchment			**WR 90**	**WR 2005**	**MAR (WR90) Net (mcm)**	**MAR (WR2005) Net (mcm)**	**MAR (WR2012) Net (mcm)**	**Change in MAR WR2005 to WR2012 (percent)**
Matlabas	A 41	516		1899	48.9	50.5	55.76	10.4
Mokolo	A 42	588		1809	312.4	263.7	258.2	-2.1
Lephalale	A 50	490		1880	141.7	143.3	141.0	-1.6
Mogalakwena River	A 61	614		1750	183.8	162.9	160.1	-1.7
	A 62	479		1883	67.3	68.8	76.0	10.4
	A 63	391		2014	38.9	40.5	43.2	6.6
Sand	A 71	392		1883	50.8	70.2	73.7	5.0
	A 72	406		1924	13.4	16.3	16.9	3.5
Nzhelele	A 80	457		1746	113.1	114.9	121.5	1.6
Upper Crocodile	A 21	667	1702	1709	209.6	198.2	185.6	-6.3
Elands	A 22	610	1774	1774	112.2	98.72	99.72	1

Pienaars	A 23	617	1762	1743	158.5	130.19	116.95	-10.2
Lower Crocodile	A24	592	1813	1813	1188.1	119.24	123.45	3.5
Marico	A 31	580	1892	1891	94.5	104.35	99.94	-4.2
	A 32	534	1940	1934	31	30.7	28.3	-7..8
	A 10	539	1950	1969	14.4	15.85	16.52	10.1
Luvhuvu	A 91	676	1631	1629	418.2	399.74	428.8	7.3
Nwanedzi	A 92	541	1763	1757	156.4	174.55	155.46	-10.9

The mean annual evaporation rate as can be seen from the table above is more than twice the mean annual precipitation. With projected reduced rainfall and increased temperatures the situation is expected to become even worse. Change in Mean Annual Run-off (MAR) show significant increase in Matlabas, Mogalakwena and A10 part of Marico catchment. A21 of Crocodile and Nwanedzi show a significant decrease in MAR of WR2005 and WR2012.

3.1.6 Salinization and sedimentation of water resources

Salinization and siltation within Limpopo WMA is spatially distributed especially in the rural areas and farms. Some of the small and earth dams are indicated to be filled up with sand such as areas of Sekhukhune. Salinization and sedimentation are highly linked to unsustainable land use such as overgrazing and conventional tillage especially on sloppy area. Often drought is followed by floods. During drought period the land has often been eroded, and as floods come, the eroded soil is washed into the water resources. Salinization and sedimentation reduce water infiltration in the ground and they also affect storage capacity of water resources as the sand fill the space that is to be occupied by water. In recent years, the area has experienced flash floods that damaged roads washing away soil structures and river banks as can be seen in Figure 4 below. When river banks are eroded, the river width is increase exposing water to evaporation.

Figure 4: Road washed by 2014 floods in Vaalwater

3.2 Water Quality

The water quality issues are mainly related to nutrient status and salinity impacts due to wastewater discharges and flow regulation especially in the former Crocodile West WMA. Figure 5 below show the green colour of water in the Hartbespoort dam, which is one of the highly polluted dams in the country. Because of polluted water in the dam, there is an excessive growth of green algae. With challenges of municipality in the country to deal with wastewater, microbial water quality issues are a serious concern. Eutrophication due to increasing nutrient concentrations is currently posing a major threat, and in the future due to climate change, the situation may be disastrous. This is currently reflected in the aggressive invasion of aquatic invasive macrophytes such as hyacinth. The excessive proliferation of these weeds leads to serious water quality problems and habitat destruction. Also, that this WMA is a shared system with other countries, water quality issues from other country may impact locally as has been seen in the past with cholera issues. The WMA has mining and potential for mining (especially coal and platinum) development which may in the long run result in acid mine drainage. Table 4 below shows the summary of water quality problems in the WMA.

Figure 5: Green algae in the Hartbeespoort dam due to pollution with high phosphate nutrients

Table 4: Summary of water quality problems in the study area

Pollution source	Associated determinant	Water quality problem	Catchment seriously affected
Agricultural activities	Pesticides, nitrate, phosphate, ammonia, E.coli, Suspended Solids (SS)	Eutrophication: algal blooms, Microcystin, low oxygen levels, bad taste and odour, increased water treatment cost and impact on aesthetics and recreational water users Poor microbiological quality: danger to human health, increased turbidity due to erosion	Matlabas, Mokolo, Sand, Lephalala, Nzhelele, Marico, Crocodile
Mining	Heavy metals, sulphates, pH	Occurrence of AMD in surface and groundwater leading to number of effects including mobilisation of metals, fish and crocodile kills and bioaccumulation	Mokolo, Sand, Crocodile
Power stations	Hardness, turbidity, temperature, Suspended Solids (SS)	Decrease in biodiversity Increase hardness of water	Mokolo
Informal settlements	Chemical Oxygen	Danger of nitrate poisoning: Blue baby syndrome	All

	Demand (COD), Nitrate, phosphate, ammonia, E.coli		
Hotels and lodges	COD, nitrate, phosphate, ammonia, E.coli	Danger of nitrate poisoning: Blue baby syndrome	All
Geology of area	Fluoride, calcium, sodium, magnesium	Negative impact on human health	
WWTW	COD, Nitrate, phosphate, ammonia, E.coli	Danger of nitrate poisoning; Blue baby syndrome Danger to human health through recreational and domestic use - washing and bathing Negative impact on ecosystem: low oxygen, eutrophication, effect of ammonia on invertebrates and fish.	All

The water quality is already a challenge, hence, when climate change projections are taken into considerations, the impact will be very serious.

4 CLIMATE PROFILE OF THE LIMPOPO WMA

4.1 Observed Trends Of Rainfall And Temperature

4.1.1. *Observed trends*

The Limpopo WMA is semi-arid and the mean annual rainfall ranges from 300 to 700 mm of which the bulk of it falls during the summer months, with the potential evaporation well in excess of the rainfall. Average temperatures range from 15^0C in winter (June to August) to 27^0C in summer (December to January) and average daily maximum temperatures in January and February months of the year reach 33^0C. ERM (2017) indicates that extreme temperatures of 44^0C have been recorded in the past. Tropical cyclones, which can bring heavy rains and strong winds, have reached the parts of Limpopo WMA in the past (ERM, 2017). At the same time, the area is vulnerable to drought with numerous below normal rainfall years impacting on water availability, and wild fires are also common in the WMA. Figure 6 below shows the trends in total annual rainfall in wet days seasonal rainfall between 1921 and 2015, indicating that the precipitation over time is significantly decreasing in the Limpopo WMA as moving to the upper parts of the WMA.

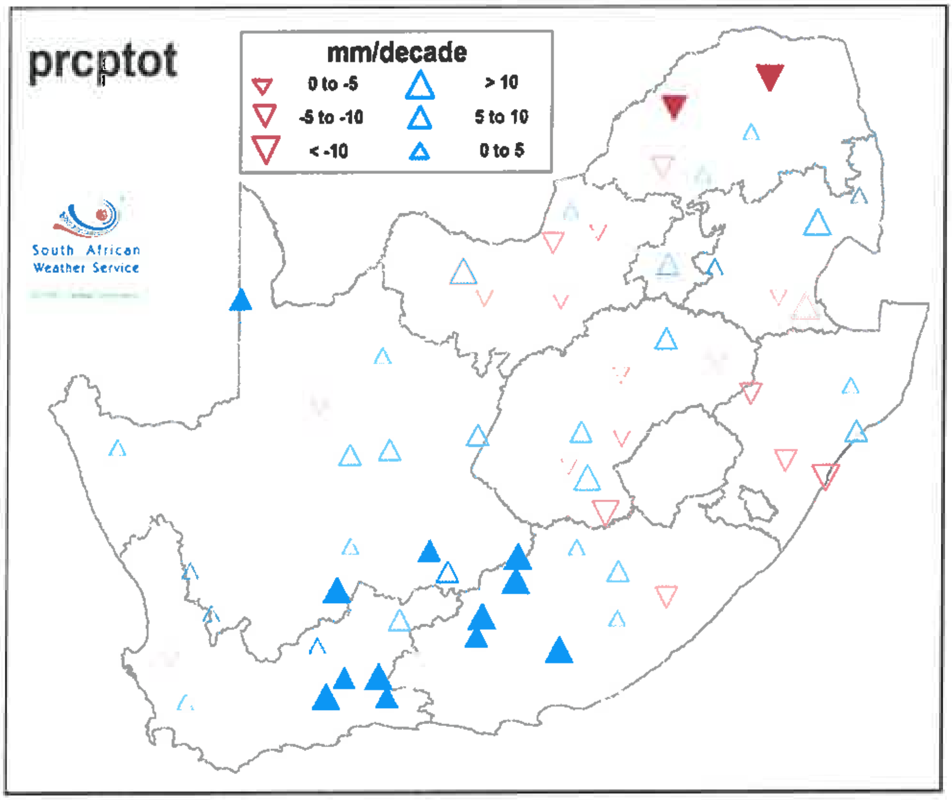


Figure 6: Trends in total annual rainfall in wet days (1921 to 2015) in mm per decade (filled triangles denote significance of trends at the 5% level). Kruger and Nxumalo (2017)

Kruger and Nxumalo (2017), as can be seen in Figure 7 below, shows that seasonal rainfall between 1921 and 2015 is decreasing over parts of the WMA. Significant decrease has been observed for the March, April and May months.

