Towards understanding rainfall variability in Namibia: An analysis of spatial and temporal variations of rainfall from 2010 to 2019

E.G. Kwembeya* and R.N. Shikangalah
Department of Environmental Science, University of Namibia, Private Bag 13301, Windhoek, Namibia

ARTICLE INFO

Article history:
Received: 4 June 2022
Received in revised form: 3 February 2023
Accepted: 3 February 2023
Published: 31 March 2023
Edited by KC Chinsembu

Keywords:
Drought
Namibia
ordinal logistic regression
rainfall variability
temperature

ABSTRACT

Namibia experienced a severe multiyear drought period between 2010 and 2019, which resulted in extremely low reservoir and groundwater levels. This study aimed at investigating the spatial and temporal variations of rainfall during the period under review. A total of 4340 rainfall records, with associated maximum monthly temperature, minimum monthly temperature and average ground temperature data were obtained from 57 weather stations across the entire country. Ordinal logistic regression analysis was used to model the relationship between the total rainfall received and selected explanatory variables namely; season, region, minimum air temperature, maximum air temperature and average ground temperature as predictors. This study revealed an increased probability of receiving higher rainfall as maximum and minimum monthly air temperatures increase. However, an increase in average monthly ground temperatures revealed a significant negative effect on rainfall. Additionally, an annually decreasing rainfall trend between 2010 and 2019 was detected with significantly higher rainfall being obtained in summer months than in winter months. This downward rainfall trend in the last decade suggested an intensification of drought, especially in Erongo, Karas, Hardap and Kunene regions. To this end, this study has revealed that having more weather stations could help in the monitoring of rainfall trends for rainwater management planning. This calls for adaptive responses which include *inter alia* diversification options, the expansion of irrigated agriculture and smart agriculture to ensure food security in the country.

1 Introduction

Climate change and variability have become two major concerns around the globe in recent years. The changes and variability manifest in storms, flood events, fires, and recurrent drought spells, all of which result in major challenges to various functions of the world. The two impact critical resources such as agriculture, energy and hydrological resources. Consequently, this affects the diverse functions of ecosystems and the livelihoods of societies, especially in dryland regions. Other services such as the economic sector that highly influence the socio-economic aspects of the societies are also negatively affected, making planning and decision-making systems for societal development very difficult in many countries.

It is therefore pertinent to closely monitor rainfall variation across the country regularly. Southern Africa has been observed to be most sensitive to rainfall variability and significantly prone to droughts (Usman and Reason, 2004; IPCC, 2007; Gaughan and Waylen, 2012). There have been several studies on rainfall trends and variability in Southern Africa (Todd and Washington, 1998; Cook, 2000; Chikodzi *et al.*, 2013; Mphale *et al.*, 2013; Akinyemi, 2017; Awala *et al.*, 2019), with most showing downward trends in rainfall and increased inter-annual rainfall variability.

---

*Corresponding author: Tel.: +264-61-2063756; *E-mail address:* `ekwembeya@unam.na;ekwembey@gmail.com` (E.G. Kwembeya)

http://repository.unam.na/handle/11070/790 ISSN: 2026-7673; eISSN: 2026-8653/c 2021 ISTJN.

Namibia is one of the driest countries in Southern Africa, and the reoccurrence of droughts has become a norm in most parts of the country. In the last decades, Namibia experienced several drought spells from 1980 to 1984, 1992 to 1993, 2002 to 2003, 2012 to 2013, 2016, and 2019 (Moorsom *et al.*, 1995; Devereux and Naeraa, 2000; Essa, 2013; Shikangalah, 2020). The average annual rainfall for almost two-thirds of the country in an average rain season has been reported to fall below 250 mm during the normal rainfall years (MET, 2013; Shikangalah and Mapani, 2019), and subsequently, the country heavily relies on groundwater systems for supplies. Furthermore, only 1% of the rainfall goes to groundwater recharge (NamWater, 2017). However, close to 80% of the country depend on groundwater system during drought periods (NAU, 2010; UNFCCC, 2010). Since a slight reduction in the amount of rainfall due to climate change can considerably affect the recharge of groundwater, this accordingly affects the country's societal development as well as the functional processes of the already vulnerable ecosystems in Namibia. Projections for the Namibian climate anticipate a further drop in the amount of rainfall and variability (UNDP, 2019), signifying further drier conditions, water stress, and a high reduction of rain-fed agricultural outputs (Reid *et al.*, 2008; Dube *et al.*, 2016).

Several studies have been undertaken to probe into climate variability by analysing rainfall and temperature trends, both on a global and a regional scale (Fauchereau *et al.*, 2003; Batisani and Yarnal, 2010; Ogunrinde *et al.*, 2019; Ahokpossi, 2018; Lázaro *et al.*, 2001). Increasing rainfall variability which has resulted in more intense and widespread droughts has been reported in most of these studies. The interannual variability of rainfall in Southern Africa has significantly increased, particularly in recent decades, since the late 1960 (Fauchereau *et al.*, 2003). In north-west Africa, Ogunrinde *et al.* (2019) reported more annual rainfall totals but with high variability within the rainy months of the year in the first 15 years of the 21st century compared to the 20th century in Nigeria. Such variability in rainfall may have a significant effect on groundwater resources and the hydrology of Nigeria (Ogunrinde *et al.*, 2019). Ahokpossi (2018) examined the temporal variation and trends of annual rainfall distribution in Benin using data from 1940 to 2015. Considerable variability in rainfall (both temporal and spatial) was reported during the period under review, with three temporal characteristics of the rainfall variability being identified, that is, a wet period (1940–1968), a severe dry period (1969–1990) and another wet period (1991–2015), each associated with an increase or decrease in the amount of precipitation or number of rainy days.

