Research Article
The Challenges to Nigerian Raingauge Network Improvement

[1]B.U. Ngene, [2]J.C. Agunwamba, [3]B.A. Nwachukwu and [3]B.C. Okoro
[1]Department of Civil Engineering, Covenant University, Ota, Ogun State,
[2]Department of Civil Engineering, University of Nigeria, Nsukka, Enugu State,
[3]Department of Civil Engineering, Federal University of Technology, Owerri, Imo State, Nigeria

Abstract: This research is geared towards establishing the link between the need for Nigeria rain gauge network improvement and the low efficiency of the current operating system with their various challenges. Nigeria currently has 87 existing and operating rain gauges while it need extra 970 gauges for proper rainfall measurement and achievement of gauge density of 874 km^2 per gauge. According to the World Meteorological Organization guideline, the required number of rain gauges to minimize cost and maximize efficiency for temperate Mediterranean and tropical flat area is in the range of 600-900 km^2 per gauge. The impact of not increasing Nigeria existing rain gauges is a 10% increase in error of any design based on the current 87 gauges. The flood devastation of the country in September 2012 due to high rainfall and release of flood water from dams are examples of effect of improper planning arising from no or inaccurate records. Equally of great importance is the negative contribution of such error to our economic development as a nation with failure of existing infrastructure being recorded in our roads, rail lines, air ports, water ways and other water resources infrastructures. Finally, it is noteworthy to observe that these largely man-made problems can be overcome with leadership that is alive to its obligation to the society it governs as we face the challenges of globalization and global climate change.

Keywords: Climate, management, network, optimization, rainfall, River Basin

INTRODUCTION

The Nigerian Meteorological Agency is by law charged with the responsibility of establishing the rain gauge network as part of the country's water and land information systems. The national data set formed is used to support climate mapping, flood early warning and other hydrological studies, while it is expected that the information is freely accessible to any interested party. The objectives of this study are summarized as follows:

- Assessing the existing rain gauge network in Nigeria for adequacy
- Studying the challenges of network density improvement

It is important to realize that measurements made in a rain gauge represent samples over an area. For this reason, the rain gauge must be located and installed so that its catch is as representative as possible of the area being sampled. Particularly, determination of mean rainfall falling on a watershed is fundamental to many hydrologic studies. It must be determined as accurately as possible, but its accuracy is highly dependent on the rain gauge network design.

An ideal method developed for designing the rain gauge network would not only allow improvement of the accuracy of mean rainfall estimation but would also have flexibility useful for relocating the gauges and improving the gauge density according to the expected level of statistical accuracy.

Almost every aspect of Nigeria development is closely dependent on an adequate supply of water (Sonuga, 1981; Revenga and Cassar, 2002). The draught of the nineteen seventies that swept most of the Sahel region of Africa, including Nigeria, has left the region with general water resources scarcity (Offordile, 1992; Batterbury, 1998). The consequence of this is low Agricultural out-put, limited water supply and inadequate water reserve for power generation that the region is faced with. This means that depletion of the few resources available would be imminent if appropriate management measures are not put in place (Tanko, 1996). For proper management of the flow water resources in Nigeria, the then Federal Military government established River Basin Development Authorities in 1976. These River Basins were charged with major objectives of water resources development and planning for more agricultural yield, abundant water for domestic supply, power generation, communication, flood/erosion control and so on. These objectives are stipulated in below section, subsection (1) of Decree No. 25 of 1976 which was modified in section 4 of Decree No. 87 of September 1979 and Act No. 7 of October 1981. To enable the attainment of the

Table 1: River basin development authorities in Nigeria and their headquarters locations

S/N	Name of river basin	Headquarter location	States covered
1	Anambra/Imo River	Aba-Owerri Road Agbala-Owerri	Anambra, Imo, Enugu Abia Ebonyi States
2	Benin-Owena Basin	Benin - Warri Road, Obayaton Benin City	Edo, Part of Delta North, Ondo, Ekiti
3	Chad Basin	Maiduguri-Marte Road, Maiduguri	Borno, Yobe and Part of Adamawa
4	Cross River Basin	Murtala Muhammed Way, Calabar	Cross River, Akwa Ibom
5	Hadejia-Jamaáre	Maiduguri Road, Hotoro, Kano	Kano, Jigawa, Parts of Baulclhi State
6	Lower Benue River	Oturkpo Road, Makurdi	Benue, Plateau, Nasarawa and Part of Kogi
7	Lower Niger River	GRA Ilorin	Kwara, Kogi
8	Niger Delta Basin	Isaac Boro Park, PH	Rivers, Bayelsa, Parts of Delta State
9	Ogun-Osun River	Abeokuta	Lagos, Oyo, Ogun Osun
10	Sokoto – Rima	Guzan Sokoto Road, Sokoto	Sokoto, Kebbi, Zamfara, Katsina
11	Upper Benue	Yola-Fufore Road, Yola	Adamawa, Taraba, Gombe Parts of Bauchi State
12	Upper Niger	Bosso-Kontagora Road, Minna	Niger, Kaduna and Fct

