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AGRICULTURAL IMPLICATION OF SUBSURFACE FLOW IN PARTS OF THE BASEMENT COMPLEX OF NORTHERN NIGERIA.

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Abstract

Graphical hydrograph separation procedure was used to study the contribution of subsurface flow and to annual hydrograph in the Upper Kaduna Catchment. Twenty sub basins were selected for the study and a total of 220 hydrographs were separated. The separated components of annual hydrograph were subjected to the Duncan multiple range ANOVA and three regional patterns of sub surface flow and soil water emerged.. Reasons suggested for this may include the geology, soil characteristics, vegetation types, slope characteristics and land use types of the study area.

The paper finally pointed out the potential of such efforts in agricultural planning in Nigeria.

INTRODUCTION

Studies of subsurface water have been of prime importance. This is because it is central to total runoff, channel flow, groundwater recharge, and water availability in the root zone, macrobe activities. Besides, it is also important to chemical, biological and physical processes within the soil layer. Furthermore, studies of water within the soil matrix can be used for outright agricultural planning especially for demarcating the soil into different cropping zones (Hewlett, 1961; Hewlett and Hibbert, 1967; Jones,1971; Zaslavsky and Rogowski A.S (1979); Fritz, et al. 1976; Sklash and Falvoden,1976; Gregory and Walling,1978; Bruinjzeel,1990; Lesack, 1993) .

Hydrological studies in Nigeria have mainly concentrated on four topical issues these are: rainfall-runoff relations, runoff response to basin parameters, water supply problems, water chemistry and groundwater studies (particularly groundwater exploration). Little work has been done in the area of runoff generation or its distribution over space. However, reasons for this may include: Lack of adequate data, low technological development (i.e. in the area of isotope technology) and finally due to the dominance of overlandflow in the explanation of runoff generation in this part of the world (Ogunkoya et al 1984).

Subsurface flow can be studied in three main ways these are: through direct measurement by instruments, use of isotope and hydrochemical methods and finally by graphical hydrograph separation. The first two methods are cumbersome, hard to come by and both give point assessment hence results obtained through them may not be representative of every part of the basin. The third technique on the other hand is available, easy to use and result obtained can be widely representative. This is because it is derived from the stream hydrograph, which is the only reflection of the stream flow characteristics. Besides, evidences are bound that where this technique is carefully applied they yield reliable results (Gregory and Walling, 1978; Olu, 1985). This paper therefore adopts the graphical hydrograph separation procedure in the analysis of the contribution of subsurface flow to total hydrograph in the study area.

METHODOLOGY

The Study Area

The study area is the upper Kaduna Catchment located between latitude $9^0 29'$ and 11^0 30^0N and longitudes 7^0E and 9^0E of the Greenwich Meridian (Fig 1). The study area experiences two seasons (dry and wet) Harmattan wind dominate during the dry season. During the harmnattan period, the range of temperature is between 1.67^0 and 4.4^0C.

January and December, are 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 occurs in July, August, September and over 25% falls in August alone. Rainfall intensity of about 285mm/hr has also been identified (Kowal, 1972). In the southern part of the study area (Kagoro) rainfall may be as high as 1,500mm and later decreases to 1000mm in the extreme month of the study area.

Four relief types are discernable, these are: gentle undulating landscape around Galma and Karami plains where slope is 1-2^0, there is also the dissected landscape around river Tubo where the slope is 3-5^0. Finally, there is the hilly landscape where 5^0 slope is common. The drainage pattern is dendritic an indication of the basement complex geology of the study area. The geology comprises of undifferentiated crystalline basement complex comprising undifferentiated metamorphic and igneous rocks. Rocks are gneiss migmitites, granite, young and older granite. Large expanse of weathered mantle is also found.

The soil is leached ferruginous formed under seasonal rainfall climatic regime. It exhibits differentiation in soil horizon and separation of free iron oxides, which forms mottle and concretion; this hinders infiltration and may promote subsurface flow. Soil aggregation is poor with tendency to compact under wet condition. Surface texture is sandy loam. Clays are predominantly kaolinite, soil p^H is around 7.1, cation exchange of clay suggests that a considerable portion of the clay is illite type. Soil is about 30-40% clay especially with depth. Vegetation is the Savanna type, riparian forest is common in the South East of the area, around Kaduna, isoberlina Savanna is vegetation dominant. This area is intensively grazed In the area of riparian forest around Kagoro large amount of litters are found on the surface.