An understanding of rainfall variability and trends is therefore very crucial to help vulnerable dryland agriculturalists and policymakers address current climate variation and future climate change. Up-to-date information on trends and variability of rainfall, temperature, drought and flooding is crucial for the future planning and sustainability of water resources of any area within the context of climate change (Ogunrinde *et al.*, 2019). In order to understand the semi-arid ecosystems, rainfall must be analysed over time (Lázaro *et al.*, 2001). As a result, the analysis of rainfall data, in this study was aimed at providing crucial information on efficient water management strategies, environmental protection, and agricultural production planning in Namibia.

Several studies have been carried out on rainfall trends and variability in Namibia (Mendelsohn *et al.*, 2013; Persendt *et al.*, 2015; Lu *et al.*, 2016; Cloete *et al.*, 2018; Awala *et al.*, 2019; Shikangalah and Mapani, 2019). However, they have mostly used few stations and mostly from commercial farming areas (Awala *et al.*, 2019). In addition, rainfall variability varies in spatial and temporal scales (Nicholson and Kim, 1997; Gaughan and Waylen, 2012) and such studies are lacking in Namibia, despite the occurrence of several droughts. Changes in climate threatens agriculture and food production through changes in conditions for ecological systems, resulting in reduced capacity to sustain the food demand. As a result, some of the cultivated areas around the world have been affected, with the great impacts in cropland being experienced in Africa. According to FAO (2021), approximately 690 million people are hungry today worldwide (FAO *et al.*, 2020), and projections showed potential land loss of 10-20 million hectares of land available for cropping in sub-Saharan Africa (Schmidhuber and Tubiello, 2007; FAO, 2016). As such, there is a need to transform agriculture and other food production systems, to enhance resilience and efficiency of these systems. Climate-Smart Agriculture (CSA) is an approach that seeks to improve the farmer's productivity and income, focusing on how the farmers can adapt to a changing climate using their local resources (FAO, 2018).

In this paper, we define drought according to (Van Loon, 2015) as a “sustained period of below-normal water availability". Normal conditions are defined here as certain minimal water levels needed for ecosystem functioning and human consumption, whose deviations result in negative socio-economic impacts. The present study aimed to investigate the spatial and temporal variations of rainfall from one year to the next during the period 2010 to 2019. Information on rainfall trends in a warming climate is very crucial for the country’s economic development, and disaster management plans.

2 Materials and methods

2.1 Source of Data

Climatic data used in this study were obtained from the Southern African Science Service Centre for Climate Change and Adaptive Land Management (SASSCAL) WeatherNet Website (`www.sasscalweathernet.org`). SASSCAL aims to provide science-based environmental information and knowledge, which includes the provision of consistent and reliable climate data for regions in Southern Africa (Kaspar *et al.*, 2015). The stations are automatic and equipped with World Meteorological Organisation (WMO) certified sensors to measure climatic parameters, including rainfall, temperature, solar radiation, relative humidity, wind speed and direction (Strohbach, 2014).

The data transmission from the stations was based on either GPRS/GSM or satellite transmission, with quality control, processed data, and the results were made available in near-real-time (Kaspar *et al.*, 2015). For this study, monthly data from 2010 to 2020 were downloaded from 57 weather stations across all the regions in Namibia. The downloaded data consisted of 4340 records of rainfall, maximum monthly temperature, minimum monthly temperature and average ground temperature.

2.2 Data Analysis

Climatic data collected between 2010 and 2020 were organised using Microsoft Excel spreadsheet. The data were then summarised to determine the percentage distribution of the data according to potential predictors. Simple linear regression was also used to determine changes in rainfall with minimum and maximum monthly temperatures as well as average ground temperature. Shifts in rainfall were determined by the nature of the regression coefficients with negative coefficients indicating decreasing rainfall (dependent variable) trend in response to an increase in temperature and positive coefficients indicating an increase in rainfall in response to an increase in temperature (independent variable).

A chi-square test was used to test the association between dependent (rainfall) and independent variables (season, station and region), while ordinal logistic regression Analysis was used to predict the dependent variable (total rainfall) given the independent variables (season, region, minimum air temperature, maximum air temperature and average ground temperature using the Statistical package IBM SPSS Statistics version 24. Ordinal linear regression was used to overcome some obvious constraints associated with a classical linear regression, including the assumption of a continuous dependent variable with equally spaced, ordered response categories and the assumption that the data are normally distributed (O’Connell, 2006).

Since the rainfall data were not normally distributed (Kolmogrov-Smirnov test, $p < 0.001$), Ordinal Logistic Regression Analysis was used to predict the dependent variable given the independent variables since it makes no assumptions about the distributions of the predictor variables. This method is applicable only for categorical dependent variables. Consequently, the Total rainfall was categorised into 0-49 mm, 50-99, 100-149, 150-200 and > 200 mm based on the frequency distribution of the data. Summer was defined as starting from October to April (7 months) and May to September (5 months) as the winter months.

The assumption that all the logit surfaces are parallel (The proportional odds assumption) was tested. The odds that an event occurs are the ratio of the occurrence of the rainfall event to the ratio of the rainfall event not occurring. This was obtained by dividing the probability that the event occurs by the probability that the event does not occur since both probabilities have the same denominator and it cancels, leaving the number of events divided by the number of non-events. The coefficients in the logistic regression model report how much the logit changes based on the values of the predictor variables.

