Civil and Environmental Research www.iiste.org
ISSN 2224-5790 (Paper) ISSN 2225-0514 (Online)
Vol.3, No.7, 2013

A Rank- Reduced Analysis of Runoff Components and Their Response Patterns to Basin Parameters in the Northern Basement Complex, Nigeria.

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Abstract

Hydrological studies are still scanty in northern Nigerian basins. Runoff components have been discovered to have different response patterns to basin variables, hence lumping them together may be misleading. This study attempt to study response patterns of six hydrological parameters namely: surface flow, interflow and groundwater flow, the annual hydrograph was also separated into dry season flow, wet season flow and total runoff. Thirty hydro- climatic variables generated from 30 sub basins of the upper Kaduna catchment covering a period of 11 year (1979-1989) were used in this study. Surface flow, interflow and groundwater flow were determined using a 3-component hydrograph separation procedure; and dry season, wet season and total runoff were defined climatologically. A total of 660 hydrographs were separated. Factor regression method was used to identify the most significant factors which explain each of these components. The results showed that these variables differ slightly from one flow type to the other. That paper concludes that lumping different flow types together will amount to generalization. There is need for caution in runoff and basin modelling; all these call for more studies.

Introduction

Runoff studies in Nigeria could be classified into 5: First, drainage basin interrelationships (Okechukwu, 1974; Ebisemiju, 1974; 1979; 1982; 1989).Second, runoff and basin parameters (Ogunkoya, 1979; Ogunkoya et al, 1984; Adejuwon, et al 1983; Anyadike and Phil-Eze, 1989). Third, runoff and erosion (Oyegun, 1982; Jeje and Agu, 1982; Jeje, 1987). Fourth, runoff and land use (Lal, 1983; Odemirho, 1984a; 1984b). And fifth, rainfall-runoff relations studies (NEDECO, 1959; Ledger, 1964; 1969). The level of hydrological investigations in Nigeria is relatively scanty, dated and largely concentrated on small river basins mostly orders 1 to 3 which would not give clear resolution of the response systems on higher order basins despite the relevance of basin scale to runoff response. This situation becomes worrisome when one compare the spate of research in southern Nigeria (a much wetter region) with northern Nigeria (a largely sub humid region). Indeed, Okechukwu (1974) unpublished study remained the only popular work on runoff response in northern Nigeria. All these studies are peculiar in nature. First, they are all dated, they were done on small basins, they all lumped together the different flow types as either annual flow or total runoff., they are all in southern Nigeria. More important many of these works did not focus on responses of runoff components.

Meanwhile, Linden and Woo (2003) have warned that extending conclusions and models drawn from other regions (countries), climate and geology to cover a separate region without further studies particularly in data sparse situations may be disastrous. Hence, a contemporary research on the subject matter in northern Nigeria is desirable. Furthermore, lessons from hydrograph studies confirmed that lumping of runoff flow types together may result in underestimation as the responses of the different flow types differ in their characteristics and contributions to runoff. However, when they isolated their responses will better understood. This understanding is relevant to the much deserved water resources development that is an important component of the Millennium Development Goals, in view of the deplorable state water and sanitation in Nigeria.

The study Area

The study area is the upper Kaduna catchment (UKC) fig1. It is located between latitude 9^0 11` and 3^0 north and longitude 6^0 and 8^0 0 east of the Greenwich Meridian. The climate of the study area is categorized as Koppen AW which is mainly a dry and wet climate. In the dry season, cold and dry Harmattan wind dominates. At thids time, the range of temperature is low; it is between 1.67^0 and 4.4^0c. January and December are usually the coldest months. Wet season starts in April and end in October. July and august are the wettest months. Around Zaria 67% of the rainfall is experienced in July, august, September, while over 25% falls in august alone. Rainfall intensity of about 285mm/hr has also been identified. In the southern part of the basin I;e Kogun sub basin in the north to 1,500mm on the Kogun sub basin.