Three land use types are discernible in the study area. These are intensively cultivated Sudan savanna around Ikara where cotton is the dominant crop. This also extends to the West around Zaria and Saminaka. Rough savanna landscape with extensive open grazing and some cultivation near Kaduna and finally areas of dry season farming around Kagoro. All these land use types are likely to promote high surface runoff in the study area.

Finally, the study area has a population of 3,969,252 (NPC, 1991). Several industries are also found petrochemical, petrol refinery, car assembly, textile industries, several food and beverages company, military hardwearing industries and several manufacturing industries. A number of urban centers are also found (Kaduna, Zaria, Kachia, Kagoro, Kafanchan, Kwoi, Birnin Gwari, Zonkwa etc). Several forests reserves are also visible (Afaka, Birnin Gwari etc). All these play significant role in the explanation of water resource characteristics of the study area.

The study is based on the data acquired from 1979-1989 (11 years). These were obtained from the records of the Hydrometeorological Department of the Kaduna State Water Board, Kaduna.

Twenty (20) sub basins whose stream orders ranges from 3-6 were selected based on available data see (Fig.1). The sampled basins include three (3) third order basins, two (2) 4^{th} order streams, nine (9) 5^{th} order streams and five (5) sixth order streams making a total of 20 streams. The selected sub basins are displayed in Table 2 and Fig. 1

Hydrograph Separation Procedure

In this study semilogarithmic method proposed by Barnes (1940) was used to determine the subsurface flow component of the annual hydrograph (Fig.2)(Linlsey, et. el. 1982, Chow 1964). The traditional hydrograph separation procedures are essentially empirical and are based upon the assumption that the beginning of hydrograph rise is the result of the arrival of surface runoff in the stream channel and that one or more lines may be drawn through the hydrograph to distinguish the surface runoff from the interflow and base flow contribution. However, in the Barnes (1939, 1940) method whereby selection of the separation lines is on inspection of recession limb for changes in curvature and this was done using semilogarithmic paper. This method was used by Smith (1969) by separating the hydrograph of the summer daily mean flows for the Beburn and Greta catchments into

3 components (i.e storm runoff, basin storage discharge and initial groundwater discharge). Similarly Olu (1985) adopted the same method in the Hadeija-Jamare River Basin in Northern Nigeria and favourable results were derived.

Barnes (1939; 1940) proposed that a stream flow component may be separated by the following procedure (Fig.2) ·

(i) plotting the hydrograph on a semi-log paper whereby tail end of the hydrograph plots as a straight-line i.e. groundwater recession (CD);

(ii) and if the straight-line plot is extended backwards up to point E directly under the inflection point I and line BI drawn the area under BEC represents the groundwater contribution to stream flow ;

(iii) if the ordinates of this are deducted from the ordinates of total hydrograph and reploted the hydrograph of surface runoff and interflow (subsurface) is obtained which plots as a straight line (HG) at the end.

(iv) by extending this backwards up to the points L which is directly under point I and drawing the line FL, the area under FLG gives the interflow component; and

(v) by deducting the ordinates of this from the ordinates of the hydrograph of surface runoff and interflow, the hydrograph of surface runoff is reploted whose tail end again is a straight line representing the surface recession or channel storage.

This method was used to separate the interflow component on each sub basin for 11 years of study on the 20 sub basins in the UKC. This makes a total of 220 interflow components of the total runoff, which comprises of a break down of 11 hydrographs per sub basin.

Statistical Analysis

The Duncan Multiple Range Analysis of Variance (ANOVA) was adopted. This is because this technique is capable of differentiating between the components in two folds. It shows differences between and within the samples by a method of mean separation and it also grouped the data; the differentiation is based on some form of mean separation where by differences is sought based on the similarities and differences of the means of the target population. The end results of the mean separation were used to group and classified the Upper Kaduna Catchment into zones of subsurface flows.

RESULTS AND DISCUSSION

The results of the 220 hydrograph separation was imputed into the Duncan model and the results of this model is presented in Tables 1and 2. The result presented in Table 1 showed that significant difference exist in the composition of the sub surface flow component from one sub basin to the other. This is clearly depicted in the differences in the F-ratio of the data. The end result of these differences is a classification of the sub surface flow contribution to total runoff in the UKC. This classification therefore illustrates the regional pattern of sub surface and soil water for the Upper Kaduna Catchment (Table 2). On the basis of the results in Table 2, the Duncan statistics has identified 3 zones of subsurface flow in UKC. The implication of the result in Table 2 is that similarities exists in the subsurface and soil water contribution to total runoff within the same region while differences exists in the sub surface and soil water contribution to total runoff between any two regions. The regional patterns of subsurface flow in the study area are discussed below.

