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TABLE OF CONTENTS

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DISCLAIMER

Water-Table Dynamics, Its Trend and Sustainability Considerations at Two Upazila of North-Western Bangladesh 01
M. H. Ali, M.H. Zaman, P. Biswas, M. A. Islam, M. T. Islam, and M. H. Khaledujjaman.

Adoption and Performance of Rice Varieties in Guyana from 2009 to 2019 09
Bissessar Persaud, Mahendra Persaud, Gomathinayagam Subramanian, and Narita Singh.

Dynamics of Groundwater Resources of Upper Benue River Basin, Nigeria 17
Joshua, Ma'aku Mark, Oruonye E.D., Zemba, A.A., and Yusuf, M.B.

Classification of Feed Additives Used in Poultry and Livestock Production: A Review 35
Stephen. N. Okey

The Value Addition of Agricultural Waste (Pig dung) in Producing Activated Carbon for Use in Veterinary Medicine, Agriculture and Environmental Remediation: A Review 47
Stephen. N. Okey, I. C. Okoli, C. R. Unigwe and O.N. Okey

Rainfall Variability Trend in Porbandar, Gujarat 64
Kunal N. Odedra and B. A. Jadeja

EDITORIAL BOARD

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Water-Table Dynamics, Its Trend and Sustainability Considerations at Two Upazila of North-Western Bangladesh

M. H. Ali[1], M.H. Zaman[1], P. Biswas[1], M. A. Islam[1], M. T. Islam[2] and M. H. Khaledujjaman[3]

1. Agricultural Engg. Division, Bangladesh Institute of Nuclear Agriculture, Mymensingh-2202, Bangladesh
2. Executive Engineer, Barind Multipurpose Development Authority (BMDA), Rajshahi Bangladesh.
3. Executive Engineer, BADC, Dhaka

Abstract:
The study aimed to determine the long-term trend of the groundwater table and to forecast the future situation of north-western part of Bangladesh. Using a non-parametric technique (through MAKESENS software), the trend was examined. The patterns of the yearly maximum and minimum depth to Water Table (WT) showed that the magnitude between the maximum and minimum is dwindling over time, implying a decreasing recharge rate. The depth to WT would be almost 1.5 times greater in 2050 and nearly twice as much in 2075, according to the projected scenario for WT. The "Discrete Space-State model" was also used to forecast the WT. Both models generally yielded findings that were quite close. If the decline of the water table is allowed to last for an extended period of time, the ecology and the sustainability of agricultural output, which is crucial for the nation's food security, could be significantly threatened. The necessary actions should be taken to sustain water supplies, which will then maintain agricultural production. Demand-side management and alternative agricultural practices (such as the introduction of crops with lower water requirements) seem to be workable alternatives for the area.

Keyword: Water-table dynamics, non-parametric method, Discrete Space-State model, sustainability

INTRODUCTION

In recent years, the primary policy goal in farm management, particularly in nations with limited water and land resources, has been the growth in food production while using less irrigation water (FAO, 2021). Since its liberation, food security has been a persistent problem in Bangladesh, one of the world's most densely populated nations. In Bangladesh's agriculture over the past 25 years, the extension of irrigated cropl and primarily accomplished through groundwater irrigation, has likely been the most significant change. The contribution of groundwater has grown from 41% in 1982–1983 to 79% in 2016–2017 (BBS 2017). In Bangladesh's north-western districts, as opposed to other regions of the nation, a far higher proportion of groundwater than surface water is used. With an average annual rainfall ranging between 1,400 and 1,900 mm, this region is classified as a dry humid zone by the climate. Less than 6% of this rainfall falls during the irrigation period for rice farming's dry season (November to April), and almost 94% rainfall occurs during May to October (Ali et al., 2021a). In order to meet the need for farming crops, particularly for Boro rice, during the dry season, all of the rivers and canals dry up, leaving the population entirely dependent on groundwater (Hossain and Mojid, 2022)

Although groundwater accounts for the majority of the area that is irrigated, excessive resource extraction in the northwest region has put the groundwater's quantity sustainability at jeopardy (Zaman et al., 2019; Ashraf and Ali, 2015). The primary causes of the current issue, according to researchers, are excessive groundwater extraction for irrigation due to ignorance, cultivation of water-intensive crops, irrational irrigation management, indiscriminate pump installation, and a lack of modern technologies (Reza et al., 2020; Adhikary et al., 2013).

According to several studies, the groundwater table in some parts of the Barind tract of the northwest region has decreased by at least 10 meters during the past 14 years (Ali et al., 2021b). Groundwater decline poses a threat to future water resources if it is not refilled on a regular basis by seasonal rainfall, with strong declining trends (0.5-1.0 meters/year) in the country's central region and moderate declining trends (0.1-0.5 meters/year) in the west, north west, and north-eastern regions during dry season. The considerable reduction in groundwater levels over the past ten years has threatened both the ability of this region to sustainably use water for irrigation and how it is affecting other businesses (Jahan et al., 2010; Ali et al., 2011). The environment, society, and the economy are all negatively impacted by persistent water shortages (Islam et al., 2013). If this usage persists, it might cause exhaustion within a few years, which would have a significant impact on the country's agriculture-based economy.

The water resources in all sectors and the water demand during dry periods were estimated and forecasted in the National Water Management Plan 2001 for a 25-year timeframe (NWMP, 2001). According to the study, water supply for domestic and commercial use in urban and rural areas will be more than twice as large as it is now, and demand for irrigation is predicted to rise by as much as a quarter (1/4) during the next 25 years. Integrated surface water and groundwater model study in the Barind area which covers 25 Upazilas of Rajshahi, Chapainawabganj and Naogaonditricts was carried out by IWM (2006). MIKE, SHE integrated with MIKE 11 Modelling system having 1000m x 1000m grid size covers about 7500 sq. km of study area. Based on available data up to 2005, study found the 11 Upazilas (out of 25) have less groundwater resources create some problem to meet the present water demand of Boro crops (IWM, 2012).

According to research by the Barind Multi-Purpose Development Authority (BMDA) (IWM, 2006), the northwest region's groundwater table varies from 1 to 13 meters below ground level during dry seasons. In some study sites, it has been observed that the groundwater level may additionally decrease by between 0.5 and 1.0 meters as a result of climate change.

Recent data on the resource and optimization for the region's sustainable agricultural development are required for the long-term usage of this important and precious resource in the Barind region. In order to assess the long-term trend of the groundwater table (GWT) in the Barind region of Bangladesh, the study was undertaken.

METHODOLOGY

Description of The Study Area

Niamatpur Upazila under Nawgaon district and Nachol Upazila under Chapai Nawabganj district are two study areas which is from $89^{o}18'$ to $89^{o}22'$ East and $24^{o}22'$ to $24^{o}51'$ North and illustrated in Figure 1.

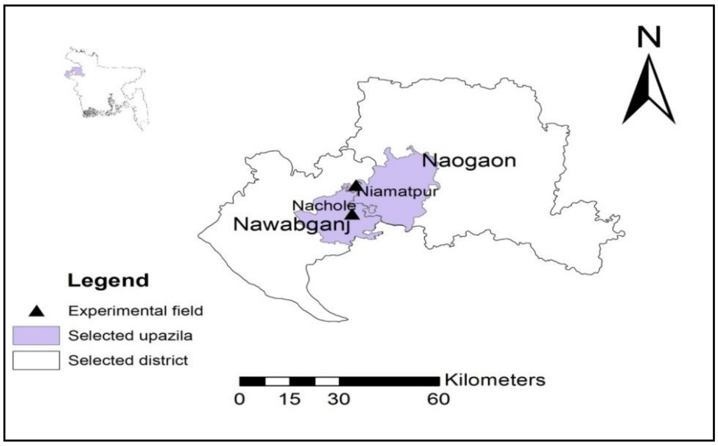

Figure 1. Location map of the study areas (Nachol and Niamatpur)

Hydro-Geological Features of The Study Area

Two separate landforms make up the geography of the area: (a) the dissected and undulating Barind tract; and (b) the floodplains. Due to the clayey and semi-to-impermeable Barind clay and high surface runoff, the elevated Barind tract has less infiltration. Three geological units make up the region's morpho-stratigraphy: (1) Barind clay residuum, which is alluvium that was developed over Pleistocene alluvium, (2) Holocene Ganges flood-plain alluvium, and (3) Active channel deposits of the Ganges and its distributaries (modern alluvium). Alluvial sand, alluvial silt, Barind clay residuum, Marsh clay, and peat are among the lithology categories (Alam et al., 1990). When it comes to hydrogeology, the region is characterized by single to multiple layered clay-silt aquitard of the Recent-Pleistocene age (thickness 3.0 - 47.5 m) (Jahan et al. 2005).

Rainfall Pattern of The Study Location

The graph in Figure 2 shows the monthly rainfall pattern from 2001 to 2020 (which was collected from BMDA Nachol office). The months from May to September is known as monsoon season, when most of this rainfall falls.

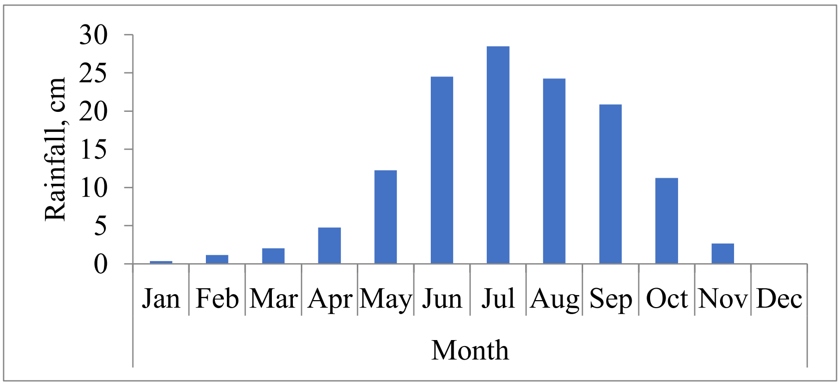

Figure 2. Monthly rainfall pattern in the study area

Water-Table Dynamics

The water-table (WT) data were collected from Bangladesh Water Development Board (BWDB) and also from Barind Multipurpose Development Authority (BMDA). To better understand the dynamics of the groundwater system, graphical representations of the seasonal and long-term patterns of WT fluctuations are provided. The long-term trend is determined using the yearly maximum depth to the water table.

Water-Table Trend Analysis by MAKESENS Model

Trends were estimated using the "MAKESENS" software. The non-parametric Mann-Kendall test for trends and the non-parametric Sen's approach for trend magnitude are the foundations of this software (Salmi et al. 2002). The non-parametric approach has the benefit of working with missing data and applying to both monotonic and non-monotonic trends. The model also makes use of Gilbert's "S statistics" and "Z statistics" (the normal approximation) (Gilbert, 1987). The *S* test is applied to time series with less than 10 data points; the *Z* test is applied to time series with 10 or more data points.

Mann-Kendall Test

The Mann-Kendall test is applicable in cases where the data values x_i of a time series can be assumed to obey the model

$$x_i = f(t_i) + \varepsilon_i \qquad (1)$$

in which, f (t) is a continuous, monotonic, increasing or decreasing function of time, and where ε_i is a set of residuals that may be assumed to come from the same distribution as the sample as a whole and have a mean of zero. The variance of the distribution is consequently thought to be constant throughout time. The examined data series' n stands for the number of yearly values. The Mann-Kendall test statistic S is computed using the following formula when the number of data values is less than 10:

$$S = \sum_{k=1}^{n-1} \sum_{j=1}^{n} \operatorname{sgn}(x_j - x_k) \qquad (2)$$

When j > k, xj and xk are, respectively, the yearly values in the years j and k; and

$$\operatorname{sgn}(x_j - x_k) = \begin{bmatrix} 1 \; if \;\; x_j - x_k > 0 \\ 0 \; if \;\; x_j - x_k = 0 \\ -1 \; if \;\; x_j - x_k < 0 \end{bmatrix} \qquad (3)$$

The theoretical distribution of S developed by Mann and Kendall is directly compared with the absolute value of S if n is 9 or fewer (Gilbert, 1987). The two-tailed test is applied in MAKESENS for four distinct significance levels of: 0.1, 0.05, 0.01 and 0.001. Salami et al. (2002) provided further information on the MAKESENS model. The formula used to forecast the WT conditions is:

$$\text{WT (m)} = B + Q \times (\text{Simulation year} - \text{Base year}) \qquad (4)$$

Where, as determined from model output, B is the intercept and Q is the slope of the trend line. The simulation years 2050, 2075, and 2100 were chosen. The year 1981 served as the base year (the first year of the data set) of our study.

WT Prediction by Discrete Space-State Model

The Discrete Space-State model was used to predict WT for several wells. This model is created by dividing the original time series data into identification and validation data. Then, the model is used to predict WT for the future time period (Roy et al., 2021).

RESULTS AND DISCUSSION

Groundwater Dynamics

The seasonal maximum and minimum water-table patterns (1981-2019) for Nachol and Niamatpur are shown in Fig. 3.1 and Fig.3.2, respectively. The water table is gradually dropping, and it has been doing so at a rate of 0.43 m/year in Nachol and 0.33 m/year in Niamatpur.

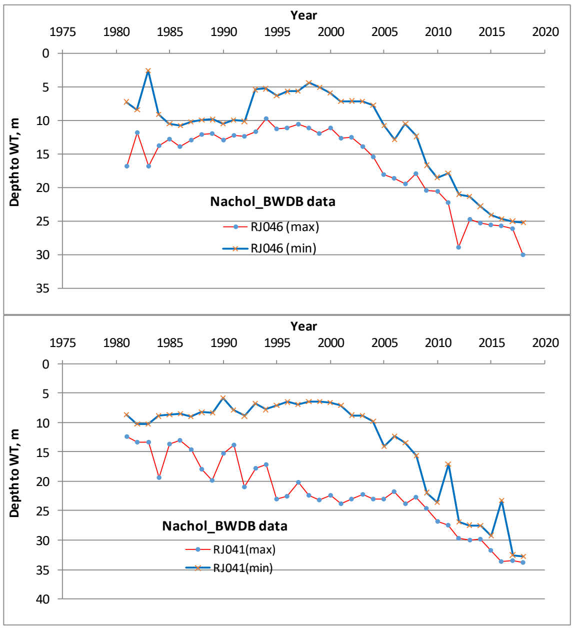

Figure 3.1. WT pattern of two wells at Nachol

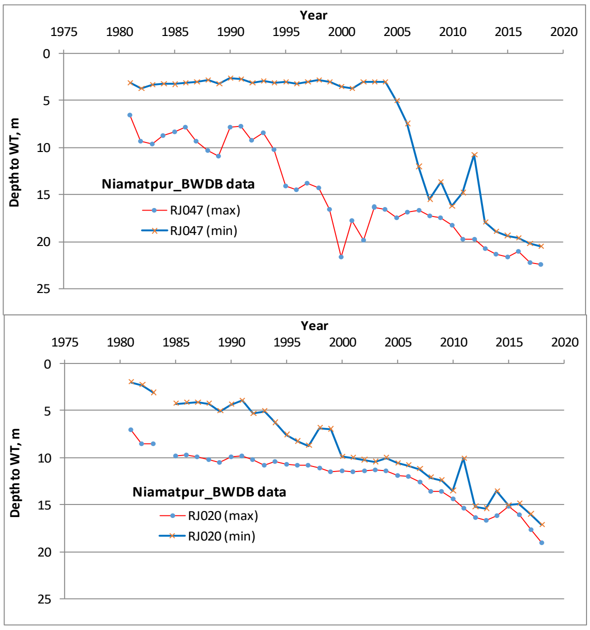

Figure 3.2. WT pattern of two wells at Niamatpur

Output of MAKESENS Model

The position of water-table (both maximum and minimum) in different wells of Nachol and Niamatpur in 1981and 2018, and the predicted scenario for 2025, 2050, 2075 and 2100 are tabulated in Table 3.1. In 2050, it is predicted that the water table will be about 1.5 times deeper. In 2075, it is predicted that the water table will be nearly twice as deep in 2018.

Table 3.1. Position of maximum WT depth in the past and simulated scenario for future, using MAKESENS software at Nachol and Niamatpur Upazilla.

Upazilla	Well no	WT depth (m) in year		B	Q	Predicted WT depth (m) in year				Significance level of trend
		1981	2018			2025	2050	2075	2100	
Nachol	GT7056006	12.3	33.45	12.38	0.523	35.39	48.49	61.57	74.66	***
	GT7056007	11.72	33.52	13.53	0.469	34.16	45.90	57.63	69.36	***
	GT7056008	4.82	25.1	5.80	0.490	27.36	39.61	51.86	64.11	***
	GT7056009	16.72	26.00	8.63	0.410	26.67	36.94	47.19	57.45	***
	GT7056011	7.37	29.69	11.30	0.518	34.09	47.06	60.01	72.97	***
Niamatpur	GT 29	8.46	19.05	7.91	0.213	17.28	22.57	27.89	33.20	***
	GT 30	9.28	21.3	7.06	0.419	25.49	35.98	46.45	56.93	***
	GT 31	7.02	13.44	6.72	0.215	16.18	21.55	26.93	32.30	***
	GT32	9.25	26.8	6.18	0.587	32.00	46.68	61.36	76.03	***

Note: B = Intercept of linear regression equation; Q = Slope of linear regression equation and *** trend is significant at $\alpha = 0.001$; ** trend is significant at $\alpha = 0.01$; * trend is significant at $\alpha = 0.05$; + trend is significant at $\alpha = 0.1$.

Output of Discrete Space-State Model

Predicted WT of some of the wells by 'Discrete Space-State model' are tabulated in Table 3.2 along with MAKESENSE output, and also presented in Fig.3.3. Except one well (GT6459030), both the models produced almost similar results. For GT6459030 well, the prediction by Discrete Space-State model is not logical according to the base data (Fig.3.3).

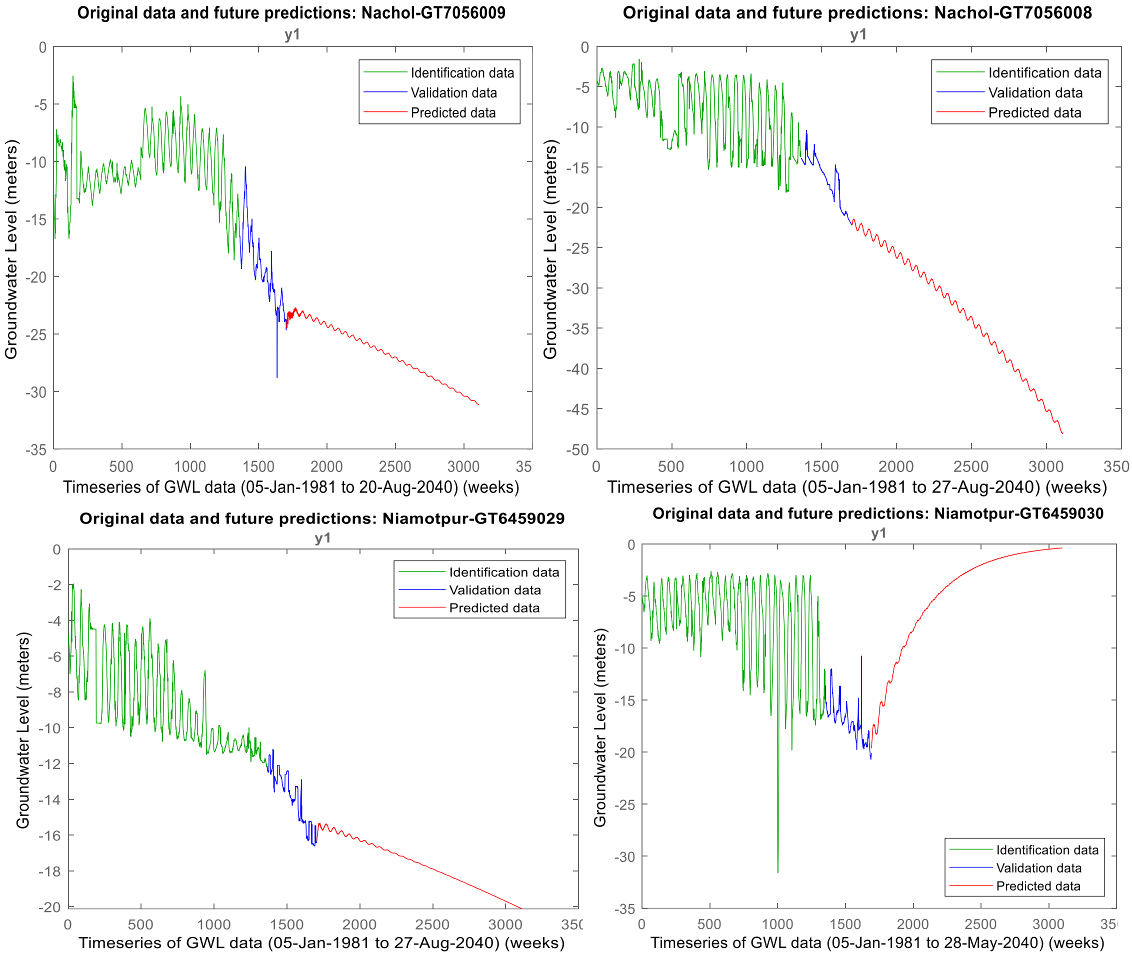

Fig.3.3. WT time series along with Predicted WT

Table 3.2 Comparative evaluation of predicted WT by Steady-State model and MAKESENS model

	Well No.	Predicted WT(m) by Steady State model		Predicted WT(m) by MAKESENS model	
		Year 2025	Year 2040	Year 2025	Year 2040
Nachol	GT7056008	30.91	47.97	27.36	34.71
	GT7056009	26.13	31.15	26.67	32.82
Niamatpur	GT6459029	17.34	20.13	17.28	20.47
	GT6459030	3.36	0.37	25.49	31.78

Discussions

The study found that groundwater usage has outpaced groundwater recharge, meaning that the water table is slowly decreasing. If this trend continues, many wells' water table depths will be roughly 1.5 times what they are now by 2050, and in virtually all cases, they will have doubled by 2075. This could lead to higher irrigation water costs, which would affect crop production.

