



Hydrological Estimation of Seasonal Variability of Rainfall Effectiveness and Intensity for Sustainable Crop Production

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ABSTRACT

The research work aimed to study the hydrological estimation of seasonal variability of rainfall effectiveness and intensity for sustainable crop production. The rainfall effectiveness and rainfall intensity were analyzed using long term rainfall data for the period of thirty years (1988-2017). The result shows that rainfall was effective in eight years only (1990, 2007, 2009, 2010, 2012, 2014, 2016 and 2017) with a corresponding positive average value of 50.42 mm, 49.35 mm, 29.25 mm, 28.29 mm, 34.94 mm, 14.36 mm, 53.05 mm and 5.21 mm which signify that rainfall amount exceeded the rate of evaporation that may effectively sustain the production of crops in the area. Conversely, the other years were estimated with negative values and rated as not effective rainfall which may not sufficiently sustain the crops in the area if irrigation is not supplemented. For the rainfall intensity, the result also revealed that about fifteen (15) years were rated as highly intense with an estimated threshold value of > 14 mm while moderately intense rainfall was found in ten years with threshold values ranges between 12-14 mm. The year 1991, 2002, 2003, 2006 and 2011 were rated as low intense rainfall (< 12 mm) in the area. It is therefore recommended that the farmers in the area should adopt the use of drought-resistant and early maturing crops to ameliorate the eminent occurrence of prolonging dry-spells in the area.

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INTRODUCTION

Climate change constitutes a very serious threat to sustainable agricultural production and food security in many parts of the world (Adebayo *et al.*, 2012). Rainfall as the primary ecological parameter has created a variety of farming enterprises, types of system in the world. It is the dominant single weather element influencing the intensity and location of farming systems and the farmer's choice of enterprises. Variation in rainfall from year to year even from season to season, when frequently marginal in amount for

agriculture, becomes more critical. Because sometimes the distribution of rainfall is so irregular, not only in amount but also in time and space, that creates water deficiency everywhere. For example in Nigeria, analysis of long-term meteorological data show discernable evidence of climate change which leads to warmer seasons; increased frequency and intensity of weather extreme events such as drought, the decline in rainfall amount by about 15-20%, increased incidence of a dry spell (Adebayo, 1998; Anuforum, 2010; Muhammad *et al.*, 2013). These variations



may produce dry spells which may not last for several days, weeks, or even months varying from place to place depending on the distance from the seas or mountains, topographical alignment, and the formation of an abnormal pressure system. Therefore, the emergence of such wayward behaviour of rainfall from year to year gives rise to different cropping patterns and imbalances in levels of agricultural productivity (Singh and Dhillon, 1994). Similarly, the trends remain unchanged in Yola South LGA, food production was adversely affected due to apparent variability in timing and decreased in rainfall amount coupled with an increased in temperature and heat stress that led to a complementary reduction in food production per unit area, starvation of livestock due to loss of pasture and vegetation cover, drying of streams and lakes, desert encroachment, and subsequently caused farmers lost their sources of livelihood. (Sadiq, 2020).

Therefore, a fore-knowledge of rainfall effectiveness and intensity with such abnormalities of rainfall is likely to prove the immense help not only to farmers but to the authorities concerned with the planning of irrigation schemes (Singh and Dhillon, 1994). Thus, crop production and rainfall relation are correlated based on the aspect of rainfall effectiveness (R_e) and rainfall intensity (R_i). It is based on this background this research work saddled to estimate the seasonal variability of rainfall effectiveness and intensity for sustainable crop production in Yola South LGA, of Adamawa State Nigeria.

STUDY AREA

The study was conducted in Yola South LGA of Adamawa State, Nigeria which lies on latitude $09^{\circ} 14'N$ and $09^{\circ} 20'N$ of the equator and longitude $12^{\circ} 25'E$ and $12^{\circ} 28'E$ of the Greenwich meridian with an average annual rainfall of 850 mm-1000 mm with over 41% of rain falling in August and

September. Temperature also has a significant temporal variation in the study area; with an average maximum temperature of $42^{\circ}C$ having an average relative humidity of about 29% (Adebayo, 1999; Upper Benue River Basin Authority, Yola, Nigeria. 2018).

