Atmospheric Conditions and Precipitation in Arid Environments: A Case of Namibia

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***Abstract*-This study evaluates the atmospheric conditions and precipitation interactions in Namibia to provide the basis for monitoring and improving conditions relating to water storage, recharge, and quality, as well as preserving small quantities of available fresh water, and improving existing water resource augmentation programs. Atmospheric conditions including temperature, wind speed, relative humidity, solar radiation, atmospheric water-holding capacity, and aerosol load, morphology, and size distribution were determined for the Southern African Science Service Centre for Climate Change and Adaptive Land Use (SASSCAL) weather/research stations situated in the Kuiseb, Cuvelai-Etosha and Okavango-Omatako Basin, in Namibia. Inferential statistical analysis of the atmospheric conditions, and historical meteorological and hydrological data yielded information on the occurrence (onset, intensity, and frequency) of precipitation in Namibia. The study also showed that the water-holding capacity of the Namibian atmosphere increased as the temperature increased; aerosol pollution close to Cuvelai and Kuiseb masked the ground and reduced moisture supply; thus, the Namibian warm climate increased risks of drought during non-rainy periods, and floods during rainy periods, but at different times and/or places.**

Keywords- Precipitation; Meteorological Parameters; Aerosol Load; Aerosol Morphology; Total Suspended Particles; Atmospheric Water-holding Capacity

I. INTRODUCTION

Precipitation forms as water vapor condenses, usually in rising air that expands and therefore cools. The upward motion comes from air rising over mountains, warm air riding over cooler air (warm front), colder air pushing under warmer air (cold front), convection from local heating of the surface, and other weather and cloud systems [1]. Precipitation is intermittent; Trenberth [1] reported that precipitation characteristics greatly depend on temperature and other atmospheric conditions. Heated by the sun's radiation, the ocean and land surface evaporate water, which then travels with winds in the atmosphere, condenses to form clouds, falls back to the Earth's surface as rain or snow, and finally flows back to the oceans via rivers to complete the global hydrological (water) cycle.

According to the Intergovernmental Panel on Climate Change (IPCC) [2], increasing average global temperatures will result in a number of impacts on the hydrological cycle, including changes in precipitation. Precipitation will be directly impacted by changes in atmospheric circulation and increases in water vapor and evaporation associated with warmer temperatures. This will result in an overall increase in precipitation, though the magnitude of this increase is uncertain. Any change in precipitation amount will result in corresponding regional changes in runoff, thus impacting water supply management regimes. Water resource managers in semi-arid regions will be most vulnerable to changes in precipitation, since runoff and river flows in these areas are particularly sensitive to changes in precipitation. Additionally, changes in average rainfall affect groundwater recharge rates, thus impacting water supply.

Aerosols have complex effects on clouds and precipitation. Several researchers including Albrecht [3] hypothesized that aerosols increase cloud lifetime because increased concentrations of smaller droplets lead to decreased drizzle production and reduced precipitation efficiency. Aerosols and their effects on clouds and precipitation are one of the key components of the climate system and the hydrological cycle; however, the scientific community's understanding of aerosol effects on clouds and precipitation is inadequate [4]. Aerosols tend to suppress precipitation because the particles decrease the water droplet size in clouds [5]. All aerosol species can play important roles in the radiative balance of the atmosphere (and hence climate change and variability) on urban, regional, and global scales [6]. Aerosols often complicate expectations for changes in overall precipitation amounts. Particulate aerosols block the sun and reduce surface heating. Some aerosols, notably carbonaceous ones, absorb radiation, which directly heats the aerosol layer that otherwise would have been heated by latent heat release in precipitation following surface evaporation. Hence, aerosols affect the hydrological cycle [7] both at local and global levels.

Namibia is characterized by a complex earth-atmospheric interactions system of high temperature, low relative humidity, high evaporation, and evapo-transpiration inland; low precipitation, low temperatures, and moist air at the Atlantic coast (Namib Desert); high temperatures and frequent floods in the north-east; and high temperatures and alternating floods and droughts in the central-north. The high temperature and wind speed, low relative humidity, greater insolation, and less cloud cover naturally lead to increased evaporation and transpiration; this results in meteorological drought, which can lead to soil water deficiency and plant water stress, reduced biomass and yield (agricultural drought); and finally, depending on the time period, a hydrological drought (reduced streamflow, inflow to reservoirs, lakes, and ponds; reduced wetlands and wildlife

DOI: 10.5963/IJEP0601017

habitat).

Of all precipitation received annually in Namibia, about 83% evaporates, 14% is consumed by vegetation, 2% becomes runoff, and 1% recharges groundwater [8]. Due to shortages in surface water, the country relies heavily on groundwater reserves, which are subject to low recharge rates from rainfall and periodic ephemeral floods [9]. The increasing occurrence and severity of floods, as well as water resource shortage, is one of the worst hazards to the global ecosystem linked to global warming [10]. In this study, the impacts of atmospheric conditions (saturation vapor pressure, mixing height, temperature, wind speed, relative humidity, solar radiation, and ventilation rates, roughness, boundary layer and aerosol pollution load) on the frequency and intensity of precipitation in the vicinity of the Kuiseb, Cuvelai-Etosha, and Okavango-Omatako Basin were investigated.

This paper reports initial findings to prove the hypotheses implied by the International Panel on Climate Change (IPCC) simulations and empirical evidence, i.e. (1) warmer climate increases risks of both drought where it is not raining, and floods where it is, but at different times and/or places; (2) the water-holding capacity of the atmosphere increases (following the Clausius-Clapeyron relation) as temperature increases; and (3) aerosol pollution masks the ground from direct sunlight, thereby decreasing evaporation and reducing the overall moisture supply to the atmosphere. The premise of this study is thus: an understanding of the atmospheric water-climate interactions in Namibia can provide the basis for monitoring and improving our understanding of water storage, recharge, and quality; it can also lead to better preserving small quantities of available fresh water, improving existing water resource augmentation programs, and improving community adaptive capacity to climate change.