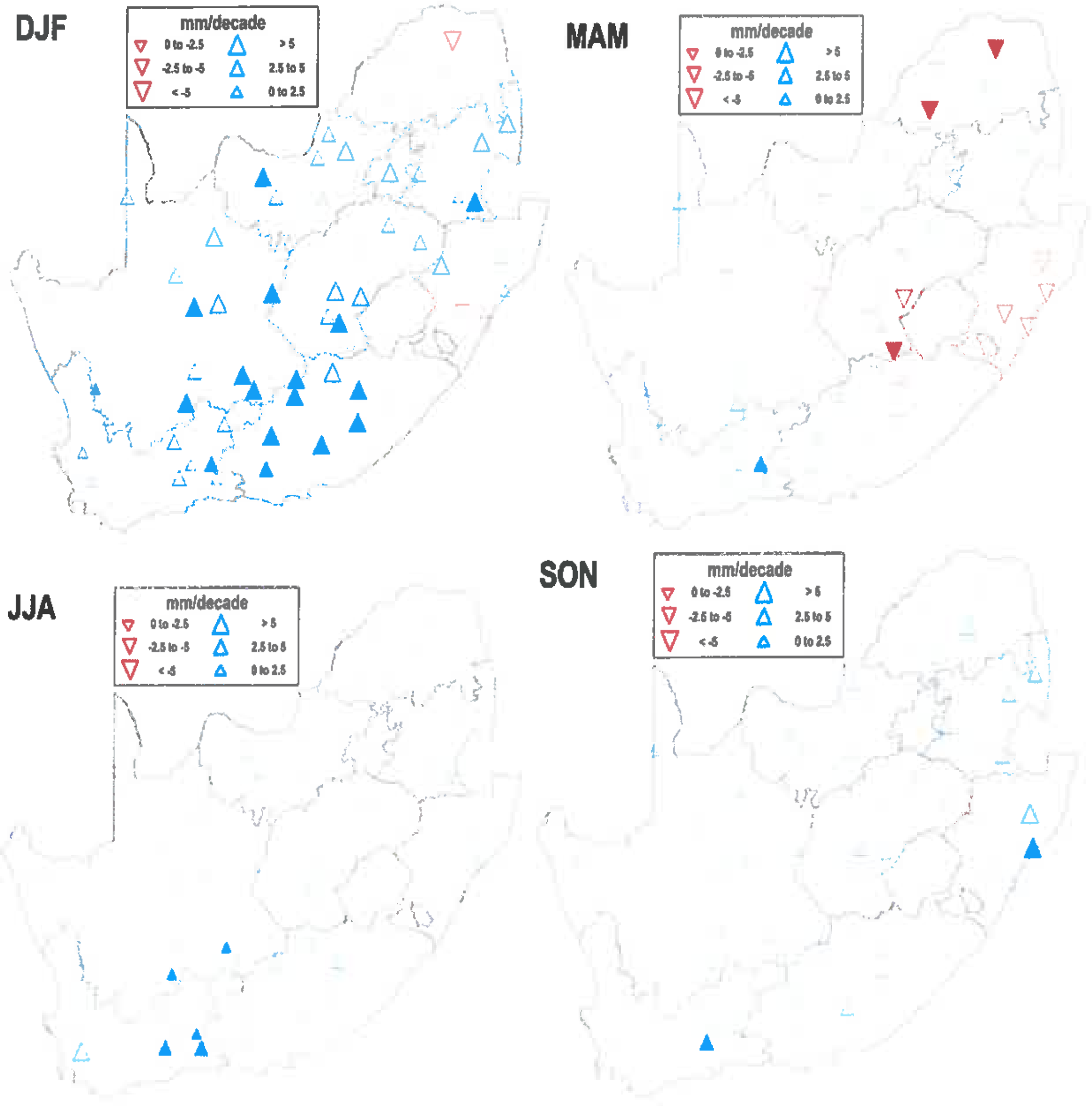


Figure 7: Trends in seasonal rainfall totals (1921–2015) (DJF: December to February – summer, MAM: March to May – autumn, JJA: Jun to August – winter, SON: September to October – spring). Shaded symbols indicate significant trends at the 5% level. High and extreme daily rainfall events (Kruger and Nxumalo 2017)

Figure 8 and Figure 9 below, shows the long term rainfall pattern measured at Polokwane and Messina. From Figures, it can be clearly seen that for most of the time, the rainfall has been below the long term averages of 450 mm for Polokwane and around 500 mm for Musina. For period between 1924 and 2011, as can be seen in Figure 9, only in 1924 and 1999 was a precipitation of above 1000 mm per annum was observed in Musina area.

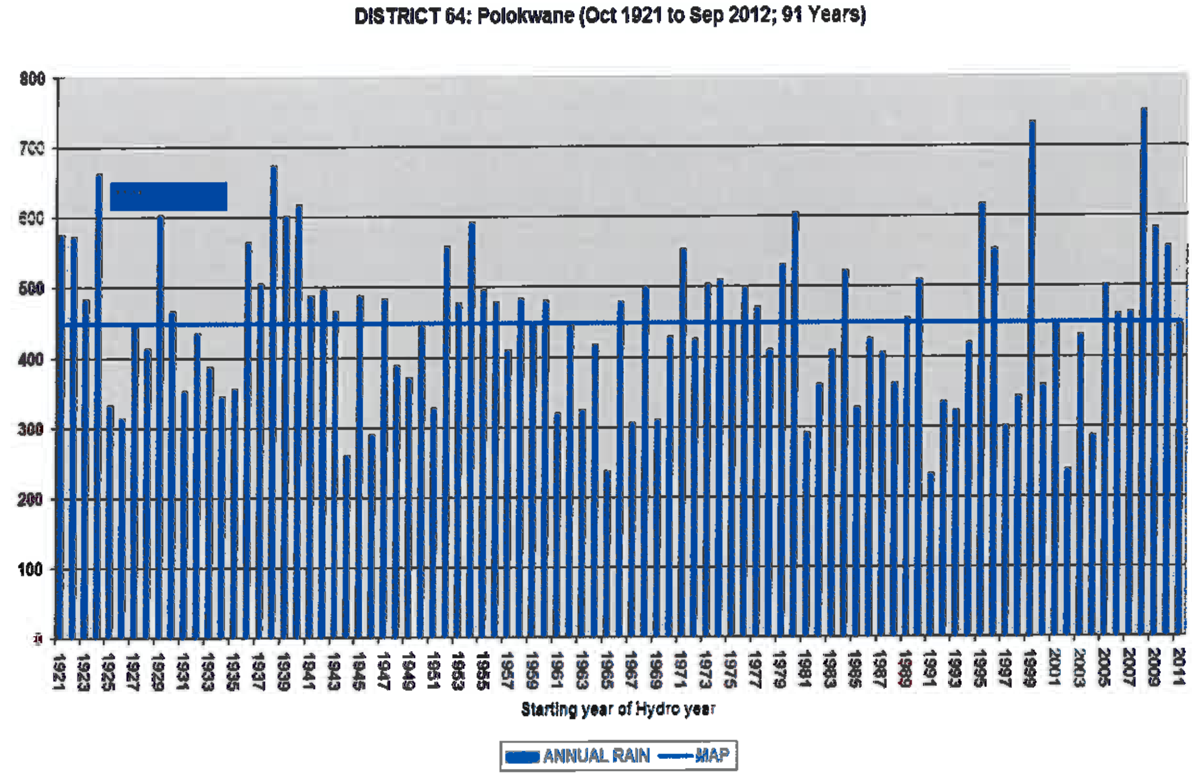


Figure 8: Long term trends of rain in Polokwane (SAWS, 2014)

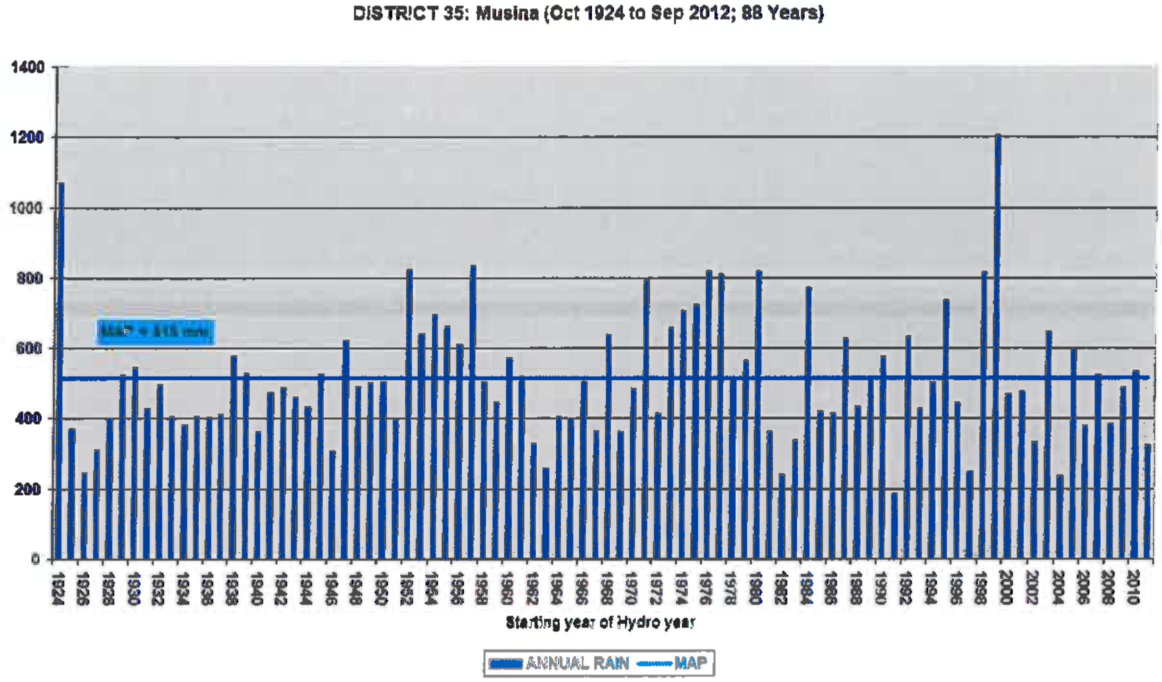


Figure 9: Long term trends of rain in Musina (SAWS, 2014)

Temperature varies from mild to hot summer temperatures ranging from averages of below 15 degree Celsius minimum and close to 30 degree Celsius maximum. Messina is one of the very hot areas with summer averages above 30^{0}C. Figure 10 below, indicates the significant increasing trend of average temperatures from 1931 to 2015.