METHODOLOGY

The data used in the research work were obtained from the Weather Station of the Upper Benue River Basin Development Authority, (UBRBDA) Yola for the period of thirty years (1988-2017). The data were subjected to analysis of rainfall effectiveness and rainfall intensity using the recommended formula as follows;

Rainfall effectiveness (R_e) is usually expressed as the actual total rainfall minus the total possible evaporation as defined by Monkhouse and Wilkinson, (1967) and Singh and Dhillon, (1994) respectively.

$$R_e = R_T - R_E \dots \dots \dots 1$$

Where;

R_T = is the actual total rainfall, R_E = is the total possible evaporation

The positive values are considered and rated as effective (if rainfall amount > evaporation rate) while the negative value is considered and rated as not effective (if rainfall amount < evaporation rate).

The rainfall effectiveness may explain how much the quantity and concentration of rain of a particular area are suitable for a particular crop. It is important to understand rain-spells and dry-spells as they are the parameter of rainfall effectiveness and they possess an important bearing on the agriculture of an area. They are the result of the prevalence of significant rainfall abnormalities. Isolated, short periods of droughts or dry-spells do not materially affect the crops; but if they are prolonged they will tend to jeopardize overall agricultural activity, as also the production and marketing structure (Singh and Dhillon, 1994).



Rainfall intensity (R_i) refers to the rate at which rainfalls in 24 hours. It is of significance as it influences the intensity of soil erosion by rain and the usefulness of rain for agriculture. The average intensity of rainfall (I) can be calculated as;

$$I = \frac{A}{n} \dots\dots\dots 2$$

Where,

A = is the total rainfall over a given period

n = is the total number of hours of rain or the number of rainy days (Monkhouse and

Wilkinson, 1971; Singh, and Dhillon, 1994). The threshold values of < 12 mm = low intense (**LI**), 12-14 mm = moderately intense (**MI**) and > 14 mm = highly intense (**HI**) were adopted in this research work for rating the intensity levels. The quantum of rainfall and the number of rainy days may be quite sufficient to meet the annual requirement of successful crop production (Singh and Dhillon, 1994).

RESULTS

Table 1: Estimated Rainfall Effectiveness (mm)