Vegetation is largely the savannah type with tall and scattered trees. In the southern UKC around Kagoro and Assob some riparian forest are found, this may be due to the heavier rainfall (1,500mm). The major land use is intensively cultivated Sudan savanna, rough savanna landscape and guinea savanna found around the Kogun and

Galma basin. In the Kogun basins extensive grazing and dry season farming is practiced. The soil belong g to the leached ferruginous soil found under season rainfall, with differentiation in soil horizons and separation of tree iron oxide, which forms mottles concretions. Soil aggregation is poor with tendency to compact under wet condition, surface texture is sandy loam. Clay is largely the kaolinite type. The soil is about 30-40%clayeye with depth.

The population of the UKC is about 3.9million (NPC). Industries include petrochemical, petrol refinery, car assembly, textile, food and beverages, military hardwearing, e.t.c. Several urbanized settlement are found in he study area such as Kaduna, Zaria, Kafancha, Kagoro, Saminaka, Zonkwa, e.g. A number of water scheme are also found. They include urban water supply schemes in Kaduna, and all local government headquarters and several communities in the state. About 411 boreholes were in the state as far back as 1995

MATERIALS AND METHODS

Data Base and Data Generation

The runoff and climatic data used in this study covers an 11 year period (1979-1989) for which data are available. These data were obtained from the Hydrological Department of the Kaduna State Water Board, Kaduna.

Morphometric and physiographic variables

The morphometric parameters were extracted from Nigerian topographical map series (1:50,000) series (Table 1). Many researchers (e.g. Okechukwu, 1973; Anyadike and Phil-Eze, 1989), have adopted 1:50,000 map series in various studies. The sheets used in this study are: 100-103, 123-126, 144-147 and 165-168 covering the UKC and published by Northern Nigeria Survey (1966). Physiographic attributes of land use and geology such as the percentage are under each geological and land use types were extracted from the 1:500,000 Geological and Land use Maps prepared for the Kaduna State Agricultural Development Project (KADP) by AERMAP of Florence, Italy, 1987. A total of 30 basin variables given in Table 2 were examined in this study. Twenty sub-basins were selected within the Upper Kaduna Catchment for this study (Figure 1).

Hydrological parameters

Six hydrological parameters were extracted in this study. These are overland flow, interflow, base flow, wet season runoff, dry season runoff and total runoff. Overland flow, interflow and groundwater flow were derived through the use of a 3 component hydrograph method. The annual hydrograph was separated into dry season, wet season and total runoff. By definition of climate science dry season and wet season last for a period of 6months each. a total 220 hydrographs were computed for these basins for the 11 years of study. These hydrographs were later separated into 3 components of surface flow, through flow and base flow using graphical logarithmic method (Linsley, et. al. 1982 and Smakhtin, 2001; Ifabiyi, 2011, a, b). A total of 660 hydrographs were separated into the 3 major runoff components. The results obtained above were later converted into percentages of total runoff. In addition annual runoff was also separated into wet season, dry season and total runoff.

Statistical Method

A reduce rank model of factor analysis and regression analyses were used to interpret the data. Factor Analysis was adopted in other to overcome the problem of multicollinearity among basin variables; hence, it was adopted to rewrite the 30 basins parameters to orthogonal factors.

The multiple regression method was used to establish a relationship between total runoff and the factor scores of the eight orthogonal factors derived from the result of factor analyses to predict runoff response to total runoff. In addition to the above, the linear regression model was also used to order the individual contribution of the 8 orthogonal factors to total runoff using the result of the stepwise multiple regression as input.