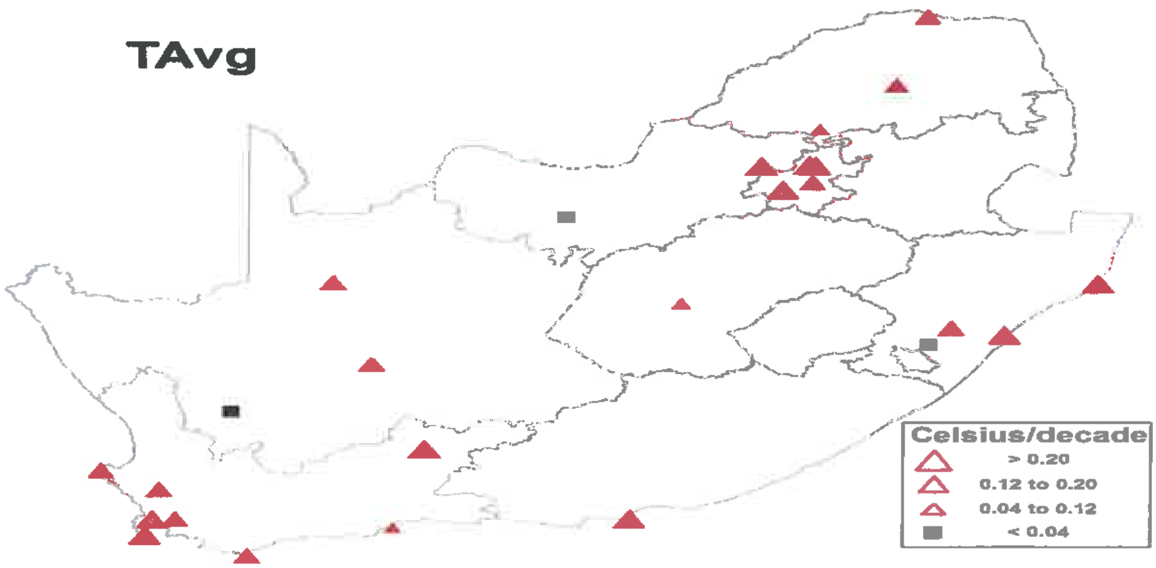


Figure 10: Trends in Average Temperature (Tavg) from (1931 to 2015) in °C per decade (filled triangles denote significance of trends at the 5% level).

The historical mean temperature and rainfall for various selected stations are as indicated in Figure 11 below. From the figures, it can be seen that November to February are the main rainfall months, and also, that is the season when temperature is very high.

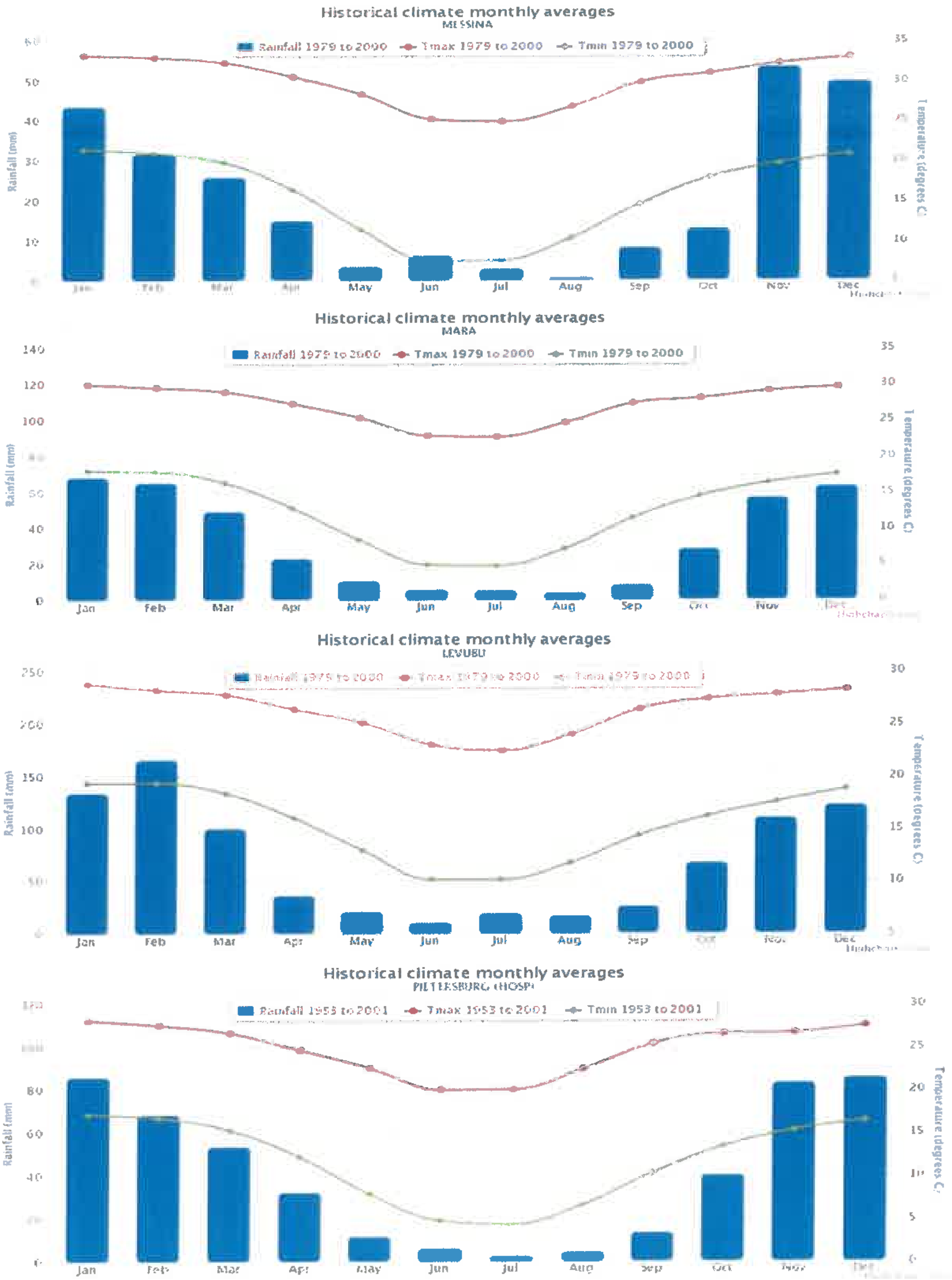


Figure 11: Historical average rainfall and temperature for Limpopo WMA

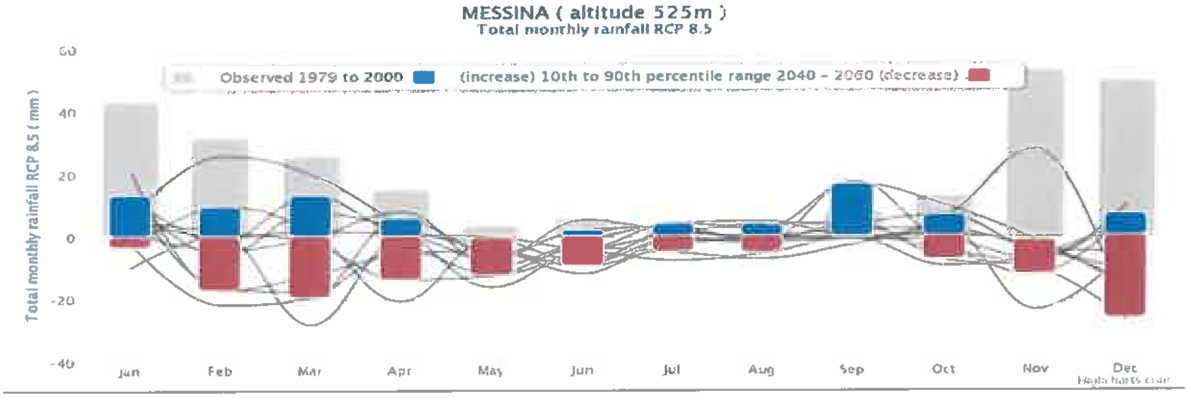
Kusangana et al (2013) indicate that long term trends analysis of atmospheric variables such as temperature; rainfall and evapotranspiration have been used extensively as proxies for detecting changes in climate. The increased frequency of occurrence of extreme events such as droughts, floods and cyclone activity in Southern Africa has also been cited as evidence of a changing climate. Kusangana et al (2013) drawn a conclusion from several studies done that temperatures are rising, with minimum temperatures rising faster than maximum temperatures. The overall result has thus been a warming trend.