Years	Apr	May	Jun	Jul	Aug	Spt	Oct	Total	Average	Ratings
1988	-241.47	-80.24	21.52	72.64	72.04	210.82	-107.52	-52.21	-7.45	Not Effective
1989	-240.95	-20.20	-61.24	13.28	328.74	-46.01	-154.58	180.96	-25.85	Not Effective
1990	-227.61	-115.75	-48.02	114.42	68.10	-11.96	-132.15	-352.97	50.42	Effective
1991**	-----	-----	-----	-----	-----	-----	-----	-----	-----	Not Available
1992	-170.78	-102.43	-62.41	-34.28	30.58	93.07	-160.46	-406.71	-58.10	Not Effective
1993	-199.54	-47.33	-38.71	68.94	-20.42	31.96	-79.91	-285.01	-40.71	Not Effective
1994	-163.51	-116.13	26.72	-56.00	158.35	-28.05	-56.77	-235.39	-33.62	Not Effective
1995	-240.23	-116.62	11.03	20.76	47.26	-77.61	-92.03	-166.40	-23.77	Not Effective
1996	-212.65	-4.06	11.03	20.76	47.26	-77.61	-92.00	-307.30	-43.90	Not Effective
1997	-129.40	-104.30	-115.69	59.50	14.00	43.20	-44.40	-276.90	-39.55	Not Effective
1998	-215.40	-163.30	-74.30	121.50	20.20	177.80	-88.00	-221.50	-31.64	Not Effective
1999	-243.90	-69.60	-35.10	10.16	132.29	147.60	53.20	-5.35	-0.76	Not Effective
2000**	-----	-----	-----	-----	-----	-----	-----	-----	-----	Not Available
2001**	-----	-----	-----	-----	-----	-----	-----	-----	-----	Not Available
2002	-268.37	-219.14	-34.38	-30.18	-13.77	158.00	-37.7	-445.54	-63.64	Not Effective
2003	-277.72	-214.83	-130.38	29.62	115.79	80.84	-35.84	-432.52	-61.78	Not Effective
2004	-263.26	-85.42	8.08	-12.60	97.60	49.02	-86.82	-293.40	-41.91	Not Effective
2005	-275.48	-148.35	-82.48	74.08	125.12	3.93	-132.55	-435.73	-62.24	Not Effective
2006	-307.00	-118.00	-12.71	0.32	65.26	92.36	-162.23	-442.00	-63.14	Not Effective
2007	-217.26	-135.92	-43.02	1.83	85.88	61.11	-121.54	-345.49	49.35	Effective
2008	-260.51	-95.94	-43.02	1.83	85.88	61.11	-121.54	-372.19	-53.17	Not Effective
2009	-166.82	-17.53	78.13	86.86	154.13	137.82	-67.84	204.75	29.25	Effective
2010	-194.83	-82.62	103.66	127.06	119.88	101.99	22.90	198.04	28.29	Effective
2011	-178.88	-71.74	-112.63	-49.56	18.94	138.22	17.66	-237.99	-33.99	Not Effective
2012	-175.70	28.87	119.12	67.06	101.5	110.62	-6.89	244.58	34.94	Effective
2013	-190.09	-22.29	-8.80	54.52	57.11	105.16	-63.78	-68.17	-9.73	Not Effective
2014	-97.82	20.05	63.29	19.86	74.37	93.55	-72.73	100.57	14.36	Effective
2015	-218.74	-163.07	37.10	89.78	163.52	137.80	-50.07	-3.67	-0.52	Not Effective
2016	-187.45	64.35	208.45	33.94	173.64	107.10	-28.65	371.38	53.05	Effective
2017	-109.80	-35.98	42.93	46.51	84.00	103.02	-94.16	36.52	5.21	Effective

** **Missing Data; Not Available**

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Table 2: Estimated Rainfall Intensity

Year	Total Rainfall (mm)	No of Rainy Days	Rainfall Intensity (mm)	Ratings
1988	1083.5	74	14.64	Highly intense
1989	982.2	62	15.84	Highly intense
1990	823.8	58	14.20	Highly intense
1991	861.8	69	12.48	Not intense
1992	969.3	64	15.14	Highly intense
1993	983.4	71	13.85	Moderately intense
1994	924.5	61	15.15	Highly intense
1995	1080.8	69	15.66	Highly intense
1996	1009.8	74	13.64	Moderately intense
1997	977.6	68	14.37	Highly intense
1998	1022.8	74	13.82	Moderately intense
1999	1113.3	73	15.25	Highly intense
2000	947.6	73	12.98	Moderately intense
2001	915.8	61	15.01	Highly intense
2002	656.7	68	9.65	Not intense
2003	784.7	77	10.19	Not intense
2004	800	60	13.33	Moderately intense
2005	799.1	62	12.88	Moderately intense
2006	764.9	71	10.77	Not intense
2007	903.4	68	13.28	Moderately intense
2008	808.9	64	12.63	Moderately intense
2009	1063.4	72	14.76	Highly intense
2010	1063.6	72	14.77	Highly intense
2011	823.2	71	11.59	Not intense



Year	Total Rainfall (mm)	No of Rainy Days	Rainfall Intensity (mm)	Ratings
2012	1085.2	81	13.39	Moderately intense
2013	827.7	67	12.35	Moderately intense
2014	1015.3	71	14.3	Highly intense
2015	979.0	69	14.18	Highly intensive
2016	1260.1	68	18.53	Highly intensive
2017	920.6	65	14.16	Highly intensive