Table 1: Procedure for generating morphometric variables

s/n	Morphometric variables	Procedure of derivation
1.	Length of mainstream	Length of principal drainage line in km(Smith,1956)
2.	Total stream length	Length of all the tributaries and principal drainage line in km (Smith,1950)
3.	Maximum relief	Differences between the highest and lowest points on a basin(Strahler,1952)
4.	Basin Length	Length of the basin along the most distant point(Schumn,1963)
5.	Basin area	Calculated via graphical method (Anderson,1957)
6.	Total segment of 1st order stream	Sum of all 1 basins (Horton,1952)
7.	Total segment of 2nd order streams	Sum of all second order stream (Horton,1952)
8.	Bifurcation ratio	Ratio of lower order to a higher order (Strahler,1964)
9.	Relief ratio	Rh=H/L, H=horizontal distance L=length of the basin along the principal drainage line (Schumn,1950)
10.	Drainage density	(∑L)/L; ∑L; H=horizontal distance, L=length of the basin (Solokov,1969)
11.	Miller's circularity ratio	CR=A/AC;A=Area of the basin (Miller's,1953)
12.	Form factor	F=A/L2: A=Area of the basin, L=Length of the basin along (Horton,1932)
13.	Lemniscate ratio	K=L2/4A, L=length of the basin. A=basin area (Chorley, et al 1957)
14.	Total stream segments	∑L=sum of all the length (Horton,1932)
15.	Channel mean slope	Lm=H/L: H= change in slope, L=Length of the basin (Horton,1932)

Table 2: The 30 hydro-climatic variables employed in the study

a. Morphometric variables	1.lenght of mainstream(km)
	2.total stream length(tsl)
	3. maximum relief (ts1)
	4.basin area (a)
	5. basin length (bl)
	6. total segment of 1st order (tsl)
	7.total segment of 2nd order basins (ts2)
	8. bifurcation ratio (rh)
	9. relief ratio (rh)
	10. drainage density (dd)
	11. circularity ratio (cr)
	12.form factor (Fa)
	13. leminiscate ratio (k)
	14.total stream segments (tss)
	15. basin order (bn)
b. Geological variables	16. percentage area of undifferentiated Basement Complex
	17. percentage area of volcanic rock (%vol)
	18. percentage area of porphyritic biotite (%pb)
	19. percentage area of undifferentiated granite (%ug)
	20. percentage area of younger granite (%yg)
	21. percentage area of quartzite (%qzt)
c. Land use variables	22. percentage area under forest (%for)
	23. percentage area under savannah (%sav)
	24. percentage area under fadama (%fad)
	25. percentage area under urban (%urb)
	26. percentage area under cultivation (%cut)
	27. percentage area under rock outcrop (%roc)
d. Hydrometeorological variables	28. dry season rainfall ((dsr)
	29. wet season rainfall (wsr)
	30. total rainfall (tr)

Response pattern of runoff

Runoff Components Reduced Modelling.

The result of factor analysis statistics reduced the 30 basin variables differently, ranging from 8 for all flow types with the exception of dry season runoff which has 9 orthogonal factors. The details are discussed below.

Overland flow. : in the instance of overland flow the 30 variables were reduced to 8 factors (i:e area, drainage network, shape, % area underlain by younger granite, % percentage area forested, % covered by savanna scrubland, basin slope, and % area of *fadama* land). Basin area has the highest contribution to the variance (26.4%), while land use has the least contribution (5.92%).

Interflow: Eight factors were also important in the explanation of interflow. Similar variables were equally identified in this instance with overland flow; however the contributions to total explanation differs compared to what obtains under overland flow. The contributions range from basin area (25.5%) to basin slope (6.47%).

Groundwater: Eight factors were also important to the explanation of groundwater in the study area. The dominant variables this time differ markedly. They include: basin area, total rainfall, % younger granite, circularity ratio, % savanna scrubland, % forest, basin order, and % area of *fadama* land. Basin order which have not been selected earlier is found to make significant contribution to groundwater. The strongest contribution was made by length of mainstream (25.4%) while the least was made by land use factor (5.92%).

Dry season runoff: nine response factors were responsible for the explanation of dry season runoff in the UKC. Close similarity exist between these factors and what obtains in the case of groundwater. The main difference was in the numbers of factors. The only difference in their contribution is % area covered by rock outcrops. The 9 factors have a contribution of 91.7%.