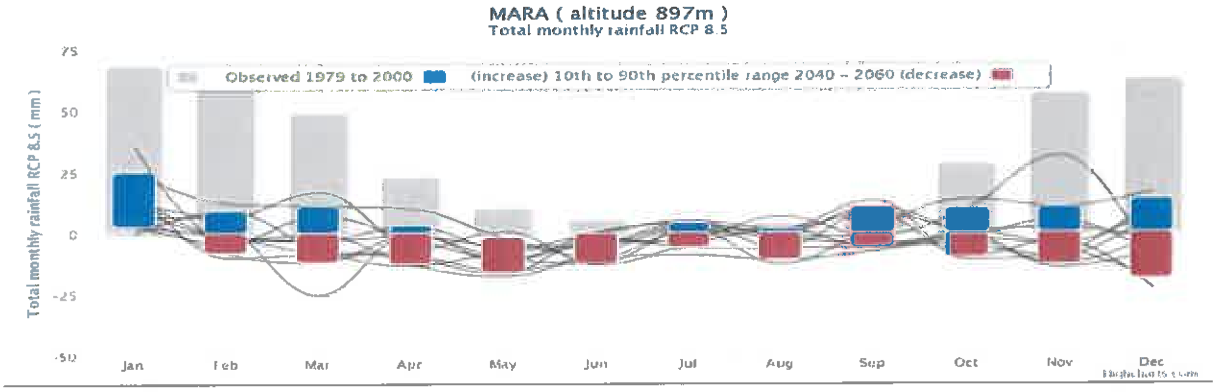
MacKellar et al., (2014) investigated the trends in annual and seasonal minimum and maximum temperatures, as well as the diurnal temperature range, over Limpopo Province, South Africa, for the period 1950 to 1999. They analysed the data for trends from 30 catchments where results shown the overall increase of 0.12°C per decade in the mean annual temperature for the 30 catchments, over the 50 year period. A non-uniform pattern of changes in temperature was evident across the different catchments; 13% of the catchments showed negative trends while 87% showed positive trends in their annual mean temperature. Furthermore, 20% of catchments showed negative trends while 80% of catchments showed positive trends in their diurnal temperature range. The seasonal trends showed variability in mean temperature increase, of about 0.18°C per decade in winter and 0.09°C per decade in summer. The significance of this work lies in the linkage of temperature to the hydrological cycle.

Changes in temperature and rainfall have a direct effect on the quantity of evapotranspiration and on both quality and quantity of the runoff. Consequently, the spatial and temporal availability of water resources, or in general the water balance, can be significantly altered with any changes in temperature. Warming will increase the frequency and intensity of tropical storms in the Indian Ocean and consequently, that coastal areas may be subject to flooding due to rising sea levels.

4.1.2. Future Climate Projections

According to the Status Quo Analysis Report for Water Resources (DWA, 2013), projected changes in rainfall in Zone 1 shows a great deal of spread and uncertainty as the region falls between areas projected to get wetter (central and eastern South Africa) and areas projected to get drier (Zimbabwe and Botswana). Projections indicate general drying (but with possible slight wetting) depending on their representation of the regional climate gradient, so this is an area of significant uncertainty. Key climate variability impacts include likely reduction in rainfall, particularly in the summer rainfall period and significant increased temperatures, and thus evaporation. Figure 12 shows the future climate projected.





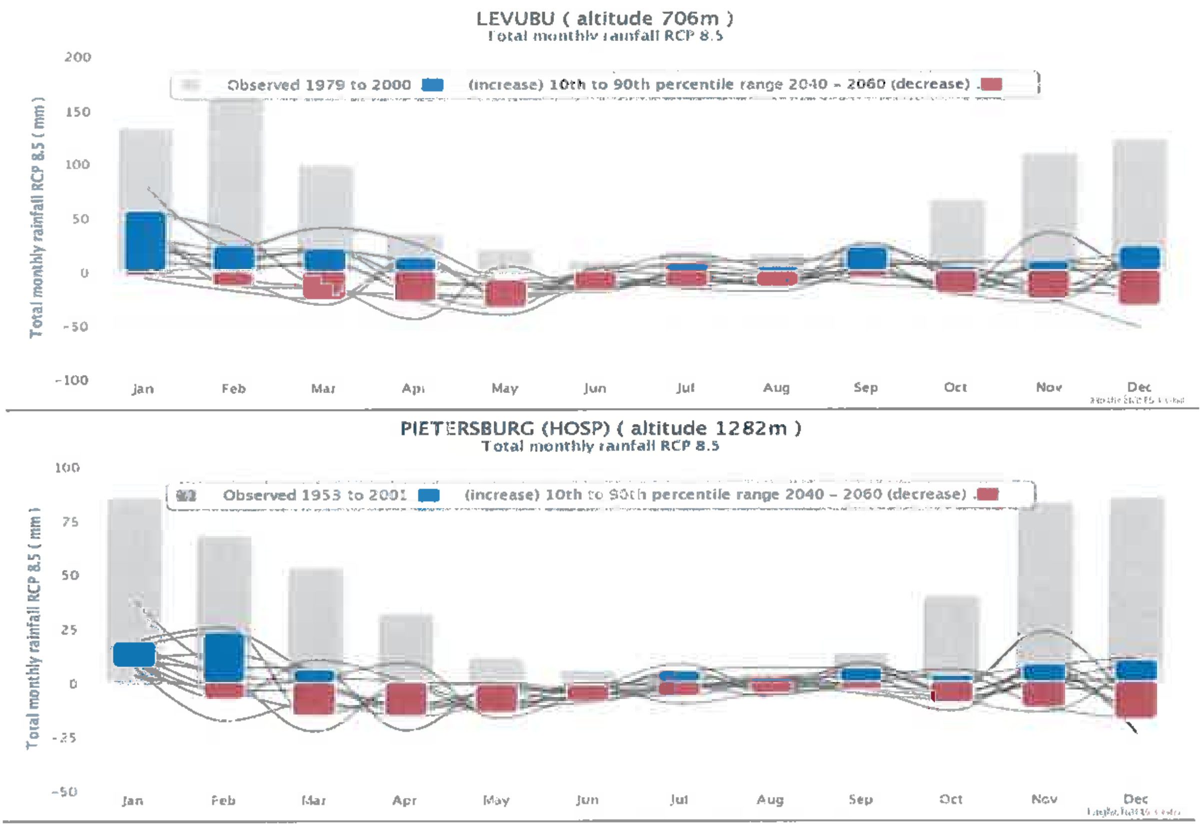


Figure 12: Future climate projections for areas in Limpopo WMA

The climate projections for Limpopo WMA suggest that temperatures are likely to increase by 2- 30C by the 2050s relative to a 1961-2000 baseline, that there is likely to be significant increase in hot and very hot days (days where temperature exceed 300C and 350C respectively), and that there are likely to be increased heatwave events. Dry spells are projected to increase in duration between March and August (i.e. in autumn and winter), suggesting increased drought risk.

4.1.3 Identified climate trends and water resource related challenges

4.1.3.1 Challenges related to drought and high temperature

The following are challenges related to drought and high temperature:

- Increased demand in water supply. With increasing population, that requires more food, there is a need to grow more food leading to more water usage.

With climate change, temperature increase would result in high evaporation, thus more demand for water supply for domestic use and food security. Currently, Limpopo WMA is one of the main tropical fruit producer, and the main tomato producing area in South Africa. Hence, with increased temperature, and reduced rainfall as a result of climate change, there would be increased demand of water supply.

- Increased deterioration of water quality. Eutrophication due to increasing nutrient concentrations is currently posing a major threat, especially around Gauteng province part of the Limpop WMA, and in the future due to climate change, the situation may be disastrous. This is currently reflected in the aggressive invasion of aquatic invasive macrophytes such as hyacinth. With expansion of mines within the WMA, acid mine drainage may also become a challenge.

4.1.3.2 Challenges related to flooding and intense rainfall

The following are challenges related to flooding and intense rainfall:

- Spill of mine waste dams, municipal treatment plants, and acid mine drainage challenges. With flooding, the pollution is carried downstream, as has been observed from dams in the Crocodile River sub-catchment, especially the Hartbeespoort Dam.
- Runoff to known water resources reduced. With mining and land use changes, landscape is altered and some voids created trap the water that was supposed to flow into rivers.

5 CLIMATE CHANGE, RISK AND VULNERABILITY CONCEPTS

5.1 Climate change

IPCC (2007) defines Climate Change as a long-term significant change in the climate over time, influenced by natural or human activities. It includes, for example:

- Unpredictable rainfall patterns leading to lack of access to safe water
- Rising temperatures and drought leading to crop failure and food insecurity
- Increased likelihood, frequency and intensity of hazards and risks, such as drought, floods and landslides and more severe cyclones (hurricanes/typhoons).

5.2 Risks

According to Knoesen (2011), risk is a function of hazard and vulnerability and, consequently, all those parameters that constitute hazard and vulnerability. It has been suggested that risk management should be imbedded within Adaptive Management. With the first step of the risk management process being hazard determination/identification, and the first step of Adaptive Management including scenario development, the integration of hydrological hazards and climate change scenarios is believed to provide an important first step in the risk / adaptive management process. Risk management control sequence of action involves the following:

- What is the threat? (*Hazard identification*).
- What are the chances of it occurring? (*Statistical hazard determination*).
- How severe could the impacts be? (*Vulnerability determination*).
- Are the effects acceptable or tolerable? (*Risk evaluation*).
- What can be done to minimise the effects? (*Risk mitigation and control or Adaptation*).