DISCUSSIONS

The result on the rainfall effectiveness in table 1 shows that rainfall intensity is not effective in the year 2002 having a positive value of rainfall exceeding evaporation in one month only (September = 158.00 mm) while other months (April, May, June, July, August and October) were found with the negative values which signify that evaporation rates exceeded that of rainfall. This result signifies that the rainfall was not effective to support the production of crops in the year due to the presence of dry-spells in almost all months. Continues application of water is highly required to supplement the water requirement for successful crop production. Thus, this finding agrees with the recent report of Sadiq, (2020) who used the rainfall decile index (RDI). He found out that the year 2002 was characterized as exceptional drought (D4) season which caused exceptional damage to crops, pastures and drying of water reservoirs, dams, and low agricultural production. Thus, droughts lead directly to poor crop yield. (Binbol *et al.*, 2018).

Also, the consecutive years of 1990,1992, 1993 and 1994 were estimated with only two months each of effective rainfall amount exceeding evaporation rates. However, the year 1990 was assessed as effective rainfall with an average rainfall

of 50.42 mm greater than the evaporation rate. Conversely, the year 1992, 1993 and 1994 were considered as not effective with a negative value of -58.10 mm, -40.71 mm and -33.62 mm respectively. These findings also revealed that the years were affected with dry-spells in five (5) months each which is not sufficient to effectively support the growth of crops in the area (table 1). Cropping activities were seriously affected by the presence of drought- spells in the area. According to (Sadiq, *et al.*, 2020a) in the study area reduction of crop yield was revealed as the major effects imposed by the drought intensity in the area by 18 % of the farmers. Thus, climate change impacts on agriculture include biological effect on crop yield, the resulting impact on prices, production, consumption and the impact on per capita calorie consumption and malnutrition (Mohammed *et al.*, 2013).

Furthermore, in the area dry-spells were experienced in four (4) months in the year 1989, 1995, 1996, 1997, 1998, 2003, 2004, 2005, 2006, 2007, 2008, 2011 and 2013 (13 years see figure 2) were all estimated as not effective having evaporation rates greater than the rainfall amount except in the year 2007 which was considered effective which indicates that the rainfall amount exceeds the evaporation rates in the area with a positive value of 49.35 mm as depicted on table 1.



These results show that the cropping system may not be successful in these years except in 2007 due to the presence of dry-spells (4 months) than the rain-spells (3 months). This is because most of the types and varieties of crops grown in the area are rice and maize with more than 90 days of the complete lifecycle. Therefore, irrigation supplementation is required to achieve optimum crop growth and yield production. This result conforms with the findings of Sadiq, (2020) who characterized drought as exceptional (D4) occurred in the year 2003, 2004 and 2005 which imposed an acute damaged to crop productivity, pasture availability and reduction in groundwater potential for irrigation farming in the study area. Sadiq, *et al.*, (2020a) reported a similar result that physiological stress and low crops growth were caused due to drought condition was conceived by 12 % of the farmers in Yola South LGA, of Adamawa State.

Moreover, 1988, 1999, 2009, 2015 and 2017 were estimated to have experienced four (4) months of effective rainfall as depicted in figure 1. Similarly, the year 2009 and 2017 were rated with effective rainfall amount that exceeded the rate of evaporation with positive values of 29.25 mm and 5.21 mm respectively. The implication of these results on crop production in the area may be positive due to the sufficient amount and duration of rain-spells most especially in the year 2009 and 2017. However, the year 1988, 1999

and 2015 were rated as not effective with negative values of -7.45mm, -0.76 mm and -0.52 mm of evaporation rates than the rainfall amount as portrayed in table 1 respectively. Even though, these values were insignificant to have adverse effects on crop growth and development. Thus, the duration of the rainfall (4 months) is considered sufficient to support the cereals as the major crops grown in the year.

