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Quantification and delineation of aridity boundaries in Northern Nigeria.

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ABSTRACT

This research aims to delineate aridity boundaries as to inform policy and guide dryland management in Northern Nigeria and to quantify the dryness of the climate in the northern zone of Nigeria, geo-informatically delineate aridity boundaries, produce aridity map, show decadal trends and assess the land area in northern Nigeria covered by varying degrees of aridity. Climatic data from 1979 to 2018 for thirteen states was sourced from Nigerian Meteorological Agency (Nimet) and downscaled dataset were gotten to project aridity for 2050 fitted into the Modified Thornthwaite's Moisture Index to reveal the degree of dryness of Northern Nigeria and (QGIS 2.18.24) was used to delineate aridity boundaries and quantify area covered by varying degrees of aridity. Results revealed that the worst-case scenario aridity wet semi-arid class for 1979 to 2018 occupied a landmass area of 2569.5 Km^2 and recorded decadal differences of over 765.4% increase in 1979-1988 and 14.1%, 14.0%, and -100% for 1989 to 1998, 1999 to 2008 and 2009 to 2018 decades respectively. Projected aridity for 2050 under the business as usual scenario the worst case of aridity would resurface engulfing a 2059.6Km^2 calling on policymakers to take actions to avert the projected effect. Delineation of aridity boundaries and quantification of the dryness of the climate will guide dryland management and inform policy actions in the northern zone of Nigeria.

Globally dryland or arid land occupies an area of about 47.2 per cent (70.30 million km^2) of the world landmass with the human population living in these areas being affected by varying degrees of aridity (WFB), (2016). Climate Change, the greatest human challenge facing the world, continues to aggravate and expands these drylands, thus threatening the livelihoods of billions of people, obliterating human settlements, inducing forced migration, and exacerbating rural poverty and social conflicts (Nasiru, 2015). Due to global warming, aridity is increasingly a problem in many regions of northern Africa countries. Aridity has been exacerbated in Northern parts of Africa, savannahs, due to the extraction of water for irrigational purposes, such practice exposes the land to the evaporative force of the atmosphere (Nasiru, 2015), leaving the soil dryer than in natural conditions.

Aridity is regarded as an environmental hazard and a social disaster that expose the population to water scarcity caused by rainfall deficit (Wilhite, 2000). Desertification is a physical symptom of aridity, according to Maliva and Missimer, (2012), aridity indicates the proneness of a place to desertification. Expansion and contraction of drylands depend upon inter-annual variability of zonal precipitation. This variability generally has an impact on the livelihood opportunities for the local population reducing the production of crops and livestock which will hinder the achievement of goal 2 (Zero Hunger), 13 (Climate action) and 15 (Life on Land) of the Sustainable Development Goals targeted at 2030.

Landscape images of barren, dry land, scanty vegetation and low soil moisture (Maliva and Missimer, 2012) is a common feature of northern Nigeria and the northern regions of West Africa. The dry lands or degree of aridity are classified using the aridity index (AI), which is the ratio of the total annual precipitation and the potential evapotranspiration (*PET*). Such classification provides the basis for the definition of aridity as the water deficit that occurs to some extent throughout the hydrological year. Millennium Ecosystem Assessment report (MEA, 2005) estimated that almost 10 to 20% of the susceptible drylands have already undergone land degradation. It is estimated that almost 2 billion hectares of land in over 170 countries of the world is at risk of desertification and over 1.3 billion people are directly affected by desertification (United Nations Convention to Combat Desertification (UNCCD), (2019). The consequences of desertification and aridity may also expand in the future as a projected 1.5°C to 2.0°C rise in global average temperature and increase in land areas affected by droughts are expected by the year 2100 (Intergovernmental Panel on Climate Change (IPCC), 2019).

Nigeria is a country with diverse ecological and climatological zones and topographical characteristics of potential agricultural productivity. The agricultural land of Nigeria has the potential to produce all types of crops where moisture is not a limiting factor. However, almost all areas that lie above latitude 8° of the cultivated area are undergoing a degree of moisture stress which could lead to failed crop production. This is the main reason why researchers have become increasingly concerned about drought, aridity and desertification (Croitiru, Piticar, Imbroane & Burada, 2013).

Geo-informatics has been described as "the science and technology dealing with the structure and character of spatial information, its capture, its classification and qualification, its storage, processing, portrayal and dissemination, including the infrastructure necessary to secure optimal use of this information" (Raju, 2019). This study uses the geo-informatics tool to delineate aridity boundaries and produce aridity maps to inform policymakers and governments on appropriate measures to be taken to monitor aridity and desertification under climate change and extreme events conditions.