5.3 Vulnerability

According to the Intergovernmental Panel on Climate Change (IPCC) (2007), "vulnerability is the degree to which the geophysical, biological and socioeconomic systems are susceptible to, and unable to cope with, adverse impacts of climate change, including climate variability and extremes". In simple terms, vulnerability is the state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt. Vulnerability is a function of the character, magnitude, and rate of climate change and climate variation to which a system is **exposed**, its **sensitivity**, and its **adaptive capacity**. Vulnerability is driven by dimensions of exposure, sensitivity, and adaptive capacity which can either be quantitatively measured or qualitatively characterized. These dimensions or measures can be defined as follows as indicated by IPCC (2007):

- **Exposure** is the extent to which a given system will be subjected to or come into contact with a climate change impact, such as increased temperature and changes in rainfall patterns. Exposure is a measure of the magnitude and extent (i.e., spatial and temporal scales) of exposure to climate change impacts.
- **Sensitivity**, then, is the extent to which a given system can be affected by a particular climate change impact. Sensitivity is a measure of how a system is likely to respond when exposed to a climate-induced stress (e.g., high temperature and floods or drought). Sensitivity is based on inherent qualities and characteristics of an entity or system, and is an internal feature. In this study case, the biophysical characteristics of the sector or sub-sector, which influence how it responds to changes in temperature or rainfall. Together, the combination of exposure and sensitivity amount to the potential climate impact, or "risk". That the system is exposed to climate change, does not necessarily qualify it as being at risk of potential impacts. This is due to the sensitivity and adaptation potential. If the sensitivity to climate is low, then the risk is moderated. Also, if the system is sensitive to changes in climate but not exposed to climate change, then the risk will be low as well. The degree of exposure and sensitivity, in terms of magnitude and rate, hence is key to expected risk. Because a system faces a risk of climate change impacts, this does not automatically make it vulnerable, as vulnerability is a function of the system adaptive capacity.
- **Adaptive capacity** is the extent to which a system is able to exploit opportunities and resist or adjust to change. Adaptive capacity is a measure of the potential, ability, or opportunities available to decrease exposure or sensitivity of a system to a climate induced stress (i.e., adapt). Adaptive capacity is often estimated based on proven historical ability to cope with the changes in question, and for the future it is assessed

through proxies such as levels of education and income or even effective programs or policies being put in place to help the sector cope with changes in a positive manner. The greater the adaptive capacity, the lower the vulnerability; and the lower the adaptive capacity, the greater the vulnerability.

As indicated by UNEP (2012), the identification of potential key vulnerabilities is intended to provide guidance to decision makers within the sectors. Hence it is necessary as a department to understand what makes a resource or system vulnerable to climate change or climate variability, and the extent of such vulnerability. That understanding will assist in developing strategies and action plans aimed at reducing the level and extent of such vulnerability, including the ability to cope with expected changes and variability.

5.4 Criteria for identify vulnerabilities

Seven criteria's in identifying vulnerabilities as according to IPCC (2007) are expected to be considered in the assessment are as indicated below:

5.4.1 Magnitude

The magnitude of an impact is determined by its scale (e.g., the area or number of people affected) and its intensity (e.g., the degree of damaged caused), such as income or revenue losses. Cost of anticipating and adapting to certain biophysical impacts such as large sea level rise is an example of magnitude indicator. Non-monetary indicator would be the number of people affected by certain impacts such as water shortage.

5.4.2 Timing

A harmful impact is more likely to be considered 'key' if it is expected to happen sooner rather than in the distant future. Important aspect of timing is the rate at which impacts occur. In general, adverse impacts occurring suddenly (and surprisingly) would be perceived as more significant than the same impact occurring gradually, as the potential for adaptation for both human and natural systems would be much more limited in the former case.

5.4.3 Persistent and reversibility

A harmful impact is more likely to be considered 'key' if it is persistent or irreversible. Examples of impacts that could become key due to persistence include the emergence of near permanent drought condition (e.g., in semi-arid and arid regions in Africa and intensified cycles of extreme flooding that were previously regarded once-off' events (e.g., India).

5.4.4 Likelihood and confidence

Likelihood of impacts and our confidence in their assessment are two properties often used to characterise uncertainty of climate change and its impacts. Likelihood is the probability of an outcome having occurred or occurring in the future; confidence is the subjective assessment that any statement about an outcome will prove correct. An impact characterised by high likelihood is more apt to be seen as 'key' than the same impact with a lower likelihood of occurrence. Since risk is defined as consequences (impact) multiplied by its likelihood (probability), the higher the probability of occurrence of an impact the higher its risk, and the more likely it would be considered 'key'.

5.4.5 Potential for adaptation

To assess the potential harm caused by climate change, the ability of individuals, and nature to adapt to or ameliorate adverse impacts must be considered. The lower the availability and feasibility of effective adaptations, the more likely such impacts would characterised as 'key' vulnerabilities. The potential for adaptation to ameliorate the impact of climate change differs between and within systems. There is often considerable scope for adaptation in agriculture and in some other highly managed sectors. There is much less scope for adaptation to some impacts of sea level rise such as land loss in low lying river deltas. Adaptation assessments need to consider not only the technical feasibility of certain adaptations but also the availability of required resources (which is often reduced in circumstances of poverty), the cost and side effects of adaptation, the knowledge about those adaptations, their timelines, the (dis)incentives for adaptation actors to actually implement them, and their compatibility with individual or cultural preferences.

5.4.6 Distribution

The distribution of climate impacts across regions and population groups raises important equity issues. Impacts and vulnerabilities that are highly heterogeneous or which have significant distributional consequences are likely to have higher salience, and therefore greater chance of being considered as 'key'.

5.4.7 Importance of vulnerable system

A salient, though subjective, criterion for the identification of 'key vulnerabilities' is the importance of the vulnerable system or system property. Various societies and people may value the significance of impacts and vulnerabilities on human and natural systems differently. The transformation of an existing natural ecosystem may be regarded as important if that ecosystem is the unique habitat of many endemic species or contained endangered charismatic species. On the other hand, if the livelihoods of many people depend crucially on the functioning of a system, this system may be regarded as more important than a similar system in an isolated area.

6 WATER RESOURCE VULNERABILITY ASSESSMENT

Vulnerability assessment is a process for assessing, measuring, and/or characterizing the exposure, sensitivity, and adaptive capacity of a natural or human system to disturbance. The purpose of a vulnerability assessment is to generate knowledge that improves understanding of the implications of climate change. The knowledge generated by a vulnerability assessment is used to inform allocation of resources for climate change planning and adaptation (Dessai and Hulme 2004) developing policies and adaptation plans for vulnerable areas, sectors, groups, etc. as well as reducing climate change risk.

Researchers have used various methods of assessing vulnerability of water resources including indices which calculates different dimensions of vulnerability (exposure, sensitivity, and adaptive capacity) by developing indicators for each of the dimensions. Several indices have been proposed focusing on water scarcity index defined as the ration of water demand to supplied volumes. At a global level, annual level assessments have been conducted without consideration of inter-annual or seasonal variability. According to Sullivan (2011) the vulnerability assessment of water resource system can be assessed using Water Vulnerability Index (WVI). In this case, WVI is made up of a combination of measures of User and System vulnerabilities. These two sources of vulnerability are combined to generate an overall assessment of water vulnerability for a specific place. In essence, risk and vulnerability assessment is undertaken to address the following aspects of water resources:

6.1 Water resources system vulnerability assessment process – using vulnerability index

Water resource vulnerability refers to the relationship between exposure to a particular risk event, the impact of that event on water resources, and the ability of the water resource to cope with the impacts or the efforts needed to minimize the impacts (Gitay et al. 2011). The concepts of coping capacity or resilience and sensitivity are included as part of vulnerability, and they are especially important in the context of changes in the ecological character of a water resource due to climate change.

The methodology to be used in this study is adapted from UNEP (2009) "Methodologies Guidelines – vulnerability assessment of Freshwater Resources to Environmental change". As in accordance with the guideline, this assignment will follow the 'methodology guideline example' to accomplish the following:

- Desktop study to evaluate existing literature and collect the water-related data and information needed to define the most influential parameters that can define potential threats and evaluate their impact.
- Analysis of the status of water resource availability from the prevailing natural conditions, development, use and management practices as well as identification of key issues that influence resource vulnerability. Key documents and tools consulted include the CSAG, Climate Risk and Vulnerability handbook published by CSIR and the 5th IPCC Assessment Report for the projections.
- Drivers, Pressure, State, Impacts and Response (DPSIR) analysis of the water sector in order to identify and evaluate the impact of the main drivers and pressure, evaluate the current state, expected trends and expected responses to existing and future stresses.
- Estimation of the integrated vulnerability index defined in the assessment guidelines (UNEP 2009) taking into consideration the DPSIR parameters and show threats including hot spots at the catchment.
- Draw a general conclusion on water resource vulnerability that may result from natural phenomena and anthropogenic activities such as improper resource utilization, pollution, climate change impacts and finally, present conclusion and recommendations to cope with future vulnerability.

6.2 Vulnerability Index (VI)

According to the UNEP methodology, vulnerability of a river basin's water resources can be assessed from two perspectives: (a) the main threats of water resources and its development and utilization dynamics; and (b) the region's challenges in coping with these threats. Following the DPSIR framework analysis, the threats can be assessed from 3 different components of water resource and use (i.e., resource stresses; development and use conflicts; ecological security), while challenges in coping capacity can be measured within the context of the region's water resource management capacity (UNEP, 2009).

High vulnerability is apparently linked with higher resource stresses, development pressures and ecological insecurity, as well as severe management challenges. In order to quantify the vulnerability index, the indicators for each variable should be determined and quantified. The vulnerability index (VI) is estimated based on the consolidation of the values of the four main parameters mentioned below as follows: VI = f(RS, DP, EH, and MC) and can be assessed from two perspectives. The main threats to the availability of water resources, their development and water utilization dynamics. Secondly, the capacity to cope with potential national and regional threats to water availability. The vulnerability index can be assessed from the application of a number of governing equations to estimate the four parameters, as follows:

6.2.1 The Resource Stress (RS) parameter

The water stress indicator is influenced by the availability or renewable water resources and the consumption patterns of the growing population (RSs) and water variation parameter resulting from long term rainfall variability (RSv).