Regional Pattern of Subsurface Flow in the Upper Kaduna Catchment

(a) High Subsurface Flow

The percentage contribution of sub surface flow and soil water ranges between 23.39% along Tubo at Lagos road and 27.82% along Karami at Saminaka. (Table 2). Ten basins were found within this zone. Two topographical boundaries exist within the zone; these are rolling and dissected upland. For example, Karami at Saminaka, Jamana at Soba and Kudan at Hunkuyi are found on rolling plains.

Others such as Gurara at Gatan, Assob at Assob are found in the hilly part of the catchment. The conditions of this area support high amount of interflow. However, this may have to do with the pedological characteristics particularly differentiation in soil horizons and the decreasing hydraulic conductivity with depth which may likely assist the diversion of flow into lateral flow in this zone. This is the case along Karami at Saminaka, Jamana at soba, Kudan at Hunkuyi Tubo at Lagos road, Kachia at Kachia, and even along Dorogoin at kwoi. However the heavy total annual rainfall along Assob at Assob, Kogun at Kagoro and Gurara at Gatan may be the major factor responsible for their high soil water and sub surface flow contribution Also the luxuriant vegetation along Gurara, Assob, Dorogoin and Tubo basins all of which have some portions of their basins forested (Fig. 3).

(b) Moderate Subsurface Flow

Eight basins are found in this region (see Table 2). The percentage contribution of these basins to total runoff hydrograph ranges from 15.52% in Kogun at Ugwan Rimi to 21.41% along Shaho at Kachia.

Some of these basins have extensive floodplains, for example Galma at Ribako, Galma at Kuzuntu, Galma at Gubunchi and Shika at Kano Road. The soil characteristics also support the pattern of their contribution to subsurface flow. The soil of this region is increasing clayey down profile in addition, evidences of induration and surface crusting can also be found widely in this region. More importantly the impact of cultivation and grazing will discourage sub surface flow .For example, a report by National Animal Production Research Institute (NAPRI) in Shika, Zaria shows that there were 180,000 sheep and rams, 10,000 pigs, 55,000 rabbits, and over 880,000 birds around Zaria
(Galma basin) alone (Bello ,2000).

On the other hand, Chalwe at Kachia, Kogun at Jagindi and Kogun at Ugwan Rimi are found on rugged terrain while the soil profile and the weathered saprolite is thin for adequate soil water retention. However along large sub basins such as Galma at Ribako, Galma at Kuzuntu, Galma at Gubunchi Kahugu at Ikara, and Shika at Kano road the impact of evapotranspiration will definitely contribute to the relatively low contribution of sub surface and soil water to total runoff. Ogunkoya et al. (1984) has reported in southwestern Nigeria

(c) Low Subsurface Flow

Two sub basins are found within this group. These are: Chalwe at Zango Kataf (12.62) and Kwassau at Zonkwa (11.98). This zone has the least contribution of subsurface water. However, this may be due to two major factors land use types and the high rural population in this zone. For example, information from the land use map covering the UKC showed that these two basins are 100% cultivated. These conditions promoted overland flow and surface flow. Runoff generation along this zone is possibly to be through Hortonian and partial source approaches.

It is pertinent to note that despite the geographical spread of the study area, only three zones of subsurface flow and soil water are identified. These may be due largely to the common Basement Complex geology, soil characteristics and probably due to homogeneity in the land use types.

Implication for Agricultural Planning

The study identified three zones of subsurface flow in the UKC. Subsurface flow is controlled by such factors as soil characteristics (Clayey B horizon), vegetation types, land use and slope characteristics. There is the possibility that runoff generation in zone A is through variable source area-subsurface type while in zone B, the variable source area and groundwater is suspected, in zone C runoff is likely to be dominated by partial source area approach.

However, for the purpose of agricultural planning, the spatial pattern of subsurface and soil water exhibited in this research can be a guide upon which crop production can be based. Biological and chemical activities within the soil depend on available soil water. Consequent upon this, the identified sub basins of high subsurface flow with average component ranging from 23.39% to 27.82% (see Table 2) can specialize in the production of more water bearing plants such as rice and banana etc while areas with moderate subsurface flow (15.52% to 21.41%) can accommodate less water bearing crops such as maize and other grains. Finally, the sub basins with low subsurface flow with percentage contribution of between 11.98% and 12.62% are better used for the production of crops with low water requirements such as cotton and guinea corn. However, details of all these can better be fashioned out after a proper analysis of the available soil water and the crop requirements of all the suggested species of crops have been done. This is beyond the scope of this present study.