II. MATERIALS AND METHODS

A. *Description of Study Sites*

The Southern African Science Service Centre for Climate Change and Adaptive Land Use (SASSCAL) weather/research stations used for this study were Dieprivier (Namib Desert Lodge), Windhoek (NBRI), Omatako Ranch, Okashana, Sonop Research Station, and Alex Muranda Livestock Development Centre. These were selected based on their proximity to the Kuiseb, Cuvelai-Etosha and Okavango-Omatako Basin. Table 1 gives a summarized description of the study sites.

TABLE 1 LOCATION, POPULATION AND ECONOMIC ACTIVITIES AT THE STUDY SITES

Study Site/ Research Station	**Longitude; Latitude [Altitude (m)]**	**Region/ Constituency**	**Population**	**Economic Activities**	**Reference**
Alex Muranda Livestock Development Centre	19.2562; -18.3643 [1166]	Kavango West, Mankupi Constituency	Kavango has a population of about 222 500	80% dependent on agricultural activities	NPC [11] Pröpper et al[12]
Sonop Research Station	18.9039; -19.0101 [1218]	Otjozondjupa region, approximately 120 Km north-east of Grootfontein	Otjozondjupa region has a population of about 142 400	1. A state-owned farm solely used for agricultural research; it is surrounded by cattle and crop farms 2. Other activities in the region include cement mining/limestone quarrying	Kutuahupira et al. [13] NPC [11]
Dieprivier (Namib Desert Lodge)	15.8947; -24.1296 [1056]	Situated in the Greater Sossusvlei Namib Landscape (GSNL), Hardap Region	The region has a population of about 76 000	The area is characterized by farming and tourism activities such as quad biking, game drives, and hiking.	NPC [11]
Okashana	16.63852778; -18.41111 [1106]	located in the Oshikoto region	The region has a population of about 181 600	The majority of locals in this region depend on agricultural activities for a living.	Wilhelm [14] NPC [11]
Omatako Ranch	16.7291; -21.5094 [1496]	located in the Ombotozu constituency, Otjozondjupa region	The Otjozondjupa region has a population of about 142 400	Activities in the region include agriculture, tourism, and other domestic activities.	NPC [11]

DOI: 10.5963/IJEP0601017

Windhoek (NBRI)	17.0957; -22.5707 [1700]	located in Khomas region	The Khomas Region has a population of about 340 900	The multi-activities of this region include agricultural (farming with crops and animals), industrial, and domestic activities.	NPC [11]

Fig. 1 shows the exact location of the study sites within the different water basins. The black numbers represent the spatial distribution of water resources (surface and ground water) in Mm3/annum as provided by the Department of Water Affairs and Forestry, within the Ministry of Agriculture, Water and Forestry (MAWF).