6.2.2 Water Development pressure (DP) parameter

Water resource availability depends on rainfall and recharge distribution patterns. Higher frequency of occurrence and higher amounts led to enhanced water availability and dependability. Supply potential is diminished by growing demand from different sectors and from pollution from different sources, placing pressure of varying degrees on water resources development.

6.2.3 Ecological health (EH) parameter

The water ecological health parameter is a measure of the impacts of pollution from different sources on ecosystem equilibrium and protection. And arid ecosystem with low resiliency requires more time to regenerate or adjust to a reasonable stage of sustainability.

6.2.4 Management capacity (MC) parameter

Water vulnerability is improved by the implementation of effective management practices that contribute to water sustainability. Evaluation of the management capacity provides a means to evaluate how effectively the water sector is being managed.

The VI provides the estimated value ranging from zero (non-vulnerable) to one (most vulnerable) to determine the sensitivity of the stress being experienced by the water sector.

A preliminary screening of the Limpopo WMA water resources vulnerability was carried out to identify critical areas. Once the analysis of the three components of vulnerability (sensitivity, exposure and adaptive capacity) is completed, aggregating components and individual indicators of vulnerability into an overall score, or index will follow. Aggregation itself is a tool for multi-criteria decision analysis which systematically reduces all values into a single number that is comparable across both time and space.

6.3 Identification of sensitive water resource areas

Sensitivity refers to the degree to which a given community or ecosystem is affected by climate stresses. From this statement, it follows that the stresses or risks must be identified first. For mapping of sensitive water resource areas or components issues of how the development modified natural flow regime of a river system, both in regard to water quality and quantity will be considered. Figure 13 below shows the framework for water vulnerability assessment that will be considered for this assignment. Sensitivity analysis is therefore dependent on the current status of the water resources or ecosystem which may be affected by land use within the catchment (increased agriculture, urbanization, water damming etc.) impacting on runoff or groundwater recharge. The impact on water quality in the Limpopo WMA that endanger the river integrity status may be due to anthropogenic activities, such as agricultural chemicals, acid atmospheric deposit, metals from mining, urban and industrial effluents, excessive sedimentation due to mismanagement of land through cultivation and grazing. The consequences that may result includes lost topsoil, salinization, acid mine drainage from mines, nutrient enriched water altering structure of aquatic ecosystems. It follows that water resources systems or ecosystems already under some kind of stresses due to anthropogenic activities will be sensitive to increase temperature and decreasing rainfall or increasing extreme conditions such as drought and floods.

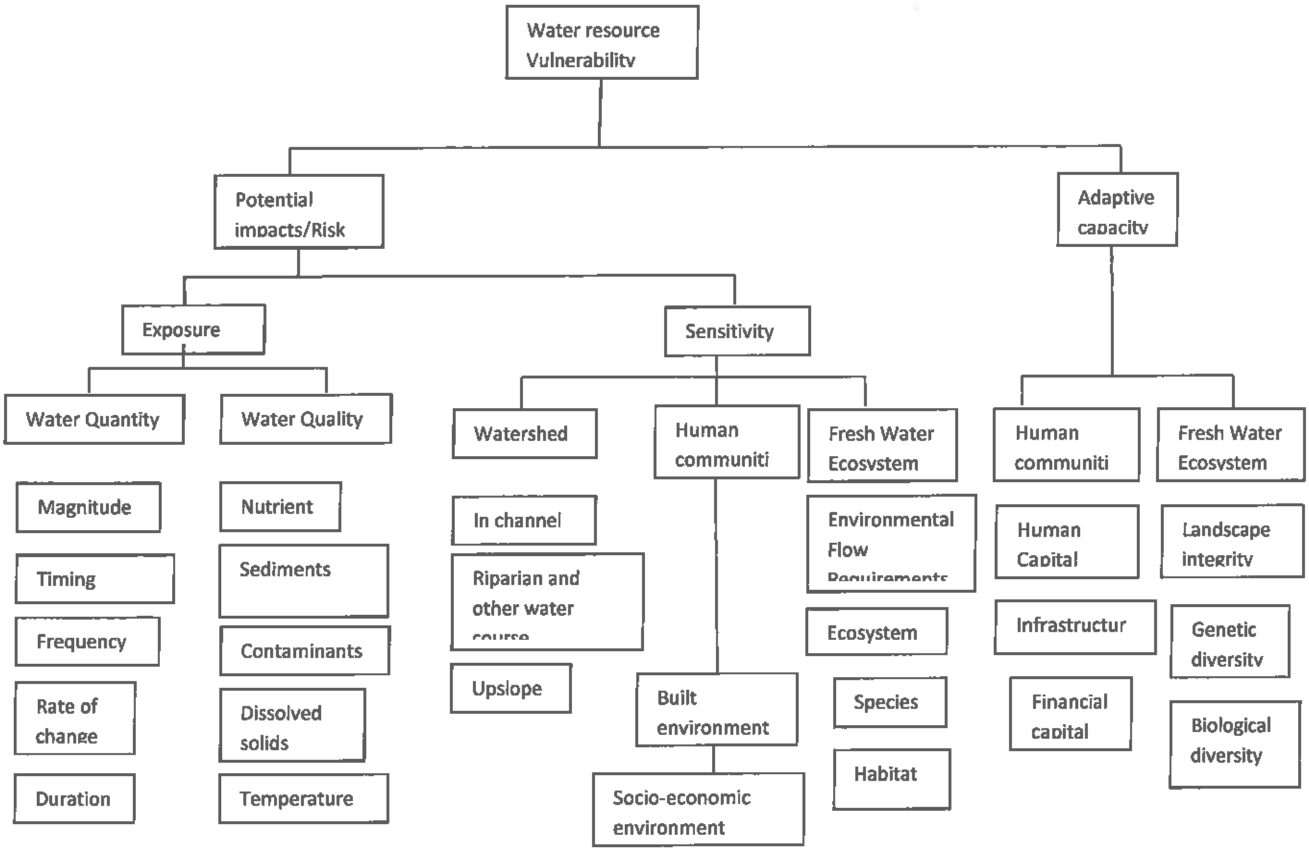


Figure 13: Framework for Water Vulnerability assessment (Adapted from Nelitz et al. 2013)

As indicated by Schulze (2014), the factors mentioned above, be either natural or anthropogenic, already render the country's water resources to be in a stressed and vulnerable state before imposition of climate change as an additional stressor which is likely to amplify these vulnerabilities. That is climate change is an added or cumulative pressure on many water resources. Points below shows some process to be followed when identifying sensitive water resource areas:

6.3.1 Identification of exposure and vulnerability to climate variability and climate change

The available downscaled climate change modelling results and projections provide necessary data on climate change drivers such as temperature and rainfall. Based on different emission scenarios, water resources systems are expected to experience varying degrees of exposure due to increasing temperatures and rainfall patterns.

6.3.2 Evaluation of the adaptive capacity of water system

For the adaptive capacity, issues such as technical skills shortage especially at the municipal sector would need to be looked into. Other thing of key importance that need consideration include aging and often dysfunctional hydraulic infrastructure that are in need of maintenance or replacement.

6.3.3 Assessment of how vulnerable selected water systems are to the effects of climate change and develop adaptation measures

Integration of various indicators of each of the three components of vulnerability assessment including exposure, adaptability and exposure is key in this process. This defines how vulnerable (high, moderate or low) is the water resource or any water resource component to the impacts of climate change currently and in future based on different scenarios chosen.

6.4 Method used for Climate Change Risk and Vulnerability Assessment of Water Resources in the Vaal

For this study, the following vulnerability assessment process was followed:

- Step1: Identify potential impacts of indicators. Indicators are a list of potential impacts that may occur as a result of climate change.
- Step 2: Assess whether the impact will take place (exposure).
- Step 3: Assess how important the risk is (sensitivity). Sensitivity is the extent to which a given system can be affected by a particular climate change impact. It is generally assed by a scale of low, medium and high.
- Step 4: Assess if we can respond to the risk (Adaptive Capacity). Adaptive capacity is the ability of a system to adjust to climate change to moderate potential damages, to take advantage of opportunities, or cope with the consequences. Adaptive capacity includes policy, institutional, social and finances to respond to changes.

Figure 14 below shows the vulnerability assessment methodology that was followed as explained above.

