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Streamflow Characteristics of the Kangimi Dam Reservoir, Kaduna, Nigeria

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Abstract – The streamflow is important because it affects decision of reservoir managers on the supply objectives needs in the time of water shortage or excess. It is therefore important to study the characteristic of Kangimi Dam Reservoir flows for effective planning and sustainable water supply. The study obtained daily stream stages of the dam for the period of 1977 to 2011 from Kaduna State Water Board. The values were corrected using Natural Geodetic Vertical Datum (NGVD) under the datum constant of 579.12 m, which was added to measured stages that gave dam height at various storage volumes. Threshold comparison was performed on the data by comparing directly the unit values and differences between adjacent unit values using 3 to 5 years record, without set too low value thresholds or too high or high-value thresholds set too low. The corrected data was superimposed on rating table obtained from National Water Resources Institute on Micro Excel Spreadsheet where best line of fits model was obtained on which storage volume of various stages of each year was generated and hence data streamflow of 1977 – 2016 generated. The generated streamflow was then grouped into four years' for plotting and comparison; hence simple statistical analysis was performed. The results indicated the thresholds range of ±2.15 with coefficient of variation value of 0.019 (2%), while the coefficient of determination, R^2 value is 0.977. The simulated storage volume indicated mean value of 29.2 Mm^3, maximum value of 37.8 Mm^3 and minimum storage volume of 19.8 Mm^3. The first decade, 1977 – 1986 shown a positive upward trend, the 1987 – 1996 and 1997 – 2006 decades indicated sharp downward trends, while the decade of 2007 – 2016 shown a sharp upward trend of which the streamflow is characterized by no-stationary behavior. The study shows that Kangimi Dam Reservoir streamflow exhibit natural climate variation that tends to sustain the yearly flows and instream activities.

Keywords: *Daily stages, Reservoir, Streamflow, Thresholds, Storage, Trends.*

1. Introduction

Hydrological data measurements are essential for the interpretation of water quality and water resources management and sustainability. Variations in hydrological conditions have important effects on water quality (Kuusisto, 1994), especially in reservoir streamflow and its characteristics. Streamflow is the volume of water passing through a point in a given time, usually, it comprises of baseflow and storm-flow. Streamflow is measured across a stream within a connived location along the stream stretch. During the minimum flows it help to know whether a stream is perennial, intermittent, ephemeral or sustainable to provide objective supplies, and the relative contributions of baseflow and storm-flow to stream discharge. While in the other hand, information like relative frequency, duration of extreme high and/or low flows and the duration of certain stream levels are also used to reveal.

Streamflow is useful to man and his environ in many ways. It provides water for domestic; industrial use; irrigation water for crops; hydroelectric power generation; and instream uses such as transportation; and recreational. Records of streamflow are the basic data used in developing reliable surface water supplies (Jacinto *et al.,* 2016), of which, information on the availability of flows and its variability in time and space are recorded. The records are therefore used in the design, planning, operation and management of surface-water related projects, and also to enforce the laws with respect to water conservation and water quality control. Occurrence of excess stream flow can create floods causing extensive damage to environment and hazard to biota. Records of flood events obtained at gauging stations are used for the basis of bridges design, culverts, dams, and flood-control reservoirs, and for flood-plain delineation and flood-warning systems (Jacinto *et al.*, 2016).

Many factors have been found to affect streamflow in several ways. The changes and variation in air temperature here lead to climate change, in turn that have been found to influence snow and cloud cover melting, which alternately, altered the size and timing of high spring streamflow (United State Environmental Protection Agency (USEPA), 2016). High rainfall is expected to influence higher streamflow in some places, or heavier storms leading to larger peak flows. On the other hand, frequent or severe droughts, however, could reduce streamflow in certain areas due to high evaporation, dry air temperature and insufficient rainfall. The extent of water use during the summer period, greater than storage capacity has been found to lower streamflow (Abdul Umar *et al.*, 2018). The control of flood and drought management benefit from streamflow if the characteristics are identified reducing the anticipating hazards, and increasing the potential buffering capacity of water storing facilities.

A lot of authors have reviewed and analyzed streamflow measured data, and different methods have been involved. (Water Action Volunteer-Volunteer Monitoring Factsheets Series (WAV-VMFS), 2006; Ajami, N. K *et al*., 2008; Wang et al., 2011). When a record of streamflow is required, a relationship between the height of water surface and the rate of discharge at a specific point is required. Approaches such as velocity-area method (WAV-VMFS, 2006), salt dilution gauging (Moore, 2004), staff gauging (Arseneault, 1976), Current Meters (Jacinto *et al*., 2016), pre-calibrated structures (Andrews, 2004) as well as continuous stage record (Jacinto *et al*., 2016) will be briefly explain here.