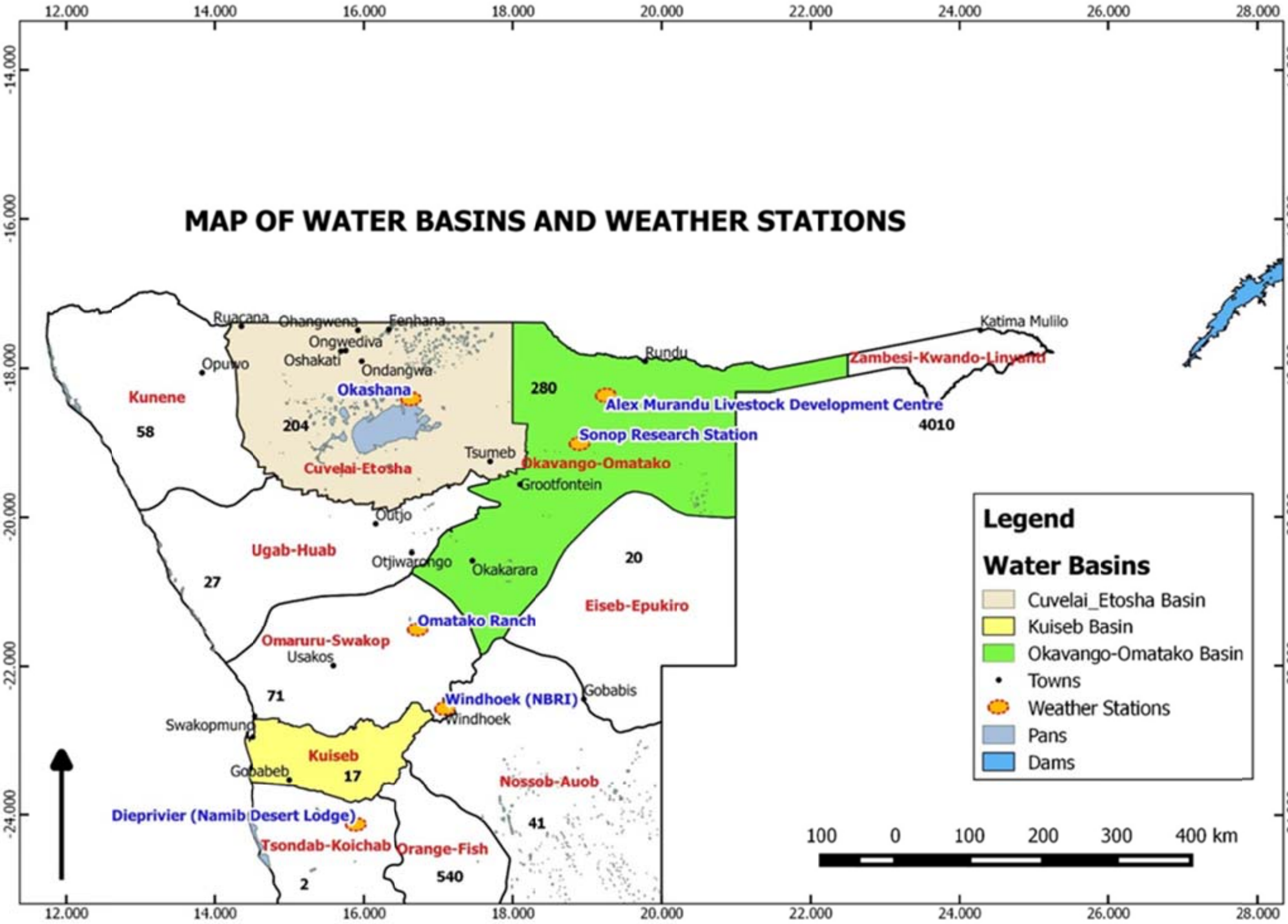


Fig. 1 Location of study sites/weather stations and Basins used in this study

B. Extreme Precipitation Events Experienced Around the Study Sites

The study sites in this research were chosen to demonstrate the varied precipitation extreme events relating to the atmospheric conditions, and their impact on water management strategies for the country. Namibia is characterized by alternating floods and drought in the Northern regions, and frequent drought in the south; the country experienced the worst drought in 1982/3 [15] and the most intensive flood in 1934 [16].

The Alex Muranda Livestock Development Centre, located in the Kavango Region, has been severely affected by both drought and flood over the past 10 years [14]. Tshilunga [17] reported that the periods of the most extreme precipitation events at the Okashana and Kavango regions (Alex Muranda and Sonop Research Station) were 1982/3, 2013, and 2015 for drought, and 1934, 2004, 2007, 2009, and 2011 for flood. The extreme events, together with the land clearing for agricultural activities and the actual farming activities at these study sites, could potentially contaminate the main water sources (i.e. groundwater at Okashana and the Okavango River at Kavango) in the two regions.

The Dieprivier (Namib Desert Lodge) is located in the Namib Desert. The inhabitants of the area are solely dependent on underground water that is extracted through boreholes. There is no extreme precipitation events recorded for this study site.

The Windhoek NBRI study site experienced drought in 1982/3 and flood in 1934, 2009, and 2011 [15]. The water used in Khomas (Windhoek) consists of reclaimed water, surface, and groundwater.

DOI: 10.5963/IJEP0601017

C. Sampling and Analysis of Aerosols

Sampling and morphological analysis of aerosols/atmospheric particulates were conducted in Ondangwa and Windhoek to determine the effects of aerosol pollution on moisture supply and precipitation within the Kuiseb and Cuvelai-Etosha Basins. Ten aerosol pollution measurements and morphological analyses were made in 5 locations in Ondangwa during January 2014. Samples for Windhoek were collected from seven (7) locations, namely Cimbebasia, Rocky Crest, Greenwell Matongo, Freedomland, Goreangab, Hakahana, and Havana in February 2014. The sampling and analysis procedures are explained in Kgabi et al. [18].

Aerosol Optical Depth data was obtained from a CIMEL Multiband photometer CE318-N, an AERONET sun photometer installed at the Namibia University of Science and Technology in Windhoek, Namibia. A sun photometer collected Aerosol Optical Depth data at 15 minute intervals throughout the daylight hours. A detailed description of the instrument and operation procedures is given in CIMEL [19] and the quality control is expounded in Holben et al [20].

D. Analysis of Atmospheric Conditions

Inferential statistical analysis and simulations of the atmospheric conditions based on meteorological data (obtained from the official website of the SASSCAL project) were conducted to generate information on precipitation occurrence (intensity and frequency) in Namibia.

The water-holding capacity of the atmosphere was determined by computing the saturation vapor pressure following the Clausius-Clapeyron (C-C) equation (which also governs the amount and type of precipitation), which is simplified in terms of the August-Roche-Magnus equation. The relation implies that saturation water vapor pressure changes approximately exponentially with temperature under typical atmospheric conditions, and that the water-holding capacity of the atmosphere increases by about 7% for every 1 °C rise in temperature [2].

III. RESULTS AND DISCUSSION

A. Intensity and Frequency of Precipitation

Changes in the location, type, amount, frequency, intensity, and duration of precipitation depend on climatic variations [1]. Fig. 2 shows the mean annual precipitation for 2010 to 2015 for the six study sites.

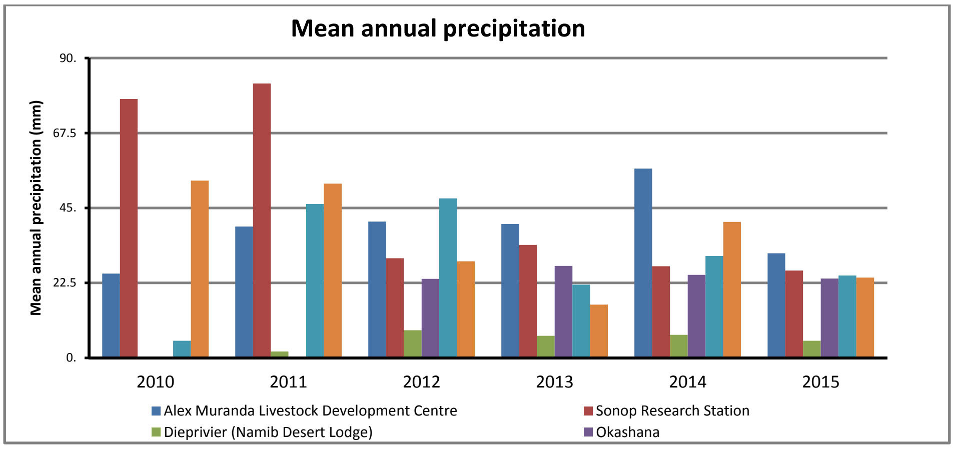


Fig. 2 Annual precipitation for the six study sites

The rainfall intensity shown in the Figure positively correlates to the availability of surface and ground water (i.e. 280, 204 and 27 Mm3 for Okavango-Omatako, Cuvelai-Etosha and Kuiseb respectively) in the Basins presented in Fig. 1.