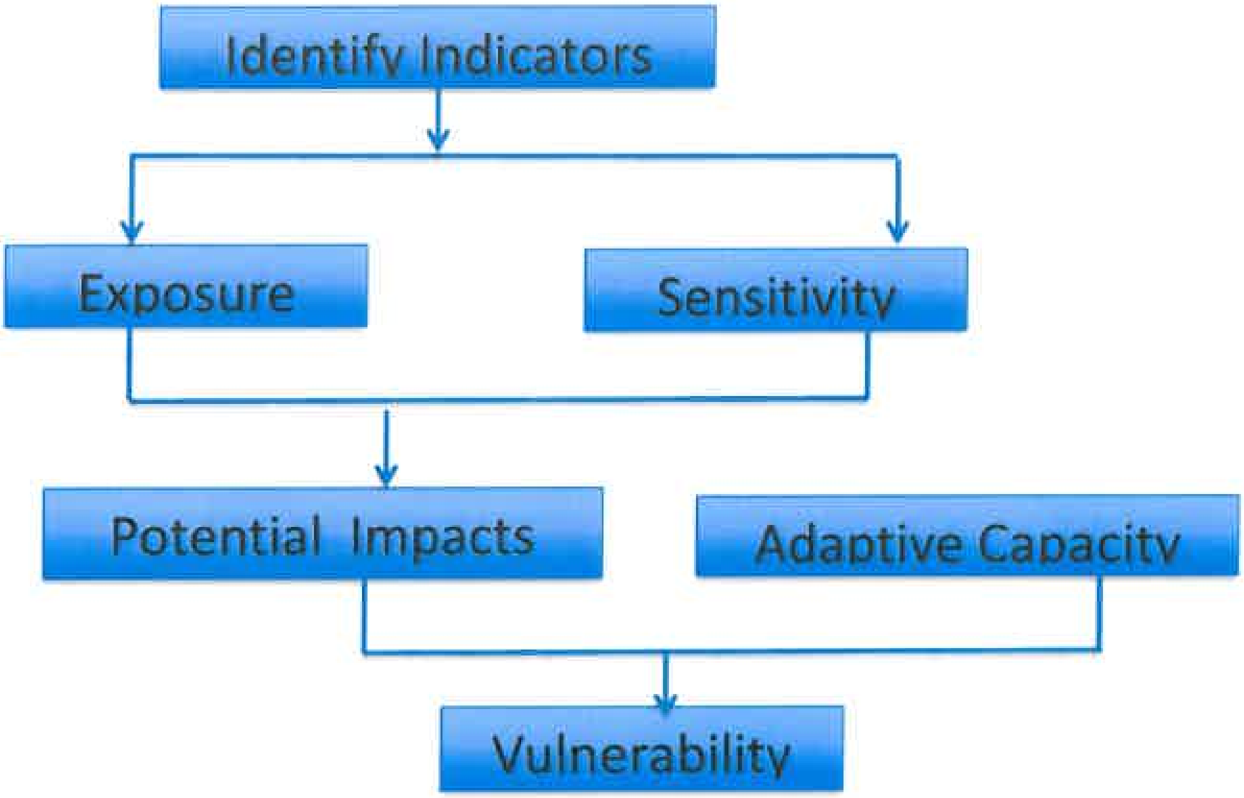


Figure 14: Vulnerability Assessment Methodology

7 RISK AND VULNERABILITY ASSESSMENT FOR LIMPOPO WMA

7.1 Introductions and observation

The process followed for risk and vulnerability assessment of climate change on water resources in the Limpopo WMA involves the following:

- Literature review of local and international work on risk and vulnerability assessment especially on water resources. That assisted in guiding what to do and how to do it.
- A profile overview for the catchment in terms of water resource situation, and the current and projected climate variability and climate change was compiled. The information on water resources was sourced from the National and Regional Offices of Department of Water and Sanitation, water reconciliation studies, and from literature review. The climate information was sourced from literature review, Department of Environmental Affairs Long Term Adaptation Scenarios (LTAS) study, University of Cape Town Climate Science Analysis Group (CSAG), 5th IPCC Assessment Report, CSIR and South African Weather Services.
- Field survey to understand the situation within the catchment was conducted. The field survey included discussion with water users along the catchment. Issues of interest were the trends of climate, water quantity and quality over time. Information was gathered about past and current climate observation and water resources issues from people familiar with the WMA.
- Attended stakeholders meeting and reviewed minutes of past meeting to understand issues (Reconciliation Strategy for the Crocodile West Water Supply System; Limpopo Water Management Reconciliation Strategy)
- The observation from field work survey, literature review, and stakeholders input was then integrated. The climate change projections was then overlaid or imposed on the current water resources situations to estimate the probable risk and vulnerabilities that may occur. Table 5 shows the land use, its possible impacts on water resources, and possible impacts that may arise due to climate change.

From the process indicated above, water resources and areas at high risk and highly vulnerable was identified using the IPCC assessment process. Table 6 below show some identified vulnerability.

Table 5: Land use, its possible impacts on water resources, and possible impacts that may arise due to climate change

Land Use	**Possible impacts on water resources**	**Possible impacts due to projected climate change (frequent drought and floods, and high temperatures)**
Mining	-Acid Mine drainage - Mining activities resulting in erosion, then sedimentation and siltation	-Increased pollution as floods spread pollution. -Increased concentration of pollutants due to high temperatures
Settlement	-Increased sanitation problems leading to -water quality impacts -Waste Water discharged from treatment plants (In Limpopo Reconciliation meeting, one attendee indicated that raw sewage is often seen flowing into water resources) - Floods collect waste from settlement into water resources (e.g., Jukskei river around Tembisa and Alexandra). - In some cases, the waste do block storm drainage system creating localised flooding	Increased pollution as floods spread pollution. -Increased concentration of pollutants due to high temperatures -Evaporation of flooded area as a result of poor storm drainage
Irrigation Farming	-Drop in level of ground water due to over exploitation (Koster, Elands and Marico river) -Return flows of water containing pesticides and chemicals from irrigated lands - Groundwater resources in the Mogalakwena and Sand cathcments is indicated to be extensively utilised, and possibly over exploited by the dominating irrigation sector	-With increased temperatures and requirement for irrigation, ground water level is expected to decrease even further. -Water pollution and increased algal blooms
Water resource	Evaporation of water from dams	Increased temperatures cause further evaporation
Rain fed crop cultivation	-because soil is disturbed during cultivation, this lead to soil erosion that ultimately end up in water resource leading to sedimentation and siltation - siltation leads to reduced water infiltration thereby negatively affecting groundwater recharge -sedimentation reduces the storage capacity of water resources -fertilizers and pesticides applied on crops end up in water resources as they are washed off during rain periods	-Water quantity reduced and demand increased - increased water quality challenges
Urban settlement	-Increased population leading to increased water demand Increased population leading to increased settlement development that may result in storm water drainage problems. -Challenge of water supply as infrastructure will be over-burdened -The expanding urban and industrial requirements of	-Increased demand of water quantity -Increased water quality problems

	Polokwane and Makhado LMs, currently supplied by Albasini dam, rely heavily on water transfers from adjacent WMAs. This includes transfers from Ebenezer Dam, Dap Naude Dam, Flag Boshielo Dam, and Nandoni Dam in the Olifants River Catcments	
Livestock grazing	-Demand for meat lead to increased livestock, resulting in overgrazing, erosion, then sedimentation and siltation	Increased demand of water quantity
Rainfed Agriculture	because soil is disturbed during cultivation, this lead to soil erosion that ultimately end up in water resource leading to sedimentation and siltation - siltation leads to reduced water infiltration thereby negatively affecting groundwater recharge -sedimentation reduces the storage capacity of water resources -fertilizers and pesticides applied on crops end up in water resources as they are washed off during rain periods	-Increased demand of water quantity -Increased water quality challenges
Communal settlement	-Pit latrines that are not lined lead to underground water pollution -Communal grazing system results in overgrazing, erosion, then sedimentation and siltation of water resources.	-Increased demand of water quantity -Increased water quality challenges
Allien plant & Bush encroachment	-High evapotranspiration resulting in groundwater reduction - Bush encroachment outcompeting grassland leading to reduced water infiltration	Reduced water quantity and water storage

Potential climate related risks were identified through assessment of the interaction between the climate baseline and future climate scenarios, and the current water resources issues and conditions. Water quality and quantity related issues were noted and from there, vulnerability was assessed based on exposure, sensitivity, and adaptive capacity. Table 6 below shows the vulnerability assessment.

Table 6: Vulnerability Assessment table

WMA	Indicator	Exposure	Sensitivity	Adaptive Capacity	Vulnerability	Comments
Old Crocodile (West) Marico	Surface water level	Medium	Medium	Low	Medium	Taking projected increase temperature and decrease in rainfall into considerations, plus increase population and demand for water use by different water users, the surface water is expected to decrease.
	Ground water level	Medium	High	Low	High	Ground water levels are currently affected in areas where it is being utilized especially for irrigation such as in Marico, Lower crocodile and Elands catchment. Poor recharge due to reduced rainfall, and evapotranspiration are part of the reason for vulnerability.
	Water Quantity	Medium	Medium	Low	Medium	Consideration of surface water and ground water levels

	Water Quality	High	High	Low	High	Water quality is currently a challenge, and with projected climate changes, and increased population the situation seems will continue being bad.
	Siltation and Sedimentation	Medium	Medium	Medium	Medium	As a result of conventional tillage, overstocking and overgrazing, and droughts followed by floods, soil is disturbed getting prone to erosion, then deposited to water resources during floods.
	Water for Water resources (e.g., Stream Water) Reduction Activity	Medium	Medium	Medium	Medium	Due to Invasive plants and bush encroachment
	Loss of Riverine Ecosystem	Low	Medium	Medium	Medium	Due to sand mining, the riverine ecosystem is removed. This in the long run lead to river width to enlarge there by turning deep and small width rivers into wide rivers. This result in water to be exposed for evaporation
	Loss of Wetland ecosystem	Medium	Medium	Medium	Medium	Due to long periods of drought, some wetlands have disappeared. With projected reduction in rainfall and increased temperatures, the situation may get worse
	Evapotranspiration	High	High	Low	High	With projected reduction in rainfall and increased temperatures, plus bush encroachment, evapotranspiration would be high
	Transboundary water Transfer	Medium	Medium	Medium	Medium	Crocodile West/Marico WMA has in-transfers (Vaal WMA) of which the situation from those catchments may affect the water situation in the Limpopo WMA.
Limpopo WMA (North)	Surface water level	Medium	Medium	Low	Medium	Taking projected increase temperature and decrease in rainfall into considerations, plus increase population and demand for water use by different water users, the surface water is expected to decrease.
	Ground water level	Medium	Medium	Low	Medium	Ground water levels are currently affected in areas where it is being utilized especially for irrigation. Poor recharge due to reduced rainfall, abstraction by alien vegetation and bush forest, and evapotranspiration are part of the reason for vulnerability.
	Water Quantity	Medium	Medium	Low	Medium	Consideration of surface water and ground water levels
	Water Quality	High	High	Low	High	Water quality is currently a challenge, and with projected climate changes, and increased population the situation seems will continue being bad.
	Siltation and Sedimentation	Medium	High	Medium	Medium	As a result of conventional tillage, overstocking and overgrazing, and droughts followed by floods, soil is disturbed getting prone to erosion, then deposited to water resources during floods. Some dams are indicated to be filled with sediments.
	Water for Water resourc	Medium	Medium	Medium	Medium	Due to Invasive plants and bush encroachment water abstraction. Some developments also change water ways, where some of water does not reach rivers, instead do evaporate, e.g. mining.