The first consideration is to locate a general gauging station. Its precise location is so selected as to take advantage of the best locally available conditions for stage and discharge measurement and for developing a stable stage-discharge relation. A continuous record of stage is obtained using bridge pile or installing a structure to be monitored by a competent local observer and record the water-surface elevation in the stream. Discharge measurements are initially made at various stages to define the relation between stage and discharge. Discharge measurements are then made at periodic intervals, usually monthly, to verify the stage-discharge relation or to define any change in the relation caused by changes in channel geometry and (or) channel roughness. At many sites the discharge is not a unique function of stage; variables other than stage must also be continuously measured to obtain a discharge record. Discharge ratings are established, and the gauge-height record is reduced to mean values for selected time periods. The mean discharge for each day and extremes of discharge for the year are computed.

From previous prediction and trends analysis of the reservoir by Abdul Umar *et al* (2018), their results does not characterize the streamflow of the dam. However, the sediments flows and soil erosion that have taken placed within the years is enough to have distorted the normal flows either reducing the flow quantity, stages-volume or increased the sediment loading which could be a benefit value to the reservoir manager and the extent of its power generation potential, hence calls for the characterization study. The study is therefore aimed at characterize the Kangimi Dam Reservoir flows for effective planning, its potential and sustainable water supply.

1.1. Study Area

The Kangimi Dam Reservoir (KDR) is located in Kaduna, Nigeria along latitude 10°46’N and longitude 7°25’E. The water impounded was to augment the existing water supply to Kaduna Water Board intake during low flows in Kaduna River, and to irrigate arable land of about 1,619 ha upstream Kaduna River. It covered about 12 km^2 area and has potential capacity to produce 1.109 MW of electricity (Otun *et al.*, 2012), and can accommodate recreational opportunity (Ayinla *et al.*, 2018). The reservoir also found to accommodate cattle rearing activities that have brought the resources under sedimentation treat as found by Abdulkareem and Agunwamba (2018).

2. Materials and Methods

2.1. Data collection

The data source for this study is secondary data from Kaduna State Water Board (KSWB) as no streamflow measurement was carried out. The Organization has been saddled with responsibilities of collecting and storing hydro-geological information from virtually all stream and rivers in Kaduna State. Excluded from its mandatory, the responsibility of supplying portable water to the communities within the State, thus, making the data collected more reliable, though with caution. The daily water stages data for the period of 1977 - 2011 were obtained, though the datasets were characterized with missing records due to gauge not operational or data not observed (Kaduna State Water Board Hydrological Book, 1977). Some of the data collected were recorded in metric unit, but later converted to SI unit. The missing datasets for each month were carefully modeled using least square method, for the preceding months, since the data are continuous time series. The modeling was performed on Excel Microsoft environment 2007 version.

2.2. Data Analysis and Methods

The datum adjustment for the purpose of correcting gauge-height values was performed using Natural Geodetic Vertical Datum (NGVD) method provided by World Meteorological Organization (WMO), (1993). The datum constant for the site was 579.12 m (KSWB Hydrological Book, 1977), this was added to recorded stage values which gives dam height at various storage volumes. Statistical threshold comparison was carried out on the corrected values by visual arrangement before carry out the analysis which was done by comparing directly the unit values and differences between adjacent unit values using 3 to 5 years record among the data, and properly done not to set too low value thresholds set too high, and high-value threshold set too low. A rating table of year 2012 from National Water Resources Institute (NWRI) was plotted on Microsoft Excel Spreadsheet and exponential best of fits was produced and was used to generate storage volume at various stages of each year's flow (see Abdul Umar *et al.,* 2018) which help to extent the streamflow data from 1977 – 2016.

Descriptive statistical and trend analysis were performed on the data from 1977 – 2016 and the four decade years grouped data of 1977 – 1986, 1987 – 1996, 1997 – 2006, and 2007 - 2016. Trend analysis has been widely used for hydrological data (Zhang *et al*., 2001; Birsan *et al*., 2005) and normally used as measure of trend magnitude or its significance (Pellicciotte et al., 2006). The tool is suitable for non-normally distributed and nonlinear trends data, robust against outliers with high standard than other many in used (Hess *et al*., 2001). The null hypothesis of randomness H_o which defined the data ($x_1 \ldots . x_n$) are in a simple *n* independent and identically distributed random variables. The alternative hypothesis H_A is that the distributions of x_k and x_j which are not identical for all $k, j \leq n$ with $k \neq j$. The null hypothesis is rejected at a significant level α if $|Z_s| > Z_{crit}$, where Z_{crit} is the value of the standard normal distribution with an exceedance probability of $\alpha/2$. When Z value is positive, it is an indication of upward trend, while when negative it is an indication of downward trend in the tested time series. The significant trends are generally report at the 5% significance level or confidence level ($\alpha = 0.1$ or $\beta = 1 - \alpha = 0.95$, respectively) as taken for this study.