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Table 1: Duncan ANOVA Results Depicting the Regional Pattern of Sub surface Flow and Soil Water in the Upper Kaduna Catchment.

DF	ANOVA SS	MEAN SQUARE	F VALUE	PR >F
19	3877.457	204.07	2.36	0.0018 **

*** Significant at 0.05 level*

Table 2: Pattern of Subsurface flow Contribution to Total Runoff in UKC (1979-89)

S/no	Sub basin	% Contribution.	Remark
1.	**Karami at Saminaka**	28.82	**High contribution**
3.	Jamana at Soba	26.09	
4.	Kachia at Kachia	25.50	
5.	Kogun at Kagoro	24.59	
6.	Gurara at Gatan	24.58	
7.	Assob at Assob	24.53	
8.	Karami at Kauru	23.86	
9.	Dorogoin at Kwoi.	23.82	
10.	Kudan at Hunkuyi	23.42	
	Tubo at Lagos road	23.39	
11	**Shaho at Kachia**	21.42	Moderate contribution
12	Shika at Kano road	21.11	
13	Galma at Ribako	20.92	
14	Galma at Gubunchi	19.83	
15	Kogun at Jagindi	18.44	
16	Galma at Kuzuntu	17.85	
17	Kahugu at Ikara	16.95	
18	Kogun at Ugwan Rimi	15.52	
19.	Chalwe at Zango Kataf	12.62	Very low contribution
20.	Kwassau at Zonkwa	11.98	

Source: Authors Computation (2004)