The odds ratios (Exp (B) reflected the changing odds of a case falling at a higher rainfall category. Odds ratios > 1 suggest an increase in the probability of being in a higher category as values in the independent variable increase, whereas odds ratios < 1 suggest a decreasing probability with increasing values in the independent variable, and odds ratios equal to 1 suggest no predicted change in the likelihood of being in a higher rainfall category as values increased on the independent variable.

3 Results

Between 2010 and 2020, weather stations were established in different years. The number of weather stations available differed from region to region, with Erongo and Otjozondjupa having the highest number of weather stations whereas Omaheke and Ohangwena had only one station each (Figure 1). However, the annual yearly rainfall was comparable. For example, both Ohangwena and Omaheke had only one station, and evidently, Omaheke had more rainfall than Ohangwena in 2019 and 2020 (Figure 2). Also, Omaheke had more rainfall than Otjozondjupa, from 2016 to 2020. Erongo region received the least rainfall over the years in Namibia. All regions had functional weather stations at least from 2015 to the first quarter of 2020, therefore this period reflected annual yearly rainfall in regions. Erongo, Hardap and Karas were more comparable as all had recordings starting from 2011 while Otjozondjupa, Okavango and Khomas had the earliest stations, from 2010 to date (Figure 2).

3.1 Descriptive statistics

The total monthly precipitation ranged from 0 mm to 320.7 mm with a mean of 19.5 mm and a standard deviation of 41.1379 mm (95% CI 38.896 – 43.262); Maximum monthly Air Temperature ranged from $19.4°C$ – $48.4°C$ with a mean of $34.68°C$ and a standard deviation of $4.307°C$ (95% CI 4.21892 – 4.3958); Minimum monthly Air Temperature ranged from $-14.6°C$ – $24.2°C$ with a mean of $8.38°C$ and a standard deviation of 5.6929 (95% CI 5.5729 – 5.803) and Average Monthly Ground Temperature ranged from $8.3°C$ – $33°C$ with a mean of $21.57°C$ and a standard deviation of 4.213 (95% 4.145 – 4.2845).

3.2 Bivariate Analysis

Chi-square tests of association revealed that rainfall had a significant association with region and season ($\chi^2 = 406.173$, $p < 0.001$ and $\chi^2 = 438.895$, $p < 0.001$ respectively). A highly significant moderate positive correlation between minimum monthly air temperature was obtained (Spearman's rho$= 0.535$, $P < 0.001$), whereas a highly significant weak positive correlation between maximum monthly air temperature, was obtained for the period 2010-2020 (Spearman's rho$= 0.190$, $P < 0.001$).

Average ground temperature, minimum and maximum monthly air temperature significantly influenced the total rainfall for the period 2010–2020 ($p < 001$). Rainfall increased by approximately 28 mm/decade/degree Celsius increase in minimum monthly air temperature; by approximately 3 mm/decade/degree Celsius increase in maximum monthly air temperature and by approximately 22 mm/decade/degree Celsius increase in average ground temperature.

3.3 Ordinal logistic regression model

For the overall model, the log-likelihood statistics indicated that season, region, year, minimum air temperature, maximum air temperature, and average monthly ground temperature influenced the total rainfall ($\chi^2 = 1735.797(16)$, $p < 0.001$. The test of parallel lines was not significant (Test of parallel line, $\chi^2 = 54.308$, $p = 0.247$). This indicated that the assumption of parallel lines was satisfied. The explanatory power of the specified variables as indicated by the pseudo R^2 (Nagelkerke R^2) was 49.9%.

Season, region, year, minimum air temperature, maximum air temperature, and average monthly ground were significant predictors in the model. The result of the parameter estimates of the ordinal regression analysis for the effects of region, season, temperature, and year are presented in Table 2. As maximum and minimum monthly air temperatures increased, there was an increased probability of receiving higher rainfall ($B = 0.097$, $p < 0.01$; $B = 0.416$ respectively). An increase in air temperature was likely to result in rainfall falling in a higher category. The monthly minimum Air temperature was a significant positive predictor of rainfall with a predicted increase of 0.416 in the log odds of getting higher rainfall. The monthly maximum Air temperature was also a significant positive predictor of rainfall with a predicted increase of 0.097 in the log odds of getting higher rainfall. The odds of being in a higher rainfall category increased by a factor of 1.517 for every unit increase in minimum air temperature, and by 1.102 with every one unit increase in maximum monthly air temperature. Whereas for an increase in average monthly ground temperatures there was a -0.722 predicted decrease in the log odds of receiving high rainfall ($B = -0.722$, $p < 0.01$).

The year was a negative significant predictor of rainfall with a -0.087 predicted decrease in the log odds of receiving rainfall in higher categories ($B = -0.087$, $p < 0.01$). The odds of being in a higher rainfall category decreased by a factor of 0.917 every year. The number of stations was also a significant positive predictor of rainfall with a predicted increase of 0.099 in the log odds of getting higher rainfall. Significantly higher rainfall was obtained in the summer months (the rainy season) than in the winter months (dry season) ($B = 6.977$, $p < 0.01$) (Figure 2). With regard to the influence of region on the total rainfall, the results showed that Erongo, Karas, Khomas and Kunene ($B = -7.888$, $p < 0.01$; $B = -1.587$, $p < 0.01$; $B = -0.926$, $p < 0.01$; $B = -1.043$, $p < 0.01$, respectively) had significantly less total rainfall compared to the Zambezi and Otjozondjupa regions. However, Omusati and Otjozondjupa regions ($B = 0.820$, $p < 0.01$, $B = 0.696$, $p < 0.01$), had higher cumulative rainfall compared to the Zambezi region (Table 2). Significant rainfall differences were not obtained between Zambezi region and Oshikoto, Ohangwena, Omaheke, Okavango and Hardap regions.