3. Results and Discussion

3.1. Thresholds and Descriptive Statistical

The threshold comparison revealed the range of ±2.15 with the mean of 26.849 m, and the coefficient of variation indicated the value of 0.019 (2%) as descriptive statistics analysis estimated the result which indicated a good data according to Novak (1985). For further result confirmation, the mean differs from median by 0.020%, the value of which Novak (1985) recommendation stated that median should not differ from mean more than 10%.

The statistics summary for streamflow over the 40 years is presented in Table 1. The Table shows that the mean streamflow value available within the total year data of 1977 – 2016 is lower compared to all decade's mean values except that of 1997 – 2006 decade. The effect is probably due to hydro-climatic variability that refused to show in cumulative 40 years lump data whereas emanated in decades. The statistical results showed that 1977 – 1986 and 1987 – 1996, respectively, indicated similarity in means, whereas, the 1977 – 1986 is greater differ in minimum and lower differ in maximum values compared to 1987 – 1996 (Table 1). The 1997 – 2006 exhibited lowest mean (28,091,278 Mm^3) and minimum (19,714,657Mm^3) streamflow, but produced highest and maximum flow within the 40years time series, and yet it could hardly be characterized as most wetted part of streamflow period. These results are characterized as non-stationary behaviour.

Table 1: Summary Statistic of the projected and Decades Streamflow

Year	Mean (m^3)	Minimum (m^3)	Maximum (m^3)
1977 – 2016	**29,487,463**	**19,714,657**	**37,705,742**
1977 – 1986	30,234,465	23,436,213	33,891,979
1987 – 1996	30,089,183	22,444,652	34,483,136
1997 – 2006	28,091,278	19,714,657	37,705,742
2007 – 2016	29,534,925	20,408,396	35,593,833

Also, Table 1 shows that since inception of the reservoir, streamflow magnitude of the time series has not exceeded its capacity of 59.6 Mm^3 when the maximum flow magnitude of the reservoir is put to consideration. This could not be true but probably there may be some reason(s) for this situation. An opinion of this study is that perhaps, there is no enough runoff at initial stage of the reservoir as shown in the first decade of the analysis (Table 1), while maximum flow progressively increased along the decades study. A later time, the reservoir depleted as a result of silt and soil particles movement into the reservoir coming from the agricultural land development and catchment manipulations. Similar observation was observed by Ayinla *et al* (2017) in their research.

3.2. Trends

Figure 1.0 presents the statistical trend analysis of the time series data of decade's streamflow while the extents of the various correlations in the series are presented Table 2.

