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Nigerian Rain Gauge Station Optimization and National Development: The importance of Head Count

Nigerian Rain Gauge Station Optimization and National Development: The importance of Head Count

Ngene Ben U[1]* and Obianigwe Njideka[1]

[1]Department of Civil Engineering, Covenant University, Ota
*Corresponding author email: ben.ngene@cu.edu.ng

Abstract. Effective planning for water resources infrastructures requires accurate and up to date data of the water source. The aim of the research is the optimization of the number of rain gauges required for planning for the volume of water in a watershed which is an absolute necessity for the economic development of the nation. To achieve this, the statistical tolerable error method of non-weighted approach was used to determine the optimum number of rain gauges required for an area that efficiently estimates the rainfall of the watershed. The result obtained indicates that Nigeria require a minimum of 1057 rain gauges to cover its land area of 923300 Km^2 and meet the World Meteorological Organisation (WMO) requirement for the Tropical, Mediterranean and Temperate zone. However, Nigeria has 87 existing and operating rain gauge stations presently. This number is grossly inadequate and need to be increased substantially by the opening up of extra 970 stations to meet the minimum requirement of WMO and hence enhance national development through proper water resources planning.
Keywords: rain gauge, watershed, rainfall, network density, statistical accuracy and optimum

1. Introduction

The number and spread of rain gauge network are important parameters of measuring the development of a nation. This is because the effective use of a water resource of a country is dependent on accurate estimation of the amount of rainfall and use of such data in nature planning. Areas of interest in planning of water resources include: Agricultural practices, irrigation, forestry, fisheries, tourism and disaster management especially during flooding, construction activities, flight operations and navigation.

Critical factor to the use of precipitation data according to Mutreja, 1990 as stated by [2] is to have a properly designed network of rain gauges in the watershed to collect the data. This translates to the planning for adequate number required in a given area that will help capture the necessary information for reliable analysis. Network density is therefore an absolute necessity in water resources management as it provides estimates of the expectation of rainfall that will be needed for all the functions mentioned above. Wekena, in his work in 2006 had pointed out that expansion of irrigation development for examples without the knowledge of the water sources will have the negative effect of reduction of agricultural yield and water stress. World Meteorological Organisation report WMO, in 1965 has set the standard requirement of minimum number of gauges stations for various regions of the world. The standard is to ensure accurate measurement of rainfall in a catchment that will enable proper planning and development of nation's water resources. Where there is a shortfall as it is currently the case in Nigeria, effective development and management of the country's water resources that is on scale commensurate with expectation will be impaired.

Figure 1 shows the current location of rain gauge stations in Nigeria according to records obtained from the Nigerian Meteorological Agency.

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Fig. 1 Nigeria rain gauge stations (source: Ngene, 2009)

The general lack of proper record keeping, storage and retrieval system in the country is the greatest challenge facing a study of this nature. This work therefore assesses the adequacy of the existing rain gauge network in Nigeria taking cognizance of the WMO requirement and make suggestion as the adequacy or otherwise of the current number.

As noted by [6]; [7], every aspect of Nigeria development as indeed all nations of the world is closely tied to adequate supply of water. The consequences of low agricultural output, limited water supply, inadequate water reserve for power generation and currently the challenge of Herdsmen farmers' conflict in the country can attest to the need for planning for what is available. Proper management of available water resources in Nigeria lead the Federal Government in 1976 to establish the River Basin Development Authorities by decree no 25, 87 of 1979 and Act 7 of 1981. Table 1, shows the 12 River Basins in Nigeria with the head office location. The grouping of states was to ensure that areas with similar geographical and hydrological attributes will harness what is common to them.

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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 Agballa-Owerri	Anambra, Imo, Enugu Abia, Ebonyi
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 Bauchi
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
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

Source: Ngene, 2009

The stated objective development of the nation water resources infrastructure is still not being effectively realized four decades after for reason that is outside the scope of this work.

Combining the efforts of the River Basins, Nigerian Meteorological Agency, State Agricultural Development Agencies, Schools (as it used to be years back) and other Research Institutes should give Nigeria the required head counts in terms of rain gauge station numbers to meet the WMO standards. No coordination amongst these organisations, have ensured that the Nigeria dream of having an efficient network of rain gauges remains a dream. According to the WMO 1965 report in the study by Ngene *et al* in 2015b, Nigeria which is in the Tropical, Mediterranean and Temperate zone require to cover 600-900 Km^2/gauge. With an existing and operating rain gauge number of 87, covering an area of 923300 Km^2, this translates to 10600 Km^2/gauge. To minimally capture Nigeria rainfall volumes to meet WMO standard for proper planning, the country will need the injection of minimum of 970 gauge stations according to [5]**.**

Planning with the small number that is currently available to the country today accounts for flood devastations in the country, roads and rail lines being washed away, failures of waterway programmes other water resources infrastructure and generally errors in economic analysis and development as witnesses in the nation. The drought of the nineteen seventies that swept most of the Sahel region of Africa, including Nigeria, has left the region with general water resources scarcity [8]. The consequence of this is the low Agricultural out-put, limited water supply and inadequate water reserve for power generation that the region is faced with [5].