stated objectives, 12 River Basin Authorities were established by grouping together contagious States with similar geographical and hydrological attributes. The distribution is shown in the Table 1 with various River Basin State headquarters and their location.

Achievement of the stated objectives are possible only by effective management plans based on accurate information on hydrological elements especially rainfall (Hendrick and Comer, 1970). Most River Basins in Nigeria and the Nigeria Meteorological Agency estimate their rainfall information using a network of manually operated rain gauges. These rain gauges are located mostly in city Centre's and project location thus, information on rainfall for water resources planning and studies which need high precision, may not be achieved. This is justified by the fact that the present network operates at a density lower than the minimum density established by the world metrological organization (WMO, 1965) for tropical zones, Mediterranean and temperate zones of 600-900 km^2/gauge. The density with the highest number of gauges (65 in 1987) in the Upper Benue River Basin, that is, 1906 km^2/gauge. The reality on the ground today indicates that the values are much lower at 17 existing and operation stations, as observation stations are being closed down due to paucity of fund for installation and maintenance of both old and new stations to the detriment of accuracy in estimation. Therefore, in network design problem, accuracy in estimation and cost are the two controlling factors (Ngene, 2009).

As reported by Ologunorisa (2009) very few studies have been carried out on content analysis of hydro meteorological networks in the tropics. For the few studies, it is observed that location of stations was based more on political reasons than the need for appropriateness in achieving stated objectives.

(Oyebande, 1990) using the WMO Standard gave the optimum number of rain gauges for Nigeria as 1074. For this study, the country was divided into sections with geological and hydro meteorological similarities. The (Yemag, 1992) project was however for the upper Benue River Basin alone with an area/gauge ratio of 900-3000 km^2/gauge. (Tanko, 1996) used Shihs' principle to estimate the area/gauge ratio of

2510 km^2/gauge for the same River Basin which is still above the WMO Standard.

The objective of this work is to situate the inadequate number of rain-gauge stations in Nigeria to the various challenges of establishing and running the stations.

MATERIALS AND METHODS

Precipitation: Precipitation is the primary input vector of the hydrologic cycle. Precipitation includes all forms of moisture falling from the atmosphere to the earth's surface, primarily produced from water vapour present in the air.

In tropical countries such as Nigeria, rain forms the bulk of precipitation as such the word "precipitation" can be interchangeably used with rainfall (Tanko, 1996).

There is a wide variety of rain gauge types. However, to select a rain gauge for a particular watershed, the best criterion, which mostly governs the choice, is compatibility with other gauges being used within a country.

In Nigeria, the installation and observation of rain gauges throughout the country are controlled by the department of meteorological services, Federal Ministry of Aviation with its headquarters in Oshodi, Lagos-Nigeria. The department has been collecting, archiving, interpreting weather and preparing climate information for many years. Three gauges used for the measurement of rainfall are:

- Non recording gauges
- Recording gauges
- Weather radars

Errors of rainfall measurement: Rodda (1967) noted that despite early progress in rainfall measurement and advancement in technology, rainfall measurement results is still marginally near to the solution or the true value. The difference between the measured and true rainfall is attributed to measurement errors.