Table 2 shows precipitation variations with temperature, solar irradiance, and relative humidity.

DOI: 10.5963/IJEP0601017

TABLE 2 PEARSON'S CORRELATION COEFFICIENTS OF RAINFALL AND OTHER METEOROLOGICAL PARAMETERS

	at	WS	RH	LW	SI	ST
Alex Muranda	-0.541	-0.360	0.603	-0.815	-0.518	-0.633
Sonop	0.366	-0.443	0.439	0.139	0.582	0.396
Dieprivier	0.835		0.499	-0.475	-0.105	0.886
Okashana	0.932	-0.643	-0.601	-0.477	0.967	1.0
Omatako	-0.819	0.590	0.566	0.286	-0.755	-0.772
Windhoek	0.291	-0.423	0.503	0.502	0.540	0.006
AT - Air Temperature, WS - Wind Speed, RH - Relative Humidity, LW - Leaf Wetness, SI - Solar Irradiance, ST - Surface Temperature						

According to Tremberth and Shea [21], clues to changes in precipitation come from local correlations of monthly mean precipitation with temperatures. Atmospheric temperature is a measure of temperature at different levels of the Earth's atmosphere. It is governed by many factors, including incoming solar radiation, humidity and altitude.

Negative correlations of air temperature (AT) and surface temperature (ST) to rainfall were observed at the Alex Muranda and Omatako study sites; the high positive correlation of AT and ST to rainfall at the Dieprivier and Okashana sites confirm that a warm Namibian climate increases risks of drought where it is not raining, and floods where it is, but at different times and/or places. Even as the potential for heavier precipitation occurs from increased water vapor amounts, the duration and frequency of events is curtailed, as it takes longer to recharge the atmosphere with water vapor.

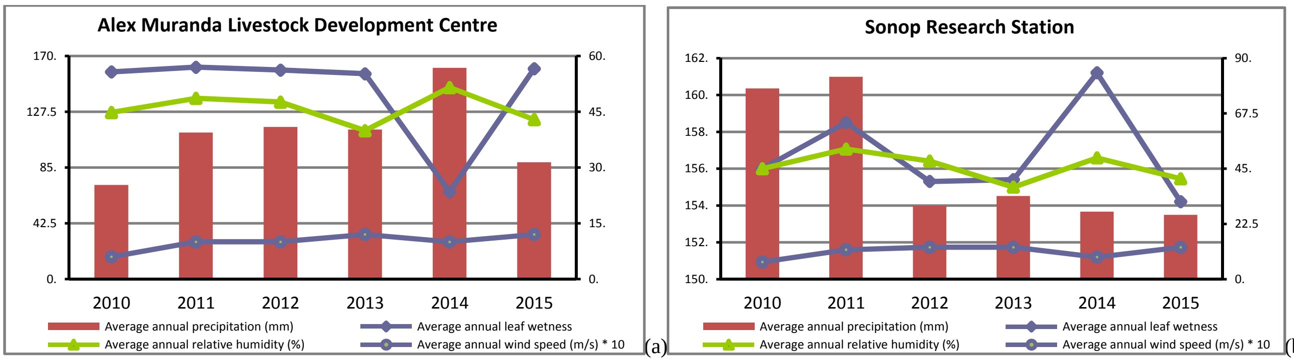
The negative correlation of wind speed to rainfall was also predicted because the low rate of precipitation onset might also be linked to the low wind speed. Wind must lift moisture to the atmosphere to a level where cloud condensation can occur.

B. The Namibian Atmosphere

Namibia is exposed to air movements driven by three major climate systems or belts, namely the Intertropical Convergence Zone (ICZ), Subtropical High Pressure Zone (SHPZ), and the Temperate Zone (TZ). The positions of the systems determine how much rainfall the country gets. The ICZ feeds in moist air from the north, while SHPZ pushes moist air back with dry, cold air. The SHPZ usually dominates, thus giving Namibia dry weather. Air in a high pressure zone descends, heating and drying as it reaches lower levels [22]. The Namibian atmosphere is thus assessed in this section based on the moisture content and the water-holding capacity.

1) The Moisture Content of the Atmosphere:

Fig. 3 shows the variation of precipitation with relative humidity (the amount of water in the air in relation to how much water the air can hold at a particular temperature), leaf wetness, and wind speed. Most countries have sufficient water vapor in the atmosphere, and clouds that produce rain shield the sun and reduce evaporation. However Namibia is characterized by high and rapid evaporation, and a lack of rainfall [22].



(a) (b)