Wet season runoff, eight factors were identified as relevant to wet season runoff in the UKC. They are: length of mainstream, total rainfall, leminiscate ratio, %younger granite, % area forested, % area of savanna scrubland, maximum relief, and % area covered with *fadama* These factors contributed about 86% . The pattern exhibited by these factors is similar to what obtains in the case of overland flow.

Total Runoff: eight variables were selected as important. These factors were completely similar in their order of contributions with wet season runoff and overland flow. They are: length of mainstream, total rainfall, leminiscate ratio, %younger granite, % savanna scrubland, maximum relief and % fadama.

High level of redundancy were generally observed in the data set as 30 variables were reduced to only 8 and 9 factors with minimal loss of information. Similarities were observed in the responses of flow types, but that is not to say that these flow types are completely the same in their response patterns. For example in the cases of overland low, interflow, wet season runoff and total runoff they appeared similar in the composition of factors but little variations can be seen in their pattern of contributions. This pattern is expected in view of the similarities in the mode of the generation of these components. Rainfall plays a dominant role in the hydrology of the tropics and therefore these 3 flow types respond more rapidly to rainfall events compared to the others. In the same vein, groundwater and dry season runoff also trend the same pattern and this could also be explained within the context of dry weather flow which is a crucial source of water recharge to these 2 flow types. Rather than lumping together all these flow types as annual or total runoff the above showed that some if not all these flow types exhibit different response patterns.

Runoff Component Ranking.

In a further analysis, relationships were established between flow types and basin factors (Table 3). These are discussed below.

i. **Total runoff:** the 8 orthogonal factors predicted 94.9% explanation of the variance in the equation. All the factors entered the equation.

ii. **Wet season runoff:** the result of the multiple regression show that the 8 factors in table 3 predicted 94.6% of wet season runoff. This was later reduced to 93.4% by the stepwise regression and basin area was ranked as been the strongest predictor while % forest remained to 2.46%. the 8 factors was reduced to 4 factors

iii. **Dry season runoff:** the 9 orthogonal factors predicted 91.7% explanation to the variance of dry season runoff. This was later ranked to 2 factors namely: % rock outcrop and length of mainstream. These factors have 78.8% and 85% explanation respectively.

iv. **Overland flow: t**he 8 factors contributed 81.7% to the explanation. These factors were reduced to 2 factors: total rainfall (58.3%) and leminiscate ratio (13.8%) they both have 71.1% explanation.

v. **Interflow**: the result also show that 8 factors with 82.6% explanation were reduced into 2 orthogonal factors. The 2 factors are leminiscate ratio and total rainfall. They both have 46.1% explanation.

vi. **Groundwater flow: the** basin factors predicted 86.0 % of the groundwater response in UKC. This is later reduced to 3 factors: total rainfall, % forest and % younger granite. They contributed 76.7% to the variance in the explanation of groundwater flow.