These are broadly classified by Ward (1975) and Morley and Ismail (1981) as systematic error and random errors. Systematic errors, they observed, are

Table 2: Number of existing and operating stations against watershed area

S/N	Name of river basin	No. of operating stations	No. of existing stations	Area (Zone I)	Area (Zone II)	Area (Zone III)	Total area of basin (km^2)
1	Anambra/Imo River	8	14	15960	10215	-	26175
2	Benin-Owena Basin	4	13	33730	-	-	33730
3	Chad Basin	5	25	94628	-	-	94628
4	Cross River Basin	4	14	9900	-	-	9900
5	Hadejia-Jamaáre	5	15	50490	-	-	50490
6	Lower Benue River	6	30	127710	-	-	127710
7	Lower Niger River	5	22	73515	-	-	73515
8	Niger Delta Basin	4	9	32790	-	-	32790
9	Ogun-Osun River	8	22	37164	-	-	37164
10	Sokoto-Rima	4	22	139838	-	-	139838
11	Upper Benue	17	65	34597	40770	69478	144845
12	Upper Niger	17	40	114460	19972	18083	152515
	Total	87	291				923300

errors from sitting, exposure, wind effect etc. Random errors on the other hand are results of observational mistakes, varieties of rainfall, microclimatic irregularity etc. Generally, errors of rain gauges network can be reduced with improved density of the network (Rodriquez-Iturbe and Mejia, 1974).

Rain gauge network density: A precipitation gauge measures the rainfall at one geographical point and cannot be representative of the precipitation on a larger area except in its immediate vicinity. The larger the area, great the error in the assumption because meteorological conditions may occasionally produce intensities at a point greater than any possible combination of circumstance could produce over an area greater than a few hectares (Mutreja, 1990).

Rain gauges are used in measuring the amount of water that falls over given watershed or catchments. Using a number of well-planned rain gauges over a catchment constitute the network. The catchments area in kilometer square per the number of gauges gives the network density. Arising from too dense a network is the issue of cost implication or the high error resulting from low-density network.

In his research work, (Ngene, 2009) used Shih approach to design the precipitation network for Nigeria, Table 2. Accordingly, the 87 existing operating gauge stations need to be upgraded with 970 more gauges for proper rainfall measurement. From this study, it is also known that 204 gauges stations are existing but need to be reactivated by equipping them with new rain gauge instrument. This implies that only 766 new stations need to be established in the country to meet with world meteorological organization requirement for temperate Mediterranean and tropical flat area.

Data collection: Information for network improvement was obtained from the Nigeria Meteorological Agency, various River Basin Development Authorities and some State Agricultural Development projects. The data consist of monthly rainfall records for existing network, with ten years consistent records considered (Fig. 1).

The study area is Nigeria, which is located within latitude 4°-14°N and longitude 2°-15°E with an area of 923,378 km^2 (MOW, 2014). The climate within this area is relatively uniform with only the major Rivers providing important differentiation of vegetation type and agricultural practice (Gbuyiro *et al.*, 2002). The climate of Nigeria can be conveniently classified into Rainy and Dry seasons. Each of these seasons last for six months on the average i.e., April to October for rainy seasons and dry season is November to March. The main annual rainfall ranges from less than 500 mm in the extreme north to about 2500 mm along the coast.

Theory of analysis: For each catchment area using the River Basins, the area is subdivided into n strata. The mean rainfall for each station is:

$$R_{ki} = \sum_{\phi=1}^{M_{ki}} \left(R_{k\phi i} \Big/ M_{ki} \right) \qquad (1)$$

where,
ϕ = The time interval,
R_{ki} = Mean rainfall of the K_{th} station in the ith stratum
M_{ki} = The total number of observation
$R_{k\phi i}$ = The recorded rainfall

The mean rainfall for a whole zone can be given by:

$$R = a_1 R_1 + a_2 R_2 .... + a_m R_m \qquad (2)$$
$$= \sum_{i=1}^{m} a_i R_i$$

where, a_i is the weighting ratio or ratio of stratum area to the area of the catchment. From these data, the variance and covariance is also obtained.

The precision reliability standard error from a two stage, statistical sample theory was given by Shih (1982):

$$E = \tau \alpha \sigma(\tilde{R}) = \overline{R} \beta \qquad (3)$$

where, $\tau \alpha$ values are taken from a t-table for α confidence level with $(N - 1)$ degree of freedom; β the

Fig. 1: Rain gauge stations in Nigeria

degree of accuracy. For stratified sample method with optimum allocation, combining relative variance with standard error formulae and making; β and N the subject matter:

$$\beta = \tau\alpha\left(\frac{1}{N}\left\{\sum_{i=1}^{n} a_i\left[S^2_{\sigma i} - \sigma_{okLi}\right]^{\frac{1}{2}}\right\}^2\right)^{\frac{1}{2}}\left(\sum_{i=1}^{n} a_i\tilde{R}_i\right)^{-1} \quad (4)$$

And:

$$N = \left\{\left(\tau\alpha\sum_{i=1}^{n} a_i\left(S^2_{\sigma i} - \sigma_{okLi}\right)^{\frac{1}{2}}\right)\left(\beta\sum_{i=1}^{n} a_iR_i\right)^{-1}\right\}^2 \quad (5)$$

where, α and β are the desired levels and statistical accuracy chosen based on factors such as impacts of land use conditions, population density, economic development and the importance of water resources in the country (Shih, 1982).