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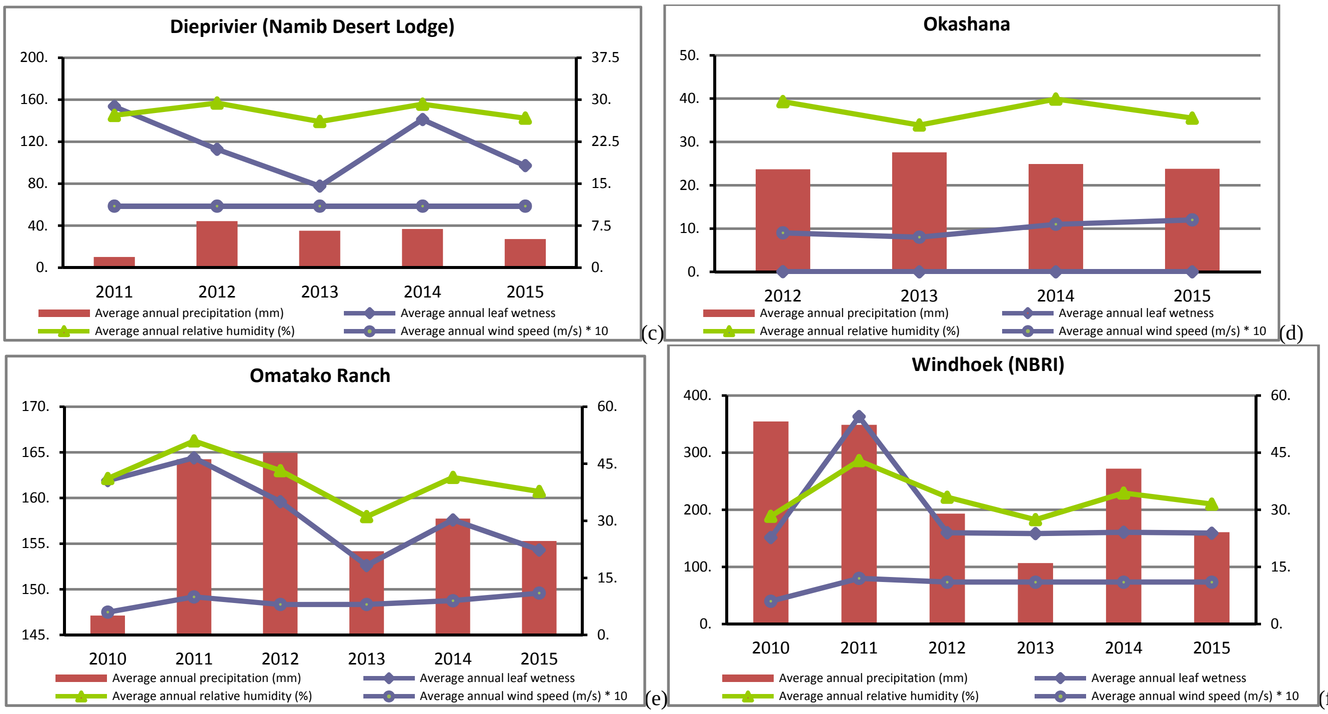

Fig. 3 Annual variation of precipitation with relative humidity, leaf wetness, and wind speed

Precipitation and dew are the main sources of leaf wetness. Under rainy conditions, leaves intercept part of the precipitation, causing free water on the leaves [23], [24]. Thus, an increase in relative humidity (RH) and leaf wetness occurred in conjunction with increases in precipitation observed for all the study sites (Fig. 3(a-e)). This confirms the notion that a lack of moisture in the atmosphere leads to fewer clouds, intense radiation, and high daytime temperatures. The leaf wetness data was used in the place of evapotranspiration, which is the main component of the global water and energy cycle. It should be noted that the absence of precipitation and an increase in evapotranspiration leads to increased risk of drought, as surface drying becomes enhanced. It also leads to increased risk of heat waves and wildfires; once the soil moisture is depleted, heat increases temperatures and wilts plants [7]. Thus, the global increase in precipitation closely matches the increase in surface evaporation (and moisture levels).

2) Water-Holding Capacity of the Atmosphere:

Basic theory, climate model simulations, and empirical evidence all confirm that warmer climates lead to more intense precipitation events due to increased water vapor, even when the total annual precipitation is slightly reduced; there is the possibility for even stronger events when the overall precipitation amounts increase [25]. Fig. 4 shows the saturation vapor pressure (a measure of the water-holding capacity) of the atmosphere.

Data for years 2011 (flood year) and 2013 (drought year) were chosen to demonstrate that the most robust changes in precipitation with climate variability are those associated with the thermodynamic aspects that relate to the Clausius-Clapeyron (C-C) relationship. The flood in 2011 mainly affected 6 northern regions, namely the Oshana Oshikoto, Omusati, Ohangwena, Zambezi, and Kavango regions [14]. Drought affected the Kunene Zambezi, Kavango, Oshikoto, Oshana, Omusati and Ohangwena regions.

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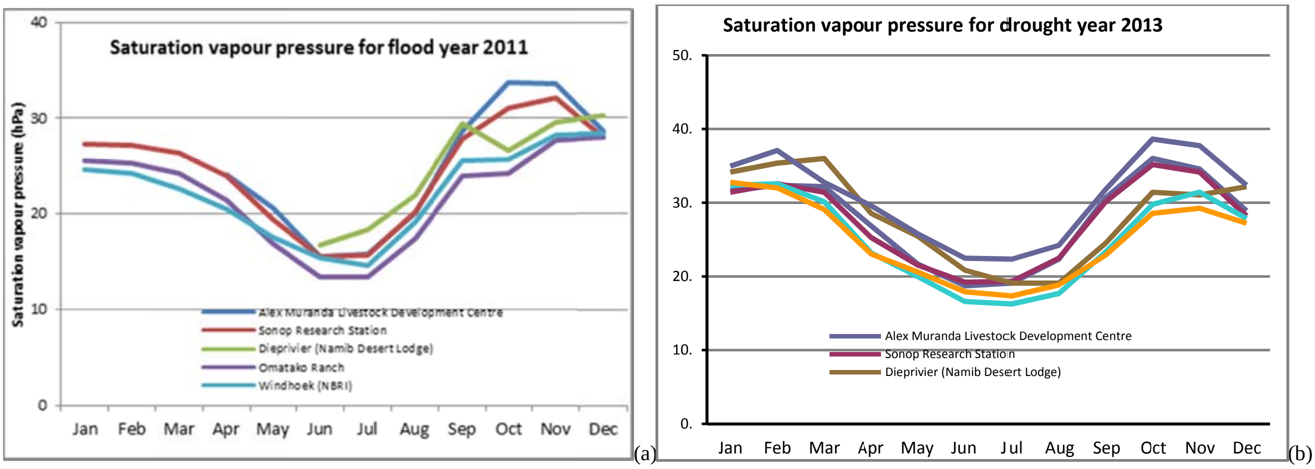


Fig. 4 Saturation vapor pressure for typical (a) flood year - 2011, and (b) drought year - 2013

The water-holding capacity was higher during the drought year. It was also observed that the water-holding capacity (saturation water vapor) of the Namibian atmosphere increased exponentially as temperature increased. Hence, even as the potential for heavier precipitation may occur from increased water vapor amounts, event duration and frequency may be curtailed, as it takes longer to recharge the atmosphere with water vapor. A warmer climate, therefore, increases risks of both drought where it is not raining and floods where it is, but at different times and/or places [1]. Beyond climate impacts on extremes, local and regional weather factors also play an important role in producing extreme weather events [1].