The AI is calculated as an indicator to identify and delimit regions that suffer from water deficit, a condition that can severely affect agriculture and resources development (Sawa *et al*., 2015). Accordingly, the Objectives of this paper is to Quantify and delineate aridity boundaries to inform policymakers and guide dryland management in Northern Nigeria.

2.0. Material and Methods

2.1. Study Area

The study area covers states in northern Nigeria. The states are Adamawa, Bauchi, Borno, Kaduna, Kano, Katsina, Kebbi, Niger, Plateau, Sokoto, Taraba, Yobe and Zamfara. It falls within Latitude 13°81N to 6.72°S, and Longitude 14.65°E to 2.69° W (Global Weather Data for SWAT) and the area cuts across the Sahel, Sudan and Guinea Savannah and covers a total land area of approximately 643,813.999 km^2 Quantum Geographic Information System (QGIS 2.18.). The annual rainfall of Northern Nigeria ranges between 250 mm to 1700 mm per annum with the rainfall decreasing as you go far north through Guinea, Sudan and Sahel Savannah.

2.2. Data Source and Aridity determination

Rainfall, temperature and evapotranspiration records from 1979 to 2018 (forty years) for Adamawa, Bauchi, Borno, Kaduna, Kano, Katsina, Kebbi, Niger, Plateau, Sokoto, Taraba, Yobe and Zamfara were sourced from Nigerian Meteorological Agency (Nimet). The data were fitted into Modified Thorntwaite's moisture index aridity models. For this study, Modified Thornthwaite's moisture index was chosen because it was able to bring out the worst-case scenario for Nigeria.

2.3. Modified Thornthwaite's Moisture Index

Three aridity indices De Martone, UNSECO and Modified Thorntwaite's moisture index widely used were evaluated using the weather data for the study Area. The modified Thorntwaite's Moisture Index was selected and used for the study as the model best describe the situation in the study area giving the least, medium and worst-case scenario. Additionally, the modified Thornthwaite's moisture index could spot out minute differences in soil moisture deficit in the evaluation of the models.

The moisture index is defined using the mean annual rainfall and means annual potential evapotranspiration as;

$$I_m = \frac{(R - ET_o)}{ET_o} \times 100$$

Where I_m is moisture index in percentage; R is the Mean Annual rainfall in mm, and ETo is the Mean Annual Potential Evapotranspiration in mm.

2.4. Trend Analysis

The yearly aridity results obtained were analysed to show the decadal trends of aridity of the study area. Aridity for the four decades was also derived.

2.5. Geo-Informatics and data processing

The aridity results obtained from the assessment were interpolated in a GIS environment (QGIS 2.18.24) to delineate, classify and produce the decadal aridity maps of Northern Nigeria.

2.6. Interpolation, Contouring and Area measurement

The analysed results of decadal aridity were interpolated in a QGIS 2.18.24 environment to show their spatial distribution within the extent of Northern Nigeria. The Inverse Distance Weighting (IDW) interpolation method was used to plot the aridity maps. The results of the interpolated raster were clipped to the masked layer of northern Nigeria to produce the maps. Contours were extracted from the raster file for aridity at 10mm intervals joining points of equal aridity in the QGIS 2.18.24 environment. The area measurement tool in the QGIS 2.18.24 environment was used to determine and measure the area covered by each aridity class.

3.0 . Results

3.1. Decadal Changes in aridity in Northern Nigeria

3.1.1 . Distribution of aridity for 1979 to 1988.

Result of aridity for 1979–1988 decade as shown in Fig.1 judging by the Modified Thornthwaite's Moisture Index (1948) which agrees with the Intergovernmental Panel on Climate Change (IPCC, 2007) by its rating revealed that Yobe state with an aridity index of -46.51 and Borno state with -37.19 was Wet Semi-Arid in the decade in-view and

Sokoto with -15.15 and Katsina state with an index of -13.40 were both classed under ‘Dry sub-humid’ and Zamfara state with an index of 29.29, Adamawa with 38.27, Kebbi with an index of 39.41 and Bauchi with 46.76 were all ‘Humid’. While Taraba state with an aridity index of 72.60, Niger state with an index of 80.86, Kaduna with an index of 102.45 and Plateau state with an index of 124.50 were all ‘Very Humid’.

From the interpolated results, as can be seen in Fig. One and tab. 1 as measured in the QGIS environment the Wet Semi-Arid region with an index (<=-26) covered a total land area of approximately 24,806.28 km^2 totalling up to 3.85% of Northern Nigeria as revealed by this research. The Dry sub-humid class with an aridity index between (-26-0) engulfed a total land area of approximately 106654.18 km^2 making up to 16.57 % of the study area and the Wet Sub-Humid class with an aridity index of between (0-20) covered an approximate total land area 88,233.67 km^2, which is about 13.70 % of the total area.