Raghunath (1986) reported a simple approach that relates the number of gauges to the coefficient of variation and error to be tolerated. The relation was of the form:

$$N = \left(\frac{C_v}{e}\right)^2 \quad (6)$$

This approach though simple is insensitive to the distribution of the gauges and the catchment area. The two approaches as described above were used in designing the Nigerian Rain gauge network density.

DISCUSSION OF RESULTS AND CHALLENGES
DISCUSSION OF RESULTS

From optimization results for Anambra/Imo river basin shown in Table 3 which also apply for other basins, stratified with optimum allocation of gauges estimate mean rainfall better than random sampling method and stratified without optimum allocation of gauges. Spatial variance for random sample and stratified with and without optimum show closeness. This closeness is based on the assumption that spatial variance is a hydrological characteristic, that is, independent of the sampling method. Stratified method with optimum allocation of gauge gives lower percent relative error at low mean rainfall than the other two methods. The current study have shown that at reduced

71

Table 3: Comparisons of regression estimates for the relative standard error of monthly mean rainfall for Anambra/Imo River basin

Zone	Method of estimation	Regression coefficient		Standard error of regression estimate %	Correlation coefficient
		α	β		
I	Random sample	72.21	-26.39	7.57	-0.681
	Stratified without	70.50	-28.90	6.85	-0.535
	Stratified with	52.65	-21.36	5.72	-0.527
II	Random sample	120.62	-45.06	12.53	-0.647
	Stratified without	58.16	-21.38	6.31	-0.610
	Stratified with	52.0	-20.75	5.99	-0.613

number of existing and operating rain gauges, the density per gauge has increased way above the world meteorological organization requirement.

Challenges of network improvement:
Difficulties in network design: Water can be considered as one of the important fundamental natural resources largely determining the economic potential of the country. Only rainfall network was considered in this study though other network such as evaporation, surface water levels, sediment discharge, temperature and ground water may be considered in any improvement process. The following challenges are faced in network improvement:

- Proper design of a network of rain gauges in a given watershed to collect the necessary precipitation.
- Though rainfall information could be estimated using weather sensors such as satellites and radars, cost of installation, operations and maintenance especially in developing country, such as Nigeria, is high.
- All the River Basins in Nigeria, State Agricultural projects, schools and colleges and indeed Nigeria Meteorological Centre depend on rain gauge network for rainfall information estimation which accuracy depends on the density used and locations.
- It is important to continuously check the precision of the existing network in estimating rainfall and establish an optimum network.
- Due to lack of complete rainfall data for some stations, interpolations are used to cover up for missing ones.
- This study has shown that as a result of the low number of existing and operating rain gauges. The rainfall information collected in Nigeria may not be reliable.
- Part of the maintenance difficulty faced at Tiga dam in Kano after its construction in 1978 was the inadequacies of the original design arising from poor hydrological investigation and the flooding of nearby Bagauda earth embankment dam (Eadie *et al*., 1992).
- Again the flood disaster that has claimed life and properties around Ogunpa River in Oyo station in 1980 may be attributable to inadequate rain gauge (Nigeria Tribune 13th August 2011). This is to

enhance prediction of the volume of expected flood and hence a design to properly channel the floodwater.

LIMITATIONS TO DATA COLLECTION IN NIGERIA

Quite a lot of obstacles are laid on the way of any individual seeking data for any purpose in this country even from government agencies, individuals and corporate world. Primary data is very important in any research endeavor as it form the basis of analysis. Wrong or inaccurate data therefore increases the chance of arriving at wrong result or hypothesis. The following list is an indication of the areas an individual sourcing for data in Nigeria must not overlook when sourcing for information for any research work.

Logistics:
- High cost of traveling between cities for data that can be located in one office within an organization.
- Vast nature of the country hence visiting many cities for data that can be centrally located.
- Haphazard address system sometimes lead to delay in finding the location of offices and sites.