C. Aerosol Pollution and Precipitation

1) Aerosol Build-Up:

Table 3 shows the total suspended particulate concentrations for Ondangwa, selected to represent human activities in the Cuvelai Basin; in the absence of data for Walvis Bay, Windhoek was selected to represent human activities that are likely to impact the Kuiseb Basin.

TABLE 3 TSP AND CORRESPONDING METEOROLOGICAL PARAMETERS

	SAMPLING PERIOD	**CONC (mg/m^{2}day)**	**PRECIPI-TATION [Ave(Sum)]**	**RH (%)**	**TEMP (^{0}C)**	**WIND SPEED (m/s)**
			Ondangwa			
Onalulago1	31/12/13 - 6/01/14	775.57	-	39.5	27.2	7.4
	6 - 12/01/14	560.63	-	29.0	24.6	8.4
Onalulago2	31/12/13 - 6/01/14	1043.11	-	39.5	27.2	7.4
	6 - 12/01/14	592.19	-	29.0	24.6	8.4
Omapalala	31/12/13 - 6/01/14	798.11	-	39.5	27.2	7.4
	6 - 12/01/14	958.94	-	29.0	24.6	8.4
B1 Road	31/12/13 - 6/01/14	52.67	-	39.5	27.2	7.4
	6 - 12/01/14	816.15	-	29.0	24.6	8.4
Oniipa	31/12/13 - 6/01/14	888.29	-	39.5	27.2	7.4
	6 - 12/01/14	924.37	-	29.0	24.6	8.4

DOI: 10.5963/IJEP0601017

Ave		**708.8175**		**34.25**	**25.9**	**7.9**
Windhoek						
Cimbabasia	21/02 - 14/04	3647.89	4.73 (264.81)	60.29	20.95	7.49
Greenwell	24/02 - 15/04	758.15	4.77 (257.45)	60.81	20.81	7.51
Rocky crest	24/02 - 15/04	937.67	4.77 (257.45)	60.81	20.81	7.51
Freedomland	9 - 22/02	3338.15	2.54 (43.17)	55.19	22.69	8.13
	9/03 - 2/04	683.83	6.39 (178.82)	59.81	21.19	7.37
Hakahana	9 - 16/02	1726.32	2.69 (29.61)	59.40	22.50	8.60
Havana	9 - 22/02	2923.59	2.54 (43.17)	55.19	22.69	8.13
	9/03 - 14/04	1345.42	4.53 (181.01)	59.64	20.51	7.90
Goreangab	9 - 22/02	2286.04	2.54 (43.17)	55.19	22.69	8.13
	9/03 - 14/04	5051.81	4.53 (181.01)	59.64	20.51	7.90
Ave		**2069.38**	**4.08 (147.8408)**	**58.49**	**21.55**	**7.89**

Seventy percent of the measurements taken in Ondangwa exceeded the limit 30-day average (600 mg/m2day) residential dust rates set by the South African National Standards [26], while the Windhoek concentrations exceeded both the residential (600 mg/m2/day) and industrial (1200 mg/m2day) dust rates.

Enhanced aerosol concentrations can also suppress warm-rain processes by reducing particle sizes and causing a narrow droplet spectrum that inhibits collision and coalescence processes [27]. Figure 5 shows the annual mean irradiance at the study sites.

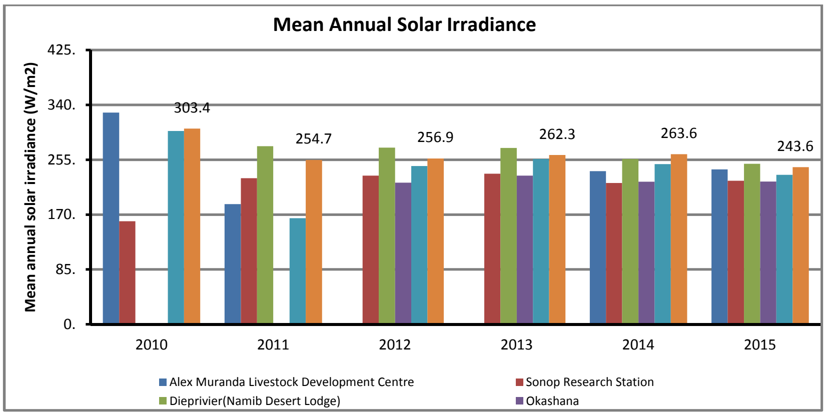


Fig. 5 Mean annual solar irradiance

The relatively high insolation (the solar radiation that reaches the earth's surface) values (mean annuals of 243.6 to 303 W/m2) for Windhoek observed at the NBRI study site (Fig. 5), and the mean daily values of 930.88±88.11 reported by Kgabi et al. [18] for the spring season (September and October 2014) confirm Power and Mills' [28] observation that changes in insolation amount are likely due to changes in aerosol amounts in the atmosphere. Typically, an increase in aerosols will decrease global and direct irradiance and increase diffuse irradiance; this could explain the high TSP levels in Windhoek.