The Humid class with an aridity index of (20 - 50) had a total land coverage area of 202,022.28 km^2 for the decade in-view which is approximately 31.70 % of northern Nige-

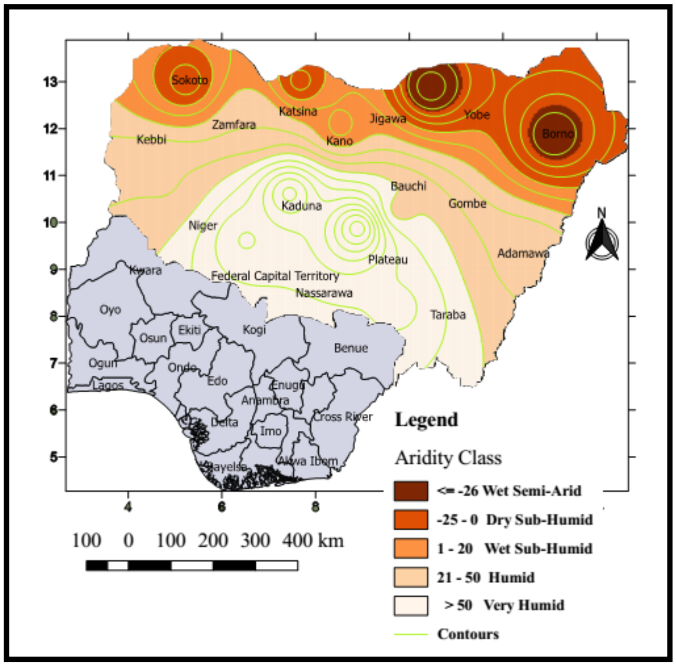

Figure 1: Decadal (1979 to 1988) distribution of aridity in Northern Nigeria

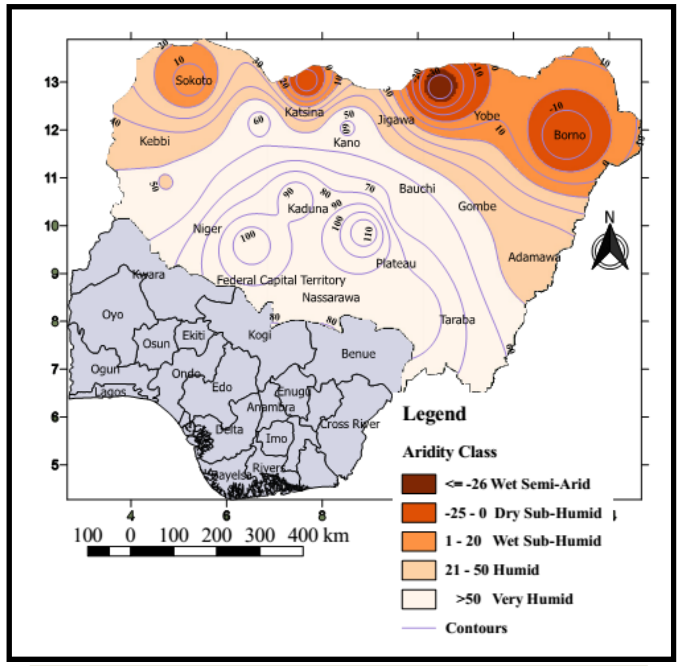

Figure 2: Decadal (1989 to 1998) distribution of aridity in Northern Nigeria.