Overall rainfall was very low over the last decade (2010-2019) (Figure 3). In particular, the drought was great in 2013, 2015, 2018, and 2019 as most parts of the country had less than 40 mm monthly average rainfall throughout, especially in Erongo, Karas, Hardap and Kunene regions (Figure 3). The year 2019 was the worst of all as most of the regions had an average monthly rainfall of less than 20 mm. Although only a quarter of 2020 was available at the time of the study, more rainfall was received compared to the last decade.

4 Discussion

An in-depth understanding of the historical and current trends and variation of rainfall is highly necessary in the hydrological and agricultural sectors of a region (Ogunrinde *et al.*, 2019). For example, it has been reported that environments with a climatic characteristic of semi-aridity exhibit high rainfall variability, increasing significantly as the climate changes (Awala *et al.*, 2019; Batisani and Yarnal, 2010; Gökçekuş *et al.*, 2021). The unpredictability as to how much it will rain in specific months generates some uncertainty in the agricultural sector. The upward rainfall trend has implications for rainy season floods, whereas the downward trend suggests dry season drought intensification in the area (Awala *et al.*, 2019). In terms of managing the impacts of drought and floods the capacity for disaster risk preparedness, rather than disaster response, should be strengthened (Dirkx *et al.*, 2008).

Observations over the last decade indicate that there has been an increase in temperatures and a decline in the annual rainfall in Southern Africa (Morishima and Akasaka, 2010; Kusangaya *et al.*, 2014; IPCC, 2015), and it is expected that a further decline in rainfall of up to 5% will occur (Hoerling *et al.*, 2006). This study has demonstrated that this prediction will be true for average ground temperatures in Namibia, but not for average air temperatures. An increase in monthly air temperatures positively influenced total rainfall amounts during the period 2010 to 2020. Due to climate change and variability, the average rainfall is predicted to fall by 10% by 2050 in Namibia and it is expected that is will lead to a decline in environment carrying capacity of 10% in southern and 15% in central Namibia, where about 1.2 to 1.6% of carrying capacity will reduce for every 1% change in rainfall (UNDP, 2019). Such conditions are likely to be tremendously dire for Namibia as around 62% of the population lives in the rural areas and close to two-thirds depend on agricultural activities (MET, 2013).

During the drought of 2012 to 2013 (Figure 3), around 42% of the total population experienced food insecurity (Essa, 2013). In 2019, another worse drought was experienced as confirmed by the present study and agriculture production fell by 17.5% (Bank of Namibia, 2019). Consequently, one-third of the population ended up depending on drought relief support systems due to food insecurity (SADC, 2019). Understanding the spatial and temporal variability is important for planning and management of resources under these dynamics of climate change.

According to this study, the highest maximum Air Temperature for the country was $48.4°C$ recorded in Otjozondjupa station 52 (Omatjene) in November 2013. This was much higher than the officially reported highest temperature of $43.5°C$ which was recorded at Gobabeb on 21 February 1970 according to Mendelsohn *et al.* (2013). In addition, Mendelsohn *et al.* (2013) also reported that the lowest official temperature was $-10.5°C$ recorded at Rohrbeck, north-east of Mariental, on 2 August 1974. Interestingly, according to this study, the lowest minimum Air Temperature was $-14.6°C$ recorded at Kleinberg in 2016, in the Erongo region. This may point to the fact that some parts of the country are becoming warmer while others are becoming colder thereby exerting different rainfall effects in these areas. The present study detected an annually decreasing rainfall trend between 2010 and 2019 (Figure 3) further confirming the previously reported predictions by UNDP (2019). This downward rainfall trend in the last decade suggested an intensification of drought, especially in Erongo, Karas, Hardap and Kunene regions. Furthermore, the study also shows that the warmer the country gets (air temperatures), the higher the likelihoods of rainfall (Table 2). This could be expected to occur in short periods as the predicted intense rainfall in Namibia (Hoerling *et al.*, 2006; Reid *et al.*, 2008; Dube *et al.*, 2016), hence being not much beneficial to the country making planning and proper management of the resources necessary.

The results of this study support similar studies conducted in the region which have demonstrated increasing rainfall variability in environments with a climatic characteristic of semi-aridity (Gökçekuș *et al.*, 2021). This study has revealed that Namibia has undergone extreme rainfall variability in the past decade. Rainfall variability and trends play a major role in Namibia, as rainfall is the primary source of water for agricultural production on which a good percentage of the economy may depend. Consequently, these results provide a good background for carrying out drought-related studies in the future. Comparable results were obtained in a study of the spatio-temporal rainfall trends and rainfall variability in Botswana between 1958 and 2019 undertaken by Gökçekuș *et al.* (2021). Gökçekuș *et al.* (2021) reported that, like many southern African countries, Botswana experienced extremely volatile rainfall patterns, that have contributed to droughts during the period from 1958 to 2019 (Gökçekuș *et al.*, 2021).