Groundwater is a valuable resource, but it can't be regenerated on a large scale. So, we need to make sure that we use it sustainably so that we don't extract too much from the aquifer over time. This is called sustainable groundwater utilization. If groundwater levels are falling over time, this means that we're using too much groundwater and it's not being replenished fast enough. The groundwater level is dropping, and this could lead to a number of environmental and ecological disasters. If we don't take measures to prevent groundwater mining, these disasters could become permanent obstacles to the region's socioeconomically sustainable development. So, measures should be taken to prevent groundwater mining. We can do this by using management techniques like demand-side planning (e.g., cultivating low water-demanding crops, efficient irrigation management, converting to natural rainfall-matching cropping pattern – such as Aus rice) and looking for surface water sources, which would reduce our dependence on groundwater. There is also an urgent need to change the monopoly of rice-based cropping patterns.

CONCLUSION

The MEKESENS software is used to predict the future and take into account how much water is being taken out of the ground each year. If the rate of water withdrawal continues at the same pace, the ground will be lowered by 1.5 times by the year 2050. This could have many negative consequences, including less water for plants and animals, higher pumping costs, and environmental damage. So, preventive measures should be taken to avoid undesirable circumstances.

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Adoption and Performance of Rice Varieties in Guyana from 2009 to 2019

Bissessar Persaud[1], Mahendra Persaud[2], Gomathinayagam Subramanian[1], and Narita Singh[3]

1. Faculty of Agriculture and Forestry, University of Guyana Berbice Campus, Tain, Guyana
2. Plant Breeder, Guyana Rice Development Board, Burma Rice Research Station, Guyana
3. Faculty of Natural Science. University of Guyana Turkeyen Campus, Georgetown Guyana

Abstract:
Rice (Oryza sativa L.) production has been the pillar of the agriculture sector in Guyana and is the staple food for its people. It is currently the largest agricultural industry in the country, which serves as the bedrock for the Guyanese economy and is by far the most important constituent of the livelihoods of its people. The production of paddy has increased over the last decade, with the highest recorded in the First Crop 2019 of 525,649 Metric tons (Mt) at 6 t/ha. Over one hundred and seventy thousand (170,000) families benefit directly or indirectly from the rice industry. The Guyana Rice Development Board (GRDB) through its Research and Extension program, play a pivotal role in improving rice yields thus increasing the revenue earned. (www.grdb.gy). The adoption of technology is to make full use of an innovation as the best course of action available. The adoption of technology is consisted of the need of a new technology, creating awareness of a new technology, the interest the farmers have over a new technology, the deliberation the farmers have in accepting it, the willingness to try and evaluate a new technology and finally to adopt a technology for commercial purposes. Therefore, the objective of this study is to determine the extent of farmers' "adoption and performance of rice varieties from 2009 to 2019. Over the last decade the GRDB would have released seven local high yielding varieties mainly the GRDB 9, GRDB 10, GRDB 11, GRDB 12, GRDB 13, GRDB 14 and GRDB 15. Prior to release, these varieties would have tested by the various departments at the Research Station for pest and disease tolerance/resistance, fertilizer and crop nutrition response and mainly the yield obtained. These varieties were further tested using the Advance Yield Trial (AYT) at the Research Station and in small plot of pilot farmers (plot size of 9m2). After two crops of AYT, these varieties were further tested in innovators field as an On Farm Trial (OFT) plot size of 45m2. Each variety was tested using the OFT with at least 30 innovators (lead farmers) of the various rice growing districts. The main parameter taken during the OFT were, plant height, plants/m2, flowering data, response to plant nutrients, fill and unfilled grains per panicle, 1000 grain weight and lodging. At the end of the trial a Farmer Field Day was held in each rice growing Region to evaluate the performance of these varieties. These varieties were well adopted by farmers across the various rice growing Regions, and due to their high yielding ability, variety such as the GRDB 10 occupied approximately 40% of the total cultivation while the GRDB 15 occupied approximately 10% at the moment.

Keywords: Oryza sativa L, GRDB, Varieties, Advance Yield Trial, Adoption,

INTRODUCTION

Rice (*Oryza sativa* L.) production has been the pillar of the agriculture sector in Guyana and is the staple food for its people. It is currently the largest agricultural industry in the country, which serves as the bedrock for the Guyanese economy and is by far the most important constituent of the livelihoods of its people. The production of paddy has increased over the last decade, with the highest recorded in the First Crop 2019 of 525,649Mt at 6 t/ha. Over one hundred and seventy thousand (170,000) families benefit directly or indirectly from the rice industry. The Guyana Rice Development Board (GRDB) through its Research and Extension program, play a pivotal role in improving rice yields thus increasing the revenue earned. (www.grdb.gy).

The adoption of technology is to make full use of an innovation as the best course of action available. The adoption of technology is consisted of the need of a new technology, creating awareness of a new technology, the interest the farmers have over a new technology, the deliberation the farmers have in accepting it, the willingness to try and evaluate a new technology and finally to adopt a technology for commercial purposes (G. L. Ray 2011).

Rice varieties such as the GRDB 10, GRDB 12, GRDB 13, GRDB 14 and GRDB 15 have gained acceptance and widely cultivated in the rice growing regions in Guyana. These varieties are known for producing high yield that is forty bags plus per acre and are tolerant to lodging, they occupied over 80% of the total cultivation in Guyana. The average productivity in Guyana for 2019 is 5.85 t/ha with GRDB 10 as the most dominant variety, which occupied approximately 40% of the total acreage cultivated (www.grdb.gy).

The adoption of certified and improved high-yielding rice varieties is an important avenue for increasing agricultural productivity and improving the standard of living of the farmers in developing countries. It's an option for the farmers to get rid of hunger and food insecurity by improving crop productivity, reducing food price and making more food accessible for the poor households. Further, promoting the adoption of improved crop varieties in a sustainable manner helps to improve welfare of the households (Asfaw et al, 2012).

The determinants to the adoption of rice varieties have been investigated for various countries including India (Kumar et al, 2016), Malaysia (Adedoyin et al, 2016), the Philippine (Mariano et al, 2012), Nepal (Ghimire et al, 2015), Bangladesh (Hossain et al, 2006), Benin (Dandedjrohoun et al, 2012), Nigeria (Ologbon et al., 2012), Ethiopia (Asmelash, 2012) and Kenya (Okello et al, 2016). Some studies conducted in Pakistan mainly focus on adoption of rice varieties and technical efficiency of rice production and impact of institutional credit on rice productivity (Khalid Bashir and Mehmood 2012). No study was done in Guyana to examine the adoption and performance of the GRDB varieties therefore, this paper aimed to fill this gap of the adoption and performance of rice varieties from 2009 to 2019.

MATERIALS AND METHOD

Over the last decade the GRDB would have released seven local high yielding varieties mainly the GRDB 9, GRDB 10, GRDB 11, GRDB 12, GRDB 13, GRDB 14 and GRDB 15. Prior to the release, these varieties were known as promising lines and would have tested by the various departments at the Research Station for pest and disease tolerance/resistance, fertilizer and crop nutrition response and yield obtained. These lines were further tested using the Advance Yield Trial (AYT) at the Research Station and in small plot of pilot farmers (plot size of 24m^2). After two crops of AYT, these lines were further tested in innovators fields using the On Farm Trial (OFT) with plot size of 225m^2. Each variety was tested using the OFT with 30 innovators (lead farmers) of the various rice growing districts in Guyana. Data were collected by both Extension officers and the plant breeding team, the data collected include, plant height, plants/m^2, flowering data, response to plant nutrients, fill and unfilled grains per panicle, 1000 grain weight and lodging. Data were analyzed using the simple statistical tool that include frequency, average, mean etc. At the end of the cropping season a Farmer Field Day was held in each of the rice growing Region to evaluate the performance of the Candidate variety. Once the necessary requirements were fulfilled, these lines were then released and named as varieties by GRDB for commercial cultivation by the farmers. Over the decade these varieties mentioned above were adopted by farmers mainly for their high yielding ability, tolerance to pest/disease and lodging, crop duration and low input cost. These varieties occupied over 80% of the total acreage cultivated.

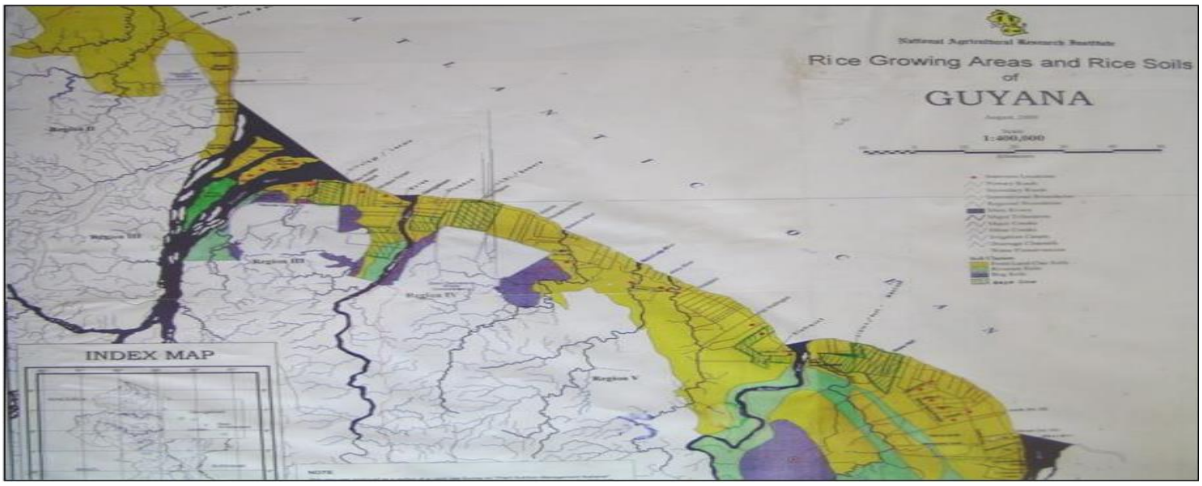

Figure 1. The yellow area represents the rice growing regions on the low coastal plain of Guyana

RESULTS AND DISCUSSION

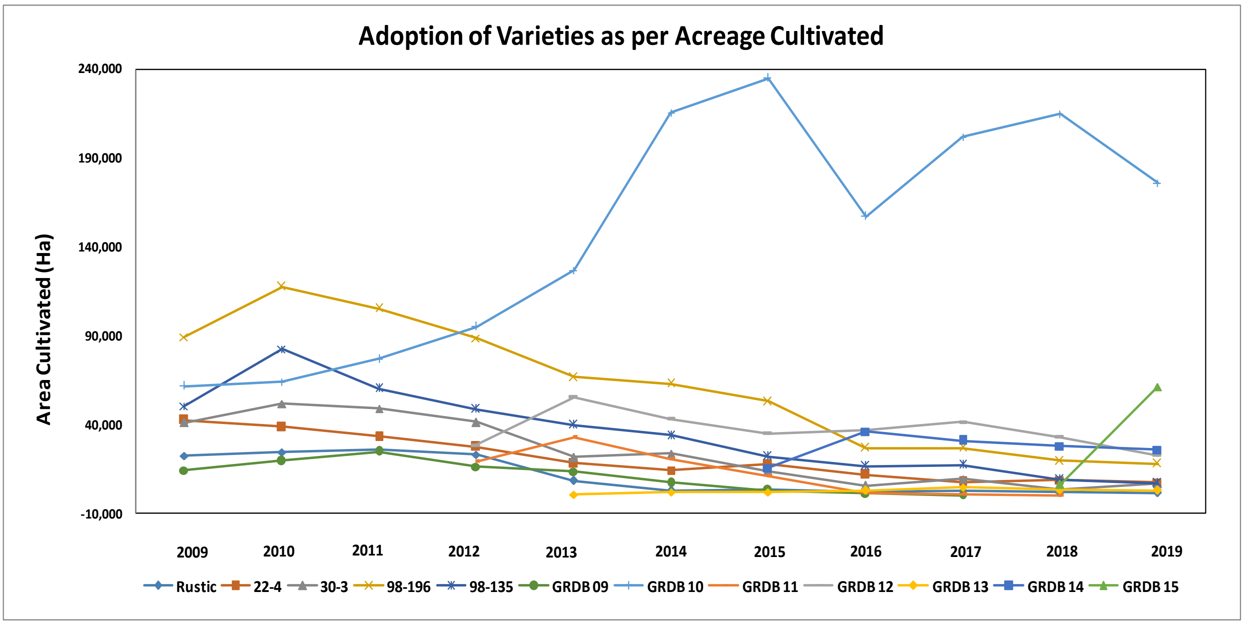

Figure 1

Varieties such as GRDB 10, G98-196, G98-135, G98-30-3 and G98-22-4 were highly adopted as per the acreage cultivated from 2009 to 2012. The GRDB 10 variety was the most outstanding variety as per acreage cultivated; to date it occupied approximately 40% of the total cultivation. The Rustic and GRDB 9 were lesser adopted as per the acreage cultivated during the same period (2009 to 2012). It can be seen from the figure that, when a new variety is introduced for cultivation, there is a reduction of the older rice varieties. For instance, during the year of 2012, when the variety GRDB 12 was introduced, there was a drastic reduction in the cultivation of variety G98-30-3 and Rustic. The same occurred during the year of 2015 when GRDB 14 was first cultivated the older varieties kept reducing as per acreage cultivated. The GRDB 10 variety reaches its peak of cultivation in 2015. The variety GRDB 15 was introduce for cultivation in 2018 and as of 2019, there was a massive increase in the cultivation of the variety but at the same time there was a decrease in the cultivation of variety GRDB 10. It is clearly note that the adoption of improved rice varieties leads to increased output. This is consistent with the findings of (Wiredu et al. 2010).

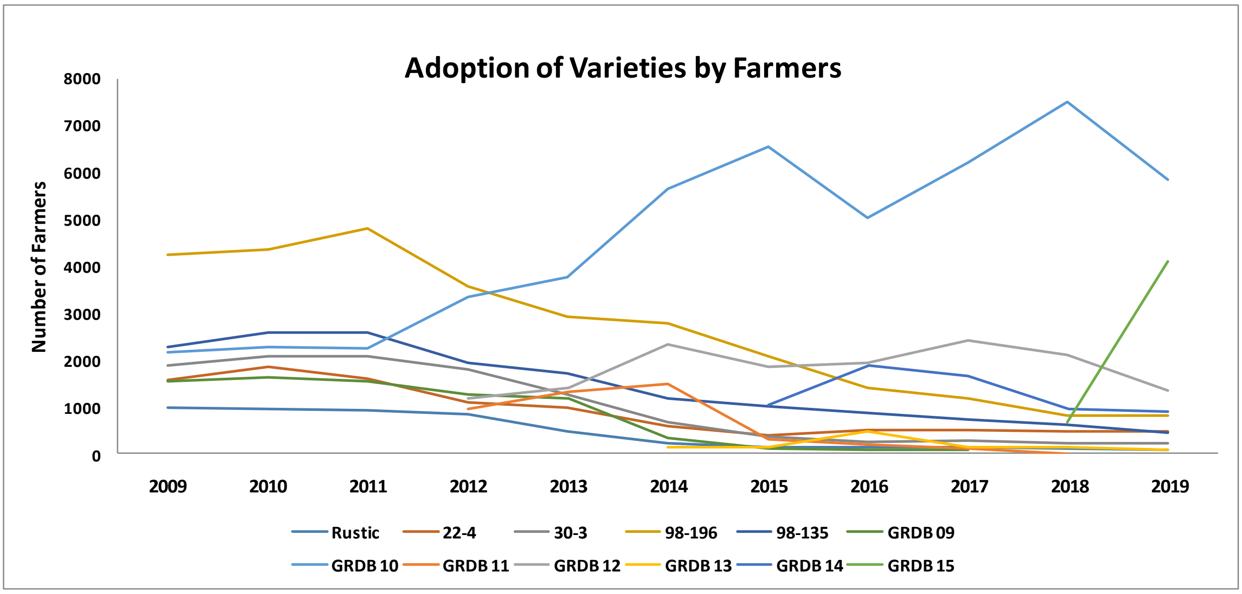

Figure 2

There are similarities between Figure 1 (Adoption of Rice Varieties as per Acreage Cultivated) and Figure 2 (Adoption of Rice Varieties by Farmers) for the ten (10) year period. This is obvious since it was the varieties that were cultivated by the farmers. Varieties such as GRDB 10, G98-196, G98-135, G98-30-3 and G98-22-4 were highly adopted by farmers between the years of 2009 to 2012. The GRDB 10 variety was the most dominant throughout the ten (10) year period among farmers. While the Rustic and GRDB 9 were submissive among farmers cultivated during the same period. Currently, variety GRDB 15 has hiked up from 1,000 farmers to 4,000 farmers while variety GRDB 10 has reduced from approximately 7,500 to 6,000 farmers. This is coincide with the study of (Khanal et al, 2016) who stated that farmers who continue to grow old and obsolete varieties do not gain the benefits they could get from growing newer ones. Gender difference is found to be one of the factors influencing adoption of new technologies. Due to many socio-cultural values and norms males have freedom of mobility and participation in different meetings and consequently have greater access to information and subsequently adoption of new varieties (Tadesse, 2008).

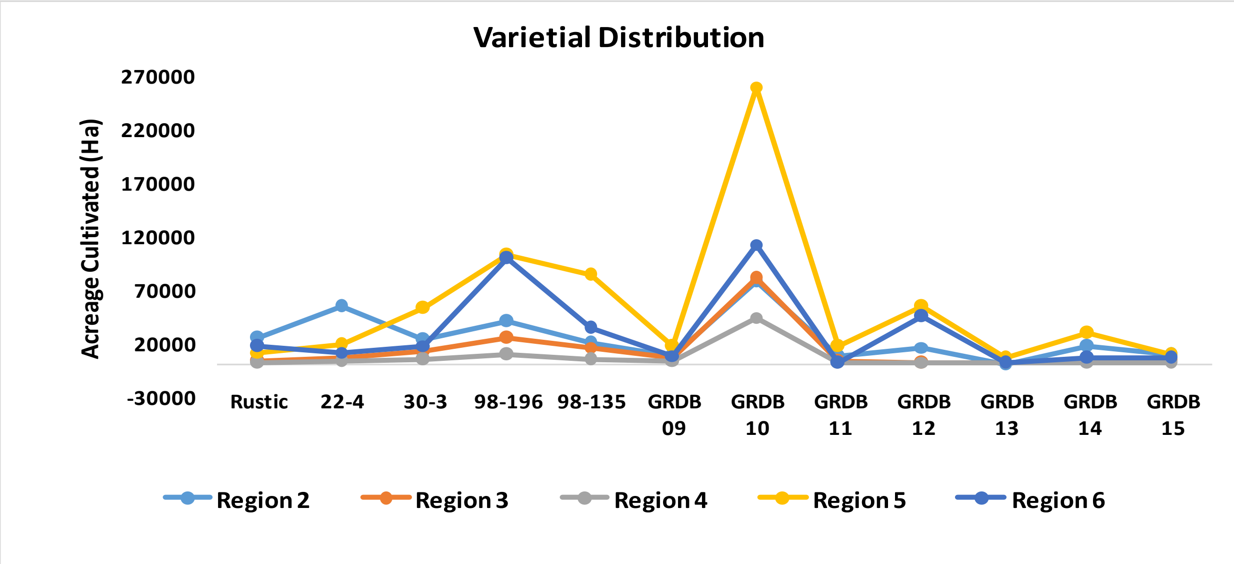

Figure 3

Administrative Region number five (5) is known for the highest rice producing Region in Guyana. Therefore, this region cultivated the highest amounts on all of the rice varieties except Rustic and 22-4. The highest cultivated rice variety of region number five is variety GRDB 10 (approximately 260,000 hectares for the 10 years period) while the lowest were GRDB 13 and Rustic (approximately 1,500 hectares for the same period). Region number four is the lowest cultivating Region amongst all. For this region, variety GRDB10 was the highest cultivated (approximately 4,500 hectares or 70% of its total cultivation) and varieties Rustic, 22-4, GRDB 9, GRDB 12, GRDB13, GRDB 14 and GRDB 15 were marked the lowest cultivated varieties for the period. From the data collected it was noted that the variety GRDB 10, GRDB 12 and G98-196 were highly distributed in region 6.