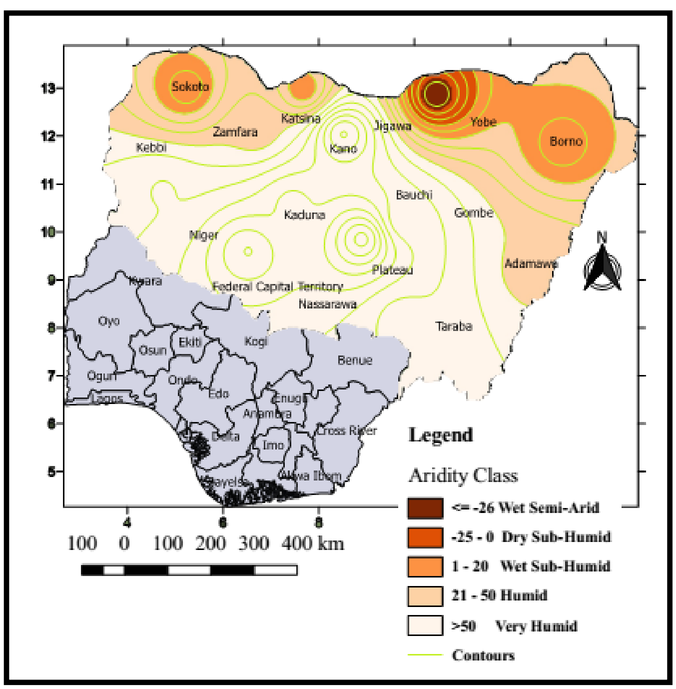

Figure 3: Decadal (1999 to 2008) distribution of aridity in Northern Nigeria

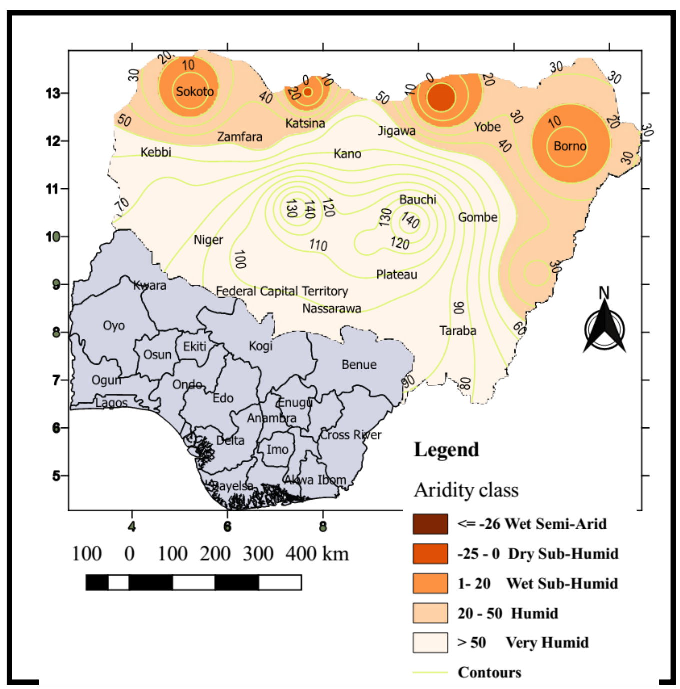

Figure 4: Decadal (2009 to 2018) distribution of aridity in Northern Nigeria

Table 1: Land area of Northern Nigeria in km^2 covered by varying degrees of aridity.

Land Area(km^2)						
Aridity Classification	(1971-2018)	1979-1988	1989-1998	1999-2008	2009–2018	Projected Aridity (2050)
Wet Semi-Arid	2569.45	24,806.28	5501.9	5,499.46	0	2059.644
Dry Sub-Humid	35206.342	106654.18	50,373.00	12,058.95	4,901.12	10184.007
Wet Sub-Humid	102806.646	88,233.67	87229.91	79,255.87	62,898.34	14402.802
Humid	147005.849	202,022.28	151,692.36	154,614.11	176,764.73	98650.387
Very Humid	356225.712	222,097.60	349,016.83	392,385.61	399249.81	518517.159

Table 2: Percentage of land area under varying degrees of aridity to northern Nigeria landmass of 643,313.99 km2.

Land Area(km^2)						
Aridity Classification	(1971-2018)	1979-1988	1989-1998	1999-2008	2009–2018	Projected Aridity (2050)
Wet Semi-Arid	0.40	3.85	0.85	0.85	0	0.32
Dry Sub-Humid	5.47	16.57	7.82	1.87	0.76	1.58
Wet Sub-Humid	15.97	13.70	13.54	12.31	9.77	2.23
Humid	22.83	31.38	23.56	24.01	27.46	15.32
Very Humid	55.3	34.49	54.49	60.94	62.0	80.54

ria. In comparison, the Very Humid Class covered a total area of 222097.6 km^2 making up 34.50 % of the total land area of northern Nigeria.

3.1.2. Distribution of aridity for 1989 to 1998.

Results of aridity for 1989 to 1998 decade as can be seen in Fig. 2 also judging by the Modified Thornthwaite's Moisture index that best suits the climatic conditions of the study area revealed that Yobe state with an aridity index of -35.03 was 'Wet Semi-Arid' and Borno and Katsina state with indexes of -18.08 and -16.83 were 'Dry sub-humid' respectively. Sokoto state with an index of 4.65 was 'Wet Sub-Humid' while Adamawa and Kebbi State with aridity indexes of 45.48 and 49.82 respectively were Humid. Kano, Bauchi, Zamfara, Taraba, Niger, and Plateau with aridity indexes of 61.04, 60.41, 62.62, 90.00, 107.36, and 118.84 respectively were revealed to be 'Very Humid'.