These findings indicate that Namibia, like Botswana, is already being impacted by climate change which is accelerating the intensity of rainfall variability. Much land used for agricultural purposes is already marginal, and extreme changes in rainfall variability could negatively affect agricultural production in these areas (Reid *et al.*, 2007). As far as predictions for the future are concerned, it is not obvious whether Namibian rainfall will be reduced. However, this study supports the predictions made by Dirkx *et al.* (2008) that stronger rainfall variability is likely to remain the key aspect of the Namibia's climate in the future.

The findings of this study imply that crop production was affected during the period 2012 to 2019; mostly in regions such as Erongo, Karas, Hardap and Kunene where climate was extreme. While there are many options to adapt and mitigate climate change, climate-smart agriculture (CSA) can be used to move away from old and unsuccessful ways of dealing with climate change. This intervention has been practised successfully around the world, including in countries such as Malawi, Zambia and Botswana (FAO, 2016, 2021). CSA is underpinned by three pillars: sustainable increase in agricultural productivity and incomes; adapt and build resilience of people and agri-food systems to climate change; and reduce greenhouse gas emissions (FAO, 2021). By focusing much more on the first two pillars in the above-identified regions, CSA may assist in helping farmers to identify agricultural strategies that are most appropriate, effective and efficient within their local contexts where long spells of rainfall variability pose a practical challenge to agricultural production. It goes without saying that knowledge of the spatial and temporal variations in rainfall should therefore be part and parcel of information packs for CSA in Namibia and beyond.

5 Conclusion

This study highlighted the variability of rainfall in Namibia and showed clear declining rainfall trends over the last decade, 2010-2019. The droughts were severe in 2013, 2015, 2018, and 2019, with 2019 being the worst as average monthly rainfalls were less than 20 mm for all the regions. In those years, all regions were affected equally with reference to those with normally high rainfall such as Zambezi, Kavango and Otjozondjupa, and those with normally low rainfalls such as Erongo, Karas, Hardap and Kunene regions. The study also showed that the minimum temperatures are getting low, and the maximum temperatures have risen in the last decade. Furthermore, the study also showed that rainfall is highly influenced by temperature. The ground temperatures decrease the rainfall while the air temperatures showed to lead to higher rainfall, which could be potentially valuable for Namibia. Due to the large spatial rainfall variability shown, the study recommends more weather stations in order to produce more reliable rainfall data, particularly in the regions where weather stations are few.

Acknowledgements

We are grateful to SASSCAL for providing the data, funded by the German Federal Ministry of Education and Research (BMBF) under promotion number (01LG1201N).

References

Akinyemi, F.O., 2017. Climate change and variability in semiarid Palapye, Eastern Botswana: An assessment from smallholder farmers' perspective. Wea. Climate So 9(3), 349–365.

Ahokpossi, Y., 2018. Analysis of the rainfall variability and change in the Republic of Benin (West Africa). Hydrological Sciences Journal, 2018. 63(15-16), 2097–2123.

Awala, S.K., Hove, K., Wanga, M.A., Valombola, J.S., Mwandemele, O.D., 2019. Rainfall trend and variability in semi-arid northern Namibia: Implications for smallholder agricultural production. Welwitschia International Journal of Agricultural Sciences 1, 1–25.

Bank of Namibia, 2019. Economic Outlook - July 2019, Media Release. `https://www.bon.com.na/CMSTemplates/Bon/Files/bon.com.na/f0/f0f40ed8-c16d-420b-8534-38ef1bd1f4b9.pdf`. Accessed 11 October 2019.

Batisani, N., Yarnal, B., 2010. Rainfall variability and trends in semi-arid Botswana: Implications for climate change adaptation policy. Applied Geography, 2010. 30(4), 483–489.

Chikodzi, D., Murwendo, T., Simba, F.M., 2013. Climate change and variability in Southeast Zimbabwe: Scenarios and societal opportunities. American Journal of Climate Change 02(03), 36–46.

Chikodzi, D., Murwendo, T. and Simba, F.M., 2013. Climate change and variability in Southeast Zimbabwe: Scenarios and societal opportunities.

Cloete, G., Benito, G., Grodek, T., Porat, N., Enzel, Y. 2018. Analyses of the magnitude and frequency of a 400-year flood record in the Fish River Basin, Namibia. Geomorphology 320, 1–17.

Cook, K.H., 2000. The South Indian convergence zone and interannual rainfall variability over Southern African. Journal of Climate 13, 3789–3804.

Devereux, S., Naeraa, T., 1996. Drought and survival in rural Namibia. Journal of Southern African Studies 22(3), 421–440.

Dirkx, E., Hager C., Tadross, M., Bethune, S., Curtis, B., 2008. Climate change vulnerability & Adaptation Assessment Namibia. Final Report March 2008. Developed by Desert Research Foundation of Namibia & Climate Systems Analysis Group for the Ministry of Environment and Tourism.

Dube, T., Moyo, P., Ncube, M., Nyathi, D., 2016.The impact of climate change on agro-ecological based livelihoods in Africa: A review. Journal of Sustainable Development 9 (1), 256–267.

Essa, A., 2013. Namibia battles worst drought in decades, Aljazeera, 09 October 2019, `https://www.aljazeera.com/indepth/features/2013/10/namibia-battles-worst-drought-decades-201310851010116562.html`. Accessed 12 October 2019.

Fauchereau N., Trzaska S., Rouault M., Richard Y., 2003. Rainfall variability and changes in Southern Africa during the 20th century in the global warming context. Natural Hazards, 2003. 29(2), 139–154.

FAO. 2021. Climate-smart agriculture case studies 2021 – Projects from around the world. Rome. `https://doi.org/10.4060/cb5359en`.