The roughness parameter for both Windhoek and Ondangwa were estimated to be 1.0m following the World

DOI: 10.5963/IJEP0601017

Meteorological Organisation (WMO) [29] since the aerosol measuring sites for this study were not in the centre of the city, but have regular large obstacle coverage similar to suburbs. Roughness length, though not a physical length, can be considered a length-scale representation of surface roughness. According to Linacre and Geerts [30], a lower roughness length implies less exchange between the surface and the atmosphere. Thus, the aerosol pollution in Windhoek and Ondangwa masks the ground from direct sunlight, thereby reducing the overall moisture supply and the precipitation.

Polluted air usually contains much higher concentrations of water-soluble particles, which means pollution-rich clouds tend to have numerous, but smaller droplets that scatter more light and become more reflective [5]. The aerosols also increase cloud lifetime because increased concentrations of smaller droplets lead to decreased drizzle production and reduced precipitation efficiency [3].

2) Aerosol Size Distribution:

Aerosol Optical Depth (AOD) measurements were taken in Windhoek to determine the dominant aerosol mode (see Fig. 6). The AOD is a measure of aerosols (e.g. urban haze, smoke, desert dust, sea salt) distributed within a column of air from the instrument to the top of the atmosphere [31].

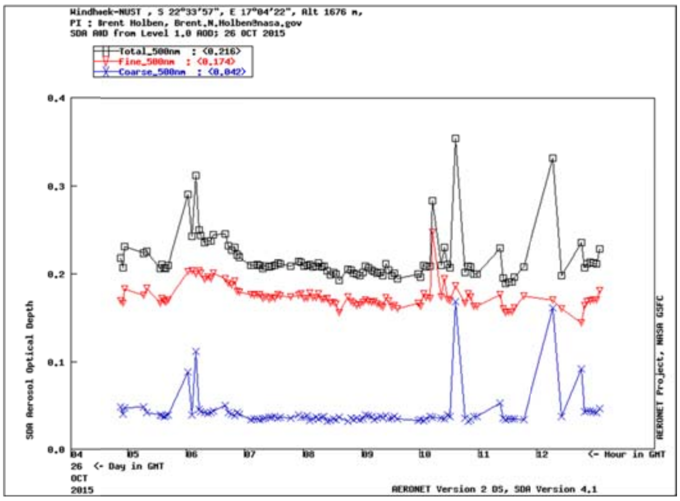


Fig. 6 Aerosol Optical Depth measured in Windhoek during October 2015

An AOD of 0.01 is an indication of an extremely clean atmosphere, while a value of 0.4 indicates very hazy conditions [31]. Thus, the values in Fig. 6 suggest a moderate to high aerosol load.

Angstrom Exponent/Parameter – an estimate of the size distribution of aerosols from spectral aerosol optical depth, typically from 440nm to 870nm, was used to determine the typical hourly size distribution of the aerosols (Fig. 7).

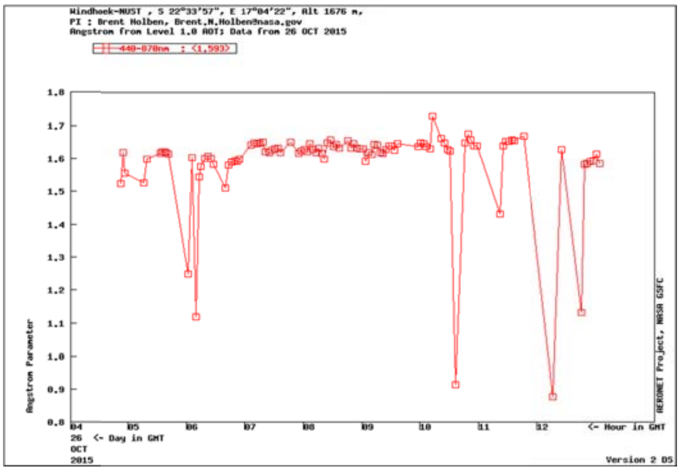


Fig. 7 Hourly size distribution of aerosols in Windhoek

Fig. 7 shows the dominant occurrence of course mode aerosols observed in Windhoek during the day, while Fig. 8 shows the implications of aerosol size distribution on possible precipitation onset.

DOI: 10.5963/IJEP0601017

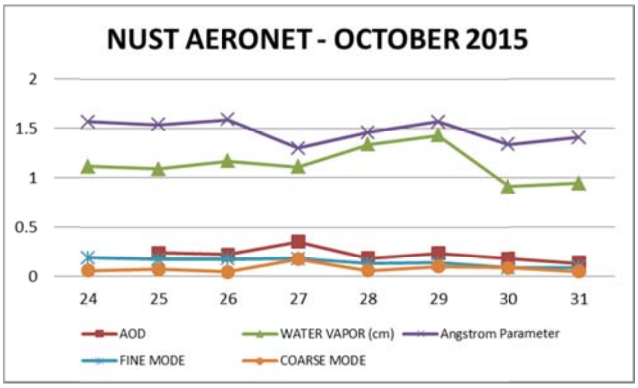


Fig. 8 Aerosol size and water vapor

The angstrom parameter greater than 2.0 is an indication of the presence of fine mode particles (e.g. smoke and sulfates); while the values near zero indicate the presence of coarse mode particles, such as desert dust [32].

3) Aerosol Morphology:

Different particle types have different impacts on climate; some warm (e.g., black carbon) while others cool (e.g., sulfates and nitrates) [33]. It is important to understand the types of aerosols since they react differently when exposed to sunlight. Figs. 9 and 10 show the types of particulates observed from Windhoek and Ondangwa, respectively.