From results of interpolation and maps as seen in Fig. 2 and tab. 1 as measured geo-informatically showed that the 'Wet Semi-Arid' region with an aridity index of (<= ¯26) covered a total land area of 5501.90 km^2 accounting for about 0.85 % of the study area, the 'Dry sub-humid' with an index between (¯26-0) covered a land area of 50,373.00 km^2 making up to about 7.82 % of the total study area and the 'Wet Sub-Humid' aridity class with an aridity index of between (0-20) accounted for an approximate 87,222.91 km^2, making up about 13.55 % of the total study area in the decade in-view.

While the 'Humid' aridity class with an aridity index between (20-50) measured up to 151,692.36 km^2 making up about 23.56 % of the entire land area and the 'Very Humid' aridity class covered a total land area of 349016.83 km^2 making up a total of 54.21 % of northern Nigeria.

3.1.3. *Distribution of aridity for 1999 to 2008.*

Results of aridity for 1999 to 2008 decade, as seen in Fig. 3 judging by the Modified Thornthwaite's Moisture index by it rating revealed that Yobe state with an aridity index of -36.5 was 'Wet Semi-Arid' and Sokoto, Borno and Katsina states with aridity indexes of 3.66, 4.48 and 12.31 respectively were 'Wet Sub-Humid' according to its rating. While Zamfara and Adamawa State with aridity indexes of 42.7 and 45.89 respectively were 'Humid'. Taraba, Kebbi, Bauchi, Kaduna, Niger, Kano and Plateau states with aridity indexes of 65.71, 70.58, 72.17 92.90, 110.38, 110.6 and 132.96 respectively fell into the 'Very Humid' aridity class for the decade in-view.

The 'Wet Semi-Arid' aridity class with an aridity index (< = - 26) as revealed by the results of the interpolation on the map as seen in Fig. 3 and Tab. 1 showed that it covered a total land area of 5499.46 km^2 making up about 0.85 % of the study area and the 'Dry sub-humid' aridity class with the aridity of (-26 - 0) occupied a total area of 12,058.95 km^2 approximately 1.87 % of the total area and the 'Wet Sub-Humid' aridity class with an aridity index of (0 - 20) occupied an area of 79255.87 km^2 making up about 12.31 % of the total land area, and the 'Humid' aridity class with an index of (20 - 50) occupied a total area of 154614.11 km^2 making up about 24.02 % and the 'Very Humid' aridity class occupied a total land area of 392385.61 km^2 making up 60.95 % of northern Nigeria.

3.1.4. *Distribution of aridity for 2009 to 2018:*

Results of aridity trend for 2009 to 2018 decade, as shown in Fig. 3 judging by the Modified Thornthwaite's moisture index, the rating revealed that Yobe and Katsina state with aridity index of -6.52 and -1.30 are 'Dry sub-humid' in this current decade revealing moisture deficiency while Sokoto and Borno state with aridity index of 1.73 and 4.85 are 'Wet Sub-Humid' respectively. Adamawa and Zamfara states with indexes of 27.78 and 43.51 respectively are

Humid. The 'Very Humid' aridity class is occupied by Kano, Kebbi, Taraba, Niger, Plateau, Bauchi and Kaduna states with aridity index of 69.25, 71.63, 98.58, 104.63, 122.32, 145.54 and 145.66 respectively for the current decade.

From the findings of this research, it has revealed that the 'Wet Semi-Arid' with an aridity index of (< = - 26) was completely lost strong revealing evidence of climate change in the study area. The 'Dry sub-humid' class with aridity index of (-26 - 0) reduced drastically recording only a 4901.12 mk^2 accounting for just 0.76 % of Northern Nigeria. The 'Wet Sub-Humid' aridity class with an aridity index of (0 - 20) occupied a total area of 62,898.34 km^2 making about 9.77 % of the study area as is shown in Fig. 3 and tab. 1 The 'Humid' aridity class with an index of (20 - 50) occupied a total land area of approximately 176764.73 km^2 summing up to 27.46 % of the study area. While the 'Very Humid' aridity class covered a total land area of 399249.815 km^2 making up 62.01 % indicating an increase in rainfall in the decade in-view.

4.0. Discussion of Findings

4.1. Rainfall Trend

4.1.1. Adamawa State

Rainfall of Adamawa State showed a negative trend with y and R^2 values of y= -1.8741x +922.31 and R^2 = 0.0854 signalling a possible decrease in rainfall within the State implying that if the trends continue, there will be serious water deficit that will adversely affect agriculture and other livelihoods that will be depending on rain-fed agriculture.