	es (e.g., Stream Water) Reduction Activity					
	Loss of Riverine Ecosystem	Medium	Medium	Medium	Medium	Due to sand mining, the riverine ecosystem is removed. This in the long run lead to river width to enlarge there by turning deep and small width rivers into wide rivers. This result in water to be exposed for evaporation. Also due to drought, aquatic vegetation is replaced by terrestrial vegetation.
	Loss of Wetland ecosystem	Medium	High	Low	High	Due to long periods of drought, some wetlands have disappeared. With projected reduction in rainfall and increased temperatures, the situation may get worse. Also due to drought, aquatic vegetation is replaced by terrestrial vegetation.
	Evaporation	High	High	Low	High	With projected reduction in rainfall and increased temperatures, plus bush encroachment, evapotranspiration would be high
	Transboundary water Transfer	Medium	Medium	Medium	Medium	Limpopo WMA has in-transfers (Olifants and Vaal WMA) of which the situation from those catchments may affect the water situation in the Limpopo WMA. Also, there are transboundary agreement (LIMCOM) of which climate change may lead to agreement reconsiderations thereby affecting water situation in the WMA

From the table above, it can be seen that water quality and quantity are highly vulnerable to climate change. Though much of the challenge is due to human induced activities, climate change as an attribute, will amplify the challenges.

7.2 Attributes of climate change impacts on water resources

It should be taken into account that even before climate change is considered; our water resources are already stressed and impacted. Hence, climate change will magnify some of the water resources challenges. The following points highlight the attribution of climate change on indicators indicated in table 6 above:

- Surface water level – with climate change, models predict decreased, rainfall and increased temperature. These factors will affect the level of water as reduced rainfall and increased temperature will result in evaporation reducing the level of water even further.
- Groundwater level – with reduced rainfall, ground water will not be well recharged. Adding temperature, which will result in high evaporation, will lead to groundwater levels dropping even further.
- Water quantity – because of reduced surface and groundwater levels, the yield of water resources will be affected, resulting in changes in water quantity.

- Water quality – reduced rainfall and increased temperature would result in reduced dilution where total dissolved solids concentration would increase. This in some cases will lead to increased algal bloom and other water toxicity.
- Siltation and sedimentation – models project high rainfall at short space of time. Often, a flood happens after some dry spell periods. During dry spell periods, soil has been loosen up as in some cases the vegetation would have been removed. Then, when floods come, the erosion impact becomes severe leading to high siltation and sedimentation. Siltation in turn becomes a layer on topsoil that impedes water infiltration, and affects groundwater recharge. Sedimentation in turn accumulates in water resources thereby reducing the volume that should be occupied by water.
- Water for water resources reduction activity - high evapotranspiration as a result of bush encroachment due to natural vegetation adaptation, water is intercepted before it reaches the water resources. This, like stream water reduction activity, reduces the water yield in water resources.
- Loss of Riverine Ecosystem - Most of the small rivers due to increased temperatures, their water temperatures changes, or they become dry most of the time. As a result the aquatic ecosystem in the long run becomes terrestrial. The terrestrial ecosystem, such as hardy plants tend to abstract more water due to evapotranspiration. Also, some animal species who cannot adapt as a result of increased temperatures would move to tolerable areas (e.g., fish migration due to increased water temperature).
- Loss of Wetland ecosystem - Due to long periods of drought, high temperature and reduced rainfall, some wetlands have disappeared or will disappear.
- Evapotranspiration - Due to low precipitation and high temperature, and increase in bush encroachment, evapotranspiration has potential to negatively impact on water availability.
- Transboundary water Transfer – The Limpopo WMA is interlinked with other catchment due to transfers, and downstream flow and international obligations. Hence, climate change conditions in one catchment have a potential to affect and impact water resources situation in another catchment. For example, the Vaal which supply water to greater parts of Gauteng province, is highly dependent on the Lesotho Highlands Water Project. The climate change impacts in Lesotho will then impact on the Vaal system. Also, that Limpopo WMA, shares boundary with Botswana,

Zimbabwe and Mozambique, transboundary climate change issues and water resources need to be taken into account.

8 IDENTIFIED CLIMATE TRENDS AND WATER RELATED CHALLENGES

8.1 Possible Impacts On Water Resources Due To Current And Projected Climate Variables Trends in the Limpopo WMA

Climate change drivers directly affect the quantity and quality of water resources by changing run-off patterns (flow variability, duration, and timing), increasing the frequency and intensity of extreme events (drought and floods) and changing groundwater recharge rates. Non-climatic factors such as land use, population, development and others, add more stress to the water resources in addition to climate variability and climate change. Some of the issues of note are as indicated below:

8.1.1 Challenges related to drought and high temperature

The following are some of the key noted challenges related to drought and higher temperatures:

- Lower than normal precipitation levels and increasing dry spells and drought result in water shortages.
- Lower than normal precipitation levels and increasing drought result in water quality issues.
- High temperatures, heat waves and wild fires events pose a risk of water quantity and quality (due to evaporation, damage of infrastructure such as a water conveying pipelines).
- Dry spells or drought events result in increased dust generation and erosion leading to sedimentation and siltation.

The following points are expanded issues as a result of, or that lead to key points noted above:

- Decreased water supply and water quality. Most of the Towns are supplied by small dams and when there is no or there is little rainfall with high temperatures, the dam dries up leading to water supply shortage problem.
- Nutrients become concentrated in water resources leading to algal formation and toxicity of water especially in the small dams that municipalities are dependent on for

water supply. The Hartbeespoort Dam algal bloom situation due to waste water inflow from Johannesburg area is a serious problem.

- Water evaporates from the resources leading to reduction in water availability. Also, the soil moisture gets reduced leading to drier situation thereby affecting the groundwater recharge potential.
- Siltation and sedimentation of small dams due to unsustainable land use such as farming activities and drought result in erosion.

8.1.2 Challenges related to flooding or intense rainfall

The following are some of the key noted challenges related to flooding or intense rainfall:

- Flood events cause polluted water to overflows and spill. Spill of mine waste dams and municipal waste treatment plants is carried down the water resources. This cause further pollution to areas where there was no water pollution. It should also be noted that pollution impact especially from mines is cumulative over time.
- Some mines are shallow and have a decanting problem, thus with intense flooding, decanting becomes more serious.
- Floods tend to collect all the dirt and dispose it in the water resource such as river or dam.
- The Crocodile west and Marico catchment are a crop producing area, so with intense rainfall, fertilizers and pesticides may be washed away into the nearest stream, and or infiltrate into groundwater. Also, too much rainfall causes erosion leading to sedimentation and siltation.
- Projected extreme events of flash floods in the Gauteng parts of crocodile catchments, with accompanied poor drainage systems, will also have an impact on drainage of water ways which may ultimately evaporates instead of flowing into water resources, as can be seen in the Figure 15 below.

Figure 15: Poor drainage system

Table 7 below summarizes some of the climate change effect on water resources, its impact and possible consequences.

Table 7: Effects, impacts and consequences of climate change

Climate Effect	Impact	Consequences
Increased aridity (decrease in rainfall and increase in temperature)	• Supply demand deficit. • Increased demand of water. • Increase in evaporation from open water (reservoir and wetlands). • Changes in water quality. • Algal growth	• Less water available and increased competition for water. • Additional water treatment required increasing energy use. • Public health issues • Impacts on habitats and species. • Deterioration in water quality.
Intense rainfall events	• Sewer flooding and spills; flooding • Dam failure	• Pollution incidents and deterioration in water quality. • Loss of life and loss of water supply. • Potential damage and disruption
Low rainfall events	• Drought. • Habitat change due to reduced water availability.	• Less water available for users including the environment. • Poor water quality

	• Changed recharge and low groundwater levels • Change in yields for water supply. • Low flows.	
Changes in rainfall	• Erosion and sedimentation	• Reduction in water storage and yield

9 POSSIBLE SOLUTIONS TO DEAL WITH CLIMATE CHANGE RISK AND VULNERABILITY ON WATER RESOURCES

Among the adaptation solutions to deal with climate change risk and vulnerability on water resources for the Limpopo WMA, the following strategic actions as indicated in Climate Change Strategy for Water Sector should be considered:

- Water governance – this would be achieved through adaptive approach, building adaptive institutions, intergovernmental relations and collaborations, awareness and communication, building resilience and reducing vulnerability, research and development, regional engagement, and climate financing. It is crucial for every individual and sectors to know that the climate and water challenges are everyone's challenges, hence, combined efforts will go a long way.
- Infrastructure development, operation and maintenance - this would be achieved through increasing water supply and sanitation, flood protection measures, infrastructure safety, and hydro-geo-meteorological monitoring system.
- Water management - this would be achieved through scenario planning and climate modelling, vulnerability assessment, planning and strategies, water allocation and authorisation, water conservation and demand management, water quality management, resource management and protection, and disaster management.

It is also important to note that some of these strategic actions are already in place within the South African water resource management aspects. However, more monitoring, research and resources needs, need to be done to assess which of the said strategies are more suitable for specific areas.

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