FAO, International Fund for Agricultural Development (IFAD), United Nations International Children's Emergency Fund (UNICEF), World Food Programme (WFP) and World Health Organization (WHO). 2020. The State of Food Security and Nutrition in the World 2020. Transforming food systems for affordable healthy diets. Rome, FAO. 320 pp. `www.fao.org/documents/card/en/c/ca9692en`.

FAO. 2018. Climate-Smart Agriculture Case Studies 2018. Successful approaches from different regions. Rome. 44 pp. Licence: CC BY-NC-SA 3.0 IGO.

FAO. 2016. Managing climate risk using climate-smart agriculture. Rome. `http://www.fao.org/3/a-i5402e.pdf`.

Gaughan, A.E., Waylen, P.R., 2012. Spatial and temporal precipitation variability in the Okavango–Kwando–Zambezi catchment, southern Africa. Journal of Arid Environments 82, 19–30.

Gökçekuş, H., Kassem, Y., Mphınyane, L.P., 2021. Analysis of Spatio-temporal rainfall trends and rainfall variability in Botswana between 1958 and 2019. International Advanced Researches and Engineering Journal 5 (3), 444–453. `DOI:10.35860/iarej.906557`.

Hoerling, M., Hurrell, J., Eischeid J., Phillips, A., 2006. Detection and attribution of twentieth-century northern and Southern African rainfall change. Journal of climate 19(16), 3989–4008.

Intergovernmental Panel on Climate Change (IPCC), 2015. Climate Change 2014 synthesis report. Contributing of working groups: I, II and III to the Fifth Assessment Report of the International Panel on Climate Change", in: R.K Pachauri and L.A. Meyer (eds.). IPCC 2015, Geneva, Switzerland.

IPCC, 2007. Climate Change Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C. E., Eds, Cambridge University Press, 976 pp.

Kaspar, F., Helmschrot, J., Mhanda, A., Butale, M., de Clercq, W., Kanyanga, J.K., . . . Jürgens, N., 2015 The SASSCAL contribution to climate observation, climate data management and data rescue in Southern Africa. Advances in science and research 12, 171–177.

Kusangaya, S., Warburton, M.L., Van Garderen, E.A., Jewitt, G.P.W., 2014. Impacts of climate change on water resources in southern Africa: A review, Physics and Chemistry of the Earth, Parts 67, 47–54.

Lázaro. R., Rodrigo, F.S., Gutiérrez, L, Domingo, F., Puigdefábregas, J., 2001. Analysis of a 30-year rainfall record (1967-1997) in semi-arid SE Spain for implications on vegetation. Journal of Arid Environments, 2001. 48(3), 373–395.

Lu, X., Wang, L., Pan, M., Kaseke, K.F., Li, B., 2016. A multi-scale analysis of Namibian rainfall over the recent decade – comparing TMPA satellite estimates and ground observations. Journal of Hydrology Regional Studies 8, 59–68.

Mendelsohn, J., Jarvis A., Robertson, T., 2013. A profile and atlas of the Cuvelai – Etosha Basin. Windhoek: Gondwana Collection.

Ministry of Environment and Tourism (MET), 2011. National Policy on Climate Change for Namibia-2011 `http://www.met.gov.na/files/files/National%20Policy%20on%20Climate%20Change%20for%20Namibia%202011.pdf`. Accessed 28 October 2019.

Moorsom, R., Franz, J., Mupotola, M., 1995. Coping with aridity: drought impacts and preparedness in Namibia-experiences from 1992/93. Frankfurt, Germany: Brandes & Apsel.

Morishima, W., Akasaka, I., 2010. Seasonal trends of rainfall and surface temperature over southern Africa. African study monographs. Supplementary issue 40, 67–76. `https://doi.org/10.14989/96297`

Mphale, K.M., Dash, S.K., Adedoyin, A., Panda, S.K., 2013. Rainfall regime changes and trends in Botswana Kalahari transect's late summer precipitation. Theoretical and Applied Climatology 116(1–2), 75–91.

Namibia Agricultural Union (NAU), 2010. The effect of bush encroachment on groundwater resources in Namibia: "A desk top study, Namibia, Windhoek, `http://www.agrinamibia.com.na/wp-content/uploads/2018/02/`. Accessed 12 October 2019.

Namibia Water Corporation, NamWater Annual Report, NamWater, 2017. `https://www.namwater.com.na/images/docs/Namwter_Annual_Report_2017.pdf`. Accessed 30 October 2020.

Nicholson. S.E., Kim, E., 1997. The relationship of the El Nino southern oscillation to African rainfall. International Journal of Climatology. 17 (2), 117e135.

O'Connell, A.A., 2006. Logistic regression models for ordinal response variables. Sage, Thousand Oaks, CA.

Ogunrinde, A.T., Oguntunde, P.G., Akinwumiju, A.S, Fasinmirin, J.T., 2019. Analysis of recent changes in rainfall and drought indices in Nigeria, 1981–2015. Hydrological Sciences Journal, 2019. 64(14), 1755–1768.

Persendt, F.C., Gomez, C., Zawar-Reza, P., 2015. Identifying hydro-meteorological events from precipitation extremes indices and other sources over northern Namibia, Cuvelai Basin. Jàmbá. Journal of Disaster Risk Studies 7(1)

Reid, H., Sahlén, L., Stage, J., MacGregor, J., 2007. The economic impact of climate change in Namibia: How climate change will affect the contribution of Namibia's natural resources to its economy. Environmental Economics Programme Discussion Paper 07-02. International Institute for Environment and Development, London.