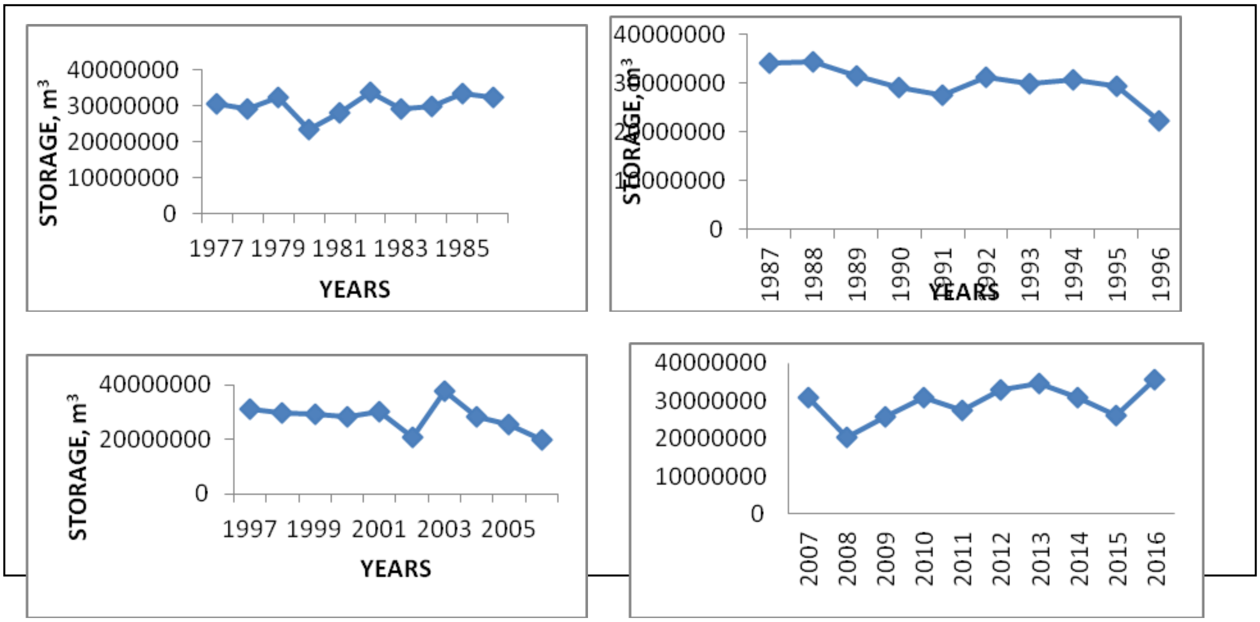

Table 2.0: Correlation Analysis Results

	1977 – 2016	*1977 – 1986*	*1987 - 1996*	*1997 - 2006*	*2007 - 2016*
Multiple R	*0.53*	*0.63*	*0.75*	*0.71*	*0.79*
R^2	*0.42*	*0.46*	*0.56*	*0.67*	*0.44*
P-values	*0.29*	*0.17*	*0.01*	*0.03*	*0.04*
F-ignificant	*0.42*	*0.15*	*0.01*	*0.04*	*0.05*

It is clear from Figure 1.0 that the four streamflow decades exhibit inconsistent upward and downward trends. The trend conducted on the long period dataset of 40 years was not statistically significant as values of F- and p- are greater than 0.05 (0.42, 0.29, respectively) couple with weak coefficients of determination, R^2 and correlation, R values of 0.42 and 0.53, respectively at confidence level of 0.95 as shown in Table 2.0. This is in agreement with Birsan *et al* (2005) findings on hydroclimatic data trends, which suggested that longer periods of data exhibit fewer or less statistically significant trends than shorter data periods. The plots characteristic of the time series dataset of 1987 – 1996 decade streamflow showed a statistically significant level at $p<0.00$ (0.01), while 1997 – 2006 and 2007 – 2016 decades datasets exhibited significant level at $p<0.05$ (0.03 and 0.04, respectively). That of 1977 – 1986 decade does not significant at any level, this may be due to initial runoff volume into the reservoir that may probably not satisfied the initial capacity. The streamflow is predominantly decreases in both means and minimum magnitude progressively from first decade to the last decade of time series (Table 1) which could be attributed to natural phenomenon of hydroclimatic data of such nature has been previously observed by Birsan *et al* (2005).

The coefficients of correlation are generally positive. At the decade time scale, correlation coefficients vary from 0.53 to 0.79, while coefficients of determination, R2 vary from 0.42 to 0.67, of which the results revealed a number of characterizations. The first is that, the reservoir has received enough runoff, all the rainfall seasons as the results tend to be positive. Again, by the suggestion of Pellicciotte *et al* (2006), when runoff is high and contribution to annual total runoff is high, correlation coefficients are always high varying between 0.47 - 0.63. This range agree with a range of 0.53 - 0.79 obtained in this study.

3.3. Implication of the Findings

The trend analysis of Kangimi Reservoir streamflow as studied in this work revealed several interesting features originated from the hydroclimatic formations and its implication on the reservoir, the water and environmental managers. The trend displayed in Figure 1.0 revealed the existence of significant decreasing streamflow from the last three decades of the time series, implication that indicated sedimentation problem of the reservoir. The progressive downward in some of later trends decade is perhaps an indication of loss of surface runoff from the reservoir through spillage from the reservoir crest. According to the time series analysis, reservoir has not been filled to its capacity since inception, thus, an indication that the reservoir is underutilized. The worst implication is that of continually reservoir storage loss to the spillage during the runoff, therefore, resulting in its objectives incapacitated and hence, economic catastrophic.

4. Conclusion and Recommendation

The long time period data clearly indicated that the trend is not significant which agreed with other studies and also exhibited hydrological data characteristics. The streamflow is characterized by non-stationary behavior as the streamflow in decades show different magnitudes in trend. The best discussion of the study is when the study is correlated with precipitation, surface runoff and hydroclimatic data of the reservoir catchment, the effect of which is ongoing research by the authors. Also the sedimentation characteristic of the reservoir to the streamflow is very essential to appreciate the streamflow losses from the reservoir.

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