2. Methodology

Precipitation is the moisture that falls from the atmosphere to the earth's surface in form of rain, snow, hail, sleet, mist etc. which is produced from the water vapour present in the air [8]. Rainfall constitutes the major form of precipitation in Nigeria in the absence of snow and other forms. The installation and observation of rain gauges in the country is controlled by the Federal Ministry of Aviation through the Nigeria Meteorological Agency (NIMET). The River Basin Authorities and Agricultural Research based organisations collaborate with NIMET in terms of data acquisition, record keeping and dissemination. NIMET has been collecting, archiving, interpreting weather and climate information for many years. To do this, it uses three forms of rainfall measuring instruments such as recording rain gauges, non-recording rain gauges and weather radar where available.

2.1 Manual Measurement

These are mainly with non-recording type of rain gauge. Any receptacle with vertical sides may serve as a rain gauge, but in order to permit more accurate observations certain refinements are necessary [9]. The standard rain gauges consists essentially of a funnel of special design supported upon an outer vessel, partly sunk into the ground within which is placed a receiver to collect the rain entering the funnel. On the rain gauges water collected by the funnel runs into a bottle standing in a copper can. The capacity of the bottle is sufficient for most occasions, but if the bottle overflows, the can retains the surplus for measurement

2.2 Automated Measurement

Automated rain gauges can be in form of recording gauges, weather Radar satellite and sensors.

(i) **Recording or Automatic Rain Gauges.** Three types of these are: (1) Tipping buckets rain gauge (2) weighing bucket rain gauges and (3) siphon rain gauges. It is often important to know, not only the total amount of precipitation, but also its intensity, or rate of fall. Recording gauges give a continuous record of precipitation in the form of a pen trace on a clock driven chart.

(ii) Weather Radar: The radar is based on the principle of echo sounding. High frequency electromagnetic waves are sent out which travel at the speed of light. An extremely small portion of this energy is reflected by objects in the sky and is detected by the radar. By calibration of the echo intensity with rainfall, it is possible to measure the intensity of rainfall [1]. Weather radar can be used to find out rainfall in hill, headwater reaches of streams where rain gauges cannot be installed due to in accessibility of the sites.

(iii) Automatic Weather stations (AWS): Recent advances in technology have led to the establishment of automatic weather stations such as the Australian Bureau of meteorology, automatic weather stations. The AWS are designed to serve the dual purposes of providing real time data for forecasting, warning and information services, as well as high quality data for the climate data base [10].

(iv) Sensors: Sensors such as the l-wire analogue-to-digital converter (ADCs) can be used to measure a wide range of environmental properties or parameters by converting the signals locally and transmitting the digital data over a common communication link. Wind speed, rainfall may be measured by an ADI computer. Each sensor has a unique ID address by which the master keeps track of it and the environmental parameter it is measuring. Sensor-specific or calibration information may be stored in the ADI's memory or eventually, by downloading from the web [11]. The information contained in the ADI may also be sent to the Automatic weather station database.

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(v) Weather Satellite: Information on weather, rainfall can also be collected via satellite orbiting the earth. A satellite is a platform for remote sensing instruments. The instruments, which may be measuring surface or atmospheric temperature or water vapour amounts in various atmospheric layers or simply making a digitized image of cloud and the surface actually senses the radiation emitted or reflected by the object under investigation. The great advantage of satellite measurement is that it provides access to remote areas with no alternative data sources and that they give continuous global coverage [12].

In order to establish the adequacy and efficiency of the number of rainfall measuring instruments, a network design of the number and location of the gauges is required. The design is accomplished through either (a) weighted approach or (b) non-weighted approach.

(a) Weighted Approach

In the method, according by Shih, in 1982, the accuracy in mean estimation and rain gauge density is achieved by the use of tolerable error method. The mean rainfall over an area is established using one of (i) Random sample (ii) Stratified sample without optimum allocation of gauges to stratum and (iii) Stratified sample method with optimum allocation of gauges to the stratum. Weighting is done using either special stratum weighted ratio, used for relocation of rain gauges to data or the weight of each stratum, that is, ratio of stratum area to the total catchment area.

(b) Non-weighted Approach

The method relates number of gauges to either the variance of the rainfall, coefficient of variation, correlation coefficient between stations or error of estimation. Mutreja in his work in 1990, used the monthly total rainfall record in a network of gauges that were fairly uniformly distributed, the coefficient of variation of the mean (C_v) for each month is given as $C_v(C')$ > 5% to determine the adequacy of the network where C' is less than 10, but

$$N = \left(C'/_{10}\right)^2 n \qquad (1)$$

is used instead if C' is more than 10

Where n represent the number of stations for which records are available.