Table 3: Summary of rank-reduced model in the Upper Kaduna catchment

Runoff Types	Factor Analysis				Regression Methods				
			Factor Loadings	**Cum Var.**	**Enter**	**Stepwise**		**R^2**	**Cum R^2**
	1	Area (a)	32.7						
Total Runoff	2	Drainage Network(tr)	15.0						
	3	Shape (k)	11.5				All Variables	Nil	Nil
	4	Geology (%yg)	10.3				Entered		
	5	Porosity (%for)	7.74	87.0	94.9		The		
	6	Impermeabilty (%yg)	7.64				Equation		
	7	Slope (mrh)	7.14						
	8	Land Use (%fad)	6.80						
Wet Season Runoff	1	Area (a)	28.6			1.	Area (a)	74.8	
	2	Drainage Network(tr)	15.0			2.	Porosity (%for)	11.5	
	3	Shape (K)	11.8			3.	Impermeability (%sav)	4.60	93.4
	4	Geology (%yg)	10.7			4.	Land Use (%fad)	2.46	
	5	Porosity (%for)	8.00	86.7	94.6				
	6	Impermeablity (%Sav)	7.70						
	7	Slope (mrh)	7.18						
	8	Land Use (%fad)	6.80						
Dry Season Runoff	1	Area (a)	29.0			1.	Land Use (%roc)	78.6	
	2	Rainfall (tr)	11.7			2.	Area (a)	8.00	86.5
	3	Land Use (%roc)	11.5						
	4	Shape (K)	11.3						
	5	Ruggedness (%yg)	8.30	89.2	91.7				
	6	Impermeability (%sav)	7.41						
	7	Porosity (%for)	7.30						
	8	Slope ((mrh)	6.80						
	9	Fadama (%fad)	5.70						
Overland Flow	1	Area (a)	26.4			1.	Drainage Network (Tr)	58.3	
	2	Drainage Network (tr)	15			2.	Basin Shape (k)	13.8	71.1
	3	Shape (k)	10.4						
	4	Ruggedness (%yg)	9.42						
	5	Porosity (%for)	8.27	86.0	81.7				
	6	Impermeability(%ug)	7.90						
	7	Slope (mrh)	7.40						
	8	Land Use (%fad)	5.90						
Interflow	1	Area (a)	25.4			1.	Shape (k)	30.9	
	2	Drainage Network(tr)	13.5			2.	Drainage Network (Tr)	15.1	46.1
	3	Shape (k)	10.8						
	4	geology (%yg))	9.25	86.2	82.6				
	5	Porosity (%for)	7.32						
	6	impermeability (%sav)	6.92						
	7	Land Use (%fad)	6.53						
	8	Slope (mrh)	6.47						
Groundwater Flow	1	Basin Area (a)	25.4			1.	Rainfall Tr)	49.0	
	2	Rainfall (tr)	14.6			2.	Porosity (%fad)	14.2	76.4
	3	Geology (%yg)	10.4			3.	Geology (%yg)	12.2	
	4	Slope (Cr)	9.42	86.0	84.3				
	5	Impermeability (%Sav)	7.12						
	6	Porosity (%por)	6.81						
	7	Basin order (bn)	6.41						
	8	Land use (%fad)	5.92						