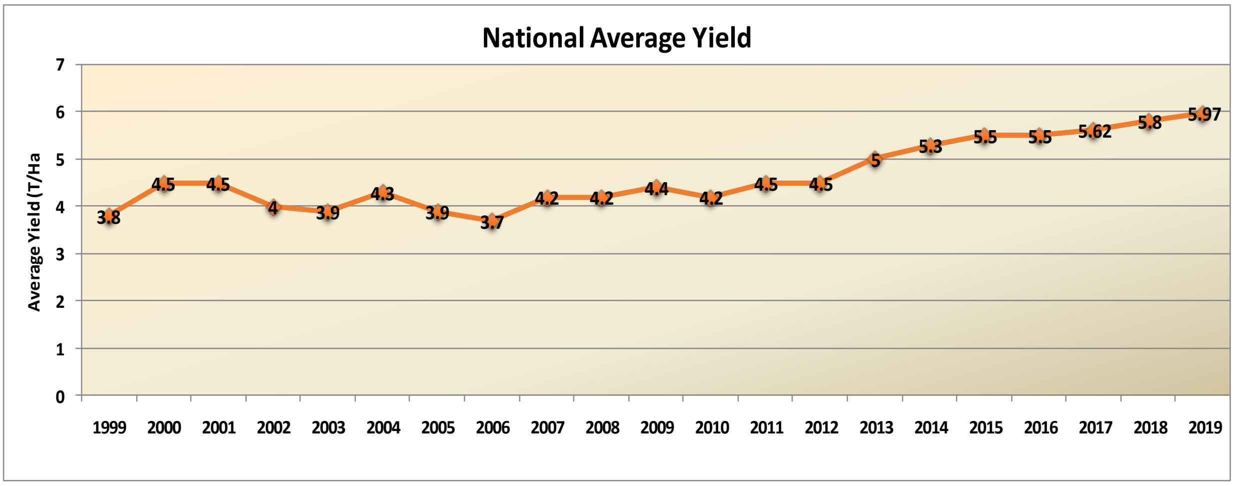

Figure 4

Over the past twenty (20) years, the national average yield has increased from 3.8 tons per hectare (T/Ha) in 1999 to 5.8 T/Ha in 2018. From the year of 2010, there has been a persistence increase of average yield to present (from 4.2 to 5.97 T/Ha respectively. The older varieties show no significant difference in average yield from 1999 to 2009. However, there was significant difference of average yield from 2010 to 2019, this is because of the introduction and adoption of newer varieties along with an Improved Agronomic Practice Package.

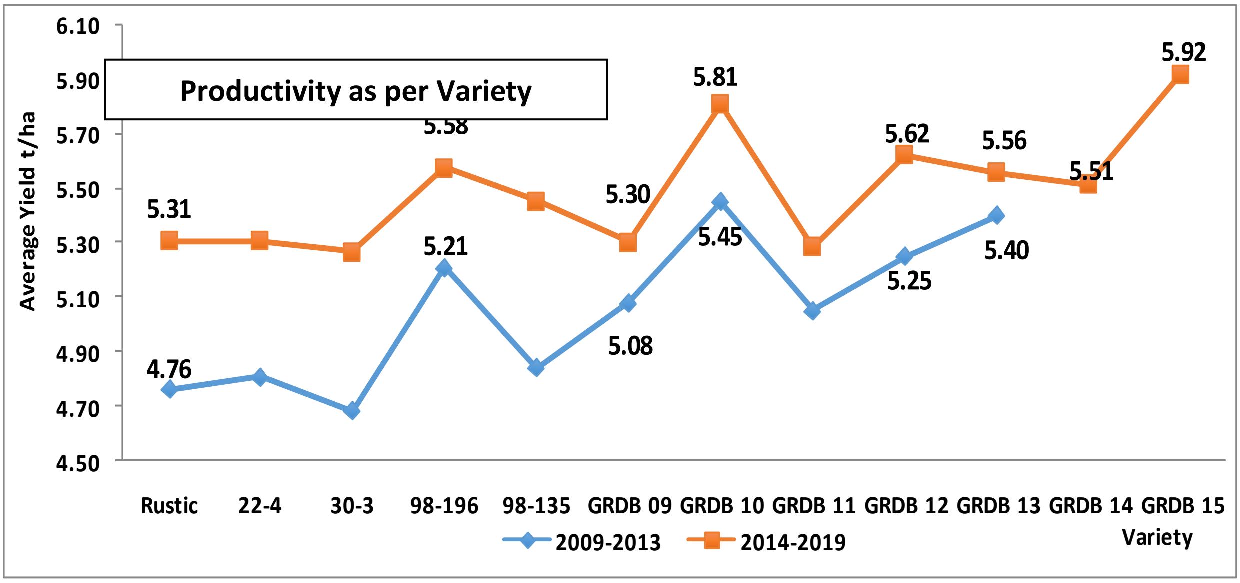

Figure 5

As compared to the years of 2009 to 2013, the total productivity as per variety is extremely higher during the years of 2014 to 2019 for all rice varieties. The productivity was at its highest (5.92 t/ha) for rice variety GRDB15 and at its lowest (4.76 t/ha) for rice variety Rustic. Productivity ranged from 4.76 to 5.40 t/ha during the years of 2009 to 2013 while it ranged from 5.31 to 5.92 t/ha during the years of 2014 to 2019.

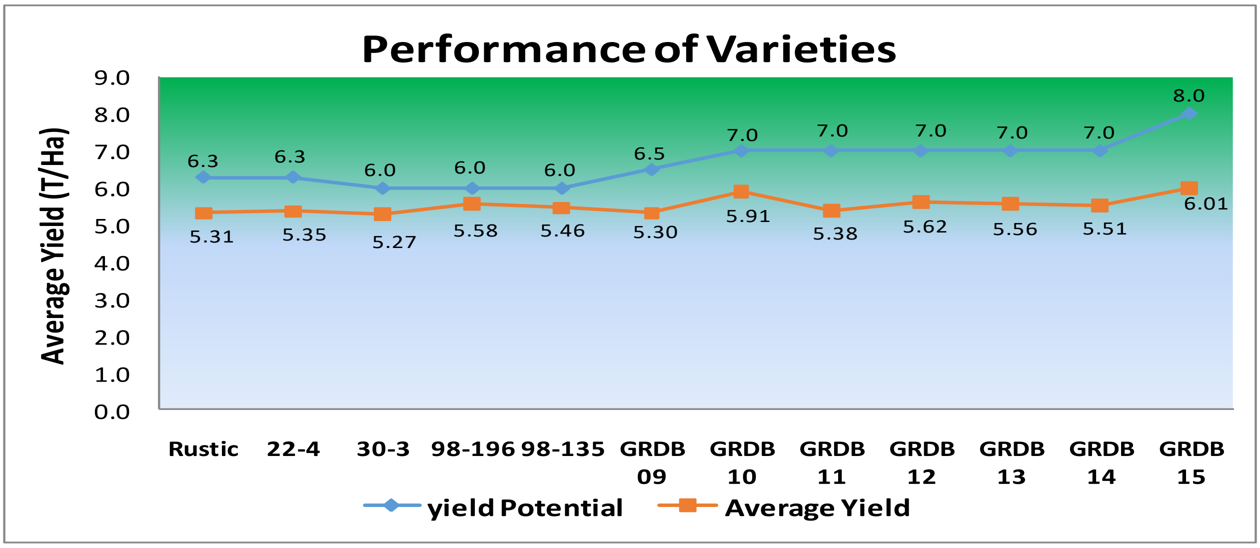

Figure 6

The yield potential is the maximum average yield that can be produced by the rice varieties. As can be seen, the average yield (actual average yield) produced was lower than the yield potential for all rice varieties. The yield potential and actual average yield came the closest for rice variety G98-196 (having a difference of about 0.5 t/ha) but came the furthest for rice variety GRDB 15 where the actual yield was 6.01 /ha as against the yield potential of 8.0 t/ha (having a difference of about 2.0 t/ha). The use of new and high yielding rice varieties along with the best Agronomic Management farmers practices narrow the yield gap, this is coincided with the work done by (Ghimire et al, 2015)

CONCLUSION

The study assessed adoption and performance of rice variety in Guyana from 2009 to 2019. The following are the major conclusions drawn from the findings of this study: The level of adoption of variety GRDB 10, GRDB 15 and G98-196 as per acreage cultivated and farmers cultivating same is highly correlated. The older varieties showed a lower level of adoption by both farmers and acreage cultivated from 2009 to 2012 ad has positive correlation with the yield of the corresponding period. It is clearly shown that the newer rice varieties introduced for cultivation gave a higher output in terms of the actual average yield. Although there is a yield gap, that exist between the potential of the variety and the actual average obtained by farmers, varieties such as GRDB 10 and GRDB 15 achieved that potential in region 4 and Region 6 by innovators who were not resistant to change.

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Dynamics of Groundwater Resources of Upper Benue River Basin, Nigeria

Joshua, Ma'aku Mark[1], Oruonye E.D.[1], Zemba, A.A.[2], and Yusuf, M.B.[1]

1. Department of Geography, Taraba state university, ATC, Jalingo, Taraba state, Nigeria
2. Department of Geography, Modibbo Adama University, Yola, Adamawa State, Nigeria

Abstract:
This study has examined the dynamics of groundwater resources of Upper Benue River Basin in Nigeria. The study adopted field survey design using both primary and secondary data. Data on groundwater such as geo-location, depth of water table and season of the year) was acquired from Upper Benue River Basin Development Authority (UBRBA) office in Yola, Adamawa State, and State Water Agencies of Plateau, Taraba, Bauchi and Borno States. Geospatial techniques were used to delineate the groundwater potential zones of the basin area. The findings of the study reveals that a larger portion of the basin area has low Ground Water Potential (GWP) (44,488.4 Km2) while the poor GWP covered (42,926.5Km2), moderate GWP was 25,732.6 Km2 and high (GWP) potential covered 11,417.3Km2. The result of the findings shows that areas of high GW potential have the least coverage while areas of low and poor GW potential had the highest areal coverage. The findings of the study reveal that the predicted groundwater depth has minimum range of 42.3m - 52.7m while the maximum range is 75.8m - 83.3m. The result shows that the water table depth is lowest at the southern part of the basin, while the northern area has high depth or lower water table heights. This reveals that access to ground water resources is relatively better in the southern part of the catchment as it coincides with the pattern of climatic variables spread across the area. Climate variability will affect the status of ground water significantly in the next 50 years and negatively impact availability and access in the basin. Based on the findings, the study recommended deliberate policy to protect the land and conserve vegetation in the basin and establishment of groundwater gauging station to help in monitoring the ground water level.

Keywords: Climate variability, Groundwater, River Basin, Upper Benue & Watershed.

INTRODUCTION

Groundwater is the critical underlying resource for human survival and economic development especially in extensive drought-prone areas of south-eastern, eastern and western Africa. Groundwater is the largest and most important water resource in Africa (MacDonald, Bonsor, Dochartaigh, & Taylor, 2012). It is often more reliable, in closer proximity to users, less vulnerable to pollution, and more resilient to climate variability than surface water (McDonald et al., 2011; Lapworth et al., 2017). Access to safe and reliable water is critical for improving health and livelihoods for low-income communities in Africa and elsewhere globally (Hunter, MacDonald, & Carter, 2010). It is estimated that about 100 million rural populations throughout Sub Saharan Africa are serviced by groundwater for domestic supplies and livestock rearing (Adelana & MacDonald, 2008; MacDonald *et al*., 2012), with most of the villages and small towns having access to groundwater supplies (Masiyandima & Giordano, 2007; Pavelic *et al*., 2012). Groundwater development has tended to flourish most in the drier western, eastern and south eastern parts of Africa, where annual precipitation is less than 1,000 mm yr-1 (Brown, Demargne, Seo, & Liu, 2010; Foster, Tuinhof & Van Steenbergen, 2012).

Water resources in Nigeria are already under stress and the country is slowly becoming a water-scarce nation. According to Population Reports of 1998, water is an essential and necessary natural resource, and its shortage puts human society at risk and under stress. Without responsive water development, lengthy and extreme droughts, seasonal volatility in rainfall, and resource degradation, growing water scarcity is projected to worsen under population pressure (Adesina & Odekunle, 2011; Adejuwon & Adelakun, 2012). Nigeria is among the 48 countries expected to face water shortage by the year 2025 (Population Reference Bureau, 2007). With an estimated population of 111.7 million people in 1995, the water per capita in Nigeria stood at 2,506 m3 yr-1. The per capita water availability is expected to drop to 1,175 m3 in 2025 with a projected population of 238.4 million people (Population Reference Bureau, 2000). Water stress, or a lack of sufficient per capita available freshwater, has a significant impact on communities including the Upper Benue River Basin (Ojeh & Semaka, 2021). Water stress can occur as a result of abuse of available freshwater resources or a decrease in the amount of available water as a result of decreased rainfall and stored water supplies (Parish et al., 2012). Rapid urbanization is straining urban water resources (Bandari & Sadhukhan, 2021), and this is evidence in the study area. Shortages of water could become a major obstacle to public health and development. Thus, the need for integrated water management to safe guard the future is paramount.

The degree of water stress experienced is further threatened by the vagaries of climatic variability. In its Fourth Assessment Report, the Intergovernmental Panel for Climate Change (IPCC) project that Africa will be disproportionately affected by climate change (Bates *et al*, 2008). The projected warming in Africa is 1.5 times the global average (Taylor, Koussis & Tindimugaya, 2009). The availability and sustainability of groundwater in many aquifers in Nigeria, like many principal aquifers around the world (US Geological Survey, 2009; Brekke et al., 2009; Alley et al, 2002), may be under threat in the next few decades because of depletion of the resource imposed by human and climatic stresses.

Increased variability in precipitation and more extreme weather events caused by climate change can lead to longer periods of droughts and floods, which directly affects availability and dependency on groundwater (Watson et al., 1998; Lehner *et al*.,2006). In long periods of droughts there is a higher risk of depletion of aquifers, especially in case of small and shallow aquifers. People in water-scarce areas will increasingly depend on groundwater, because of its buffer capacity (Lehner *et al*, 2006).

The Benue River basin which originated from the Mandara mountains in Cameroun is the major tributary of the Niger River (it empties its water into the Niger at Lokoja where confluence is formed). The major tributaries of the Benue River in Nigeria are Rivers Katsina-Ala, Donga, Taraba, Gongola and Pai (Nkeki, Henah, & Ojeh, 2013; Evans & Sunday., 2018; Usman et al., 2019). Though most studies have concentrated on the geomorphological characteristics (Overare et al., 2015; Ezekiel et al, 2015; Adebola et al, 2018), while several other studies have focused on the flooding implication (Tanko & Agunwamba, 2008; Nwilo et al, 2012; Izinyon and Ajumuka, 2013; Bello & Ogedegbe, 2015), less focus has been on the ground water potential of this significant region.

Although groundwater plays a large role in supporting social and economic development in the study area, the water resource-base is far from being adequately understood. There is a lack of systematic data and information on groundwater across Sub-Saharan Africa, with studies occurring on an ad-hoc basis without strategic oversight or coordination. The Upper Benue River

Basin (UBRB) in Nigeria lies in the semi-arid regions of the country which represent areas of significant water shortage amidst growing demand and diverse uses. The basin also suffers from occasional drought over the years. In most situations, groundwater monitoring in the basin is limited or non-existent. Furthermore, despite the huge number of wells drilled each year, groundwater monitoring systems for obtaining, compiling, and analysing information have failed in various sub regions in several nations (Allaire, 2009; Foster & MacDonald, 2014) leading to losses on the huge amount of money invested to drill such wells and boreholes since it failed to yield the relevant information for research, policy and socio-economic development. It is against this background that this study examines the dynamics of groundwater resources of the Upper Benue River Basin in Nigeria.

DESCRIPTION OF STUDY AREA

The Upper Benue River Basin, which crosses seven states of the Nigerian Federation (Adamawa, Gombe, Bauchi, Plateau, Yobe, Borno and Taraba State), is situated between latitudes 6°29'N and 11°46'N and longitude 8°55'E and 13°30'E. The basin spans 480 kilometers from West to East and 532 kilometers from north to south. The basin spans 154,328.9 km2 of land. Upper Benue River Basin is bounded to the north by Lake Chad basin, to the east and south by Republic of Cameroon, and to the west by Lower Benue and Upper Niger basins. The Upper Benue River Basin falls under the jurisdiction of the Upper Benue River Basin Development Authority (UBRBDA) which is an agency of the Federal Government of Nigeria created in 1976 for the management of the water and agricultural resources of the country (Adebayo, 1997). The UBRBDA authority also performs other tasks to raise the living standards of rural residents in the basin, such as building dams and boreholes and processing and selling agricultural products there.

The river Benue, which originates in the Adamawa Plateau in northern Cameroon and runs south-west to meet the River Niger in Lokoja, is the principal river in the basin. The Gongola River, the Mayo Kébbi, the Taraba River, and the river Katsina-Ala are among the important tributaries that join the river Benue (Nkeki, Henah, & Ojeh, 2013). The Upper Benue River Basin has a dendritic drainage pattern and is a seventh stream order system (Odiji *et al.*, 2021). The basin's qualities give it a special capacity for ground water and enable it to adjust to climatic changes.

The Upper Benue River Basin falls within the tropical continental climate type with distinct wet and dry seasons. The dry season runs from November to April, whereas the rainy season lasts for around six months (May to October) (Umar, 2006). The mean annual rainfall in the basin area varies from 2000 mm in Gembu (on the Mambilla plateau) in the south to 800 mm in Nafada in the northern part of the basin area (Adebayo,1997). As a result, rainfall decreases from south to north along the latitude, giving the southern portions of the basin more rainfall than the northernmost portions (Umar, 2006). This pattern is also followed by decrease in length of rainy season northward with a difference of about 170 days between the southern and the northern parts of the basin (Adebayo, 1997).

Due to the existence of harmattan winds that blow from the interior of the continent, the Upper Benue River Basin experiences seasonal temperature variations as well. The hottest month is April, while the coldest month is December or January with a mean temperature of approximately 17°C.

On the other hand, due to the influence of the region's high altitude, the southernmost half of the basin has relatively low temperatures throughout the year.

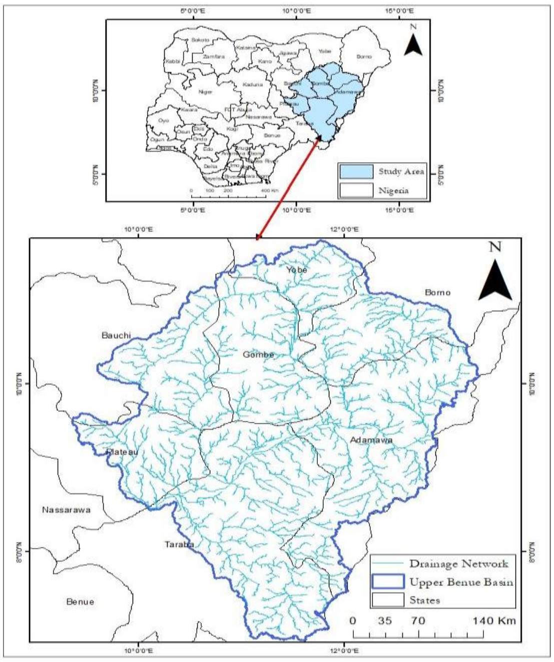

Figure 1: Map of the Study area

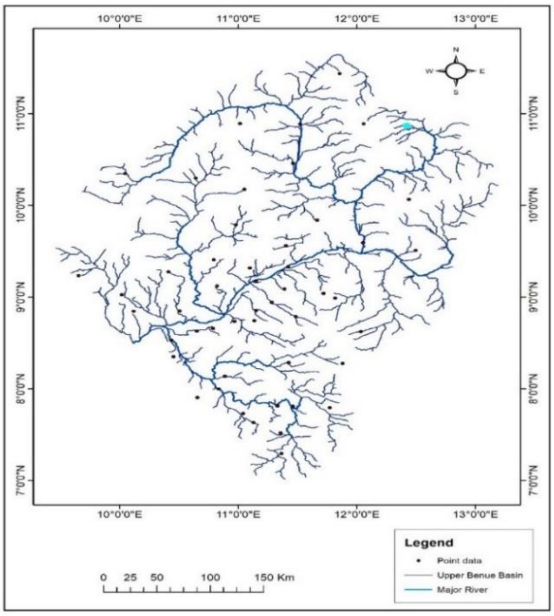

Fig. 2: Water Table data point of the study area

MATERIALS AND METHODS

This study used the field survey research design. This design allows for the collection of quantitative data and subjected to rigorous statistical analysis. This study made use of both primary and secondary data to achieved the set objectives. The primary data used include depth of water table and geographical coordinate of identified wells and borehole in the study area. The secondary data include published journals, books, online materials and archival records of government Ministries and parastatals. The data on the groundwater depth (the geo-location, depth to water table and the season of the year) was acquired from Upper Benue River Basin Development Authority (UBRBA) in office in Yola, Adamawa State, and State Water Agencies of Plateau, Taraba, Bauchi and Borno States. These agencies have partial data covering some part of the basin where they are located, thus, the data collected from all the sources were integrated to cover the entire basin. During the field survey, 32 boreholes and 19 wells were identified (fig. 2), their depth and coordinates measured. Geospatial techniques were used to delineate the groundwater potential zones of the basin area. The results of the study are presented in the form of maps, graph, and tables where appropriate. Maps were mostly chosen because it is best suited in presenting spatial relations of hydrogeomorphic characteristics.