4.1.2. Bauchi State

Rainfall of Bauchi State showed a positive trend with y and R^2 values of y = 13.094x +789.64 and R^2 = 0.5311 signalling an upward shift in rainfall far above average rainfall which can further cause erosion hazard rather than aridity within the State.

4.1.3. Borno State

Rainfall of Borno State showed a positive trend with y and R^2 values of y = 6.2731x +437.85 and R^2 = 0.3755 showing an upward increase in rainfall which will cause a drastic reduction in soil aridity within the State if the trends do not take an opposite direction, it will favour rainfed Agriculture in the State.

4.1. 4Kaduna State

Rainfall of Kaduna State showed a slightly positive trend with y, and R^2 values of y = 3.0147x +1178.8 and R^2 =0.0567 depicting a gradual increase in rainfall provided the trend does not turn otherwise.

4.1.5. Kano State

Rainfall Kano State showed a sharp upward positive trend with y and R^2 values of **y =** 16.967x +578.66 and R^2= 0.5394, which connotes a strong upward increase in rainfall within the State.

4.1.6. Katsina State

Rainfall of Katsina State revealed a positive trend with y and R^2 values of y = 3.352x +510.49 and R2 = 0.1048 also depicting a gradual increase in rainfall within the State which will positively affect rainfed agriculture and livelihood depending on rainfall within the State.

4.1.7. Kebbi State

Rainfall of Kebbi State showed a positive trend with y and R^2 values of y = 5.5582x +847.88 and R^2 = 0.2486 depicting an increase in rainfall above-average rainfall within the State.

4.1.8. Niger State

Rainfall of Niger State also showed a positive trend with y and R^2 values of y = 2.726x +1138 and R^2 = 0.167 depicting a gradual increase in rainfall with the State.

4.1.9. Plateau State

Rainfall of Plateau State showed a gradual negative trend with y and R^2 values of y = -1.754x +1294.8 and R^2= 0.0943 depicting a gradual decrease in rainfall within the State agreeing with (Murray *et al.,* 2012) findings of decreasing rainfall in areas with higher rainfall.

4.1.10. Sokoto State

Rainfall of Sokoto State showed a positive trend with y and R^2 values of y = 2.4627x +572.69 and R^2 = 0.1111 also depicting a gradual increase in rainfall above average within the State.

4.1.11. Taraba State

Rainfall of Taraba State showed a positive trend with y and R^2 values of y = 1.53x +1043.2 and R^2= 0.0303 depicting a gradual increase of rainfall above the mean rainfall within the State.

4.1.12. Yobe State

Rainfall of Yobe State showed a positive trend with y and R^2 values of y = 4.2589x +346.76 and R^2= 0.218 depicting an upward increase in rainfall within the State.

4.1.13. Zamfara State

Rainfall for Zamfara State also showed a slightly positive trend with y and R^2 values of y = 1.2638x +877.98 and R^2 = 0.0175. The higher the R^2 value, the greater the likelihood of the change depending on the sign on the y value depicting either a negative or positive increase in rainfall below of above mean rainfall of any State.

Eleven of the northern States studied are experiencing a definite upward trend in rainfall except for Plateau and Adamawa States that are experiencing a negative trend with y values of y = -1.754x +1294.8 and y= -1.8741x +922.31 respectively depicting a likely decreasing trend in rainfall below the average rainfall with the States similar to trends reported by (Nicholson *et al.,* 2000).

4.2.1. Aridity Trend

Results of this research showed varying degrees of aridity in different states of northern Nigeria at different times within the temporal scope of these findings which is agreeing with the predicted increase in aridity for the late-twenty-first century in many regions of the world (Gao & Giorgi, 2008, Feng, & Fu, 2013 and Dai, 2013). Areal increase in hyper-arid, arid, Semi-arid and Sub-Humid land types from neighbouring wetter subtypes was also observed by (Dai, 2013). (Aristeidis, 2019) asserted that once the aridity or dryness of an area increases beyond a certain level, it becomes difficult to recover, which puts northern Nigeria at risks of becoming a more degraded desert if action is not taken to avert the trend of aridity. (Reddy & Reedy in Sawa, e*t al.*, 2015) asserted that when evapotranspiration is above average and precipitation is below average, the aridity index will be negative, signalling arid conditions. When different conditions prevail, the index is positive.