Reid, H., Sahlén, L., Stage, J., MacGregor, J., 2008. Climate change impacts on Namibia's natural resources and economy. Climate Policy 8 (5), 452–466.

SASSCAL WeatherNet, 2020. `www.sasscalweathernet.org`

Schmidhuber, J., Tubiello, F. N. 2007. Global food security under climate change. Proceedings of the National Academy of Sciences, 104(50), 19703-19708.

Shikangalah, R.N., 2020. The 2019 Drought in Namibia: An overview. Journal of Namibian Studies 27, 37–58.

Shikangalah, R.N., Mapani, B.S., 2019. Precipitation variations and shifts over time: Implication on Windhoek city water supply, Physics and Chemistry of the Earth, Parts A/B/C. 112:103–112.

Southern African Development Community (SADC), 2019. Namibia: Vulnerability assessment committee results 2019, SADC Regional Vulnerability Assessment and Analysis Programme. `https://reliefweb.int/report/namibia/namibia-vulnerability-assessment-committee-results-2019`. Accessed 16 October 2019.

Strohbach, B.J., 2014. The SASSCAL/MAWF Weather Stations Network in Namibia: Overview of equipment and data transfer. Namibia University of Sciences and Technology, Windhoek, Namibia.

Todd, M.C., Washington, R., 1998. Extreme daily rainfall in southern African and southwest Indian Ocean tropical temperate links. South African Journal of Science 94, 64–70.

United Nations Development Program (UNDP), 2019. Sustainable management of Namibia's forested lands (NAFOLA). UNDP-GEF project, 2014 – 2019, UNDP. pp 01–87

United Nations Framework Convention on Climate Change (UNFCCC), 2010. Namibia second national communication to the United Nations framework convention on climate change, Windhoek, Republic of Namibia.

Usman, M.T., Reason C.J.C., 2004. Dry spell frequencies and their variability over southern Africa. Climate research. 26(3), 199–211.

Van Loon, A.F. 2015. WIREs Water 2:359–392. `doi:10.1002/wat2.1085`.

Figures and Tables

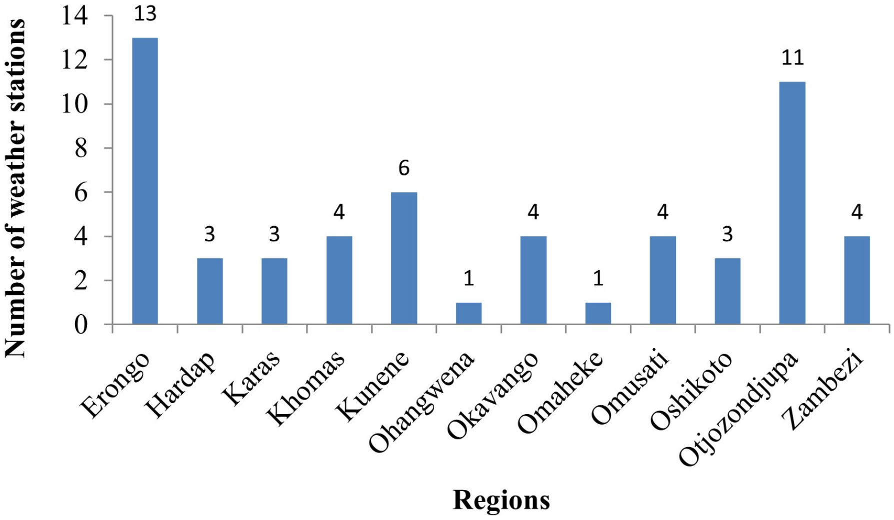

Figure 1: Total stations per regions.

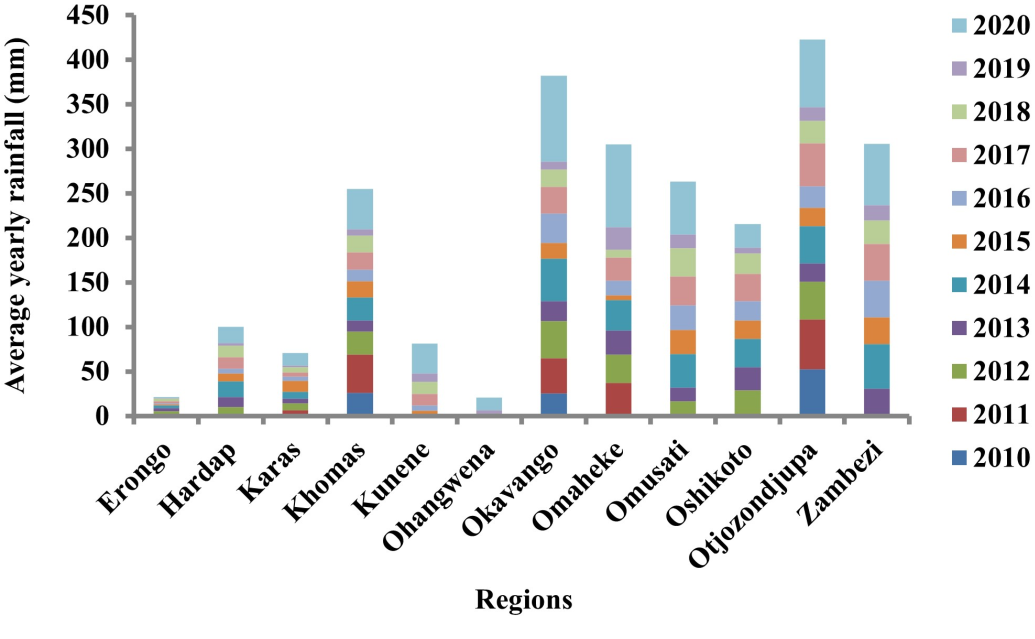

Figure 2: Annual yearly rainfall in mm based on the available stations per region.