Conversely, the rain-spells occurred for five months in the year 2010, 2012, 2014 and 2016 which were all rated as effective rainfall with an estimated average value of 29.25 mm, 34.94 mm, 14.36 mm and 53.05 mm of rainfall amount greater than evaporation rate as shown table 1. These years were recognized to have a sufficient amount and prolong the duration of rainfall that will effectively support the growth of crops grown in the area with less or no water supplementation. This conclusion agrees with the findings of Sadiq, (2020) who explained that the year 2012 and 2016 were among the five years that fell under the tenth decile with the amount of rainfall not exceeded 100 % of the occurrences rated as "Much above normal" with an abnormal dry condition but having less or no adverse effects on crop performance or soil water deficit. Thus, these years imposed flood scenarios in the area with negative impacts on farmlands, crops, animals, buildings and distraction of socio-economic activities.

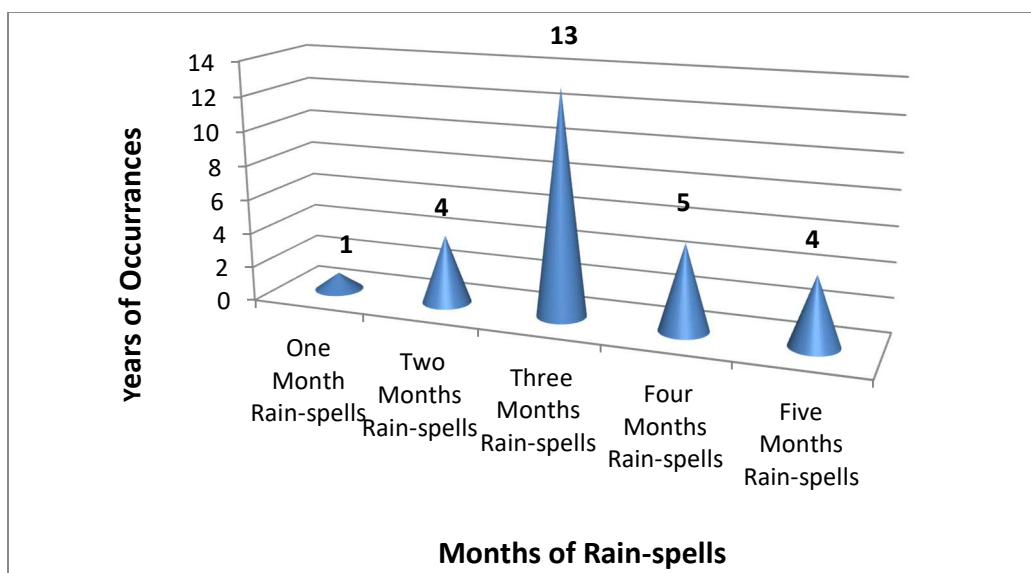


Figure 1: Shows the frequency of years that rain-spells occurred in the study area