Data:
- Long term records are sometimes lost in transit, hence short term records with potential errors are used for analysis.
- Little or no electronically digitalized storage, retrieval and use of data in government establishments.
- Data are sent to Nigeria Meteorological Services in Lagos with no copy kept at regional offices.

Data processing and storage:
- Movement of data materials from one place to another without proper records and referencing.
- Some gauges are operated for the meteorological agencies by individuals who are poorly paid without any attachment, hence no commitment to the project and are possible error sources.

Data retrieval:
- No central pool where data could be sourced in a global village of the 21st century.

- Haphazard manual record keeping resulting in loss of valuable time and energy in locating data where available.
- Low internet use by individual, corporate and government agencies. Rainfall data should be uploaded at agencies website for easy of retrieval though at cost to the user.

Human factor:
- High endemic corruption in the system which affects all levels of government activities.
- Perception of information seekers as pest who should at best be drained of all the money they can afford to give.
- Jealousy, resulting to researchers being seen as possible competitors.
- Nonexistent patriotic spirit to help researchers for the overall good of the nation through their findings.
- Absence of schedule officers sometimes mean making the journey of a researcher a second visit inevitable as other persons may not be in a position to give out required information.
- General lack of good work attitude as it concerns handling of data.

IMPACT OF OPTIMIZATION OF NIGERIA RAINGUAGE NETWORK

As earlier pointed out, Nigeria has only 87 existing and operating gauge stations out of the required 1057 stations. This leaves the country with a balance of 970 stations to be provided, inclusive of the 204 station that exist but not operating.

Not having adequate number of station is indicative of the reasons for the failure of structures such as dams, river bridges, poor agricultural yield and little or nonexistent flood estimation and control measures. The flood disaster that ravaged 9 States in Nigeria in September 2012 is an example of failure of planning due to lack of adequate rainfall data. Using (WMO, 1965) empirical formula, the Fig. 2 shows the error associated with Nigeria current number of 87 existing gauge stations and the desired 1057 gauge.

From the graph above, the error of estimate associated with the current network that is 87 rain gauges will give a 14.1% risk which can impact heavily on designs based on this, on say, culvert carrying capacity, dams and the release of water downstream, railway lines and highway and bridges. However, when the number of gauges increases to say 970 stations, the error stabilizes at around 4%.

Example and result: If a flood over a culvert is designed with a risk of 4% and the design life is 15 years, the return period of the flood on the culvert is estimated at:
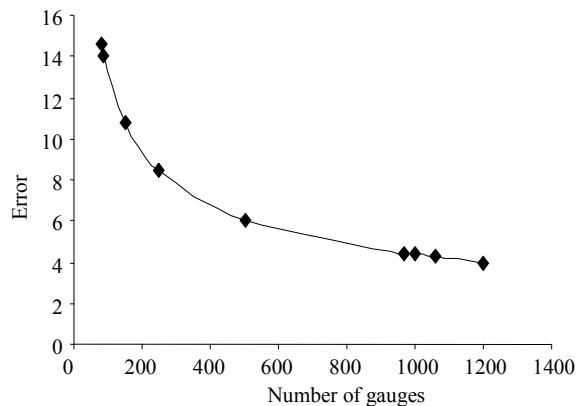

Fig. 2: Number of gauge against network error

$$R = \left[1 - (1-p)^n\right] \text{ where, } R = 4\% \text{ and } n = 15$$

And $T = 1/p = 368$ years

However, if the risk, R is increased to 14% with the same design life of 15 years, the return period of the flood on the culvert will reduce to 100 years. This indicates 4 times probability of occurrence hence more likelihood of failure within the design life of the structure.

CONCLUSION AND RECOMMENDATIONS

A new method developed by Shih was used to determine the optimized number of rain gauge station required for Nigeria to be 1057 stations with the gauge density of 874 km^2/gauge. This value falls within the world meteorological organization minimum density range of 600-900 km^2/gauge for temperate Mediterranean and tropical zone flat area. To further improve on the density or strength on data collection for rainfall information the following recommendations are made:

- All twelve River Basins Development Authority should serve as the zonal headquarters, while the Nigerian Meteorological agency Lagos office will be the final authority on weather matter, that is, data collection, storage and retrieval.
- Other state offices including the ministries and their agencies such as ministry of Agriculture, research institutions, schools and colleges should route their reports through the various River Basin collection centers in the state.
- The current Nigeria Meteorological Agency should be adequately equipped and commercialized.
- River Basin development Authority Agro meteorological services should also be commercialized.
- Efficiency in qualitative data collection and processing, demand the use of quality manpower

and equipment. Education and training of staff are therefore advocated. The equipment needs regular inspection and calibration to ensure that they are always at optimal use.