RESULT OF THE FINDINGS

Ground Water Potentials of the Upper Benue River Basin

This section highlights the factors leading to ground water potential and recharge within the study area. The various factors are rainfall, temperature, elevation, slope, drainage density, lineament density, soil types and the landuse/landcover as presented in figs. 3 -16. As input to multicriteria analytic function, thematic maps of the various environmental variables considered were generated from the various data sources employed. The maps were further reclassified ranked according to the outcome of the AHP. The thematic and reclassed layers is presented subsequently.

Precipitation

The importance of precipitation to ground water potential cannot be overemphasized. The rainfall variation for the years considered has been presented in fig. 3 and for the purpose of further analysis, the result was reclassified as presented in fig. 4. From fig. 3, it is seen that the Southern part of the catchment experiences the highest amount of rainfall followed by moderate rainfall in the central part of the study area which spans across the East and West areas. The Northern part has very low rainfall regime. The result of the study agrees with Jan, Chen and Lo (2006) which showed that residual groundwater level, was found to linearly depend on the effective accumulated rainfall amount. Similarly, the result is in agreement with the findings of the study by Wotany *et al* (2021) which established the link between rainfall and groundwater recharge in the Rio del Rey Basin in Cameroon and posited that the isotopic similarity between groundwater and June - August rains suggest a significant recharge during this period and therefore a strong determinant of level of recharge.

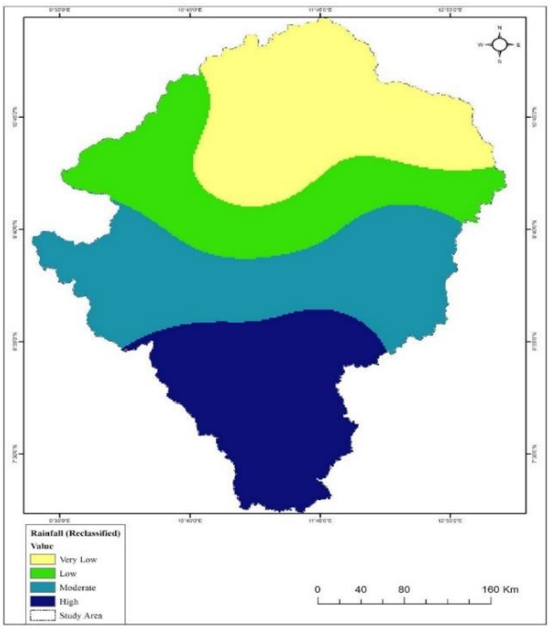

Fig 3: Rainfall Reclassified Map of the study area

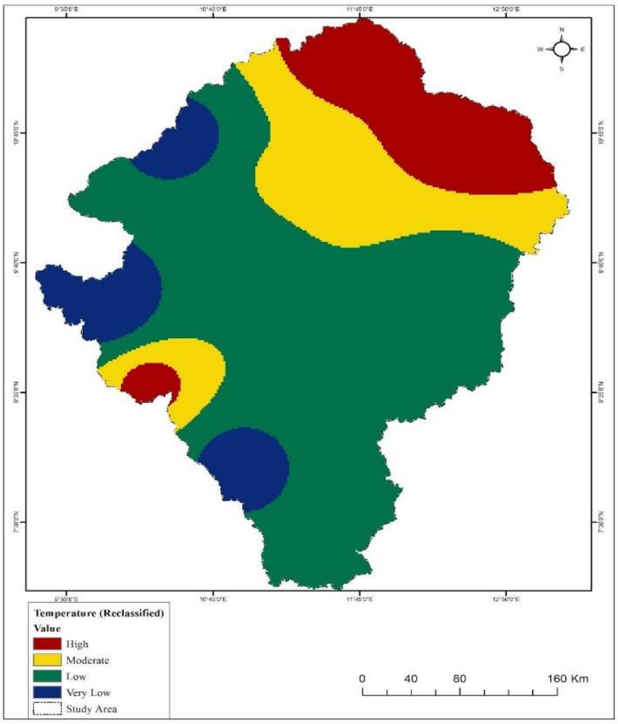

Fig 4: Temperature Reclassified Map of the study area

Temperature

As a contributor to hydrologic cycle, the temperature variation for the years considered has been reclassified as presented in fig. 4. From fig. 4, a major part of the study area has low temperature, the Northern part of the catchment area majorly has high temperature, while few areas have moderate or very low temperature. The areas of the basin with very low and low temperature are attributed to the presence of water body and parches of vegetation around the axis since these has the potential to moderate land surface temperatures. The areas with moderate and high temperature at the southwestern part of the map are areas with bare surface interspersed with rock outcrops as these could absorb so much heat with slow ability to release such heat. An *et al* (2015) observed that there is a high-temperature anomaly around the basin-bottom stagnation point where two flow systems converge due to a low degree of convection and a long travel distance, but there is no anomaly around the basin-bottom stagnation point where two flow systems diverge. In the complex basin, there are also high-temperature anomalies around internal stagnation points. Temperature around internal stagnation points could be very high when they are close to the basin bottom (An *et al*, 2015).

Elevation

The elevation of the Upper Benue River Basin is presented in fig 5.

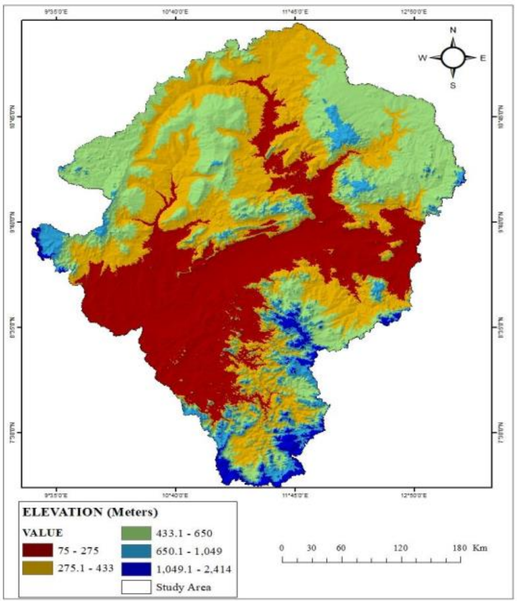

Fig. 5: Elevation Map of the Study area

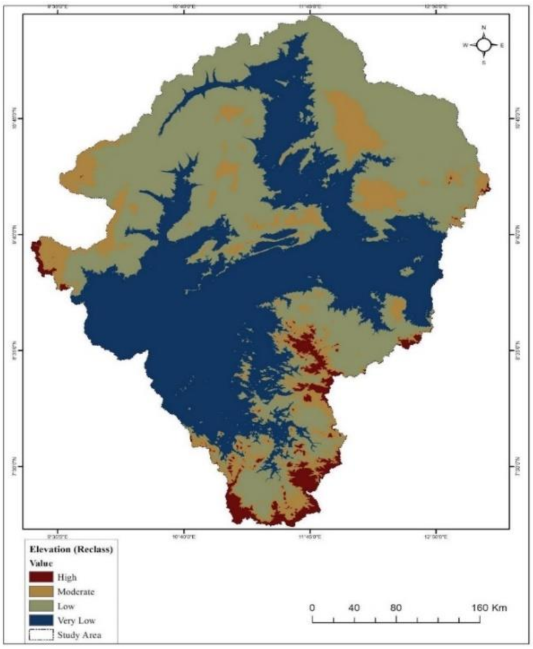

Fig 6: Elevation Reclassified Map of the study area

From fig. 5, it was observed that the lowest elevations occur in the mid-eastern to western part and high elevations in the south-eastern part and north-eastern montane flank. High elevations do not favour groundwater recharge compared to low elevations. The elevation of the study area ranged from 75m to 2414m. However, the adjoining areas around most part of the southern end of the basin with higher elevation are indicative of the numerous mountain ranges surrounding the basin such as the Mambilla and Biu plateaus. For the ease of further visual interpretation, the elevation map was further reclassified and presented in fig. 6 as it relates to groundwater potential of the basin. Fig. 6 reveals four classes of elevations which were made with their respective weight according to their effects on groundwater potential in the basin. Here, the lower the elevation, the higher the potential for groundwater recharge and on the other hand, the higher the elevation, the lower the ground water potential. Groundwater is affected by multiple factors such as land use, slope, lineament and elevation (Maqsoom *et al*, 2022)

Slope

The nature of slope directly influences infiltration and runoff. Steeper slopes result in lesser recharge due to high runoff, so it does not have sufficient time to infiltrate the surface and recharge the saturated zone. On the other hand, gentle slopes allow for infiltration and lesser runoff velocity. Figs 7 and 8 shows the slope values and reclassification map of the slope respectively.

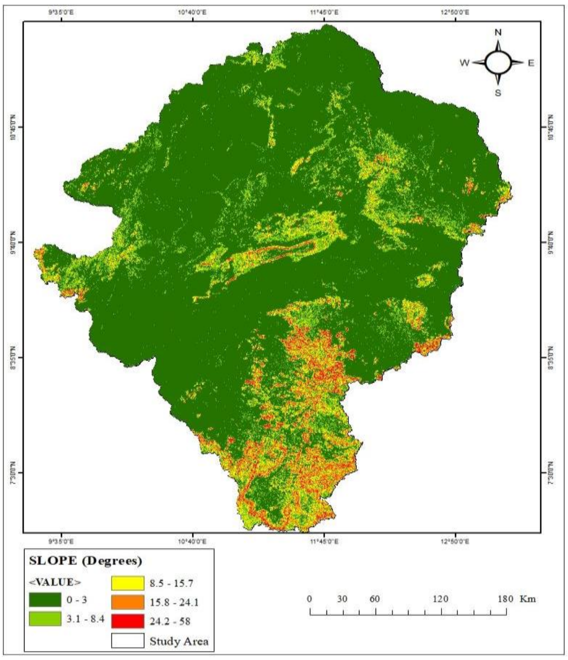

Fig 7: Slope Map of the Study area

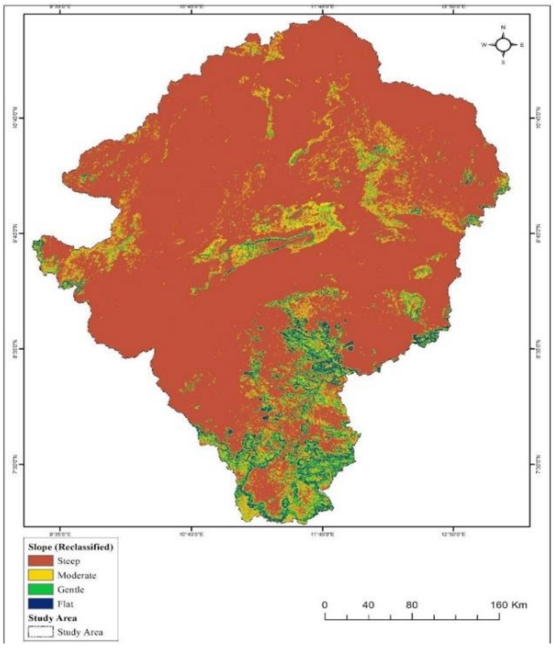

Fig 8: Slope Reclassified Map of the Study area

From fig. 7, the values of the slope ranged from 0-3 to 24.2 - 58 degrees. Between the lowest and highest values, the slope was classed as 3.1 -8.4, 8.5 -15.7, 15.8- 24.1 degrees respectively. For the purpose of better visual interpretation, the slope of the basin was reclassified as presented in fig. 8. In the reclassified map in fig. 8, it shows that a vast portion of the study area is steep with few areas being moderate and gentle, while relatively lesser portions of the land are flat. This implies that water will flow from the northern part of the basin with steep to gentle slope to the southern part which are relatively flat or undulating in nature.

Drainage Density

The drainage system of the study area was observed to be structurally influenced by the terrain. Dendritic patterns were obvious in the outcrops while parallel was common in the gentle slope in the lowlands. Figs. 9 and 10 shows the drainage density pattern of the study area and reclassified values accordingly. Drainage density refers to the proximity of stream channels and a measure of the overall length of the stream segments per unit area (Magesh *et al*, 2011). Drainage density is inversely proportional to the groundwater infiltration, thus a vital index in delineating groundwater recharge potential. The result of the findings of this study agrees with that of Abdullateef *et al* (2021) whose assessment of recharge zones in Bauchi revealed that a high percentage of the southwestern part of the study area are characterized dominantly by poor groundwater recharge potential, attributable to high elevations and impervious rock outcrops with associated steep slopes, thus limited infiltration owing to the high velocity of runoff.

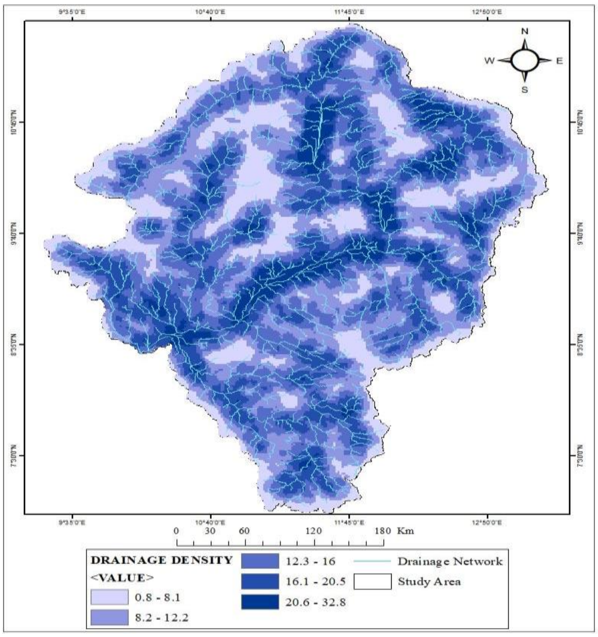

Fig. 9: Drainage Density Map of the Study area

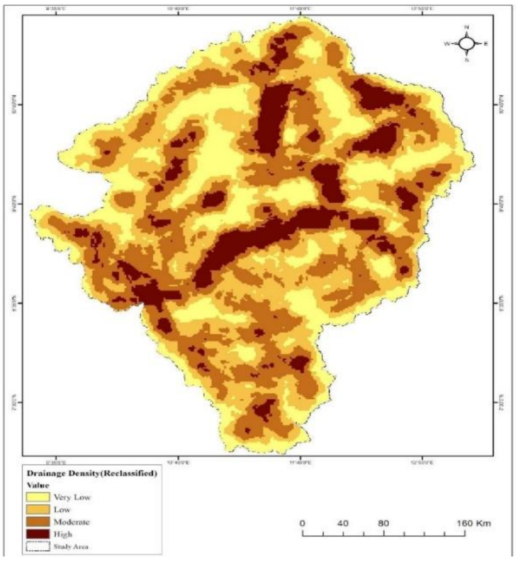

Fig. 10: Drainage Density Reclassified Map of the Study area

The result of the findings in Fig 9, while depicting the hydro-morphology, the ranges for drainage network concentration by area was classified into 0.8 -8.1, 8.2-12.2,12.3 -16, 16.1 - 20.5, 20.6 - 32.8 measured as length of channels per area (Km/Km²). As shown in Fig. 10, the values of the drainage density are reclassified to reflect the levels of density as a factor of ground water potential. Here, the areas with high density will positively contribute to the recharge rates while lower drainage density will imply lesser ground water recharge rates. The suitability of groundwater potential zones is indirectly related to drainage density because of its relationship with surface runoff and permeability (Murasingh & Jha, 2013).

Lineament Density

Usually, lineament density represents a measure of quantitative length of linear feature per unit area which can indicate groundwater recharge potential, as the presence of lineaments usually indicates levels of permeable zones. Figs. 11 and 12 reveals the spatial variation in lineament density and reclassified map of same values. Areas with high lineament density are good for groundwater potential zones (Haridas *et al*, 1998).

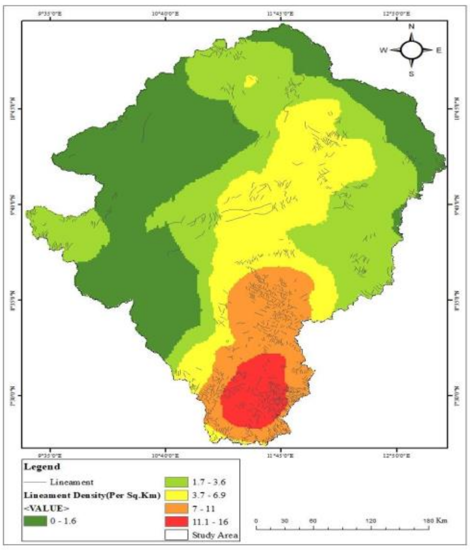

Fig. 11: Lineament Density Map of the Study area

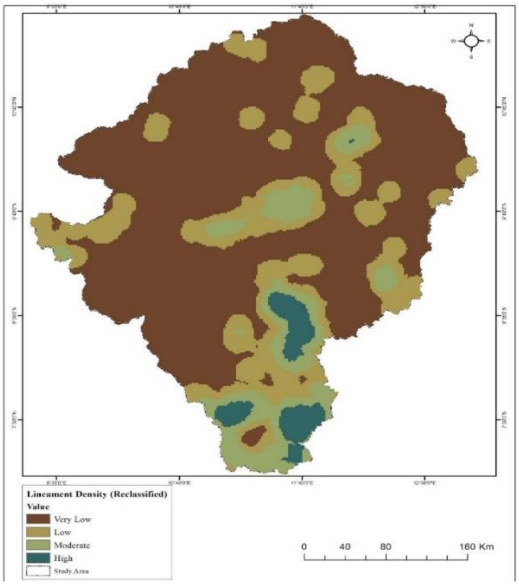

Fig. 12: Lineament Density Reclassified Map of the study area

As presented in fig. 11, the reclassified lineament density of the basin indicates that there is a higher linear density in the southern part of the catchment and it decreases towards the northern parts. The areas with lowest density had values ranging from 0 - 1.6 lineament length per area (Km/Km^2). The areas with highest lineament density ranged from 11.1 -16 Km/Km^2. The range of values were further reclassified in fig. 12 and as visualized, a larger part of the area has very low lineaments density, while the southern parts have moderate and high levels of lineament density, indicating permeable zones.

Soil Type

The accumulation of groundwater through infiltration is a direct effect of permeability. The soil type plays a critical role in infiltration rates and ground water accumulation. Fig. 13 and 14 reveals the spatial pattern of soil classes and reclassification respectively. Soil is an important factor for delineating the groundwater potential zones. The increase in water entry into the soil is affected by soil type, which is determined by the activities of pore saturation or desaturation (Saha *et al*, 2020).

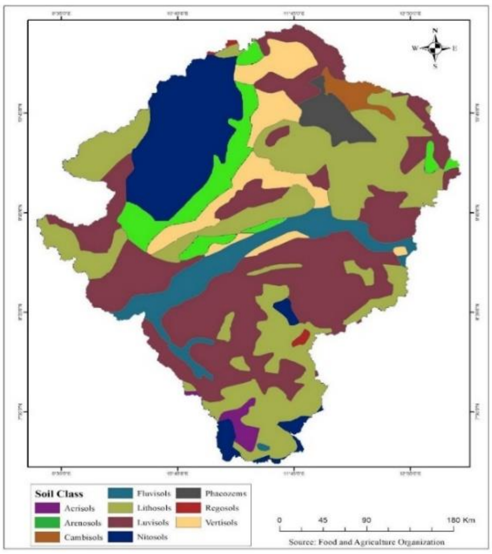

Figure 13. Soil Map of the Study area

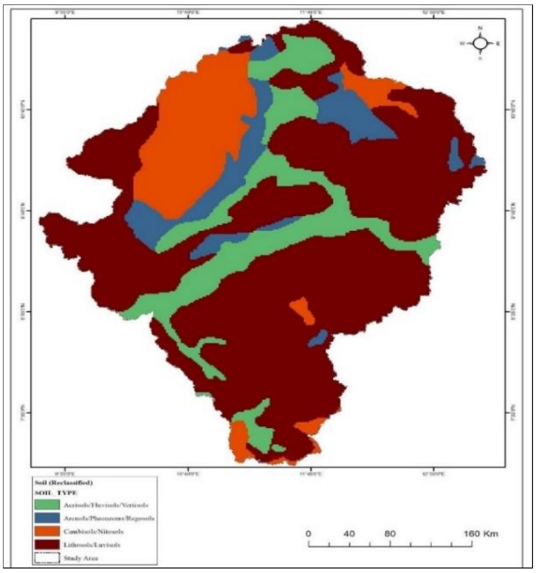

Fig. 14: Soil Reclassified Map of the Study area

As presented in fig. 13, the study area is composed of ten soil classes unevenly distributed across the area. The soil classes include: Lithosols, Luvisols, Cambisols, Nitisols Aerosols, Phaozems, Regosols, Acrisols, Fluvisols, Vertisols. As presented in fig. 14, it indicates that Luvisols and Lithosols which apparently cover a larger expanse of the catchment relatively supports higher infiltration and recharge rates, as they are typically well drained. Based on infiltration capacity, Cambisols and Nitisols moderately allow for ground water recharge. Conversely, Fluvisols, Vertisols, Acrisols and others relatively possess lower porosity and consequently lower infiltration rates. Water transport into the ground is controlled by the porosity of the soil categories. Soil type with coarse-grained matrix (e.g., lithosols) has good groundwater potential (Ifediegwu, 2021), whereas soil type with fine-grained matrix (ferralsols) has poor groundwater potential (Ifediegwu *et al*, 2019)

Ground Water Potential Generation (GWP)

Using Analytical Hierarchy Process (AHP), the results of the thematic layer earlier are integrated into weighted overlay. The outcome of the AHP computation is seen in fig. 15.