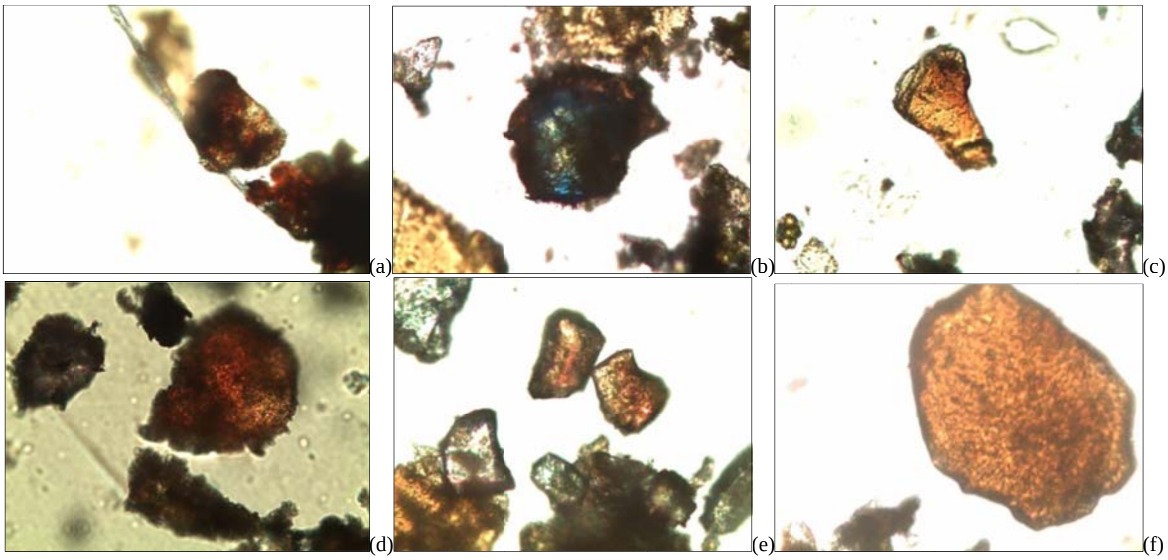
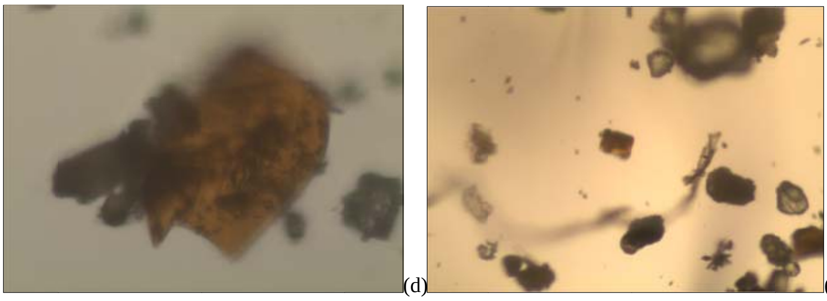


Fig. 9 Morphology of TSP from different suburbs in Windhoek - (a) Cimbebasia, (b) Freedomland, (c) Goreangab, (d) Rocky Crest, (e) Havanna, and (f) Greenwell Matongo

The shapes of atmospheric particles observed in this study can be classified into spherical, irregular, cubical, flake (geometrically irregular), fibrous, and flocks (chain-like). Brown colorizations with diamond-shaped particles accompanied by central discoloration were observed.

DOI: 10.5963/IJEP0601017



(d) (e)

Fig. 10 Morphology of TSP from Ondangwa (a) Onalulago1, (b) Onalulago 2, (c) Omapalala, (d) B1 Road, and (e) Oniipa

In general, cloudy black particles (which absorb most sunlight that hits them) indicating the presence of soot were observed on the two sites, which confirm more contribution to warming and not cooling of the lower atmosphere. The semi-direct effect of absorbing aerosols can cause evaporation of cloud droplets and/or inhibit cloud formation.

Smoke from most combustion processes reduces cloud droplet sizes and delay the onset of precipitation. The desert dust also suppresses precipitation in thin low-altitude clouds [34]. The semi-direct effect of absorbing aerosols can cause evaporation of cloud droplets and/or inhibit cloud formation.

IV. CONCLUSIONS

The water-holding capacity of the Namibian atmosphere increases with temperature increases; aerosol pollution close to Cuvelai and Kuiseb mask the ground and reduce moisture supply; thus, the Namibian warm climate increases the risk of drought where it is not raining, and floods where it is, but at different times and/or places. These changes in average precipitation will impact groundwater recharge rates, thus potentially impacting water supply.

Cloudy black particles that confirm the semi-direct effect of absorbing aerosols that can cause evaporation of cloud droplets and/or inhibit cloud formation were observed. The authors also observed the inherent limitation that cloud and aerosol properties cannot be obtained at the same time over the same location. However, these limitations can be overcome, or lessened by ground and in situ observations. The preliminary aerosol optical depth data presented in this study can also be improved by conducting long term/seasonal studies, including aerosol formation and growth observations both inland and at the coast.

It is worth noting that the findings of this study can (if related to surface area of open water bodies) serve as a baseline for effective water loss reduction from open water bodies in arid regions, as well as the planning, development, and implementation of water augmentation programs like rain and fog harvesting. The information on aerosol load and size distribution can serve as a basis for awareness of the anthropogenic contribution to aerosol pollution and precipitation inhibition, and possible control measures.

ACKNOWLEDGMENT

The authors acknowledge the Southern African Science Service Centre for Climate Change and Adaptive Land Use (SASSCAL) for access to the meteorological data. The support by Dr Brent Holben of the National Aeronautics and Space Administration - Goddard Space Flight Center (NASA-GSFC) in the form of access to the aerosol optical depth data at the Windhoek AERONET station is highly appreciated. Dr Nichola Knox is recognized for management of the aerosol equipment. Financial support by the Institutional Research and Publications Committee (IRPC) of the Namibia University of Science and Technology for TSP measurements and morphological analysis is acknowledged.

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