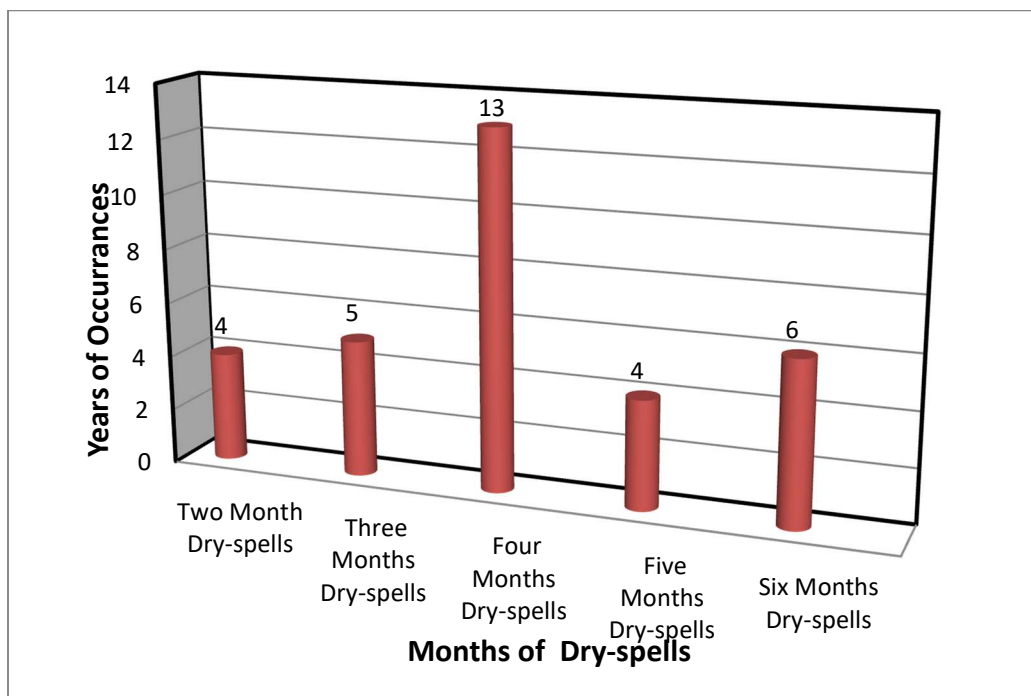


Figure 2: Shows the frequency of years that dry-spells occurred in the study area

ESTIMATION OF RAINFALL INTENSITY

Results on table 2 shows that the highly intense (HI) was estimated in the period of fifteen (15) years which were

1988, 1989, 1990, 1992, 1994, 1995, 1997, 1999, 2001, 2009, 2010, 2014, 2015, 2016 and 2017 with a values of > 14 .00 mm respectively . These findings reveal that the



area received a high amount of rainfall but with a shorter duration per storm either hourly or days. However, high rainfall intensity may lead to excessive run-off due to the fact the soil may not have the capacity to infiltrates the raindrops through its pore spaces (macro and micro spaces) thereby causing crusting of the soils, low infiltration high run-off and subsequently gradual development of soil erosion, depositions and flooding effects on agricultural lands. Thus, this might be the reason why the study area experienced adverse effects of seasonal flooding in the year 1999, 2010, 2012 2015 and 2016 respectively. Also, the moderately intensive (MI) rainfall was found in the year 1993, 1996, 1998, 2000, 2004, 2005, 2007, 2008, 2012 and 2013 with the corresponding values of 13.85 mm, 13.64 mm, 13.82mm, 12.98, 13.33 mm, 12.88 mm, 13.28 mm, 12.63 mm, 13.39 mm and 12.35 mm. The low intensive (LI) rainfall was assessed in five (5) years (1991, 2002, 2003, 2006 and 2011) with estimated values of 12.48 mm, 9.65 mm, 10.19mm, 10.77 mm and 11.59 mm accordingly. This low rainfall intensity could be an attributed reason for the prolong dry-spells experienced most especially in the year 2002 having six months of dry-spells while 200, 2006 and 2011 having four months of dry-spells respectively. A similar finding by Sadiq, *et al.*, (2020b) using Rainfall Anomaly Index (RAI) method shows that dry conditions were estimated in 15 years which mostly occurred in the recent decades (2002, 2003, 2004, 2005, 2006, 2007, 2008, 2011 and 2013) which signifies an apparent climatic change of rainfall deficit and consequently affects crop growth respectively. However, 2016 and 2012 were estimated as extremely and very wet conditions that led to exacerbated flooding in the area which damaged a hundred hectares of farmlands.

CONCLUSION

The effectiveness and intensity of rainfall variability appeared as the eminent parameters of climate change affecting the study area. The results revealed that rainfall was effective in eight (8) years having a high amount of rainfall than evaporation rates which may sustain crop growth and development. Conversely, the area experienced adverse effects of dry-spells due to the ineffectiveness of the rainfall amount which caused poor growth and development of crops and subsequently reducing the yield per unit area. However, despite the fact the area experienced prolong dry-spells, rainfall was highly intense in about fifteen (15) years while five years was considered with low intensive rainfall respectively. Based on the findings obtained from this study, farmers in the area are therefore recommended to supplement the water requirement to the crops through irrigation during the dry-spells to prevent the wilting of crops and yield reduction. Also, the use of drought-resistant varieties with low water use potential should be adopted and early maturing crops are also encouraged for sustainable production in the dynamic climatic conditions in the area.

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