Source: Author's computation

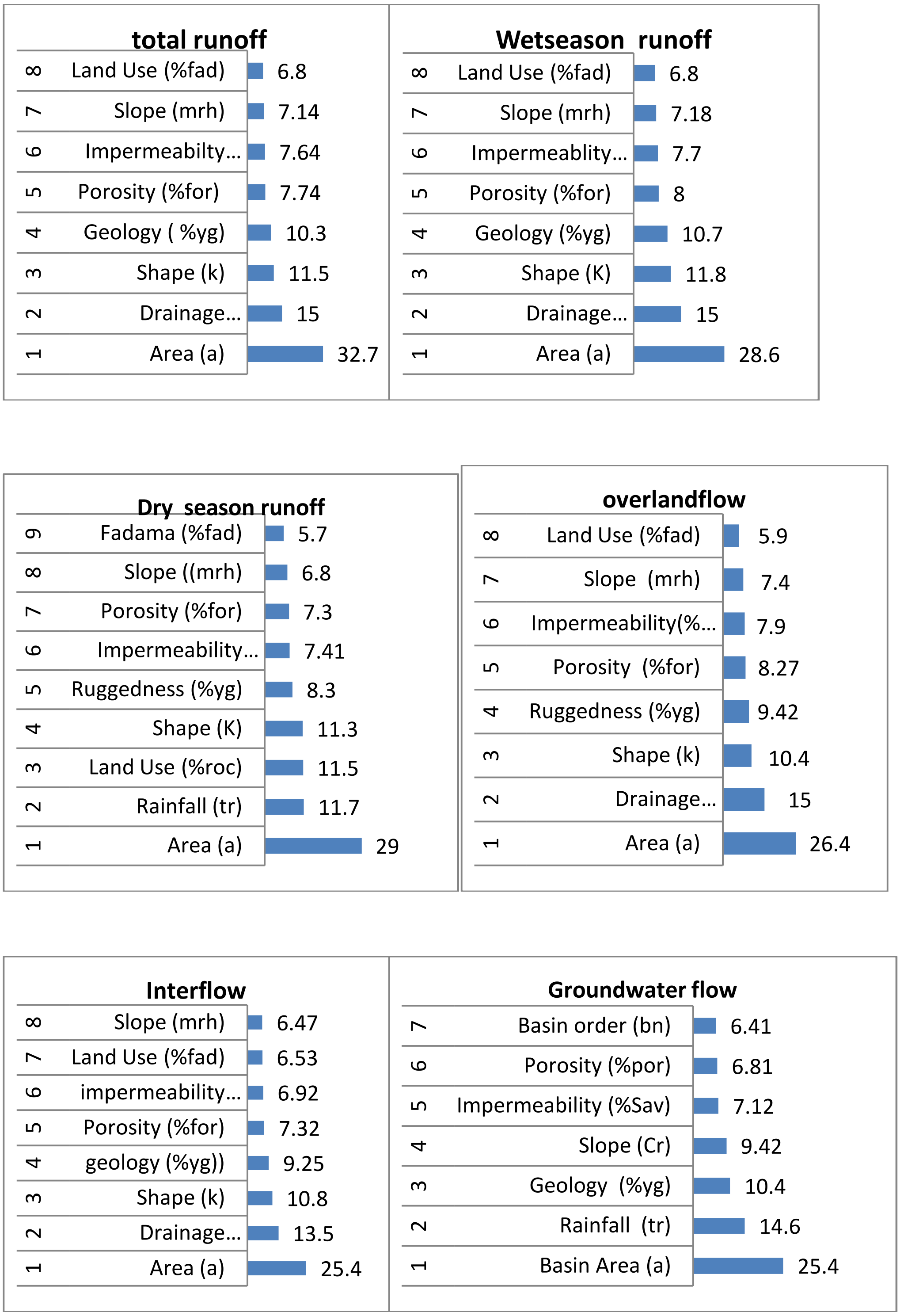

Fig 2: Characterization of pattern of explanations of factor analyses of different flow types

Table 4: Summary of Percentages of Explanation of Factor Analysis, Multiple Regression and Stepwise Regression

S/N	**Flow Type**	**Fa (%)**	**Enter (%)**	**Stepwise (%)**
1	Total	87.0	94.9	0
2	Wet	86.7	94.6	93.4
3	Dry	89.2	91.7	86.6
4	Overland	86.0	81.7	71.1
5	Interflow	86.2	82.6	46.1
6	Groundwater	86.0	84.3	76.4
	CV (%)	**0.44**	**14.9**	**55.5**

Table 5: Percentages redundancies in the expansions of response patterns of different flow types

	Flow Types	**% cumulative Variance of Factor Analysis**	**% Redundancy In Factor Analysis explanations**	**% Variance Of Multiple Regression Coefficient Of determination**	**% Ranking Stepwise Regression Coefficient Of determination**	**No Of factors In categories of ranks**	**% Ranking Difference Between Multiple Regression And Stepwise Regression**
	a	***b***	***c*** ***(b-100)***	***d***	***e***	***f***	***g*** ***(d-e)***
1	**Total runoff**	**87.0**	**13.0**	**94.9**	**0.00**	**0**	**0**
2	**Wet season runoff**	**86.7**	**13.3**	**94.6**	**93.4**	**4**	**1.20**
3	**Dry season runoff**	**89.2**	**10.9**	**91.7**	**86.5**	**2**	**5.2**
4	**Overland flow**	**86.0**	**14.0**	**81.7**	**71.1**	**2**	**10.6**
5	**Interflow**	**86.2**	**13.8**	**82.6**	**46.1**	**2**	**36.5**
6	**Groundwater flow**	**86.0**	**14.0**	**84.3**	**76.6**	**3**	**7.7**