Priorities

These are the resulting weights for the criteria based on your pairwise comparisons:

Cat		Priority	Rank	(+)	(-)
1	LULC	6.4%	6	2.3%	2.3%
2	Elevation	8.8%	5	3.8%	3.8%
3	Drainage Density	11.0%	3	5.0%	5.0%
4	Slope	5.2%	7	1.8%	1.8%
5	Soil type	4.3%	8	0.8%	0.8%
6	Lineament density	10.8%	4	3.7%	3.7%
7	Rainfall	35.8%	1	11.9%	11.9%
8	Temperature	17.6%	2	7.4%	7.4%

Decision Matrix

The resulting weights are based on the principal eigenvector of the decision matrix:

	1	2	3	4	5	6	7	8
1	1	1.00	1.00	1.00	2.00	0.50	0.12	0.25
2	1.00	1	1.00	1.00	2.00	1.00	0.17	1.00
3	1.00	1.00	1	2.00	2.00	2.00	0.50	0.50
4	1.00	1.00	0.50	1	1.00	0.33	0.20	0.17
5	0.50	0.50	0.50	1.00	1	0.50	0.14	0.20
6	2.00	1.00	0.50	3.00	2.00	1	0.33	1.00
7	8.00	6.00	2.00	5.00	7.00	3.00	1	3.00
8	4.00	1.00	2.00	6.00	5.00	1.00	0.33	1

Number of comparisons = 28
Consistency Ratio CR = 4.9%

Principal eigen value = 8.479
Eigenvector solution: 5 iterations, delta = 9.6E-9

Fig. 15: AHP computation for thematic layers

After pairwise comparison of the eight parameters considered, the result of the AHP (Fig. 15) indicates that Rainfall was ranked first with a priority of 35.8%, seconded by Temperature with priority value of 17.6%, followed by drainage density with 11%. Soil type ranked lowest with priority value of 4.3%. With consistency ratio of 4.9% < 10%, and principle eigen value of 8.5, the ranks for every criterion remains consistent and significant for the purpose of further analysis. The overall result of the AHP indicates the ground water potential of the basin as presented in fig. 16 and Table 1.

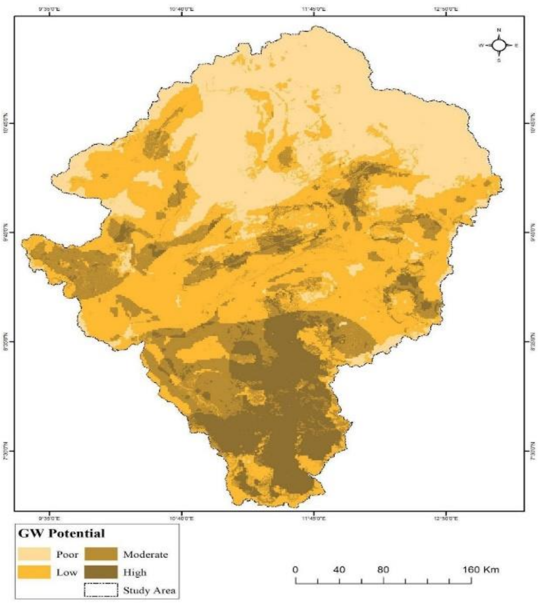

Fig 16: Ground Water Potential Map of the Study area

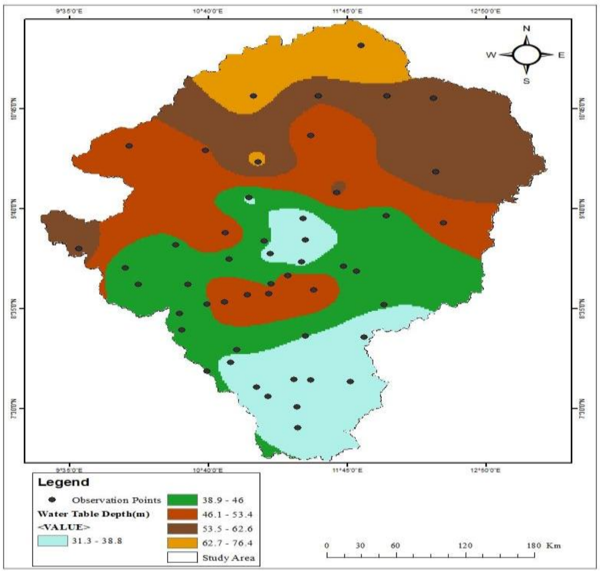

Fig. 17: Groundwater Depth of the Study area

As indicated in Fig. 16, the ground water potential is seen to be high southwards and poor at the northern end of the basin. Also, the ground water potential tends to be moderate east to west with little disparity of being low in some areas.

Table 1: Groundwater Potential Levels by Coverage

GWP Level	Area (Km2)	Area (%)
Poor	43,315.7	34.5
Low	44,822.4	35.7
Moderate	25,863.8	20.6
High	11,550.9	9.2
Total	125,552.8	100

A further breakdown of the areal coverage of various GWP levels (Table 1) reveals that a larger portion of the area has low GWP with an area of 44,822.4 Km^2, while 43,315.7 Km^2 was the area covered by Poor GWP. 25,863.8 Km^2 was experienced moderate GWP, areas of high potential covered 11,550.9Km^2. The results imply areas of high potential culminated the least coverage and conversely, areas with low and poor potential had the highest areal coverage. This result is congruent with the study of Sikdar *et al* (2004) in Bardhaman district of West Bengal who observed the groundwater potentiality of the Raniganj area to be medium (25-50 m^3/hr) with high potentiality (>50 m^3/hr) along the Damodar River.

Ground Water Recharge Performance

The Ground water table or peizometric height was used as indices for ground water recharge performance. Ground water depth data from various sources was collated and analysed in line with third objective. The result is presented in fig. 17. As presented in fig. 17, the spatial variation is generated from 52 observation points spread across the study area. As visualized, the water table depth is majorly lowest at the south part of the study area with the northern area having the high depth or lower water table heights The lowest groundwater depth range was seen to be 31.3 -38.8 meters, while the highest range was 62.7 -76.4 meters. These ultimately reflects the ease of accessibility and utilization of groundwater resources across the area.

Prospects of Groundwater Potentials in the Upper Benue River Basin

In this section, the coefficients of the joint and partial relationship between climatic variable (Precipitation and Temperature), LULC and ground water depth as was presented in Table 2, were fitted into a multiple regression model as follows:

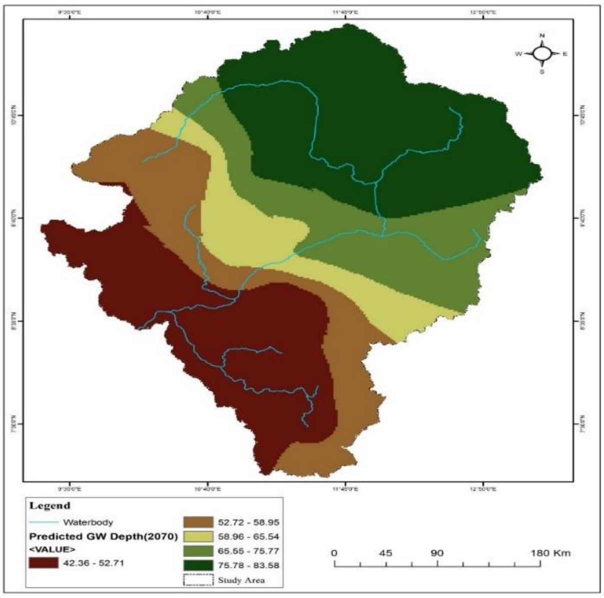

Fig 18: Predicted GW Depth for 2070

GW Depth = -378.22 - 0.028 Rainfall + 16.181 Temperature

This was subjected to raster calculation using year 2070 projected Rainfall and Temperature data from IPCC. The outcome of the raster calculation using the regression model is reflected in the prediction of the GW depth for the basin in the year 2070 (Fig. 18 and Table 2)

As seen in Fig. 18, for the predicted GW depth, the minimum range is 42.3m -52.7m while the maximum range is 75.8m - 83.3m. As observed, the water table depth is lowest at the southern part, with the northern area having the high depth or lower water table heights. This implies that access to ground water resources is relatively better in the southern part of the catchment as it coincides with the pattern of climatic variables spread across the area. This result is similar to the one obtained by Ifediegwu (2021), whose result showed good groundwater potential in the southern part of Lafia district of Nasarawa State.

Table 2. Comparison between Actual and Predicted GW Depth

Statistic	2021	2070	Difference
Min GW Depth	31.3m	42.3m	11m
Mean GW Depth	48.9m	65m	6.1m
Max GW Depth	76.4m	83.3m	6.9m

Comparing the minimum, mean and maximum values of actual and predicted ground water depth was pertinent to appreciate the long-term changes in the ground water regime. As observed in Table 2, from the 2021 data, the minimum value is predicted to increase from 31.3m to 42.3m, with an 11m difference. The mean value is also predicted to rise from 48.9m to 65m, an addition of 6.1m by 2070. The maximum values are also predicted to rise by 6.9m, as the predicted value is 83.3m, varying from the 2021 value of 76.4. This implies a relatively deeper water table which will impinge on accessibility of ground water in the future. Climate variability will affect the status of ground water significantly in the next 50 years and negatively impact availability and access. Ojeh and Semaka, (2021) observed that there is an existing challenge of access to household water in the Upper Benue Basin. This will adversely affect all socio-economic activities such as water production, beverage production etc. which depend largely on water availability as access for production.

CONCLUSION

This study has examined the dynamics of groundwater resources of Upper Benue River Basin in Nigeria. The study used survey design method. The findings of the study on the areal coverage of the various GWP levels reveals that a larger portion of the area has low GWP (44,488.4Km2), while the poor GWP was 42926.5Km2, the moderate GWP (25,732.6Km2) and the high GW potential covered 11,417.3Km2. The results imply that areas of high ground water potential have the least coverage while areas with low and poor ground water potential had the highest areal coverage. The result reveals that the water table depth is lowest at the southern part, while in the northern part of the basin have high depth or lower water table heights. Thus, access to ground water resources is relatively better in the southern part of the basin than in the northern part.

RECOMMENDATIONS

Based on the findings of the study, the following recommendations are suggested;

i. There is need for deliberate policy to protect the land and conserve vegetation in the basin to reduce forest degradation especially in the northern zone of the basin. Ground water abstraction by means of borehole should be regulated.
ii. There is the need to establish groundwater gauging station to help in monitoring the gound water level. This can be done by holistically collecting data for the different sections of the basin and integrating them into a single database.

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Classification of Feed Additives Used in Poultry and Livestock Production: A Review

Stephen. N. Okey

1. Department of Veterinary Biochemistry and Animal Production, College of Veterinary Medicine, Michael Okpara University of Agriculture Umudike, Nigeria

Abstract:
Feed cost accounts for between 65 and 75% of the total cost of production in any commercial poultry and livestock enterprise. Several approaches have been recommended towards solving the high feed cost problem including the use of unconventional local feed raw materials, manipulation of feed forms and feeding methods and use of feed additives. Nutritionists and experts in animal production have advocated for inclusion of feed additives as a means of optimizing the uptake of nutrients from alternative feed raw materials to improve production. Feed additives are substances added to feed to improve efficiency of feed utilization and acceptance, or for enhanced metabolism and animal health. Feed additives tend to fall into certain categories which describe their action in the feed or in the animal which serve as a guide to farmers in their applications. This paper presents a review of the classifications of feed additives with some as alternatives to antibiotics in promotion of health and performance in poultry and livestock. These feed additives have been classified into feed manufacturing, performance enhancing, nutritional feed additives and feed additives that improve animal health.

Keywords: Feed additives, classification, antibiotics, poultry performance, poultry and livestock

INTRODUCTION

The reason for poor poultry performance has always been attributed to change in environmental conditions, presence of diseases incidental to the production environment and poor feed quality (Baumgard and Rhoads, 2012; Ukwu, 2013). Feed quality is however usually outside the direct control of most small-scale poultry farmers in Nigeria (Okoli and Udedibie, 2017). This is because most small-scale intensive poultry farmers depend on commercial poultry feeds for the feeding of birds. Several studies have particularly shown the poor physical (Omede, 2010), nutritional (Uchegbu *et al.*, 2009) and other biophysical and toxicological characteristics (Okoli *et al.*, 2009; Omede *et al.*, 2012) of commercial poultry feeds produced in Nigeria. The feeding of such commercial feeds may not result in optimal performances in birds (Ukwu *et al.*, 2018) even when chick quality is assured. Therefore, enhancing the benefits of feeding is imperative to the improvement of poultry production in the country.

Of all the poultry inputs required for optimal commercial poultry production, feed accounts for between 65 and 75% of all cost items (Esiobu *et al.*, 2014). Thus, any improvement in the performance of poultry such as broiler and layer chickens due to their diet is capable of increasing profitability. Birds require optimal feed intake in order to remain healthy and productive (Ferket and Gernat, 2006). Poultry feeds are compounded from several feedstuffs such as cereal grains, soybean meal, meals from animal by-products, fats, vitamin and mineral premixes (Blake and Hess, 2014). These nutrients are derived from a mixture of conventional feedstuffs however, the high cost of conventional feed raw materials has necessitated the search for and utilization of unconventional feed raw material in poultry feed formulation. This has made research on feeds and feeding a vital issue with the aim of cutting down the cost of feeding animals without compromising performance (Adeola and Olukosi, 2009).

Several approaches have been recommended towards solving the high feed cost problem including the use of unconventional local feed raw materials (Okoli and Udedibie, 2017), manipulation of feed forms and feeding methods (Abdullahi *et al*., 2013) and use of feed additives (Ugwu and Okoli, 2017) have been applied to reduce cost of feeding chickens in Nigeria. Nutritionists and experts in animal production have also advocated for inclusion of feed additives (Terrence, 2005) as a means of optimizing the uptake of nutrients from alternative feed raw materials to improve production. Feed additives are substances added to feed to improve efficiency of feed utilization and acceptance, or for enhanced metabolism and animal health. Peter *et al* (2003) stated that feed additives are added for a variety of reasons which include addition of colour and flavour to diet and to alter the efficiency and speed of growth of animals. The inclusion of feed additives into compounded feed is now a common practice in animal feed industry.

Feed additives must be approved by the appropriate authority before they can be used in livestock or poultry feeds (EFSA, 2009). The principal aim of this regulation is to ensure that all additives approved for use are safe not only for the animals which are the intended target, but also those involved in its handling and the ultimate human consumers of such animal products. As a result, such additives will have to undergo series of tests to demonstrate that they are safe to handle and use. Feed additives tend to fall into certain categories which describe their action in the feed or in the animal (EU Feed Additives and Pre-Mixtures Association, 2003). They include feed manufacturing additives, performance enhancing additives, feed additives that improve animal health and nutritional feed additives.

FEED MANUFACTURING ADDITIVES

This classification refers to a group of additives which influences the technological aspects of the feed. It does not directly influence the nutritional value of the feed but may do that indirectly by improving its handling or hygienic characteristics. Examples of this class of additives are antifungal agents, pellet binders, antioxidants and feed flavors among others.

Antifungal Agents

These are chemicals or salts such as propionic acid salt (Sodium or calcium salts) used to prevent mold growth in stored feed ingredients and mixed feeds. These mold inhibitors are recommended when the grain moisture content and relative humidity are relatively high or when the grain is damaged, broken or insect-infested (Ugwu and Okoli, 2017).

Antioxidants

Antioxidants are compounds that prevent oxidative rancidity of polyunsaturated fats. It is important that rancidity of feeds be prevented because it may cause the destruction of vitamin A, D and E and several of the B-complex vitamins (Ezeokeke *et al*., 2008). The effects can be prevented by inclusion of effective anti-oxidant such as ethoxyguin (6-ethoxy -1, 2 –dihydro-2, 4 trimethylquinoline), BHT (butylated hydroxytoluene), or BHA (butylated hydroxyanisole) and vitamin E in the ration (Jacobs, 2016). Many of the most valuable products in the feed industry are readily subject to auto-oxidation. Feed ingredients which are high in unsaturated fatty acids are prone to auto-oxidation and subsequent rancidity of fat sources such as fish by-products and essential vitamins (Ezeokeke *et al*., 2008).

It is therefore important that rancidity of feeds be prevented because it may cause the destruction of vitamin A, D and E and several of the B-complex vitamins. The breakdown products of rancidity may also react with epsilon amino group of lysine thereby decreasing the protein and energy values of the ration. The effects can be prevented by inclusion in the ration with an effective anti-oxidant such as ethoxyguin (6-eloxy -1, 2-dihydro-2, 4 trimethylquinoline) BHT (butylated hydroxytoluene), or BHA (butylated hydroxyanisole) (Jacobs, 2016). These products can be used singly or in combination with each other. Most anti-oxidants function by providing the unsaturated chemical bond of a fatty acid with an opportunity to combine with a hydrogen molecule. Vitamin E can serve as an anti-oxidant both in the feed and in the cell of an animal ingesting the feed (Ezeokeke *et al*., 2008). Such antioxidants as ethoxyquin, BHT, or BHA are unable to prevent peroxidation within the cell. Consequently, they cannot reduce the dietary requirements for vitamin E. Oxidation reactions are accelerated by high temperature, light (ultraviolet and blue), ionizing radiation, peroxides, lipoxidase enzymes, organic ion catalyst (hemoglobin) and trace mineral (copper). Oxidation reactions are inhibited by refrigeration, exclusion of light, exclusion of oxygen, destruction of enzymes, metal deactivators and antioxidants (Surai, 2002).

Pellet Binders

These are used to produce firmer and stronger pellets with decreased tendency to crumble. Example is bentonite or hydrated aluminium silicate, a clay mineral with surface active properties whose effectiveness increase with steam used in their pelleting process. Hemicellulose and lignin extracts which are by-products of wood processing are also used as pellet binders (Ugwu and Okoli, 2017).

Feed Flavour

This refers to additives which improve the palatability (i.e., voluntary intake) of a diet by stimulating appetite, usually through their effect on the flavor or colour of the diet. They are sweetners used with feed of low palatability or when there is the need to increase feed intake, especially during the period of stress or sickness. Example is vanilla extracts which encourage piglets to eat voraciously.

PERFORMANCE ENHANCING FEED ADDITIVES

As the name implies, these additives improve the performance of animals when included in feeds. Growth as a performance index includes measures such as weight, weight gain, feed conversion and feed efficiency aimed at evaluating the development of chicken (Esonu, 2006). Feed additives in this category include enzymes, probiotics, xanthophylls, prebiotics, synbiotics, acidifiers, phytogenics and adsorbents or binders.

Enzymes

These are biological catalysts which bring about biological reactions without themselves undergoing any change. They comprise mainly amino acids and are involved in all metabolic and catabolic pathways of digestion. Poultry naturally produces enzymes that aid in the digestion of feed, these enzymes are not capable of breaking down completely the fibre component resulting in lower performance when fibrous materials are high in the feed (Iyayi, 2009), hence the need for an exogenous enzyme.

Probiotics
Probiotics are described as organisms and compounds that influence the balance of the intestinal microbial population to increase growth and efficiency of livestock. FAO/WHO (2001) stated that probiotics are live microorganisms which when consumed in adequate amount, confers a health benefit on the host. Probiotics promote the establishment and development of a desirable intestinal microbial population in the animal. Its ability to promote performance and health of poultry has been associated with direct uptake of dissolved organic material mediated by these microorganisms (Ezema and Ugwu, 2014).

Xanthophylls
These were originally called phylloxanthins. They are yellow pigments derived from the carotenoid group of compounds and are so named due to their contribution to the yellow band in early chromatography of leaf pigment. Xanthophyll contains either a hydroxyl group or pairs of hydrogen atom that are substituted by oxygen atoms (Esonu, 2006). They are found in leaves of most plants where they act to modulate light energy and also in bodies of animals, where they are derived from feed and dietary animal products that contain them. For example, the yellow colour of chicken egg yolks, fat and skin comes from ingested xanthophylls called lutein which is often added to feed for this purpose (Malheiros *et al*., 2016). This yellow pigment found in eggs and skin of chicken tends to modify the consumer's acceptance.

Antibiotics
For growth promotion, antibiotics are fed at lower level than for prevention or treatment of disease in both ruminants and non-ruminants. Examples are erythromycin, neomycin, oxytetracycline, and tylosin. Due to the pressure antibiotics exerted in intestinal microflora to select for antimicrobial resistance which has huge animal and public health consequences, alternatives are being researched to replace them in animal production (M'Sadiq, *et al.*, 2015).

Prebiotics
Prebiotics are generally defined as indigestible non-starch feedstuffs that beneficially affect the host by selectively stimulating the growth or activity of one or a limited number of beneficial bacteria residents in gastrointestinal tract (Gibson and Roberfroid, 2008). They are not digested by the enzymes in monogastric animals making them available for fermentation by intestinal microflora to stimulate the growth of lactic acid bacteria that suppress the growth of undesirable pathogenic species (Roberfroid, 2005). Examples are inulin and oligofructose that have strong prebiotic properties.

Acidifiers
These are organic acids that are added to poultry feed in order to reduce feed buffering capacity and to maintain the optimum pH of feed and intestinal contents, thus inhibiting the growth of pathogenic bacteria in the intestine (Ugwu and Okoli, 2017). Examples of this class of additives are formic, propionic, acetic, fumaric and malonic acids.