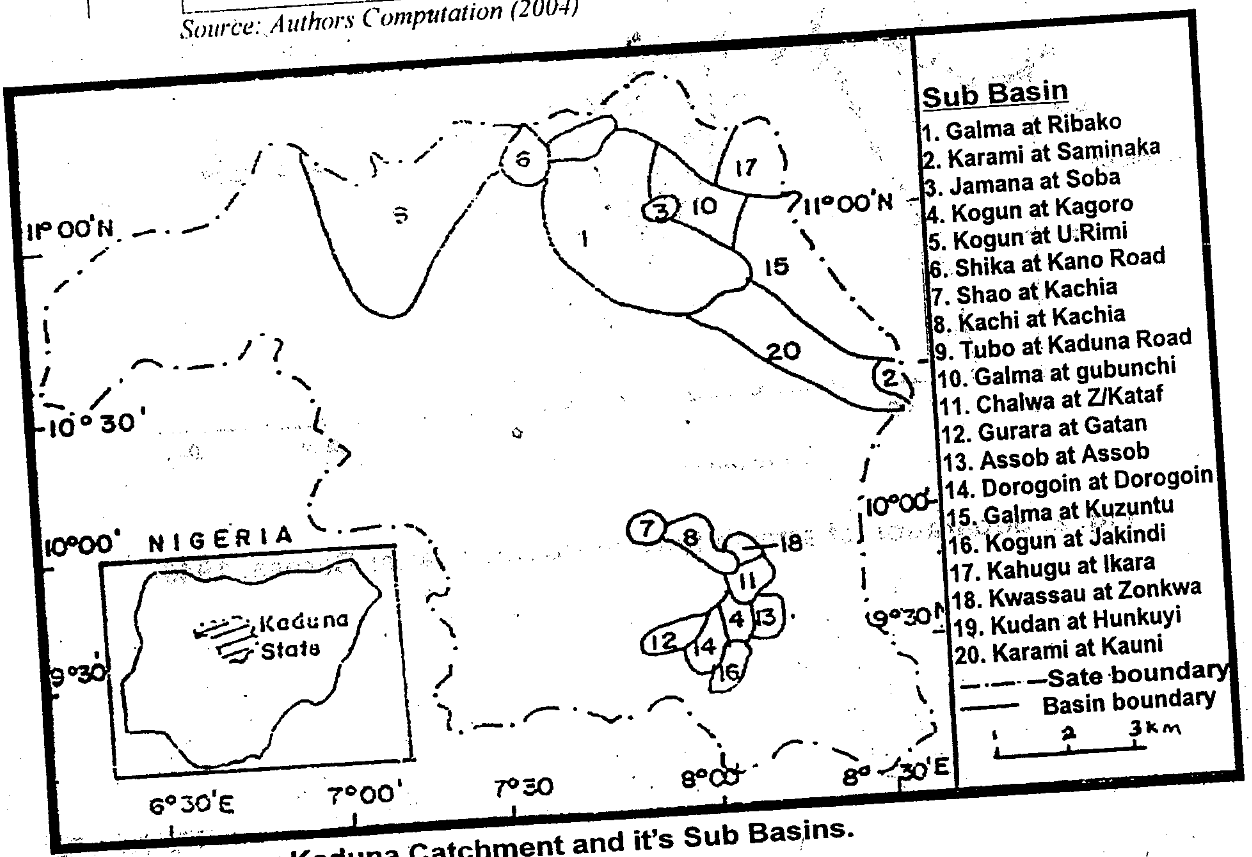

Fig. 1: The upper Kaduna Catchment and it's Sub Basins.

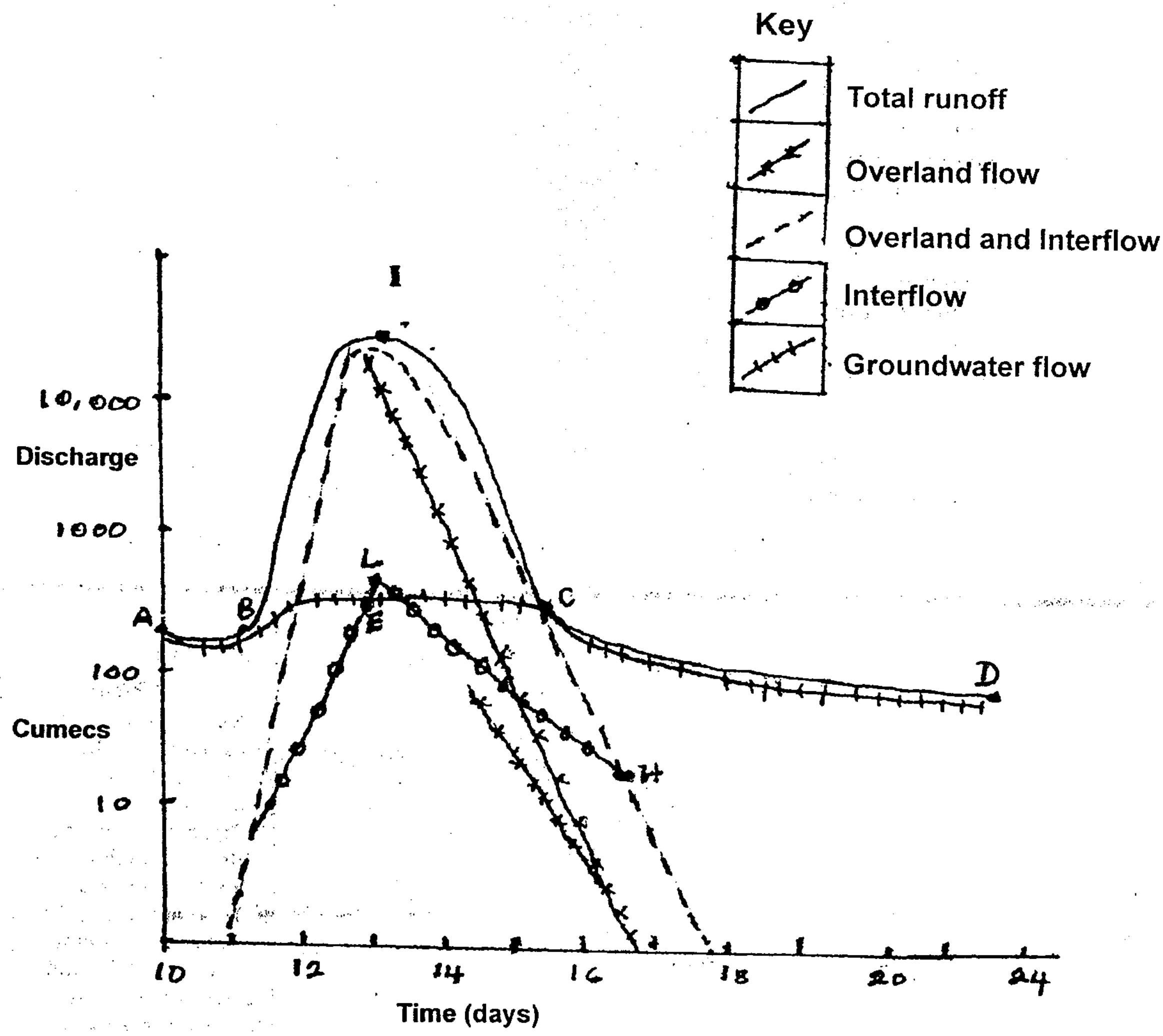

Fig. 2: Separation of stream flow hydrograph (after Barnes, 1940)