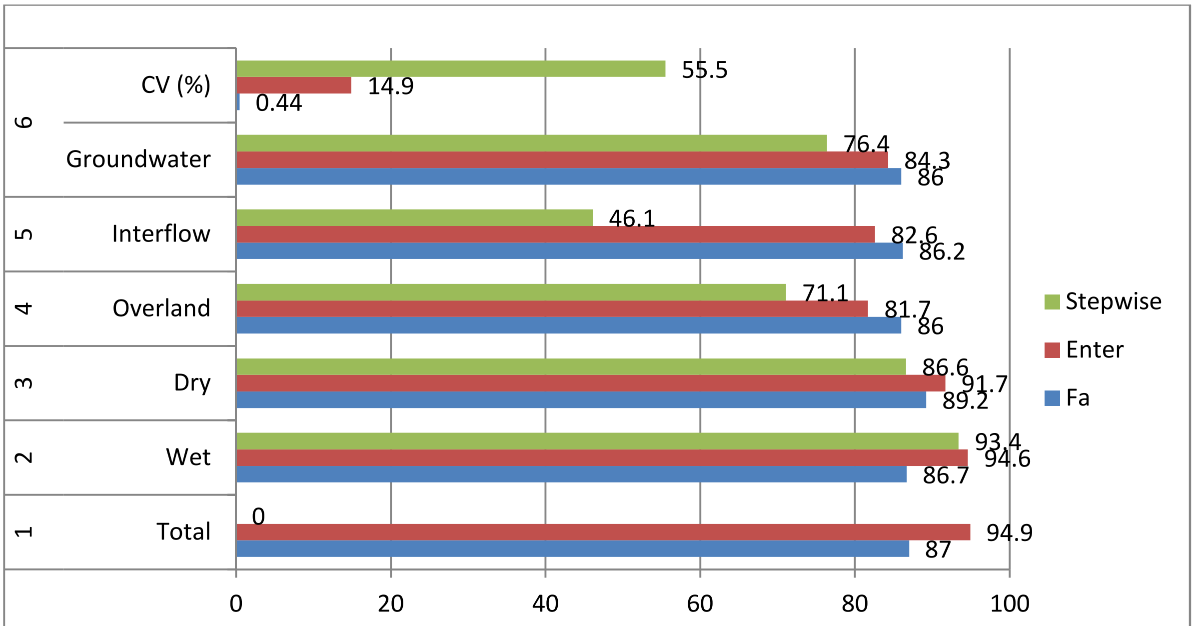

Fig 3: Comparison of percentages of explanations

The various description in Tables 3, 4, and 5 and Figures 2 and 3 which compared the factors controlling flow types and their respect percentages of explanations clearly confirms that the response patterns of various flow types differs from one another, therefore, lumping them together will lead to generalization this has been confirmed by the work of others (Ogunkoya and Jenkins, 1991; Ogunkoya and Jenkins, 1993; Jenkins, et. al. 1994).

Conclusion

It can be concluded that lumping together runoff components is rather misleading; this is because different basin variables explained response patterns of individual flow types. This demonstrated by the different percentages of explanations which vary between 86% for overland flow and 89.2% for dry season runoff; while coefficient of determination varies from 87% for overland flow to 94.9% for total runoff in the multiple regression equation and for stepwise regression it ranges from 0 for total runoff to 93.4% in the case of wet season runoff. Further, the results of dispersion test conducted for the percentages of explanation of factor analyses and coefficient of determination of the multiple and stepwise analyses regression showed that their coefficient of variations are 0.44%, 14.9% and 55.5% respectively; which signals that these variables are not similar, hence, lumping them together will be misleading, particularly for purposes of runoff or basin modelling.

This paper has revealed that behaviour of hydrological variables in the tropics and indeed, in Nigeria is largely misunderstood. Little wonder, the fatality of our hydrological mishaps. This calls for caution and further studies

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