A second non-weighted approach by [15] reported a simple method that relates the number of gauges and the coefficient of variation with the error to be tolerated as

$$N = \left(C_v/_e\right)^2 \qquad (2)$$

3. Results and Discussion

From table 2, optimum number of gauges at statistical accuracy for Anambra/Imo River Basin, it is shown that depending on the statistical accuracy desired, the optimum number of rain gauges for an area can be determined. In the table, Anambra/Imo River Basin is used as a case study, where it shown that the number of existing gauges is 14, but the existing and operating station is 8. The area covered by the River Basin represents 3% of the Nigeria land mass or 26175 Km^2. Therefore the existing and operating eight rain gauge stations will translate to 3272 Km^2/gauge which is far lower than the WMO required minimum of 600-900 Km^2/gauge.

For optimum design of network for Anambra/Imo River Basin, a tolerable error with statistical accuracy required is 10% to give 42 gauge stations. The 42 gauge stations gives the region a required minimum area per gauge of 623, however, the economic challenge of providing this optimum number will need to be given serious consideration. It is noted that the deficiency between what is existing and what is required is high, therefore to enhance the economic development of the nation, the difference need to be provided since the value is actually the minimum requirement.

Table 2: Optimum number of gauges at statistical accuracy for Anambra/Imo River Basin

	Number of Existing and Operating Raingauge Station	Statistical Accuracy	Zone I No of Gauges Required	Zone II No of Gauges Required	Zone(I + II) Optimum Design
Confidence Level	8	80%	7	6	13
		90%	9	8	17
		95%	11	10	21
Tolerable Error	8	10%	26	16	42
		15%	12	7	19

Source: Ngene, 2009

The impact of using the current Nigeria number of existing and operating rain gauges at 87 is against a projected optimum minimum value of 1057 gauges will be a risk of failure error above 14%. The increase in number to the desired minimum of 1057 will reduce the error risk to 4%. Figure 2 below shows error risk against number of gauge station and from the figure and table 2, it is seen that the lower the tolerable error the higher the number of gauges to be deployed to an area.

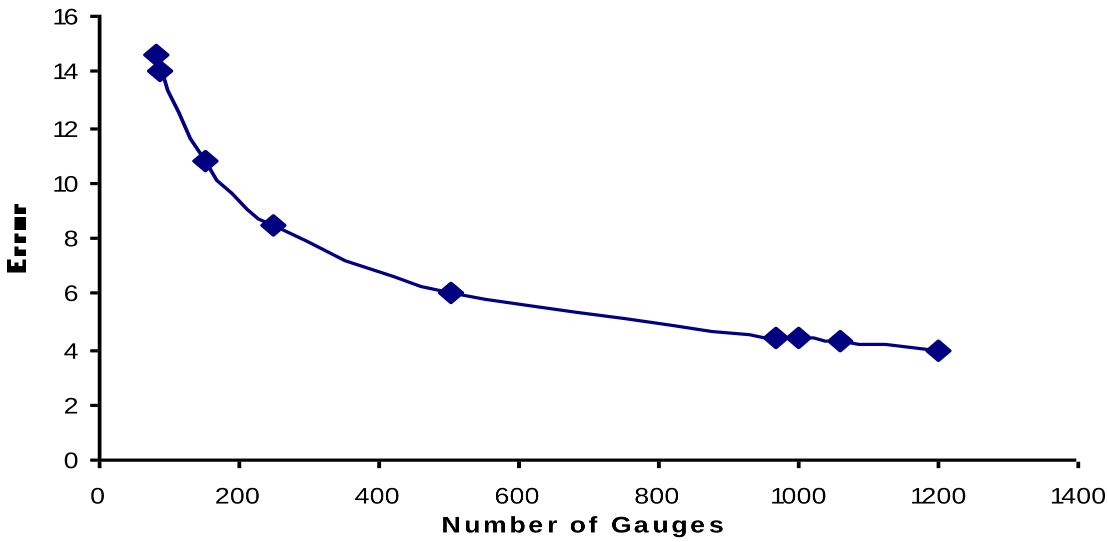

Fig 2: Number of Gauge against Network Error

The economic and financial issues involved must be given adequate consideration in a developing economy such as in Nigeria. There is no doubt that the Nigeria Rain Gauge Stations need dramatic number increase to make way for higher efficiency and reliability in qualitative data collection and use for rainfall measurement. The increase must however be weighed in with available funding options.
A typical example of this is the design of a culvert at 4% risk of error of failure and design life of 15 years will give an estimated return period of flood over the culvert at 368 years. However if the risk is increased to 14% over the same design life the return period of flood will be reduced to 100 years. This

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gives a 4 times probability of occurrence hence more likelihood of failure within the design life of the structure.

4. Conclusion

Nigeria obviously need number (head count of rain gauge stations) increase in its rain gauge station for a reliable design of structures that require the use of rainfall information in the country. The increase is realizable through improved budgetary provision and utilization of funds meant for this purpose through the Nigerian Meteorological Agency, 12 River Basin Development Authorities, Agricultural and Research based agencies of government that need the data and private organizations such as Universities, Schools and Colleges and individual farmers.

The colonial Schools of the old had such plants as part of the School system for effective teaching and learning, the need for it today is even more compelling because of the importance of accuracy in planning for national development.

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