- Satellite and radar coverage of the country is advocated to compliment the rain gauge arrangement.
- Budgetary provision for procurement and installation of new rain gauge station should be made and their effective utilization ensured.
- The cost of opening 970 new rain gauge stations which include the existing but not operating stations is put at N92 million.

ACKNOWLEDGMENT

We acknowledge with thanks the inestimable value of the information from the Nigerian meteorological agency and the various river basin authorities in Nigeria.

REFERENCES

Batterbury, S., 1998. The Sahel Region: Assessing Progress Twenty-Five Years after the Great Drought. Retrieved from: http://www.simonbatterbury.net/pubs/geogmag.html, (Accessed on: March 24, 2015).

Eadie, H.S., D.T. Coats, N. Leyland, B. Shaw and Morton, 1992. Investigation, Monitoring and Remedial Works at Tiga Dam, Nigeria" Water Resources and Reservoir Engineering. Thomas Telford, London, pp: 321-328.

Editorial – Nigeria Tribune, 13th August 2011

Gbuyiro, S.O., M.T. Lamiw and O. Ojo, 2002. Observed characteristics of rainfall over Nigerian during enso years. J. Nigerian Meteorol. Soc., 3(1): 1-17.

Hendrick, R.L. and G.H. Comer, 1970. Space variation of precipitation and implications for network design. J. Hydrol., 10: 150-163.

MOW (Maps of World), 2014. Where is Nigeria. Retrieved from: www. mapsofworld. com/ nigeria/ nigeria-location-map.html, (Accessed on: March 28, 2015).

Morley, D.A. and M. Ismail, 1981. Network density for the estimation of areal rainfall. Hydrol. Sci. Bullet., 26(4): 359-378.

Mutreja, K.N., 1990. Applied Hydrology. Tata Mcgraw-Hill Pub., Co ltd India.

Ngene, B.U., 2009. Optimization of rain gauge stations in Nigeria. Ph.D Thesis, Federal University of Technology, Owerri. (Unpublished).

Offordile, M.E., 1992. An Approach to Groundwater Study and Development in Nigeria. Mecon Services Ltd., Jos, Nigeria, ISBN: 9783095609, pp: 247.

Ologunorisa, T.E., 2009. Content analysis of hydro meteorological network in the lower Benue River basin, Nigeria. J. Appl. Sci. Environ. Manag., 13(2): 33-35.

Oyebande, L., 1990. Nigeria hydro meteorological network-an assessment. Proceedings of the 1st Biannual National Hydrology Symposium, Maiduguri, Nigeria, pp: 105-128.

Raghunath, H.M., 1986. Precipitation. Hydrology Principles, Analysis and Design. Wiley Eastern Ltd., India, pp: 16-35.

Revenga, C. and A. Cassar, 2002. Freshwater trends and projections: Focus on Africa. A Report Prepared for World Wide Fund for Nature (WWF) International, pp: 4.

Rodda, J.C., 1967. The systematic error in rainfall measurement. J. Inst. Water Engrs., 21: 173-177.

Rodriquez-Iturbe, I. and J.M. Mejia, 1974. The design of rainfall networks in time and space. Water Resour. Res., 10(4): 713-728.

Shih, S.F., 1982. Rainfall variation analysis and optimization of gauge network. Water Res. Res., 18(4): 1269-1277.

Sonuga, J.O., 1981. Planning for water supply without adequate data. Proceedings of the International Drinking Water and Sanitation Decade (1981 - 1990) Workshop, Kano Nigeria.

Tanko, J.A., 1996. Optimizing the number of existing operating rain gauges stations in Upper Benue River Basin, Yola. M.Eng. Thesis, University of Nigeria, Nsukka. (Unpublished).

Ward, R.C., 1975. Precipitation. Principles of Hydrology, 2nd Edn., McGraw-Hill, London, pp: 30-42.

WMO (World Meteorological Organisation), 1965. Guide to Hydro Meteorological Practice. WMO, Geneva.

Yemag, G., 1992. Upper Benue River Basin Hydro meteorological Stations Network Upgrade Design. Fed. Min of Agric., Water Resources and Rural Development, Upper Benue River Basin Dev. Authority, Yola Final Report.