From the research, Adamawa State experienced 45 years of positive values of aridity index ranging from 6.2 in 1989 to 111.2 in 2006 and 3 years of negative values of aridity index connoting arid conditions during these 3 years as seen in appendix i. Bauchi experienced 47 years of positive values of aridity index ranging from 11.8 in 1973 to 232.7 in 2013 and only a year of negative aridity value index of -2.9. Borno State experienced only four years of positive values of aridity index ranging from 1.1 in 1995 to 57.5 in 2007 and 34 years of negative values of aridity index connoting periods of aridity in the State. Kaduna, Niger, Plateau and the Taraba States experienced all 48 years of positive values of aridity index ranging from 32.3 in 2008 to 199.5 in 2018, 35.7 in 1987 to 156.9 in 2016, 45.2 in 1995 to 178.8 and 32.3 in 1979 to 171.7 in 2018 respectively for Kaduna, Niger, Plateau and Taraba States connoting no aridity in the State judging by Modified Thornthwaite's Moisture Index used for this research. However, the values were highly unstable indicating a possibility of a decline reversal in the values to negative values which can be seen in the negative trends of rainfall of Plateau State though has not experienced negative values of aridity but is showing a downward trend calling for urgent intervention within the area. Kano experienced 40 years with positive values of aridity index ranging from 4.1 in 1974 to 164.2 in 1997 and 8 years with negative values of aridity connoting eight years of aridity within the State. Katsina State experienced 17 years with positive values of aridity index ranging from 2.1 in 2013 to 131.1 in 1991 connoting humid years and 31 years with negative values of aridity index. Kebbi State experienced 45 years with positive values of aridity index ranging from 4.8 in 1987 to 148.7 in 1999 and 3 years with negative values of aridity index. Sokoto State experienced 21 years with positive values of aridity index ranging from 0.1 in 2004 to 33.5 in 1976 with just marginal values away from arid conditions and 26 years with negative values of aridity index connoting 26 years of aridity in the State. Yobe State experienced only three years with positive values of aridity index ranging from 24.5 in 2016 to 61.8 in 2018 and 45 years of dry period with negative values of aridity index in the State. Moreover, Zamfara State experienced 47 years with positive values of aridity index in 2007 and only one year with a negative index.

While States like Bauchi, Zamfara, Kebbi, Adamawa and Kano experienced between 1 to 8 years of arid conditions with negative aridity values signalling a susceptibility of this states to become arid and States like Kaduna, Niger, Plateau and Taraba State did not experience any period with negative values of aridity index making them humid States in Northern Nigeria. With Sokoto, Borno, Katsina and Yobe experiencing between 26 to 45 years of arid conditions with decreased aridity index with their positive values of aridity index recorded in the last few years agreeing with the trends of Feng and Fu's (2013) findings that depicted that drylands will become wetter in regions of tropical Africa, India and parts of north-western China indicating a reduction in aridity.

4.2.2. Aridity Worst-case Scenarios in Northern Nigeria 1971-2018

The worst-case scenario of aridity with negative aridity index values that has been experienced during the time frame of the research 1971-2018 is in Yobe state with the highest aridity index of -65.7 (Dry Semi-arid) in 1983. The State as revealed by this research has suffered varying degrees of aridity (moisture lag) consecutively from 1971-2015 only experiencing a few years of lower aridity degrees in 2016-2018 agreeing with ICCA, 2019 projected future climate trends based on RCPs in Northern Nigeria that showed that annual rainfall would go through a highly significant ($P<0.01$) upward shift. While Borno, Katsina, Kebbi, Sokoto, Kano, Adamawa, Zamfara, Bauchi, Taraba, Kaduna, Niger and Plateau experienced worst-case scenarios with aridity indexes of -65.6 (Dry Semi-Arid) in 1982, -62.5 (Dry Semi-Arid) in 1996, -56.2 (Dry Semi-Arid) in 1989, -42.1 (Wet Semi-Arid) in 1987, -38.5 (Wet Semi-Arid) in 1996, -22.6 (Dry Sub-Humid) in 2008, -5.2 (Dry Sub-Humid) in 2007, -2.9 (Dry Sub-Humid) in 1982, 17.4 (Wet Sub-Humid) in 2003, 32.3 (Humid) in 2008, 35.7 (Humid) in 1987 and 45.2 (Humid) in 1995 respectively as seen in table 3 below. Reynolds *et al.,* 2011 confirmed that these trends might induce the expansion of arid areas and further increase the fraction of the population that is affected by water scarcity and land degradation.