Phytogenics
These are plant-derived compounds incorporated in farm animal's diet to improve their growth (Jacela *et al.*, 2010). Their mode of action is still not fully understood but many studies have attributed their growth stimulatory effects to their antimicrobial, antioxidative, improved gut function and increased dietary palatability resulting from enhanced flavor (Windisch *et al.*, 2008). Examples are essential oil, herbs, spices and terpenes (rosemary, oregano and thyme).

Adsorbents or Binders

Adsorbents such as zeolites (especially clinoptilolite), clay minerals and activated charcoal belong to this class of additives. Zeolite and clay minerals have been used as feed additives to ameliorate mycotoxicosis and to improve performance in animals (Ugwu and Okoli, 2017). Clay minerals have been used widely in poultry diets to improve chicken performance as a result of their binding property, especially when diets contain mycotoxins. Zeolites or clinoptilolite are crystalline, hydrated aluminosilicates of alkali earth cations, with infinite three-dimensional structures with unique adsorptive properties. They have been used as feed additive in order to ameliorate mycotoxicosis and improve animal performance. Recently clinoptilolite has been approved as feed additive in European Union at the highest inclusion rate of 2% of dry matter.

In laying hen, the administration of clinoptilolite improves feed conversion rate (Olver, 1997), increases the number of eggs laid (Yannakopoulos *et al*., 1995) and improves eggs quality characteristics (Tserveni-Gousi *et al.*, 1993). In broilers, it accelerates their growth rate by increasing feed consumption and feed conversion efficiency and improves carcass quality by lowering fat percentage (Christaki *et al.*, 2001; Mirabdolbaghi *et al.*, 2002). In ostriches, it has been reported that clinoptilolite affects the total bacterial counts of the eggshells. Dedousi *et al*. (2008) observed that when used as a nest material in ostriches, it reduced the total bacterial count of egg shells compared to river sand. This finding was attributed to the fact that clinoptilolite adsorbed and immobilized the bacteria from the nest environment, resulting in a net reduction of their number. As a result, the number of free microorganism able to infect the eggs laid in nest with clinoptilolite, were less than those in nests with other materials.

The use of activated charcoal as feed additive in improving health and performance in poultry had shown to be very beneficial. Edrington *et al*. (1997) fed broiler chickens with a diet supplemented with 0.5% super activated charcoal (SAC) for 21 days and observed a 4.6% increase in body weight in comparison with control birds, however there were no effect on the feed conversion ratio. Although no serious infection was encountered during the experiment, mortality of control birds stood at 12.7% as against the experimental groups that was 0.98%. The authors attributed this effect to the presence of available microelements and the detoxification effect of charcoal. Kutlu *et al*. (1999) applied feed supplemented with 2.5% charcoal and noted that the body weight of the broilers increased by 5.9% and 7.8% at 3 and 6 weeks respectively, which were statistically higher than the control group. Majewska *et al*. (2002) observed that the addition of charcoal at 3kg per ton of feed improved the performance of meat turkeys, reduced mortality and increased the crude protein content in the breast muscle. Samanya and Yamauchi (2001) noted that when activated charcoal was added to diets of broilers, the body weight gain and feed conversion efficiency increased.

NUTRITIONAL FEED ADDITIVES

This class of feed additives supply specific nutrient(s) required by the animal for optimal performance. Much of the nutrients required by farm animals are derived from the major feed ingredients such as maize, wheat and soybean meal, but if these were the only ingredients then, the animal will not grow well due to deficiency in some essential nutrients. In the case of animals in the wild, such deficiencies are either tolerated or ameliorated by selection of a wide variety of dietary ingredients, many of which are seasonal in availability.

In modern day farming, the nutrient requirements of farm animals are well understood and all requirements can be met through direct dietary supplementation of limiting nutrients, such as vitamins, amino acids and trace minerals.

Vitamins

Vitamins are essential nutritional supplement required for optimum health and physiological functions such as growth, maintenance and reproduction (Alagawany *et al.,* 2021). They exert catalytic functions that facilitate nutrient synthesis, thus controlling metabolism and affecting the performance and health of poultry. They are classified into fat soluble (A, D, E, and K) and water-soluble vitamins (B1, B2, B6, B12, folic acid, pantothenic acid, biotin, niacin and vitamin C). Deficiency of any of the vitamins manifest as cessation of growth, incoordination, weakness, ataxia, xerophthalmia and blindness occur in chicken due to deficiency of vitamin A (Alagawany *et al.,* 2021). Exudative diathesis and encephalomalacia are seen due to deficiency of vitamin E while polyneuritis, perosis and impairment of feed utilization occur due to deficiency of vitamin B complex. Vitamins such as vitamin B12 folic acid, panthothenic acid and biotin acid are essential for normal development of hemopoietic organs and for erythropoiesis and their deficiencies leading to anemia (Alagawany *et al.*, 2021).

Diets supplemented with vitamins play an important role in disease treatment and prevention, because it enables an animal to make use of protein and energy for health improvement, FCR, growth and reproduction (McDowell and Ward, 2008). Ferdous *et al.* (2018) reported that the addition of vitamin in water improved on the hematological and serum biochemical profiles without any detrimental effect on broiler chickens. It may also improve the development of intestinal mucosa and protect enterocytes from oxidative stress (Hassanpour *et al*., 2016).

Minerals

Minerals are important components of feed which are required as activator of hormone, enzymes, skeletal and structural maintenance of bone, egg formation and for maintenance of acid-base balance and osmotic homeostasis (Ravindran, 2010). They are needed in animals for optimum health and proper physiological functions. Hence, poultry require macro element as well as micro or trace minerals in the diet. Macro minerals such as calcium (Ca) and phosphorus (P) are the most abundance element in the body (Esonu, 2006). This group also includes chloride (Cl), magnesium (Mg), potassium, (K), sodium, (Na) and sulphur (S) with their requirements in diets usually higher than 100mg/kg feed (Ravindran, 2010). Trace minerals such as manganese (Mn), selenium (Se), copper (Cu), iron (Fe) and zinc (Zn) are necessary for chicken development as a result of their requirement in many metabolic pathways as co-factors of enzymes. They are required in poultry in trace amount usually about 0.01% (Ravindran, 2010). Trace minerals are required in the physiological function necessary to sustain life, including growth, reproduction, immune system functions, energy metabolism and bone formation (Dibner *et al*., 2007).

Calcium (Ca) is a major mineral in poultry nutrition as an important component of bones, shells, blood-clot formation and muscle contraction (Talpur *et al*., 2012). Lack of calcium ions in bones led to the deterioration of the skeletal structure and reduction in bone strength (Kwiatkowska *et al*., 2017). Zinc and manganese are co-factor involved in carbonate and mucopolysachride synthesis which are necessary to bone and egg shell formation (Swiatkiewicz *et al*., 2010) coupled with their contribution in carbohydrates, lipids and amino acid metabolism (Suttle, 2010). The supplement of 12mg/kg of manganese (Mn) in poultry feed from either organic or inorganic sources was sufficient to provide optimum performance in broiler (Mwangi *et al.,* 2019). Saleh *et* *al.* (2018) reported that dietary zinc (Zn) supplementation improved growth performance, humoral immune response, antioxidant properties, nutrient digestion and reduced lipid peroxidation in broiler meat.

Copper is involved in both humoral and cell-mediated immunity (Alagawany *et al.*, 2021). It has been used in poultry production as supplement due to its microbiological activities and the ability to increase body weight (Makarski *et al.*, 2014). The supplementation of copper sulphate (CuSo4) for up to 200mg/kg feed in broilers had beneficial effects in growth. Copper is also involved in iron transport, metabolism and in the formation of red blood cells. Samanta *et al.* (2011) confirmed that copper supplementation was an effective way of improving on the hematological profiles of broiler chickens.

Selenium is an important trace mineral for the maintenance of health and growth of humans and animals (Kielizek and Blazejak, 2016). When supplemented in diet, it improved the rate of hatchablilty, fertility and the overall productive performance of chicken including meat quality (Rizk *et al*., 2017; Ravindran and Elliot, 2017). It increases bursa and thymus weight and also led to increased immunity (Hussian *et al*., 2004). Iodine is a trace mineral with several biological roles including proper functioning of thyroid gland (Alagawany *et al.*, 2021).It is a component of the hormones (triiodothyronine and thyronine) that play essential role in regulating the metabolism, cellular oxidation and intermediary cell activity of the thyroid gland (Lewis, 2004). Its supplementation can as achieve through dietary iodine sources such as sodium iodide (NaI) and potassium iodide (KI) in animal diets. In poultry, iodine supplementation is mainly achieved through mineral premix in the form of iodized salt, $Ca(Io_3)_2$ which has been reported as an essential micro nutrient in laying hens with strong impact on growth performance of birds (Opalinski *et al*., 2012).

Amino Acids

Amino acids are functional and structural unit of protein that plays vital physiological roles in the body of animals (Bortoluzzi *et al*., 2018; Debnath *et al*., 2019). They are classified into two groups: non-essential (synthesized in the body) and essential amino acids (cannot be synthesized rapidly enough to meet the metabolic requirement). Examples of ten essential amino acids are lysine, methionine, tryptophan, threonine, arginine, isoleucine, leucine, histidine, phenylalanine and valine out of which lysine; methionine and threonine are referred to as limiting amino acids in poultry (Okata, 2016; Rehman *et al*., 2019). Glycine and serine are the non-essential limiting amino acids in poultry diet (Siegert and Rodehutscord, 2019) while cysteine and tyrosine are regarded as semi-essential amino acids because they can be synthesized from methionine and phenylalanine respectively (Ravindran, 2010).

After absorption, amino acids are assembled and metabolized to form proteins that are used to build different body tissues (Alagawany *et al.*, 2021). Beski *et al.* (2015) reported that dietary synthetic amino acid supplementation to poultry diets improved feed conversion efficiency and reduced nitrogen excretion.

FEED ADDITIVES THAT IMPROVE ANIMAL HEALTH

Included in this category of feed additives are also antibiotics, probiotics, prebiotics, synbiotics, acidifiers and coccidiostats.

Coccidiostats

These are products used to control intestinal health of poultry through direct effects on the parasitic coccidial organism concerned (Williams, 2005). Anticoccidial agents are used to prevent coccidiosis. Examples of several coccidiostats available are Amprolium 250®, Intracox® and Amprolium 200® all of which are imported and marketed in Nigeria by respective veterinary pharmaceutical companies who stand as sole distributors for the parent producing companies overseas.

Antibiotics e.g. Chlotetracycline and Oxytetracycline

In this case, antimicrobial agents (antibiotics) are included in feed at a level aimed at eliminating infection or disease. This is unlike the low dose inclusion of antibiotics usually associated with growth promotion in livestock as stated earlier.

CONCLUSION

Feed cost accounts for between 65 and 75% of the total cost of production in any commercial poultry and livestock enterprise. Nutritionists and experts in animal production have advocated for inclusion of feed additives as a means of optimizing the uptake of nutrients from alternative feed raw materials to improve production. Feed additives tend to fall into certain categories which describe their action in the feed or in the animal which serve as a guide to farmers in their applications. They have been classified into feed manufacturing, performance enhancing, nutritional feed additives and feed additives that improve animal health. More so, exogenous enzymes, acidifiers, prebiotics, probiotics, synbiotics, antioxidants, adsorbents and phytogenics have also been identified as varying alternatives to antibiotics in view of the ban placed on the sub-therapeutic inclusion of antibiotics in animal diet for growth promotion purposes due to antimicrobial resistance.

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The Value Addition of Agricultural Waste (Pig dung) in Producing Activated Carbon for Use in Veterinary Medicine, Agriculture and Environmental Remediation: A Review

Stephen. N. Okey[1], I. C. Okoli[2], C. R. Unigwe[1] and O.N. Okey[3]

1. Department of Veterinary Biochemistry and Animal Production, College of Veterinary Medicine, Michael Okpara University of Agriculture Umudike, Nigeria
2. Department of Animal Science and Technology, Federal University of Technology, Owerri, Nigeria
3. God's Gift Veterinary Services, Uyo, Akwa Ibom State, Nigeria

Abstract:
The expansion of agricultural production has naturally resulted in increased quantities of livestock wastes, agricultural crop residues and agro-industrial by-products. Pig waste is a biomass that changes rapidly from the time of excretion thereby creating a serious pollution problem. The odor from pig dung is capable of diminishing air quality which brings tension and complaints between pig farmers and their neighbors resulting to litigations and risk of possible closure of farms. A review on agricultural wastes such as pig dung is desirable because of their contribution to environmental degradation and the need to convert them to value-added products such as activated carbon (AC). Activated carbon also called activated charcoal is a solid, porous, tasteless and black carbonaceous material prepared from a variety of carbon containing materials, including agricultural wastes. Activated carbon is capable of adsorbing various toxic substances which makes it suitable for use as universal poison antidote, feed additive, water purification, and environmental remediation.

Keywords: Agricultural wastes, pig dung, activated carbon, veterinary medicine, agriculture and environmental remediation.

INTRODUCTION

Agricultural wastes are residues from the growing and processing of raw agricultural products such as fruits, vegetables, meat, poultry, dairy products and crops. Agricultural wastes and by-products are being advocated for the production of adsorbents such as activated carbon (AC) due to their carbon content and the possibility of mitigating environmental pollution through such a process (Schmidt *et al.*, 2019). Activated carbon or activated charcoal or biochar as it is synonymously described when produced from agricultural wastes have been found to be renewable and relatively less expensive when compared to other activated carbon precursors of industrial and petroleum origin such as wood, coal and lignite (Mohammed *et al.*, 2018). Activated carbon also called activated charcoal is a solid, porous, tasteless and black carbonaceous material prepared from a variety of carbon containing materials, including agricultural residues (AAFCO, 2012). Emerging reports revealed that activated charcoal adsorbs more toxins than any natural substance known to mankind (Maklad *et al.*, 2012).

A classical and frequently cited early demonstration with charcoal was a lethal dose of strychnine that was mixed with charcoal by Tovery in 1831, with no harmful effect observed due to the simultaneous ingestion of charcoal. Activated charcoal is therefore one of the best antidotes against poisons such as mushroom poisoning, brown recluse spider, insect sting and different types of snake bites (Maklad *et al*., 2012). For example, in an experiment by Cooney (1980), 100 times the lethal dose of cobra venom was mixed with activated charcoal and injected into a laboratory animal without any harmful effect observed. Indeed, it is capable of adsorbing a thousand times its own weight of gases, heavy metals and poisons (Schmidt *et al.*, 2019). It is this high adsorption property that makes activated carbon useable in water purification and in the removal of undesirable odours and impurities from food. Bad odours caused by skin ulcers have been eliminated by placing charcoal-filled cloth over plastic cast on the sore. It has been effectively used to adsorb wound secretions, bacteria and toxins (Schmidt *et al.,* 2019). Activated charcoal is required by law to be part of the standard equipment in many ambulances as first aid against poisoning. Activated carbon is a very effective adsorbent for reducing the levels of mycotoxins in feed when compared with other mineral adsorbents such as aluminosilicates and bentonite (Huwig *et al.,* 2001; Bhatti *et al.,* 2018).

When mixed with water and swallowed to counteract poisoning, activated charcoal adsorbs the poison or drug, inactivating it and then carries it inert through the entire length of the digestive tract out of the body. Hence charcoal is not digested, absorbed, neutralized nor metabolized in the body (Davis, 2005).

AVAILABILITIES OF AGRICULTURAL WASTES AND RESIDUES (PIG DUNG)

The generation of agricultural wastes will continue to increase globally as developed and developing countries continue to intensify their farming systems. Generally, the sources of biomass include wood, energy crops, agricultural residues, industrial wastes; sawmill residues, and animal wastes. An estimate in 2001 gave the total number of cattle, sheep, goats, horses, pigs and poultry in Nigeria as 245 million, which all together produce 0.78 million tonnes of animal waste daily including pig dung (Akorede *et al*., 2017).

Pig waste is a biomass that changes rapidly from the time of excretion thereby creating a serious pollution problem. It is more offensive to the human environment than any other animal waste (Iregbu et al., 2014) with the chemical composition of pig manure dependent on several factors like age, water intake, digestibility of the ration, housing environment and waste management. The environmental and health concerns in all pig production systems have to do with the waste management problems (Okoli *et al.,* 2006). The odour emitted from intensive pig production system is a very serious nuisance to people living in the vicinity of pig farms and has led to health problems. Some of these odorous compounds are capable of affecting both the health and production efficiency of animals. The odour which is mainly formed from the microbial conversion of organic compounds in manure is emitted into the air from building or external manure storage sites (Lee *et al.,* 2005). Besides the foul odour, the hydrogen sulphide, ammonia and other gases emitted by pig manure can diminish air quality. This can lead to tension and complaints between pig farmers and their neighbours which in some cases can result to litigations and risk of possible closure of farms.

MANAGEMENT OF PIG DUNG

The need for more animal protein to sustain the increasing teeming population has led to an obvious increase in livestock production through the establishment of large-scale farm (Iregbu *et al.*, 2014). This invariably had given rise to monumental increase in animal wastes especially pig dung resulting to waste management challenges. The challenges of handling pig dung are recognized as a major issue in sustaining the growth of pig industry in Nigeria (Okoli *et al.,* 2006).

Twenty-two co-operative farmers' societies at Oke-Aro in Ogun State, Nigeria which host the largest pig farm in West Africa was granted 25 million naira in 2007 by the World Bank through FADAMA programme in order to buy a machine that can convert their pig dung into dry organic manure which are sold to crop farmers. This notwithstanding, there is a desperate and urgent need to extend this technology further to ensure the removal of all animal, human and industrial wastes from the environment (Iregbu *et al.*, 2014) and transform them to other value-added products. One of such technologies would be the conversion of animal dung especially pig dung to value added products like activated charcoal through thermal pyrolysis using physical method of activation (Lima and Marshal, 2004) for use in varying adsorptive applications in homes, agriculture, pharmaceutical companies and in environmental remediation.

PRODUCTION PROCESSES OF ACTIVATED CARBON

The most frequently used method of preparation of activated carbon is the carbonization of the precursors at high temperature in an inert atmosphere followed by activation process (IBI, 2015). The activation process could be achieved through physical and chemical methods.

Physical Activation

Physical activation process involves treatment of char obtained from carbonization with oxidizing gases using steam or carbon dioxide at high temperature (400-1000°C) depending on the type of precursor (Matali *et al.*, 2013; Hagemann *et al.*, 2018).

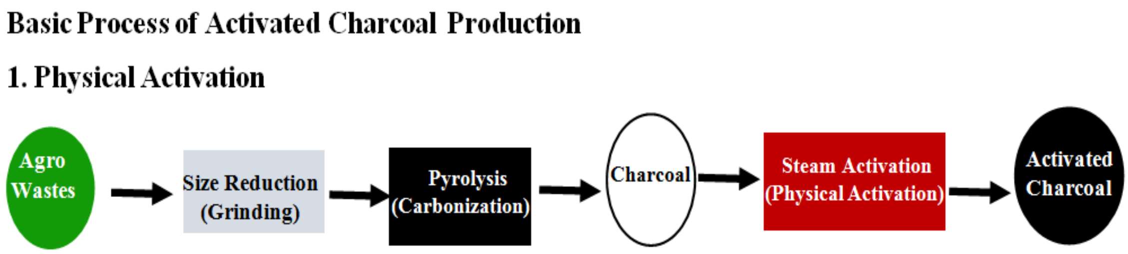

Fig. II: Flow chart for carbonization and physical activation in preparation of activated charcoal

(Source: Hidayu and Muda, 2016).

Chemical Activation

In chemical activation, the starting material is mixed with activating reagent and the mixture heated in an inert atmosphere (Ioannidou and Zabaniotou, 2005; Allwar *et al.*, 2012,). This process is usually done at a lower temperature and activation time, and it produces higher surface area and better pores when compared to physical activation ((HirunPraditkoon *et al.*, 2011). Several studies have shown that chemical activation has more benefits over physical activation in terms of lower temperature, higher yield and surface area (Zhu *et al.*, 2008; Schmidt *et al.*, 2019). On the other hand, there are some disadvantages associated with chemical activation such as washing that is required to remove impurities arising from activating reagents due to their corrosive actions. A flow chart of the chemical activation process is shown in figure 3.

2. Chemical Activation.

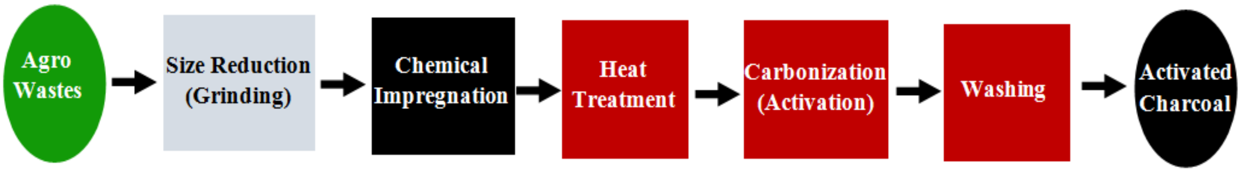

Fig. III: Chemical activation

The nature of the starting material plays a vital role in determining the quality, characteristics and properties of the resulting activated charcoal (Cagnon *et al.*, 2009; Camphell *et al.*, 2012; Abechi *et al.*, 2013). The properties of the activated charcoal produced can also be influenced by the type of activating reagents, time of activation, impregnation condition and carbonization temperature (HirunPraditkoon *et al.*, 2011).