Table 1: The percentage distribution of the data according to potential predictors.

Background variables		Frequency	Percentage
Rainfall	0-49	3765	86.8%
	50-99	322	7.4%
	100-149	141	3.2%
	150-200	67	1.5%
	> 200	45	1.0%
Season	Summer	2602	60.0%
	Winter	1738	40.0%
Region	Erongo	961	22.1%
	Hardap	276	6.4%
	Karas	252	5.8%
	Khomas	428	9.9%
	Kunene	262	6.0%
	Ohangwena	7	0.2%
	Okavango	289	6.7%
	Omaheke	103	2.4%
	Omusati	260	6.0%
	Oshikoto	240	5.5%
	Otjozondjupa	1042	24.0%
	Zambezi	220	5.1%
Valid		4340	100.0%
Missing		0	
Total		**4340**	

Table 2: Parameter Estimates of Ordinal Logistic Regression.

Independent variable		**Parameter Estimate**	**Exp(B)**	**p-value**	**95% Confidence Interval**	
					Lower Bound	**Upper Bound**
Climatic Data	**Maximum Monthly Air Temperature**	0.097	1.102	**0.002***	0.034	0.160
	Minimum Monthly Air Temperature	0.416	1.517	**0.000***	0.369	0.464
	Monthly Average ground Temperature	-0.722	0.486	**0.000***	-0.830	-0.613
	Year	-0.087	0.917	**0.000***	-0.130	-0.044
	Number of Stations	0.099		**0.002***	0.038	0.161
Season	**Summer**	6.968	1061.778	**0.000***	4.968	8.987
	Winter	0^a	1			
Region	**Erongo**	-7.873	0.000	**0.000***	-9.904	-5.842
	Hardap	-0.459		0.202	-1.164	0.246
	Karas	-1.583	0.205	**0.002***	-2.583	-0.583
	Khomas	-0.901	0.406	**0.001***	-1.415	-0.388
	Kunene	-1.049	-1.049	**0.001***	-1.668	-0.430
	Ohangwena	-20.822			-20.822	-20.822
	Okavango	0.259		0.310	-0.241	0.758
	Omaheke	0.235		0.521	-0.484	0.955
	Omusati	0.819	2.268	**0.002***	0.300	1.338
	Oshikoto	0.281		0.300	-0.250	0.813
	Otjozondjupa	0.707	2.029	**0.001***	0.278	1.137
	Zambezi	0^a	1			

[a] This parameter is set to zero because it is the reference category; *Statistically significant results in bold at 5% level.

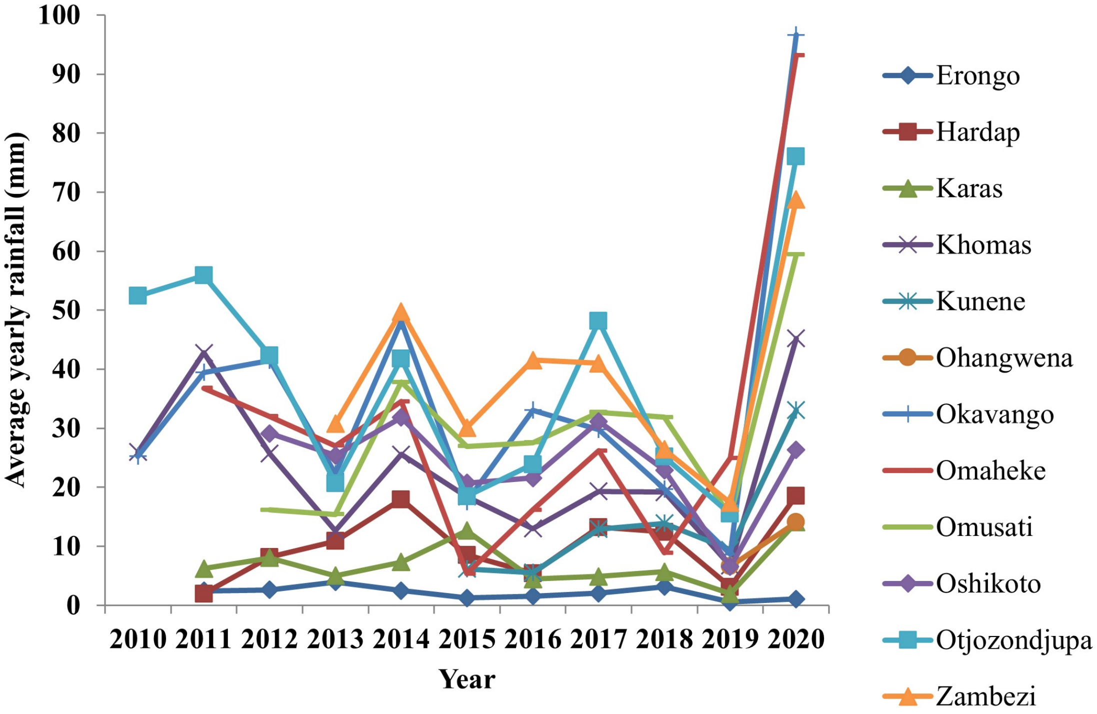

Figure 3: Temporal average rainfall variation across the 12 regions of Namibia.