4.2.3. *Dryland expansion*

(Tabari, Talaee, Nadoushani, Willems, Marchetto, 2014) reported that increased aridity has become a major environmental challenge affecting the living conditions of the people in the dryland region in many countries of the world and Climate change model results ran by (Huang and Fu 2017), suggested that under a high emission scenario about 78 per cent of dryland expansion by the end of this century will occur in less developed countries, increasing the dryland coverage rate in these countries to 61 per cent agreeing with varying expanding aridity results as seen in table 4.1, 4.2., & 4.3. Wet semi-arid aridity class recorded an over 865.4 *per cent* increase in decade 1979-1988, and Dry sub-humid class increased by 202.9 *per cent,* humid class 37.4 *per cent* while the Wet sub-humid and Very humid class experienced a -14.9 *per cent* and -37.7 *per cent* respectively for 1978-1988 decade.

The Wet semi-arid aridity class recorded an over 114.1 *per cent* increase in 1989-1998 decade, and Dry sub-humid class recorded 43.1 *per cent* increase*,* humid class 3.2 *per cent* increase while the Wet sub-humid and Very humid class experienced a -15.2 *per cent* and -2.0 *per cent* respectively for 1989-1998 decade.

For the 1999-2008 decade, Wet semi-arid aridity class recorded a 114.0 *per cent* increase and the Humid and Very humid 5.2 and 10.2 *per cent* while the Dry sub-humid and Wet sub-humid class experienced a -65.9 *per cent* and -22.9 *per cent* respectively for 1999-2008 decade. While for the 2009-2018 decade there was a milder increase with negative values of -100, -86.1 and -38.8 *per cent* for Wet semi-arid, Dry sub-humid and wet Sub-humid respectively signifying decrease in a land area engulfed by higher degrees of aridity in the 2009-2018 decade and a 20.2 and 12.1 *per cent* for the Humid and very humid aridity classes respectively agreeing with (Dai, 2013) who observed areal increases in hyper-arid, arid, semi-arid and

Table 3: Percentage of land area under varying degrees of aridity to Nigeria landmass of 923,768 km2

Aridity Classification	(1971-2018)	1979-1988	1989-1998	1999-2008	2009–2018	Projected Aridity (2050)
Wet Semi-Arid	0.28	2.69	0.60	0.60	0	0.22
Dry Sub-Humid	3.81	11.54	5.45	1.31	0.58	1.10
Wet Sub-Humid	11.13	9.55	9.44	8.58	6.81	1.56
Humid	15.91	21.87	16.42	16.74	19.14	10.68
Very Humid	38.56	24.04	37.78	42.48	43.22	56.13

sub-humid land types from neighbouring wetter subtypes are 0.62 *per cent*, 1.16 *per cent*, 2.32 *per cent* and 3.32 *per cent*, respectively.

4.2.4. Projected Aridity

(Dai, 2013), using the Coupled Model Inter-comparison Project CMIP5 generated projections using several emissions scenarios and provided an essential reference for maintaining drylands as renewable resources. (Dai, 2013) CMIP5-EM observations projected approximately one-third decreases in the subtype areas from drier to neighbouring wetter subtypes conforming with the scenario RCP8.5 for the year 2050 (The average for 2021-2050) which was chosen in order to show realistic future climate change scenario revealed that wet semi-arid, dry sub-humid, wet sub-humid and Humid would experience losses of -19.8, -71.1, -86.0 and -32.9 respectively while the very humid aridity class will be experiencing a 45.6 expansion taking over dryer region of northern Nigeria in the RCP8.5 scenario agreeing with Dai, 2013 CMIP5 generated projection and (Aristeidis, 2019) also asserted that the areal coverage of drylands could increase by an additional 7 % of the global land surface by 2100 under high-end climate change. At a 4 °, C warmer world above pre-industrial, 11.2 % of the global land area is projected to shift towards drier types and 4.24 % to wetter.

4.2.5. Management of Drylands:

Management of dryland soils has been made easy by adopting the advanced geo-informatic tool which has helped delineate aridity boundaries revealing areas needing urgent and appropriate measures and actions to be taken to avert further desertification. Serving as a tool to inform policy and decision-makers on dryland management.

From the result and maps, starting from areas with aridity index <= -26 wet semi-arid regions which suffer highest soil degradative processes so should be treated with all the restorative principles by (Daily, 1995) increase in Soil Organic matter content, Improvement in soil structural properties, Management of runoff, and protection of exposed soil surfaces in combination with adopting practices such as reforestation, conservation tillage (e.g., no-till, reduced tillage), crop rotations, manuring, and application of organic amendments is an alternative to restoring soils in this area which can be a perfect cure for all other areas with lower degrees of aridity that can be treated by introduction of trees and forage crops can protect soil surface and improve the subsoil as prescribed by De Santisteban *et al.,* (2006).

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