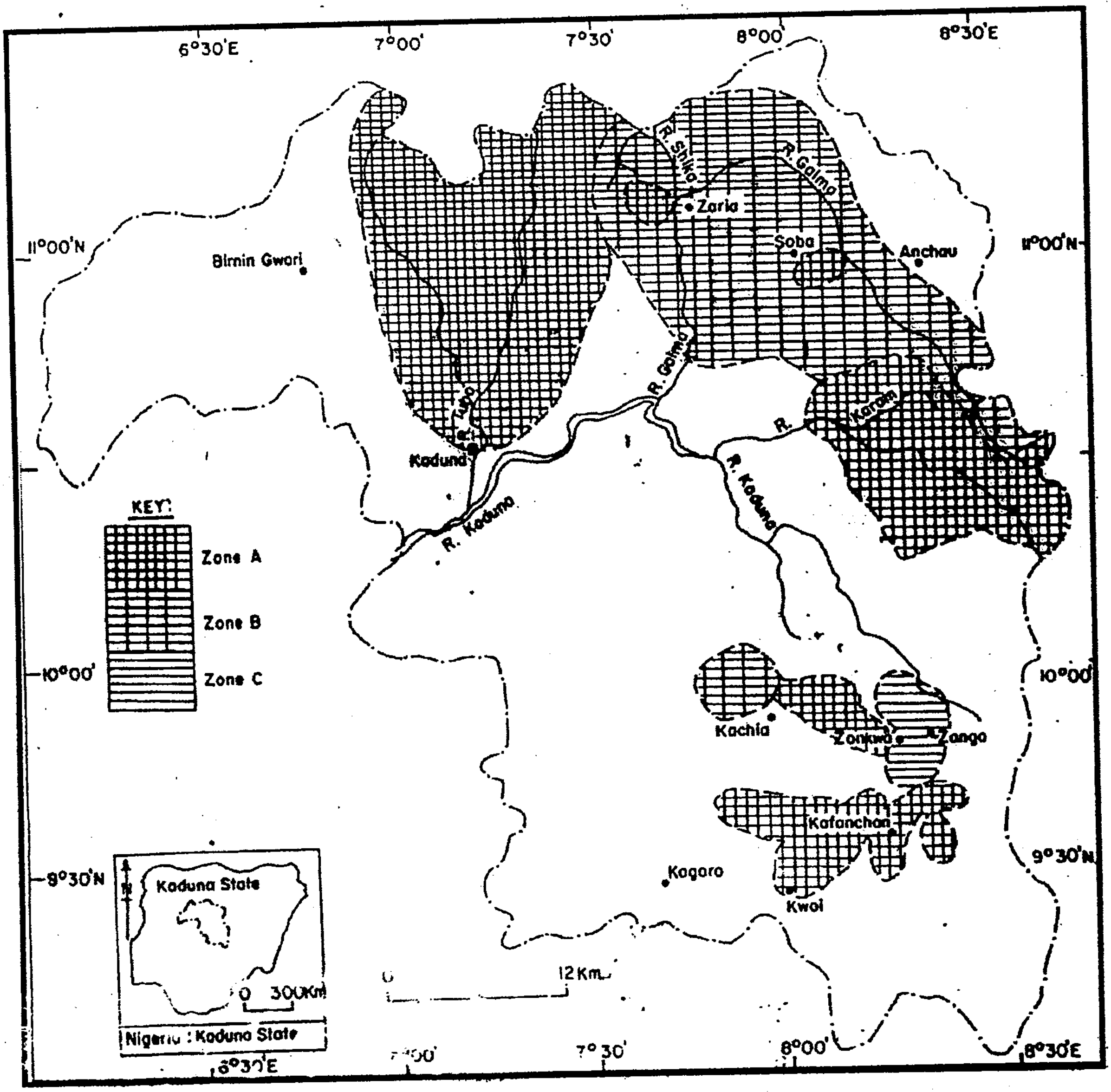

Fig. 3: Zone of subsurface flow in the Upper Kaduna Catchment