Factors Influencing Activated Carbon Yield and Its Physico-Chemical Properties

Chemical Activating Agents:

The most widely used activating agents are phosphoric acid (H_3PO_4), zinc chloride ($ZnCl_2$) and potassium sulphide (K_2S) (William and Reed, 2004). The hydroxide of alkali metals, magnesium and calcium chloride and other substances are also used. $ZnCl_2$ is efficient in producing micropore structure and greater surface area in the activated carbon, while H_3PO_4 effectively produces mesopores resulting in higher pore volumes and diameters (Donald *et al.*, 2007). Phosphoric acid is however preferred over zinc chloride which could pose environmental hazard such that activated carbon produced is contra-indicated in food and pharmaceutical industries (Al-Qudah and Shawabkah, 2009). More so, in using H_3PO_4, it is easier to recover AC during processing by only rinsing with water. It also gives higher yield of activated charcoal and has no toxic properties. The use of potassium hydroxide (KOH) as activating agent has been found to be effective in producing AC with narrow pore size distribution. The use of H_3PO_4 or KOH has been suggested to be more eco-friendly as compared to $ZnCl_2$ (Khezami *et al.*, 2007).

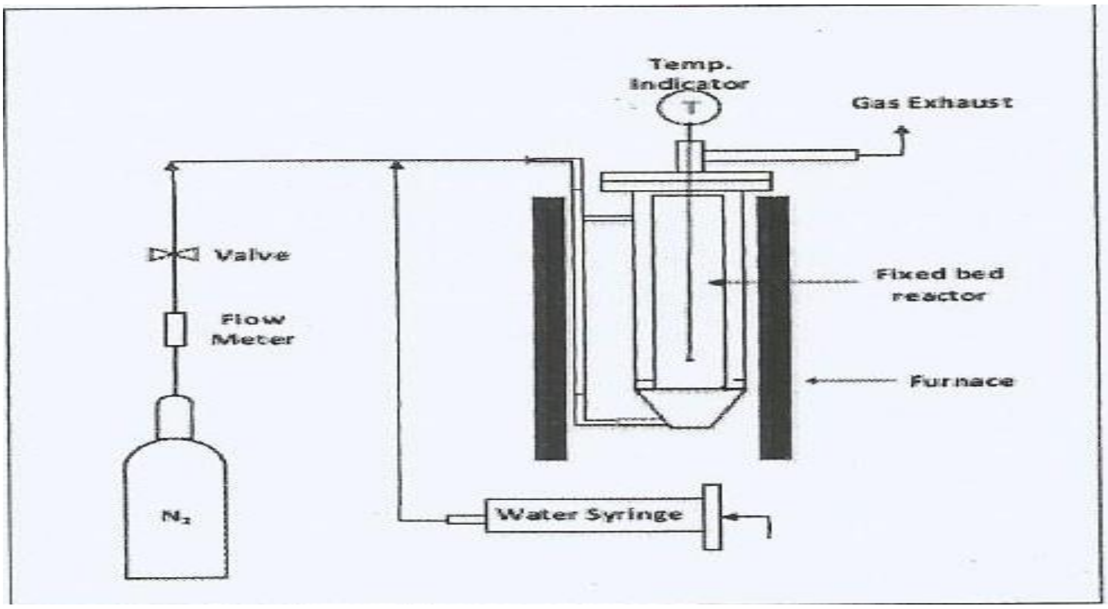

Fig. IV: Experimental set-up for preparation of activated carbon.

Source: Hidayu and Muda, 2016

Fig. V: Activated carbon Sample.
Source: Okoli, 2020

Impregnation Ratio:
An important factor in chemical activation is the degree of impregnation or impregnation co-efficient. This is the weight ratio of the anhydrous activating agent to the precursor. Impregnation ratio has significant effect on the development of pores and the adsorption capacity. Giraldo and Moreno-Pirajan (2012) used $ZnCl_2$ and KOH as activating reagents and varied the ratio from 2 to 3 and discovered that the surface area and total pore volume increased. Malik *et al.* (2006) observed similar effect in which case the increased ratio of $ZnCl_2$ brought about increase in surface area and pore volume but with a decrease yield of activated charcoal. Mdoe and Mkayula (2002) studied the properties of activated carbon derived from rice husk using KOH as activating agent and noted increase in both the surface area and the adsorption capacity but with reduced carbon yield.

It has been discovered that the development of pores in activated carbon may be influenced by the concentration of the chemical activating agents used. The effect of H_3PO_4 and $ZnCl_2$ concentration on the surface characteristics affects the development of pores with cracks found at the surface at the highest concentration of H_3PO_4 (80 wt %). More so, Ucar *et al.* (2009) used different concentration of $ZnCl_2$ to study pores development of the activated carbon derived from pomegranate seeds and noted that the external surfaces had different pore sizes and irregularly formed cavities.

Effect of Carbonization and Activation Temperatures:
Carbonization temperature will affect the activated charcoal production along with heating rate, nitrogen flow rate and carbonization time. Increased temperature would eventually increase the

release of volatiles and increase ash formation which would reduce carbon yield. Mozammel *et al.* (2002) studied the effect of temperature, time and impregnation ratio on the activated carbon yield produced from coconut shell using $ZnCl_2$ as activating agent and reported that higher temperatures resulted in better activation but lower activated carbon yield. Tsai *et al.* (1998) prepared activated carbon from corn cob and found that high temperature increased the surface area, total pore volume, density and porosity but with lower yield. More so, Alau *et al.* (2010) studied the effect of preparation conditions on quantity of activated charcoal produced from neem husk by using three different activating agents namely $ZnCl_2$, H_3PO_4 and KOH. They found that each chemical agent had different optimum activation temperatures which were 400, 500 and 350^{o}C for $ZnCl_2$, H_3PO_4 and KOH, respectively. Also, Allwar *et al.* (2012) observed the textural characteristics of activated charcoal produced from palm kernel shell using $ZnCl_2$ as activating agent at a temperature range of 400-800^{o}C and noted that the maximum micropore volume was 0.74cm^3g^{-1} at a temperature of 500^{o}C. The micropore volume of the activated carbon increased with increased temperature from 400 to 500^{o}C and decreased with further increase in activation temperature.

Nature of Agricultural Bio-Waste Material:

Several studies have shown that one of the most important factors that affect the texture of activated carbon is the nature of the starting material (Verheijen *et al*., 2010). Different agricultural bio-waste would produce activated carbon having different texture characteristics even with the same method of treatment or activation method. Khalil *et al.* (2013) prepared activated carbon from three different biomass: oil palm empty fruit bunch (EFB), bamboo stem and coconut shell using potassium hydroxide as activating agent under atmospheric nitrogen and reported irregular cavities or pores that differed from each other. Also, Martinez *et al.* (2006) observed that the texture of the carbon yield as well as development of pores is strongly affected by the nature of precursor material. They investigated two biomass materials, walnut shells and olive pits and showed that the former has a homogenous structure of carbon, while the later develops rough texture of carbon with heterogeneous surface under different concentration of the activating agent (KOH).

Other critical determinants of activated carbon quality include level of non-starch polysaccharides (NSPs) namely hemicelluloses, cellulose and lignin, pore structure, level of volatile and non-volatile fractions, and carbon and ash contents (Olivares, 2006; Dhyani and Bhaskar, 2017). Woody biomass (Baski *et al.,* 2006; Madu and Ladije, 2013), palm fruit fibre and palm kernel shell yield good activated carbon due to high content of NSPs and good pore structure. The level of volatile and non-volatile fractions can be determined by chemical analysis. These parameters influence the heating value (HV) of precursors and activated carbon quality. Chaniwala and Parikh (2002) expressed the relationship between heating value (HV) and elemental composition of precursors as.

$$HV\ (MJ/kg) = 0.3491\ (C) + 1.1783\ (H) - 0.10\ (S) - 0.0134\ (O) - 0.0151\ (N) - 0.0211\ (A).$$

The levels of the various NSPs in precursor can be evaluated by chemical analysis and they influence the decomposition temperature and behavior of precursors during pyrolysis with a range of 215-315, 315-400 and 160-900^{o}C for hemicelluloses, cellulose and lignin, respectively (Yang *et al.*, 2007).

Table: 5: Activated charcoal yield from physical and chemical activation using palm kernel shell as precursor material.

Method	Activating agent concentration (%)	Yield (%)
Physical Activated charcoal From PKS	Steam flow 10% of solid per minute for 1 hour	22
Chemical Activated Charcoal From PKS	$ZnCl_2$ 60% of solid	44

Source: Hidayu and Muda (2016).

Uses of Activated Carbon in Veterinary Medicine and Agriculture

Use of Activated Charcoal in Detoxification and in Treatment of Poisoning:

Activated carbon has been used for medical and veterinary purposes as universal poison antidote due to its physical and chemical properties, including surface area, pore size and its adsorption capacity (AACT, 1999; Alkhtib and Al Zailey, 2015; Schmidt *et al.,* 2019). It is considered as the first-line of treatment of poison after several hours after ingestion with no complications associated with its use. Chronic exposure to toxins from food and environment cause cellular damage, allergic reaction, compromised immunity leading to a more rapid aging (Chyla *et al.,* 2005). Regular use of AC helps the body to eliminate these toxins from the body to promote healthy digestive system and brain thereby making the individual feel renewed and vibrant (AACT, 1999; Alkhtib and Al Zailey, 2015). The intake of AC will remove toxic heavy metals from the body including pathogenic bacteria before they spread and multiply. It is an effective treatment for many poisons as it prevents swallowed poisons and drugs from being absorbed from the gut into the blood stream to cause harm. Activated carbon has a negatively charged porous surface that attracts the positively charged toxins or poison resulting in their binding and subsequent elimination through the entire length of the digestive tract and out of the body. This binding or adsorption is made possible by lots of pores on the AC particles that increase the surface area and available binding sites. Pore structure of activated carbon are typically classified into micropore (1 nm), mesopore (1-25 nm), and macropore (25 nm and above) based on the pore radius (Lowell and Shields, 1998; Gerd and Tondeur, 2001).

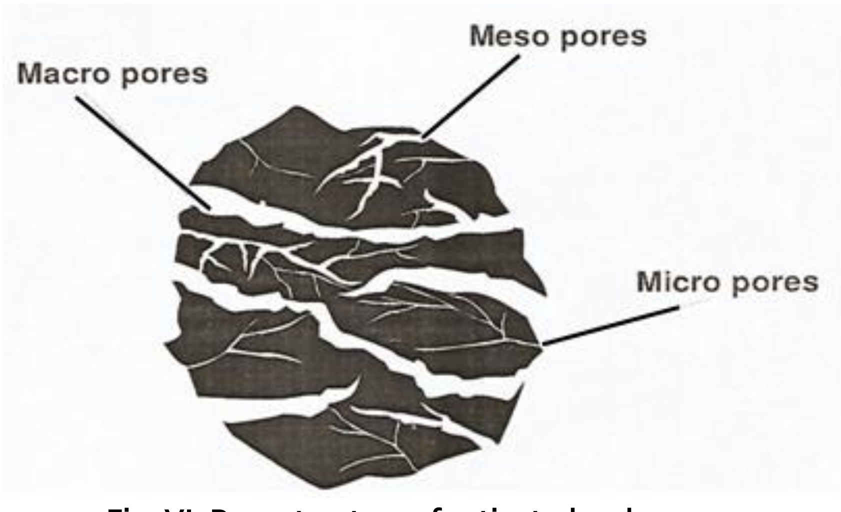

Fig. VI: Pore structure of activated carbon.
Source: Gerd and Tondeur, 2001

Gastrointestinal decontamination is accomplished in an emergency room using AC which is usually mixed with water and given to patient to drink or through feeding tube. Activated carbon has historically been used to clean water and as a treatment for many ailments. An early demonstration of the adsorptive properties of AC was in 1813 when a French chemist Bertrand drank 5 grams of a very poisonous substance (arsenic trioxide) mixed with activated carbon and survived. It should be noted that the efficacy of AC depends on how quickly it is given and the poisonous substance swallowed (Chyla *et al.*, 2005; Schmidt *et al.*, 2019). The earlier the AC is given after a drug or chemical is swallowed, the better it works. The best long-term study on the detoxification benefit of AC in animal was conducted by researchers at University of Wyoming and Duke University. They were able to establish that monkeys on the African Island of Zanzibar near East Africa eat activated carbon from burnt tree stumps in order to detoxify their digestive system. In another experiment, 100 times the lethal dose of cobra venom was mixed with AC and injected into a laboratory animal which was not harmed. It was on this basis that Cooney (1980) concluded that AC adsorbs poisons or toxins more than any other substance known to mankind and is capable of adsorbing a thousand times its own weight in gases, heavy metals and poisons.

Use of AC as Feed Additive in Improving Health and Performance in Poultry:
Activated carbon obtained from bamboo for example is a universal adsorbent because it contains a complex network of pores of various shapes and sizes (Zhao *et al.*, 2008). It was reported to have higher absorption capacity than wood charcoal, because of the special micro-pore structure of bamboo stems (Chungpin *et al.*, 2004). It has been used in powder form as oral antidote to reduce the absorption of poisons from the gastrointestinal tract. Bamboo vinegar is an acidic by-product of bamboo charcoal production which contain many compounds including phenolics, alkanes, alcohol, aldehydes and various organic acids, especially acetic acids (Lin *et al.*, 2008; Velmurugan *et al.*, 2009). These acetic acids component is capable of controlling the balance of intestinal microflora and pathogens and affects intestinal functions and metabolism (Rattanawut *et al.*, 2017; Rattanawut *et al.*, 2021). The mixture of bamboo activated carbon and vinegar has been shown to induce a significant increase in egg production by stimulating intestinal functions of laying hens in early phase of production (Yamauchi *et al*., 2010).

It has reported that AC given orally reduced intestinal *Salmonella enteritidis* and minimized the removal of normal bacteria flora (*Enterococcus faecium*) from the intestinal tract (Watara and Tana, 2005; Abit *et al*., 2014). Rattanawut *et al.* (2017) reported that bamboo activated carbon improved egg shell quality through several mechanisms including decreasing gut pH which inhibited the growth of pathogens and enhancement of the growth of beneficial intestinal organisms. The digestion and utilization of mineral nutrients were also increased due to increased secretion of digestive enzymes as a result of reduced pH level. In the same study, the intestinal villus height in the duodemm and jejumm were increased when feeding bamboo charcoal powder at 1.0% and 1.5% inclusion levels. The increased villus size provided greater absorptive surface area and a better capacity for absorbing available nutrient. Gilmore and Wang *et al.* (2003) reported that villus height is increased due to enhanced efficiency of digestion and absorption in the small intestine coupled with the increases in population of beneficial bacteria that supply nutrients and promote the vascularization and development of the intestinal villi. Choct (2009) found shorter villi when counts of pathogenic bacteria increased in the gastrointestinal tract, resulting in fewer absorptive and secretory cells.

Majewska (2011) carried out experiment to determine the effect of hard wood charcoal supplementation on the performance and carcass characteristics of broiler at varying inclusion level in the diet. The results showed that at 3% dietary supplementation, the birds were 5 and 3.5% heavier than the control and the dressing percentages and the relative weights of the muscles were also improved at 21 and 42 days respectively. The author corroborated this with the results of her earlier studies in 1999 and 2002 and attributed the results to the presence of available microelements and to the detoxifying effects of charcoal, thereby lowering the surface tension of the intestinal digesta to support liver function with respect to fat digestion. More so, the adsorption properties of AC acts curatively on the gastrointestinal tract (GIT), adsorbing gases such as hydrogen sulphide and ammonia that are formed there, including bacterial toxins and mycotoxins produced by fungi (Abit *et al.*, 2014; Kim *et al.*, 2017).

In another research by Dim *et al.* (2018) to ascertain the effect of dietary supplementation of AC on growth, haematology and serum lipid profiles of broilers, the final body weight, average daily weight and FCR favored birds placed on 6% charcoal inclusion than other groups and the control after 56 days trial period. The author noted that the results were in conformity with the report of Jiya *et al.* (2013) whose results also improved performance on inclusion of activated carbon. More so, Dim *et al.* (2018) noted that the white blood cell (WBC) count and the packed cell volume (PCV) were not affected at both the starter and finisher phases. However, the haemoglobin concentration (Hb) and the red blood cell (RBC) count were significantly improved, while the cholesterol and lipoprotein levels were significantly reduced with no effect on triglyceride at both phases. This was attributed to the ability of the birds fed activated charcoal to maximally utilize the vitamin-mineral premix in the diet, especially iron and B-complex vitamins probably due to the binding of activated charcoal with toxins and anti-nutritional factors in the gut of bird which enhanced the utilization of vitamin and minerals for the production of RBC and Hb better than in the control.

Use of Activated Carbon in Fish Pond:

The earthy odours of organic compounds namely geosmin and 2 methylisoborne (MIB) have been a problem not only in potable water supply but also in pond-based fish farming (Boonanuntanasarn *et al*., 2014). These are secondary metabolic products of some blue-green algae and bacteria which fish absorb from the surrounding water primarily through their gills and intestines on ingestion. Fish absorb them in the bottom of the pond with the highest concentration of geosmin and 2 methylisoborne (MIB) found in their intestines. These odour substances in fish ponds have made fish production a very risky business due its contribution to disease outbreaks and fluctuations in water quality (Boonanuntanasarn *et al.*, 2014). There has been limited scientific research regarding the use of activated carbon as feed additive in aquatic animals (Majewska *et al*., 2009; Ruttanawut *et al.,* 2009). Recently many types of activated charcoal including granular and powdered AC have been demonstrated to be suitable for the removal of geosmin and MIB from drinking water (Matsui *et al.*, 2013). In the study carried out by Boonanuntanasarn *et al.*, 2014), the result showed that activated carbon supplementation led to a significant reduction in the level of geosmin in fish, while MIB was not detected at inclusion rate of 30mg kg^{-1} and 10mg kg^{-1} for 2 and 4 weeks respectively.

***Use of Activated Carbon in Prevention of Mycotoxicosis*:**

Mycotoxins are toxic metabolites synthesized by certain naturally growing fungi on animal feed, feed ingredients and other agricultural crops. They constitute one of the major factors suppressing poultry productivity and product quality, hence, the control of their impact is very critical (Oguz, 2011). According to FAO (2013) approximately 25% of world's grain supply is contaminated with mycotoxins. The contamination of poultry feeds with mycotoxins is one of the major challenges associated with the poultry industry. However, research and industrial activities in Nigeria seem to neglect these realities about mycotoxins in animal production and this has probably contributed to the observed poor performance of commercial birds in the country (Ukwu, 2013).

Activated carbon is effective in the elimination of mycotoxins, such as aflatoxins that contaminate feed ingredients (Bhatti *et al.,* 2018). The adsorption effect of activated charcoal on mycotoxins and other detrimental organic compounds would positively influence the growth of broilers and layers, their immunity and carcass quality. Several studies have shown that it was effective in removing various types of mycotoxins such as aflatoxins, fumonisins, ochratoxin A, trichothenes and Zearalenone (Bhatti *et al.,* 2018). Its use in the prevention of mycotoxins contamination of feeds appears to be more effective than various minerals adsorbents such as aluminosilicates and bentonite (Huwig *et al.*, 2001; Bhatti *et al.,* 2018).

Use of Activated Carbon in Poultry Litter for Odour Control:
Activated carbon produced from agro-residue are extremely porous and excellent natural filter with a huge internal adsorption capacity for water, ammonia, ions, and other irritants than any other organic material (Sashikala *et al*., 2012). There is an immediate and obvious need to reduce or eliminate gases and odours emanating from manures in farming environment (Anukam, 2013), since these have led to complaints and litigation from the public (Iregbu, 2014).

Researchers have shown that biochar captures 63% of ammonia and other gases such as methane, nitrous oxide, hydrogen sulphide, urea, organic acids, ketones, volatile vapours and noxious liquids found in animal manures (David, 2015). The effects are achieved when 5-20% of biochar is blended with conventional litter and spread on the floor as an air purifier. Lowering of the build-up of odourless gases and improvement in air quality and livestock health has also been reported by Durunna *et al.* (2018) when graded levels of AC were incorporated in to the diets of broilers. Lower moisture content and ammonia levels curtail risk of footpad diseases, skin lesions and respiratory diseases which will ultimately improve vitality, egg production and weight gain. Depending on the type of litter, biochar can be mixed at the rate of 5-10% by volume with litter, with the effects being strong at 5% biochar but reaching saturation beyond 15%. Biochar can also be added and mixed when making silage to conserve moisture, buffer pH, retain cation and anions and provide stable environment for fermenting organisms.

Use of Activated Charcoal in Water Purification:
Water sources available to most developing countries including Nigeria are rivers, natural ponds and rainfall. A common feature about these water bodies is that they are contaminated or polluted by heavy metals discharged from industries (Tumin *et al*., 2008). Studies by Etuk *et al.* (2014 and 2016) have specifically shown that such water sources commonly used in animal feeding have negative effects on the physiological performances of broilers. One of the major ways of cleaning contaminated water is by the use of activated carbon in the adsorption of metallic ions and bacterial toxins from waste water (Schmidt *et al.,* 2019). The metal ion adsorption is more related to the surface properties of activated charcoal than their specific areas. Since most activated charcoal sold in Nigeria for this purpose is imported, the need to produce and characterize activated carbon locally becomes imperative. This will not only improve water treatment technology in Nigeria but reduce the foreign exchange spending on importation of this industrial raw material. It will also help prevent water bone disease epidemics and deaths frequently reported in Nigeria due to water pollution and contamination.

Use of Activated Carbon in Oil Spill and Environmental Remediation:
A wide range of adsorbent materials have actually been used in cases of oil spillage and water remediation in adsorbing oil including activated carbon. The adsorption property of activated charcoal is highly made use of in remediation of petroleum-contaminated water in cases of oil spillage frequently witnessed in oil producing communities (Tabbakh and Barhoun, 2018). Pollution by petroleum oils affects marine life, economy and tourism activity because of the coating properties of oil that harms the beauty of polluted sites. This brings about strong odour that can be felt several kilometers away from the affected area. It also destroys the growth of green algae and alters sea colour and landscape with monumental effects on the marine and aquatic lives (Tabbakh and Barhoun, 2018). Most importantly, activated carbon produced from agricultural wastes is one of the commonest used techniques for remediation of contaminated water. The use of agricultural residues as activated carbon precursors has also been found to be renewable and relatively less expensive and ultimately could utilize the waste effectively into wealth (Malik, 2006).

Activated carbon is also widely used as an absorbent in the purification of liquids and gases coupled with newer applications that are emerging concerning environmental protection and technological development. This purification is made possible by the vast system of pores within the carbon particles (Gerd and Tondeur, 2001). In addition, the properties of AC are also influenced by the type of activating reagents, time or duration of activation, impregnation condition, carbonization temperature and the level organic impurities (Olivares *et al.,* 2006).

Use of Activated Carbon as Soil Additive:
Activated carbon also described as biochar enhances soil water retention and improves plant nutrient availability and uptake (Zheng *et al.*, 2013; Van Zwietan *et al.*, 2010; Sandhu *et al.*, 2019) thereby improving plant productivity. This may be of significance in agricultural areas where soil nutrients are naturally depleted, prone to leaching or were draught risk successful crop production. It has additional fertilizer value and may enhance crop productivity by providing important plant macro and micro-nutrients. Nitrogen and phosphorus are two of the limiting nutrients with regards to plant growth. As a result of this, they are frequently used in agricultural systems as fertilizers to promote the growth of crops. One of the richest sources of nitrogen and phosphorus used in agricultural production is fertilizers. Fertilizers produced from livestock manure or activated carbon derived from them is high in nitrogen and phosphorus concentration (Steiner, 2008; Sandhu *et al.,* 2019).

The use of rice husk activated charcoal to fertilize the rice field has been a common practice in Asia for hundreds of years (Steiner, 2008). Adding activated carbon to the soil will help replace carbon, nitrogen and other plant nutrients that are worn out from the land during multiple harvests or due to continuous cropping. The carbon in biochar is highly stable in the soil and can be sequestered for years (Laird, 2008). Mollinedo *et al.* (2015) have also demonstrated the use of activated carbon to improve the water holding capacity of different soil samples. In their study, treatment of the soil increased the water retention in soil for up to 25% when compared with the control sample. Umeojiakor *et al.* (2018) showed that animal manure as an organic carbon source was effective in mineralizing pyrene, a polycyclic aromatic hydrocarbon (PAH) in clay soils from south-eastern Nigeria.

CONCLUSION

The expansion of agricultural production has naturally resulted in increased quantities of agro-industrial by-products, agricultural crop residues and livestock waste such as pig dung. A review on pig dung is desirable because of its contribution to environmental pollution and the need to convert it to value-added products such as activated carbon (AC). Activated carbon has been used for medical and veterinary purposes as universal poison antidote due to its physical and chemical properties, including surface area, pore size and its adsorption capacity. It is also widely used as feed additive, water purification and in odor control in poultry and fish production. The properties of the activated charcoal produced can also be influenced by the type of activating reagents, time of activation, impregnation condition and carbonization temperature. Other critical determinants of activated carbon quality include level of non-starch polysaccharides (NSPs) namely hemicelluloses, cellulose and lignin, pore structure, level of volatile and non-volatile fractions, and carbon and ash contents. The non-conversion of agro-wastes to value added products such as activated carbon is not only hazardous but a waste of economic resources when most of the activated carbons used for various adsorptive purposes in Nigeria are imported.

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Rainfall Variability Trend in Porbandar, Gujarat

Kunal N. Odedra and B. A. Jadeja

1. Department of Botany, M. D. Science College, Porbandar

Abstract:
Rainfall is a principal element of the hydrological cycle and its variability is important from both scientific as well as socioeconomic points of view. This study presents an analysis based on the rainfall variation over 31 years from 1991 to 2021 in Porbandar, Gujarat located in the western region of India. The data were analyzed using fundaments statistical parameters and trends in rainfall were investigated using Mann-Kendall Test and Sen's method. In Porbandar, the average monsoon rainfall from 1991-2020 for the monsoon months of May to October is about 539.11 mm. Mann-Kendall value Z and Sen's estimator β show the non-significant but decadal-increasing trend in rainfall. The negative value of Z statistic and Sen's estimator β for the month of August, September, and October shows a non-significant downward trend while the positive for July month shows a non-significant upward trend. Overall, there is a steadily increasing trend of rainfall in Porbandar. These observed changes in rainfall, although most time series are not convincing as they show predominantly no significance, along with the well-reported climatic warming in monsoon and post-monsoon seasons may have implications for human health and water resources management over bio-diversity-rich Porbandar district.

Keywords: Rainfall, Porbandar, Mann-Kendall Test, Sen's Method

INTRODUCTION

Hydrological processes are usually regarded as stationary; however, there is growing evidence of trends, which may be related to anthropogenic influences and natural features of the climate system [1]. Serious concerns are drawn on the catastrophic nature of floods, droughts, and storms caused due to the significant variations in the regional climate including the rainfall pattern taking place on a regional level. Trends in precipitation have been observed for the last century in many parts of the globe. Over this period, precipitation increased significantly in eastern parts of North and South America, northern Europe, and northern and central Asia whereas precipitation declined in the Sahel, the Mediterranean, southern Africa, and parts of southern Asia [1].

Southwest monsoon rainfall over India exhibits variability in all time scales from diurnal to epochal. The yearly variability of monsoon rainfall has been studied by many researchers [2, 3, 4, 5]. Sinha Ray and Srivastava [6] have reported a decreasing trend in rainfall over most parts of the country except over northwest India and a few stations in northern India. Joshi and Rajeevan [7] have observed an increasing trend in monsoon rainfall over the west coast and northwest India. A preliminary analysis by Ray et al. [8] using 40 years of data for Gujarat found that mean seasonal rainfall has increased over Saurashtra and south Gujarat region (along the west coast) and has remained more or less the same over the north Gujarat region and adjoining Kutch.

Climate change, in particular, the rainfall variability has become a major abiotic factor affecting the prospect of agriculture, livelihood security, flood management, availability of fresh water, and melting of glaciers. Information on the temporal and spatial distribution of rainfall is important for a variety of applications in hydrology and water resources management [9].

METHODOLOGY

Study Site

Porbandar is situated in the western part of the Kathiawar Peninsula on the Arabian Sea coast. The geographical location of Porbandar is 69° 36' 21.4740'' E Longitude and 21° 38' 26.0700'' N Latitude. This district was carved out of Junagadh District and is surrounded by Jamnagar and Devbhoomi Dwarka districts to the north, Junagadh and Rajkot districts to the east, and the Arabian Sea to the west and south [10]. The general climate of the district is sub-tropical and is characterized by three well-defined seasons, i.e., summer - from April to June, monsoon - from July to September, and winter - from October to March. Mean maximum daily temperatures range from 29 to 34°C and mean minimum daily temperatures from 14 to 27 °C. The average precipitation days (≥ 1.0 mm) is 1.82 [11]. The average relative humidity (%) is 62.68 [11]. The mean monthly sunshine hours are 10.61 [11]. The location map as well as the study area is shown in Fig. 1.

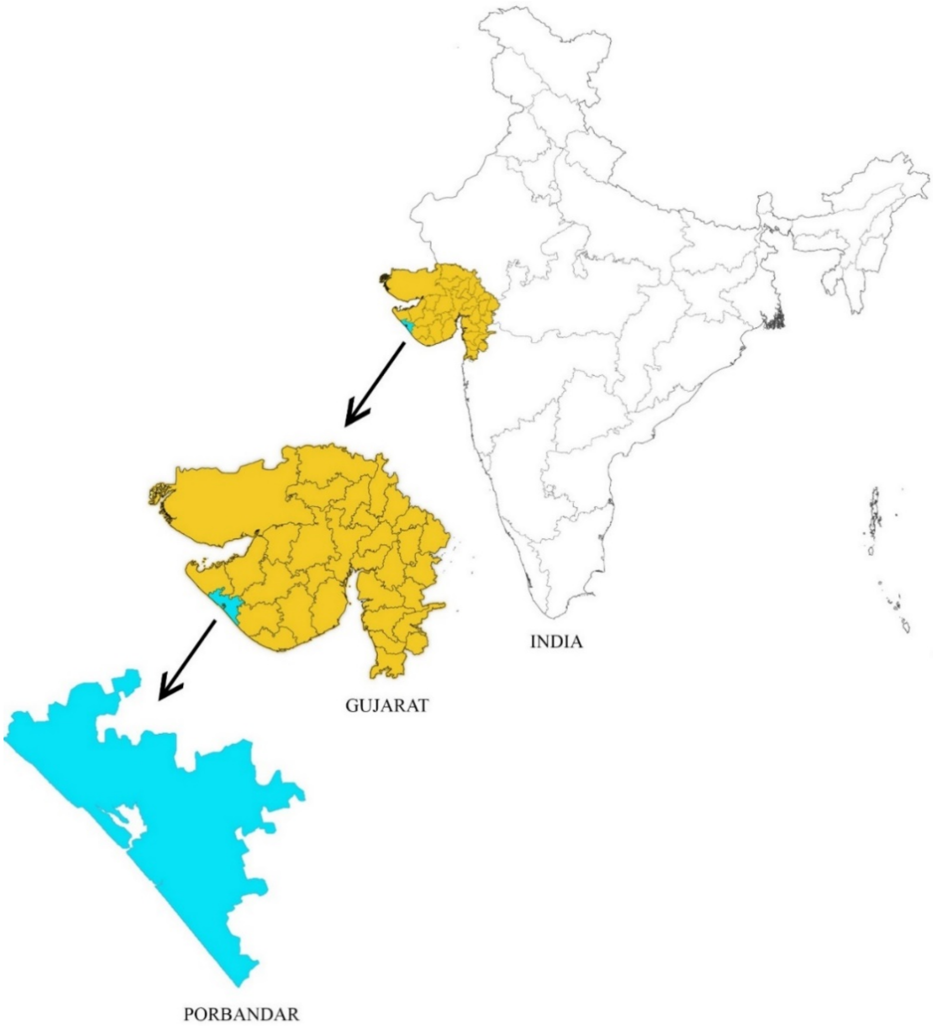

Fig. 1: Location Map of Study Area

Data Collection

The monthly rainfall data is downloaded from Indian Meteorological Department's Climate Data Online portal [12] using Chat GPT an AI language model developed by Open AI for the period 1991-2021. India Metrological Department (IMD) has defined four climate seasons viz. winter (January to February), pre-monsoon (March to May), monsoon (June to September), and post-monsoon (October to December). The rainfall data for May, June, July, August, September, October, and monsoon season data were prepared using the monthly rainfall data.

Statistical Analysis

At first, the data were divided into decadal basis viz. 1991-2000, 2001-2011, and mean rainfall per month for the whole monsoon season were obtained. The data were statistically analyzed using basic statistical parameters like mean, standard deviation, skewness, and kurtosis. In general, trend analysis can be done by both parametric and non-parametric tests but in this present work, the non-parametric tests were done as it does not require data to be normally distributed and free from outliers. In the present work, the Mann-Kendall test and Sen's slope method were used to detect the direction and magnitude of a trend.

Mann-Kendall Test:

Mann–Kendall test, this non-parametric test, which is usually known as Kendall's statistic, has been widely used to test for randomness against trends in hydrology and climatology [13].
The Mann-Kendall statistics S is given as

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i)$$

Where x_i and x_j are time series ranked from i=1,2 ..., n-1 and j=i+1...,n respectively.

$$Sgn(x) = \begin{cases} 1, & if\ x > 0 \\ 0, & if\ x = 0 \\ -1, & if\ x < 0 \end{cases}$$

A positive sign of statistic S indicates an upward trend while the negative sign indicates a downward trend of the data. For the sample size n ≥8, variance of the Mann-Kendall statistics is given by

$$\mathrm{Var(S)} = \frac{[\mathrm{n(n-1)(2n+5)} - \sum_t \mathrm{t(t-1)(2t+5)}]}{18}$$

Where t is the extent of any given tie.

The standard normal variable **Z** is computed by

$$\boldsymbol{Z} = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}} & if\ S > 0 \\ 0\ if\ S = 0 \\ \dfrac{S-1}{\sqrt{Var(S)}} & if\ S < 0 \end{cases}$$

The **Z** follows a standard normal distribution and **Z**>o signifies an upward trend whereas **Z**<o signifies a downward trend.

Sen's Method:

Sen's estimator. If a linear trend is present in a time series, then the true slope (change per unit time) can be estimated by using a simple non-parametric procedure developed by Sen in 1968 [14].

The slope of the trend line in the sample of N pairs of data can be estimated by

$$Q = \frac{x_j - x_i}{j - i}$$

Where x_j and x_i are the data values at times j and i (j>i) respectively.

The median of these N values of Q is Sen's estimator of slope which is calculated as

$$\boldsymbol{\beta} = \begin{cases} Q\left(\frac{N+1}{2}\right) & \text{if N is Odd} \\ \frac{Q\left(\frac{N}{2}\right) + Q\left(\frac{N+2}{2}\right)}{2} & \text{if N is Even} \end{cases}$$

In the end, **β** is computed by a two-sided test at 100 (1-α) % confidence interval and then a true slope can be obtained by the non-parametric test. A positive value of **β** indicates an upward or increasing trend and a negative value of **β** gives a downward or decreasing trend in the time series.

RESULT AND DISCUSSION

Preliminary Analysis

According to data obtained, in Porbandar rainy days belong to six months May to October. The average rainfall in Porbandar during the period of 1991-2021 is 539.11 mm. The average rainfall per year is shown in Fig. 2. The average rainfall par the last three decades is shown in Table 1. The highest average rainfall is observed during the last decade (2011-2021). The decadal distribution of monthly rainfall is shown in Fig. 3.

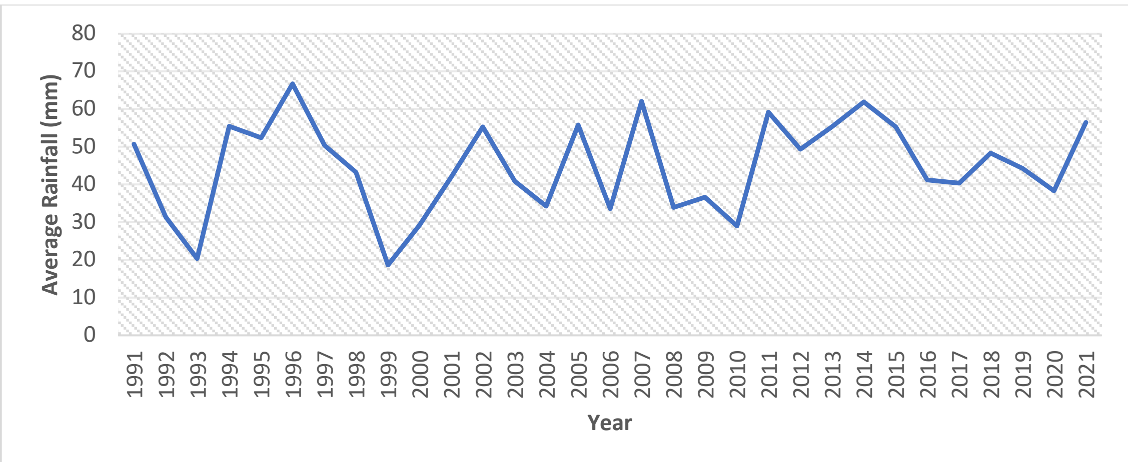

Fig. 2: Average rainfall per year for the period of 1991-2021 in Porbandar

Table 1: Average decadal rainfall in Porbandar

Decade	Average rainfall (mm)
1991-2000	502.32
2001-2010	508.51
2011-2021	600.38

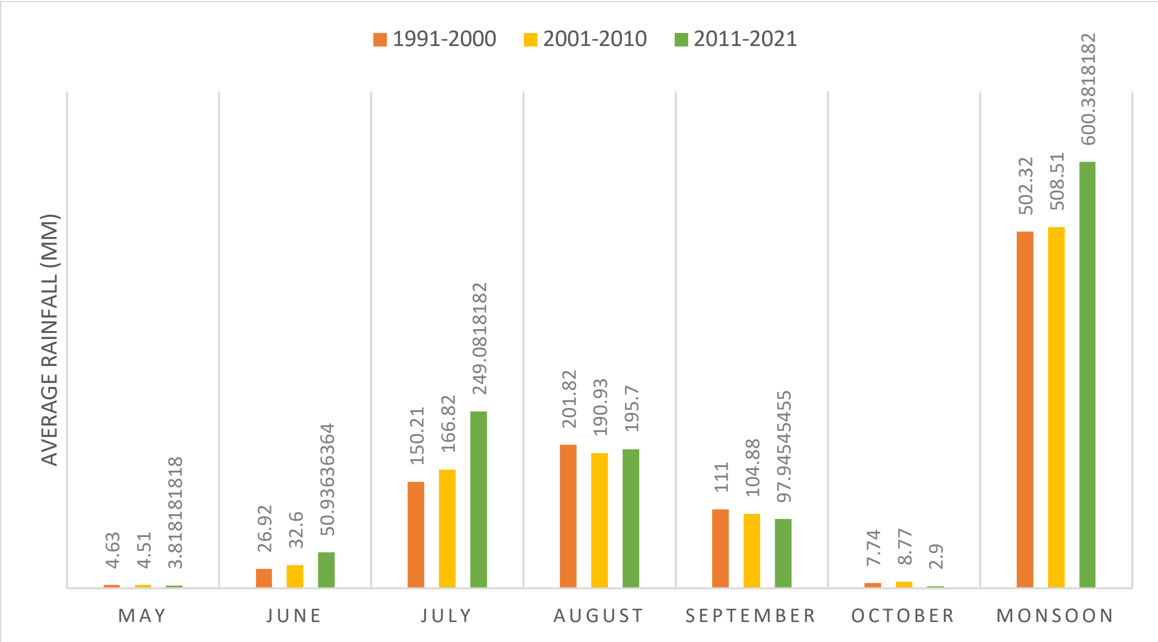

Fig. 3: Decadal distribution of monthly rainfall of Porbandar (1991-2021)

The mean rainfall of the monsoon season from 1991-2022 is 539.112 mm and SD is 149.060. The skewness, which is a measure of the asymmetry in frequency **distribution** around the mean, is -0.313 indicating that the monsoon rainfall is not much asymmetric and lies to the right over the period 1991-2022. Kurtosis, which describes the peakedness of a symmetrical frequency distribution, is -0.618 for the monsoon season. (Table 2).

Table 2: Statistical parameters of rainfall from 1991-2022 of Porbandar

Time Series 1991-2021	Mean (mm)	SD (mm)	Skewness	Kurtosis
May	4.303	6.252	2.061	4.548
June	37.274	32.688	1.100	1.005
July	190.651	83.446	0.026	-1.095
August	196.135	65.947	0.071	-0.822
September	104.393	36.938	0.873	1.346
October	6.354	6.984	1.367	1.472
Monsoon	539.112	149.060	-0.313	-0.618

Trends in Rainfall

Mann-Kendall Test showed no significant trend in monsoon season rainfall (Table 3). The negative value of **Z** statistics for the month of August, September, and October shows a downward trend. The **Z** value for the month of July is 2.8554 which shows a statistically increasing trend.

Sen's method showed an increasing trend in monsoon season rainfall (Table 3). The negative value of **β** statistics for the month of August, September, and October shows a downward trend. The **β** value for the month of July is 4.80 which shows a statistically increasing trend.

Table 3: Mann-Kendall value Z and Sen's estimator value β for the period 1991-2022

Time Series 1991-2021	Mann-Kendall value (**Z**)	Sen's estimator (**β**)
May	0.13852	0
June	0.9518	0.56
July	2.8554	4.80
August	-1.2577	-2.15
September	-1.0878	-0.75
October	-1.6174	-0.18
Monsoon	0.61187	2.15

CONCLUSION

Precipitation, being one of the most important variables has an influence on ecosystems and agriculture and their response to climate change. The statistical analysis of the rainfall data of Porbandar from 1991-2021 shows that there is an increase in average rainfall in the last decade (2011-2021). The month of July shows an increasing trend while the month of August, September, and October shows decreasing trend. Overall, there is non-significant but a steadily increasing trend of rainfall in Porbandar. It is hoped that this analysis will provide input data for a management system and to enable the development of optimal water allocation policies and management strategies for water and agriculture manager to bridge the gap between water needs and obtainable water supply.

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